TAGGING METHODS FOR STOCK ASSESSMENT AND RESEARCH IN FISHERIES

Report of Concerted Action

FAIR CT.96.1394 (CATAG)

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Foreword

The overall objective of FAIR CT.96.1394 (1997-99) was to achieve improvements in the methodology of fish tagging techniques with emphasis on applications in fisheries research and stock assessment. The report consists of ten chapters. The first three are essentially introductory, sketching the background and concerns that led to the Concerted Action, and describing its rationale and objectives. Chapters 4 to 8 address the various objectives of the project, whilst Chapters 9 to 11 provide a conclusion and additional information. Chapters 4 to 8 are based on the deliberations of four separate working groups, which tackled different aspects of the subject and then presented their conclusions for debate in a plenary session.

Chapter 4 is devoted to conventional identification tags and tagging techniques. The content is comprehensive, but not exhaustive, because this area has been reviewed before. Responsible for this chapter were: Mr. Curt Insulander, (SRI, Sweden), Dr Josianne Støttrup (DIFR, Hirtshals), Mr Stig S. Pedersen (DIFR, Silkeborg) and Mr. Vilhjalmur Thorsteinsson (MRI, Reykjavik).

Chapter 5 is concerned with electronic tags and provides the most up-to-date compilation of the field, covering tag function, engineering and methodology in some detail. This chapter provides the technical core of the report. Participants in the workgroup were: Dr Geoff Arnold (CEFAS, Lowestoft), Dr Tor G. Heggberget (NINA, Trondheim), Mrs Marianne Holm (IMR, Bergen), Dr Niall Ó Maoiléidigh (FRC, Dublin), Mr Johannes Sturlaugsson (IFF, Reykjavik) and Mr Sigmar Gudbjornsson (Star Oddi Ehf, Reykjavik).

Chapters 6 and 7 are devoted to the legislation governing tag use, and the numerous welfare considerations underlying fish tagging programmes. One workgroup was devoted to both of these tasks and consisted of: Prof. John Davenport (University College, Cork), Dr Etienne Baras (LDFA, Belgium), Dr Gianna Fabi (CNR, Ancona) and Dr Gisli Jonsson (IEP-Keldur, Reykjavik).

Chapter 8 is concerned with data analysis and modelling, since development in these areas is crucial to maximising the opportunities provided by novel electronic technology, as well as tagging experiments generally. The participants in this workgroup were: Dr Olav Rune Godø (IMR, Bergen), Dr. ing. Federico Borghini (United Kingdom), Mr Tapani Pakarinen (FGFRI, Helsinki) and Dr George Tserpes (IMBC, Crete).

The report concludes with three short sections: Chapter 9 is devoted to the future of fish tagging, Chapter 10 details the features of the CATAG website and Chapter 11 (Annex) lists the addresses of the partners in the CATAG project.

1. INTRODUCTION

Systematic tagging of fish for scientific purposes has been conducted for more than a century. When it was started, this new approach represented an exciting methodology for obtaining fundamentally new information about fish migration and movements as well as on the dynamics of exploited fish population. However, it is now clear that tagging has not developed as an extensively-used method for monitoring and management of major European commercial fish stocks in the way that might have been expected. Undoubtedly, much effort has been invested in tagging experiments, but the results have generally only been used for qualitative evaluation of distribution patterns. Instead, fisheries management has tended to focus on statistical analysis based on a variety of modelling approaches, often based on expensive sampling programmes or catch data. A major reason for the under-utilisation of tagging in the quantitative evaluation of fish stocks has been uncertainty about data quality.

Recent developments in technology have created a new situation both with respect to types of tags and the range of data that can potentially be collected. We are on the threshold of fundamental new knowledge, both with regard to the understanding of biological relationships and a full appreciation of fish-environment interactions. For the first time it is becoming possible to get detailed information about life cycle properties of individual fish. Furthermore, new and alternative population assessment methodologies are likely to emerge from these developments, as well as opportunities to validate existing modelling approaches. This new technology has arrived at a time when there is a crucial need for sustainable management of the marine environment and its resources. New approaches in tagging methodology may give us alternative solutions where traditional methodologies have failed.

Consequently, it is time to take a retrospective centennial view of tagging practice and achievements, to sum up the state of the art, and thereby establish a firm basis for identifying future possibilities and needs. Such a task can only be accomplished through the interaction of scientists with a wide scientific and geographic spread. This report represents the outcome of such an exercise, achieved through an EU concerted action programme (‘CATAG’).

The chapters in this report have been individually prepared by subgroups with special interests and competences within the fields they covered. It is also assumed that the report will often be read by chapter of interest, and not as a complete and integrated publication. The report also provides the basis of a developing, living website (http://www.hafro.is/catag) in which material is presented in discrete, accessible sections. By intention therefore, those issues covered by several of the subgroups are retained in their individual chapters even though this results in a degree of duplication.

CATAG takes advantage of the 1994 EU-supported workshop on "Electronic Tags in Fisheries Research and Management" (14-17 November 1994; Lowestoft, England [Arnold & Lundgren, 1999]). After that workshop some of its participants reunited on discussions which led to the application of another CA project which is this CATAG project.

2. RATIONALE AND OBJECTIVES

Scientific assessments form the basis of fish stock management for the major commercial stocks of European fresh and saline waters. One of the available tools for assessment consists of tagging. In stock assessment, fish caught in a fishery are tagged, released back into the environment and allowed to mix thoroughly with the rest of the population. At some time later both tagged and untagged fish are caught in the fishery. From the ratio between the two categories it is possible to estimate population (assuming a good relationship between the tagged:untagged ratio and the catch:population ratio). Although the motivation for such programmes is often to obtain quantitative measures for use in monitoring and management of commercially-exploited fish populations, there have been few good examples of this in practice. A major problem has been disagreement among scientists concerning the reliability of recapture results and the validity of the models used to handle the tagging data collected. Therefore, a thorough review is needed of the limitations and problems associated with existing techniques and methodology.

Rapidly-developing microelectronic technology has stimulated the design and development of new electronic ‘smart’ fish tags and many new instruments are already on the market. This situation poses questions and challenges. To what extent can these new approaches be used to solve specific problems and overcome limitation inherent in present methodology? Furthermore, are there new technological approaches in sight, which can form the basis for new approaches and cost-efficient solutions to problems within quantitative fisheries’ biology?

Stock enhancement programmes have become an integral part of present approaches to both population conservation and compensatory releases to maintain fisheries. An important European issue in this context is the impact of salmonid aquaculture on wild populations. Tagging techniques in general, and the application of new technology in particular, may provide useful tools for the evaluation of the benefits of stocking exercises.

The CATAG concerted action (CA) had three objectives:

- To assess the past, present and future use of tags
- To assess reliability of tagging methods with emphasis on their applicationin fisheries research and stock assessment
- To facilitate improvements in tagging methodology and application

A CA facilitates a broad European perspective of the subject, secures relevant information that can be shared among partners and reduces the risk of duplicated work. Most importantly, it can initiate and encourage new multinational initiatives in technological and theoretical development within the field. The fact that much past European effort in tagging has neither been directly applied nor the results properly published, supports the idea that an international initiative can provide an improved platform for future scientific approaches in the field.

3. GENERAL CONCERNS

There are several subjects in tagging that are independent of tag type, species and area. These include strategic planning and decisions made prior to tagging, proper sampling of fish for tagging, treatment of fish during the tagging process, and finally, efficient means of obtaining consistent high quality recapture information. These are all crucial aspects for the success of a tagging programme that tend to be overlooked or may be considered too late to be dealt with in an appropriate way.

3.1 STRATEGIC PLANNING OF TAGGING PROGRAMMES

There are some general aspects that should be considered when planning a tagging operation. A careful assessment of the objectives, relating them to a cost/benefit analysis is useful before deciding on the most appropriate tags and tagging methods. Chapters 4 and 5 have good descriptions of various tags and the pros and cons of their use. The analysis should include the entire process from deciding on the hypothesis to be tested, to the evaluation and presentation of the results. In this process the number of fish to be tagged in relation to the expected number of recoveries must be considered, as well as the number of recoveries needed for the statistical analyses planned for the data. In this report chapter 8 is concerned with plans of experiments, data handling and modelling. The planning process ought also to include some consideration of other experiments performed with the tag of type that has been selected and the species of fish it is proposed to use. The CATAG web-site (http://www.hafro.is/catag) has online various examples of tags, tagging methods and examples of experiments being carried out in various places.

Legislation governing tagging practice is not something that many think about when planning a tagging experiment. It is important though to look at general legislation which concerns tagging because this may save problems at a later stage when the experiment is in full swing or when it is published. This report has a special section devoted to the legislative control of tagging in various European countries (chapter 6).

In planning tagging procedures it should be appreciated that the handling time for each fish needs to be short. This is necessary for better fish survival, and also for the economy of the project. If a method is used for the first time it is very important to practice or rehearse the tagging procedures, to minimise handling time. One can practise on dead fish, or follow the effects of tagging on fish held in captivity. Many tagging methods have been tested by controlled survival and tag retention experiments. If it is not possible to get such information from the literature some experiments of this sort should be planned. Chapter 7 of this report is written for those who want to know about possible health and behaviour changes associated with tagging, best surgical procedures, most appropriate anaesthetics and disinfectants.

In planning for each tagging or marking programme one should check if the local tag recovery and refunding system applies to the recaptured tags derived from the programme, or if some special arrangements have to be made. Section 3.3 deals with the recovery of tags and further information is provided in Chapter 5 (Section 5.6).

3.2 TREATMENT OF FISH DURING CAPTURE, TAGGING AND RELEASE

Here we are concerned with the wellbeing of the fish during the time it is in the fishing gear, hauled aboard a vessel, maintained within a holding tank, tagged or marked and then released.

3.2.1 Capture of fish for tagging

The most important consideration during capture is the survival of the fish to be tagged or marked. Different species of fish vary a great deal in how vulnerable they are when handled. Some, like plaice, can endure much handling without problems. Others can hardly be touched without their life expectancy being greatly reduced. Fish for tagging can be obtained by any conventional capture methods, but the suitability of the catching method may vary and one should survey the best methods available for catching the fish. However, planning of tagging experiments is often constrained by the requirement that tagging must be carried out at certain locations - where only a limited selection of fishing techniques may be available.

When fish are using much energy during ‘flight or fright’ reactions, lactic acid is produced by glycolysis in the muscles. An excess of this can build up in the blood if the fish does not have time to recover (Wendt & Saunders, 1965, 1973). It should be realised that the process of fatigue in fish continues while resting after handling, i.e. the increase of lactic acid in the blood continues after the fish has been stressed (Wendt & Saunders, 1973). The fatigue process is also temperature-dependent. Build up and recovery are slower at low water temperatures and the total increase of lactic acid is less than at higher water temperatures where lactic acid can reach lethal levels (Wendt, 1967). This indicates that resting fish should be kept relatively cool.

Commercial fishing methods are normally designed to optimise harvest and not to keep fish alive and healthy. This means that individual fish may have been stressed for long periods in the gear and thus become less fit for tagging. Soaking time for stationary fishing gears should therefore be limited, while towing times for active fishing gears, such as trawls, should be reduced. Seasonal variation in vulnerability to stress and/or damage during the tagging process can lead to incompatibility between experiments and obviate comparison. This factor should be taken into account during planning.

It should also be appreciated that trawls and other active fishing gears can cause considerable damage to fish. This can stem from the spines of fish or invertebrates such as sea urchins, entrained rocks or sharp garbage items, or may stem from the fishing gear itself (Jakobsson 1970; Jones, 1979).

Fish with closed swimbladders (physoclistous species) are very vulnerable to pressure changes (e.g. Harden Jones & Scholes, 1985) when hauled too quickly by fishing gear from depth to the surface. The physiology of the swimbladder of physicist species is dealt with in some detail in chapter 5, which also provides more information on capture and handling fish (Section 5.3).

3.2.2 Treatment before, during and after tagging

The following factors need to be considered:

- Quality of water in holding tanks (freshness, oxygen content, temperature)
- Suitability of the holding tank design (depth of water, space, texture)
- The nature and concentration of necessary anaesthetics or pacifiers
- Sterilising media for treating wounds

- Sufficient immobilisation of the fish (tagging cradles, troughs or holders; Jones, 1979)
- Adequate recovery time after anaesthesia
- Appropriate conditions for releasing the fish, in particular their vulnerability to the dropping from too great a height into the water; predation (from other fish, mammals and birds); fishing gear or propellers; violent movements of the boat

The vulnerability of fish during the process from capture to release of tagged fish makes it crucial that the whole sequence is kept as short as possible, since prolonged handling may harm the fish more than the tagging itself.

3.3 QUALITY AND CONSISTENCY OF RECAPTURE INFORMATION

Even if performed technically as well as possible, no tagging experiments could be regarded as successful unless accompanied by good reporting rates of recaptured tagged fish. Most fisheries research institutes have well established offices or systems to receive recaptured tags or information about tags and marks. If a tagging experiment or monitoring programme is dependent on tags and information being returned to the laboratory controlling releases, it is necessary to have such a system in place.

The work of receiving tags and information on tags and marks should be organised in such a way that all incoming tags are responded to immediately and all information filed. Lack of immediate interest by an institute will discourage fishermen from returning tags. It should be made very clear to all those who come across tags or marks what they should do with them - where to send the tags and what information to give. It is very useful to produce envelopes with the return address of the main fisheries institute in the neighbourhood on the front, and, on the back, a check list of all the information the institute wants to accompany the recaptured tag. It is important that as many people as possible should know that all tags and marks need to be returned and/or reported to the nearest fisheries institute. Refunds and information on the release of the tag (e.g. where and when released; what increments of growth have occurred since release) will in most cases make people motivated to return tags, as will some information concerning the experiment, its objectives and possible benefits to the fishing community.

The number of tags reported could be increased by several directed actions. In these actions it is important to emphasise the high scientific value of the reported tag and the overall benefit to industry and consumers of better knowledge. Protection and enhancement of stocks for better catches in future should also be highlighted. When dealing with Data Storage Tags, not only must the need to return the tag be shown, but it must also be clearly emphasised that such tags carry data of great importance for scientific research.

Publicising the need for reporting recovered tags include the following: advertisements in trade and local/national newspapers; setting up posters where the presence of tagged fish occurring in a certain area is highlighted; presentation of results in fisheries papers combined with statements of the need to get more data by obtaining more tag returns; and, where appropriate, personal contacts with fishermen in particular areas.

In some cases, when large shoals of fish have to be scrutinised for tags, direct co-operation between the institution originally tagging the fish, and the fishing industry itself may be necessary. If possible, the whole catch should be scrutinised for tags, but if this is not feasible for practical reasons, a proportion big enough to make it probable that sufficient tags will be found should be sampled.

Co-operation between institutions within the country as well as international agreements of exchange of reported tags should be established. To further underline the mutual benefit of such exchanges, offers of some exchange of data will be beneficial to the evaluation of the tagging results.

Besides information on tagging programmes and data exchange, the fishermen reporting tags need more incentive to send in each tag. An adequate reward scheme can take several forms. Simplest is a direct payment per tag reported, but alternatives include receiving souvenirs or the chance to take part in a later draw or lottery. This must be combined with effective publicity, and the encouraging information described above.

Examples of actions and particular arrangements, announcements and rewards to improve return rates of tags are numerous and some can be viewed on the CATAG web-site (http://www.hafro.is/catag). The web-site also features an example of how it can be used to aid searches for the origin of release for a tag that is found. The Internet is used and viewed by more and more people. Web-site information can be increasingly useful for the retrieval of tags both internationally and internationally. It will not be too long before a captain of a fishing vessel will have access to the WWW in the wheelhouse and can use a web-site to trace tags that his crew have found in the catch.

3.4 REFERENCES

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4. IDENTIFICATION TAGS AND MARKS

4.1 INTRODUCTION

The need to identify individual fish or groups of fish has been a basic requirement in fisheries science for many years. This has led to the development of a myriad of tag (defined as man made objects attached to a fish) and mark (defined as identifiable characteristics, either natural or applied to a fish) types, generally referred to as ID-tags. Applications depend on the purpose of the exercise, the species and size of the individual fish, or the number of identified individuals required for the study. New types of tag are continuously being developed to deal with the conflicts arising from information requirements on the one hand, and practical applications (permanency, identifiable, recognisable, effect on fish behaviour, etc) on the other.

One of the objectives of this project was to review tags and marks, but since simple ID-tags and ID–marks have been extensively reviewed, a summary of methodologies is given here. Electronic tags are dealt with in Chapter 5. An extensive literature on simple ID-tags and ID-marks is available with good reviews, such as Parker *et al.* (1990), Nielsen (1992) and Jones (1979). During the development of the CATAG project, a web-site was established (http://www.hafro.is/catag) for the dissemination of findings of the project. The web-site contains short but comprehensive details on marking or tagging methods and examples of their uses.

4.2 TAG AND MARK TYPES

External tags and marks are used to identify a group of fish or a number of individual fish. They are easy to detect, usually without special equipment or knowledge.

Internal tags or marks are mostly not visible from the outside and may need special equipment or intrusive methods to be detected to identify individual or groups of fish. An advantage of internal tags or marks is that in some cases a large number of fish may be tagged simultaneously and at a very early stage of the life history. An external tag or mark may be used to call attention to the presence of an internal tag or mark.

The categorisation employed in the following sections has been adapted from Parker *et al*. (1990).

4.3 APPLICATION OF METHODS

The numerous methods and the applicability of marking and tagging fish and other aquatic animals have been extensively reviewed (see for example Jones 1976, Laird & Stott 1978 or Wydoski & Emery 1983 for reviews of methods; Jakobsson 1970, Jones 1979, Parker *et al*. 1990, or Nielsen 1992, for more comprehensive reviews).

4.3.1 External tags

External tags are defined as visible tags applied externally on the fish. It follows that the tag is easily detectable and no special equipment is required for detection. These types of tags may carry an individual code, a batch code and/or visible instructions for reporting. Examples of these types of tag include ribbons, threads, wires, plates, disks, dangling tags and straps (McFarlane *et. al*., 1990).

The use of external tags for identifying individuals or groups of fish is the oldest recorded and most widely used technique applied. External tags have been used for both scientific and assessment purposes. The justification for any type of tag on a fish is the future recovery or recapture and the resultant information collected. The more advanced

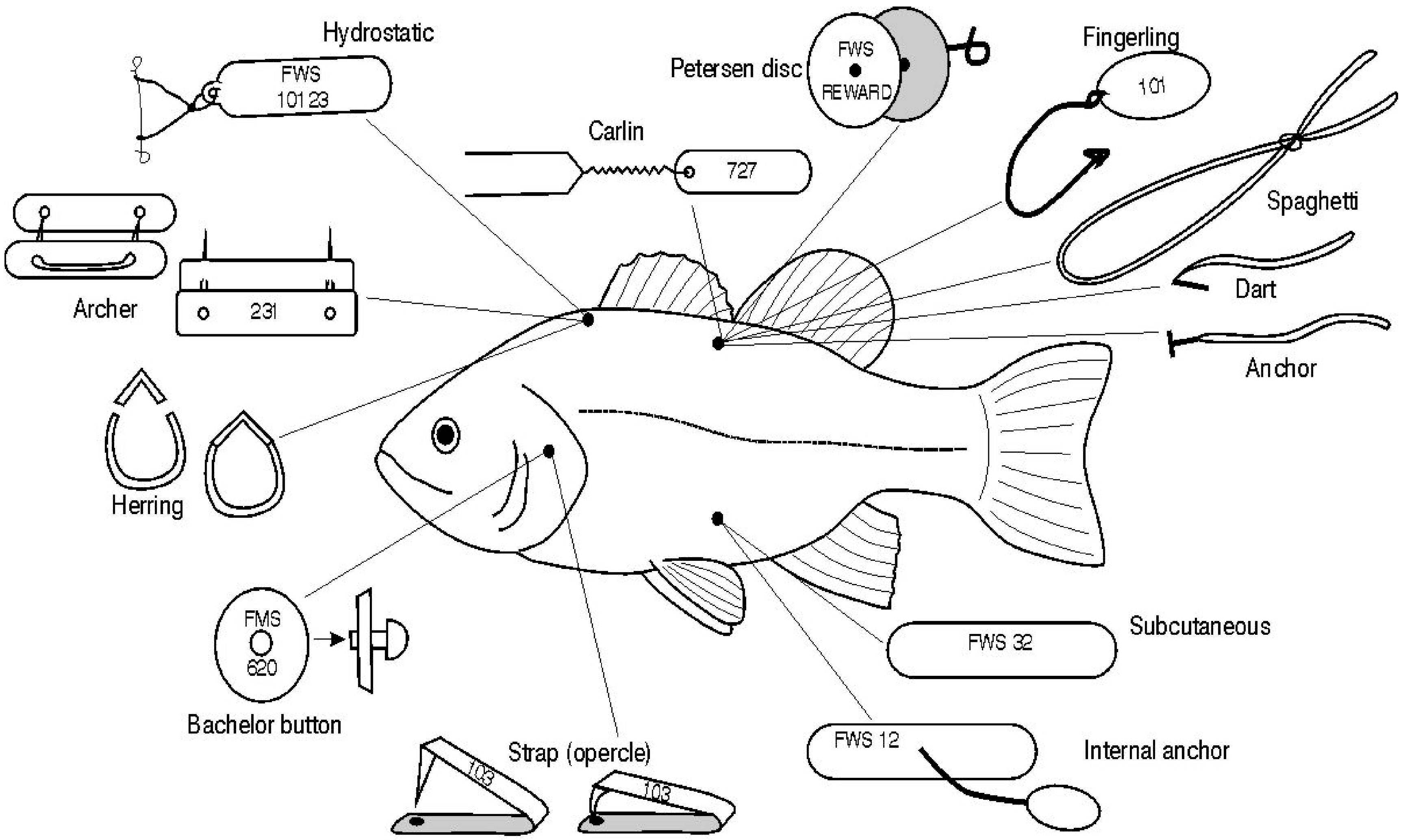

Figure 4.1 Principal types of external fish tags and attachment sites (redrawn from McFarlane *et al.*, 1990).

external tags can carry extra information on individual fish together with reporting instructions, information on rewards etc. The best known examples of external tags are probably T-Bar Anchor Tags (Jones, 1979; Morgan & Walsh, 1993) and Carlin tags (Carlin, 1955) and various modifications of these. Several different external tagging methods have been evaluated by Bartel *et al.* (1987), Dunning *et al.* (1987), Mattson et al. (1990), McAllister *et al.* (1992), Nielsen (1988), Nakashima & Winters (1984), Weathers et al. (1990) and Rasmussen (1980, 1982).

From the existing literature, the following advantages and disadvantages of using external tags can be summed up:

(a) Advantages

- Inexpensive, or simple to produce, which may make their use cost effective
- Easy and fast to apply, requiring only simple technology for the application
- Useable for a large range of fish sizes (depending mainly on the size of the tag)
- Applicable to large numbers of fish and to a great range of species
- Easily detected due to the exterior attachment
- Numbered tags enable the identification of individual fish
- Provide space for printing information and encouragement of tag-returns from all fisheries, which is a cost-effective reporting method
- Can give a broad geographical and seasonal return distribution
- Because of low cost, can provide a large number of returns, and sufficient data for statistical analysis and assessment
- Long tag-retention time (depending on the type of tag)

(b) Disadvantages

- Information is limited to identification of the fish and its origin, i.e. reporting does not provide information on the fish during the interim period from release until recapture
- Precision of the information on recoveries may be variable, since recoveries often come from all fisheries
- Return rates may be variable, since they often depend on reporting from all fisheries
- May affect growth, health and survival, due to penetration of the skin, providing an access route for infections, and due to the continuous drag on the tag if this protrudes from the fish
- Fouling of the tags may be a problem. Overgrowth of algae, barnacles and mussels may increase the drag on the tag considerably and may also make detection difficult
- May become entangled in aquatic vegetation or in fishing gear
- Tag losses may be high, depending on tag type, fish species and experience of the tagging personnel
- Can be difficult to apply or may not be applicable to very small fish
- May affect behaviour and swimming/hiding performance of the fish

4.3.2 External marks

An external mark may be defined as a mark visible on the outside of the fish and employed to identify individual fish or groups of fish, but without any information regarding reporting format. Examples of external marks are visible modifications of the fish body (or fins), pigments, dyes, stains, brands, and meristic or morphometric characteristics.

External marks are mostly used to identify a small number of individual fish or to distinguish between larger groups of fish. The techniques are suitable for field studies in relatively confined areas where recoveries are controlled by the institute that has conducted the marking. Use of external marking of individual fish has been limited in scope. Marks are often simple, cheap and quick to apply, but they carry limited information. Several different external marking methods have been evaluated by Coombs *et al.* (1990), Laufle *et al.* (1990), Knight (1990), Nielsen (1988) and Moffet *et al.* (1997). External marks like fin-clipping have often been used as a means of calling attention to the presence of internal tags.

External marks may be entirely natural. Morphological traits like scale numbers, number of fin rays, gill rakes or truss measurement may distinguish groups or populations of fish (Sneath & Sokal, 1973; Schweigert, 1990).

The advantages and disadvantages of external marks are listed below:

(a) Advantages

- Marks are inexpensive and usually rapid to apply; this makes their use popular for many types of studies
- They are ideal for identification of separate populations or batches
- They are usually simple to apply and personnel may not need to be specially trained
- Little or no effect on fish growth, health and behaviour is produced
- Marks can be suitable for a range of sizes, since the fish do not have to carry a tag
- Marks may have long duration, depending on the type of mark
- They can be applicable to large numbers of fish and to many species

(b) Disadvantages

- A limited number of codes or combinations are possible
- Returns from a broad geographical area and for a long span of time e.g. commercial or recreational fisheries - cannot be expected
- In most cases researchers or surveyors have to recover the marked fish themselves
- There are possibilities for recognition errors, due to confusion between marks
- Marks may deteriorate with time

4.3.3 Internal tags

Internal tags are defined as tags inserted or injected into the fish (body cavity, muscle or cartilage) and carried internally. They can be used to identify individual fish or groups of fish. Most of them, including Coded Wire Tags (CWTs), have to be removed from the fish to be identified, but the more advanced ones, such as Passive Integrated Transponder Tags (PIT tags) can be read without removing the tag, thus providing a completely non-destructive means of identification. Examples of internal tags include plastic or glass tubes, metal plates, small pieces of magnetised metal (CWTs) or semi-electronic tags transmitting information (by radio waves) when an electrical current is induced (PIT tags).

The need to identify fish individually and to identify groups of fish with certainty with minimal influence on behaviour, health or survival has led to the development of internal tags. The single tag type applied to the largest number of fish is probably the CWT (Schurman & Thompson, 1990). These are small pieces of magnetised stainless steel (size 0.5-2.0 mm x 0.25 mm), which may have a binary code engraved in the surface or laser etched Arabic numbers, either for individual or batch identification. CWTs are normally injected into the snout of a fish and are often combined with an outer mark, to aid recovery.

Detection often relies on automated screening of catches, particularly in the relevant industries (grading, processing). These tags are extensively used for tagging large numbers of fish, but special detection equipment is needed. CWTs may, due to their small size, be applied to a large range of fish sizes. Buckley & Blankenship (1990) evaluated the use of CWTs. For further information on the use and applicability of CWTs see the web-site of NMT (http://www.nmt.inc.com).

Magnetic Body Cavity Tags (MCTs) are steel plates inserted into the body cavity of the fish. The tags are detected during fish processing with magnets placed at strategic positions in the industrial units. This type of tag has been used for research and management purposes for the Atlanto-Scandian herring stock (Jakobsson, 1970; Monstad, 1990) and is apparently an important method for the monitoring of this resource (Anon., 1997).

PIT tags (size approx. 12 mm x 2 mm) could, in larger fish be injected into any part of the fish where the flesh is thick enough to retain the tag, but are most often positioned loosely in the abdomen. PIT tags are normally used on smaller numbers (up to hundreds) of fish. PIT tags have also found use in aquaculture, to identify breeding individuals. The specialised equipment for reading the tags limits the recovery to areas where catch can be screened, or in fresh water where fish can be guided through very narrow passages. The use of PIT tags has been evaluated by (amongst others) Prentice *et al.* (1990), and Van-Dam & Diez (1997).

The advantages and disadvantages of internal tags are summarised as follows:

(a) Advantages

- Tags have little or no effect on growth, health and survival
- They are suitable for a wide range of sizes and many species of fish
- High retention rates are exhibited
- With suitable equipment, very large numbers of fish may be tagged by semi- or fully automated tagging procedures with minimal handling of the fish (CWTs)
- Individual recognition of fish is possible
- Repetitive and non-destructive recoveries are feasible (PIT tags)

(b) Disadvantages

- Expensive equipment is required for tag application and detection (CWT, MCT, PIT)
- Expert personnel are needed for tagging (and retrieval of CWTs)
- Recovery of specimens of fish may be labour-intensive (CWTs)
- Tag retrieval and identification can be labour-intensive (CWT)
- Tag migration within the body of tagged fish may reduce the probability of recognition (CWTs)

4.3.4 Internal marks

Internal marks may be defined as marks not visible from the outside of the fish. Internal marks are either naturally-occurring or artificially produced marks, that characterise either individuals or, more often, groups of fish. Often they are marks in the bony structure, and may be produced in various ways.

Internal marking is most often applied to batches of fish, when marking needs to be done in a very mild and non-invasive fashion, and when it is acceptable that recovery of information necessarily involves sacrificing or damaging the fish. Marks can be produced chemically. In this case detection may require analysis of the chemical composition of the bones (for example stable strontium). Alternatively, the mark may be detected visibly (e.g. alizarine or oxytetracycline revealed by ultraviolet light). Applications involving the use of certain chemicals can be controversial because of later human consumption of marked fish or because of entry of unwanted chemicals into the food chain. In most cases the final concentrations in the fish are very low and may be negligible. Brothers (1990) gives an overview of various otolith marking techniques, while Reinert et al. (1998), Akinicheva & Rogatnykh (1996), Ruhle & Winecki-Kuehn (1992), Monaghan (1993) and Ennevor (1994) provide information on various internal marking techniques.

Marks can also be produced by inducing a controlled growth pattern, leaving distinct 'checks' in the bony structures. Internal marks may also be entirely natural biological phenomena. These include morphological traits (e.g. number of vertebrae, or pyloric caeca) that distinguish groups of fish from each other (Sneath & Sokal, 1973; Schweigert, 1990), or the presence of parasites belonging only to certain fish populations (Kabata, 1963).

Advantages and disadvantages of internal marks are summarised below:

(a) Advantages

- There are minimal immediate effects from handling and marking.
- Chemical marking is most often carried out by submersion in a chemical solution, or by adding a chemical to the feed so is simple, rapid, inexpensive and applicable to very large numbers of fish.
- Distinct growth patterns are produced in the natural environment and can be induced through a strictly controlled temperature regime.
- Natural marks are, by definition, carried by the fish, so no extra marking or additional handling is needed.
- Effects on behaviour, growth, health and survival of fish are minimal (often absent).
- Normally the techniques are applicable to a wide range of fish sizes.

(b) Disadvantages

- Recovery usually requires sacrificing fish (for example for the removal of otoliths).
- Recovery and analysis may be expensive, very time- and labour-consuming, and consequently may not be cost effective.
- Analysis demands expert personnel and specialised laboratory facilities.
- Marking natural populations chemically requires holding fish for a period of time long enough to produce the marks - this has resource/space implications.
- The techniques can be difficult to apply to natural populations in field studies.

4.3.5 Internal tags - externally and visibly detected

These are tags that are placed sub-cutaneously on fish in positions where they are visible from the outside. A well known examples of this type of tag exist, the Visible Implant Tag (VIT) or a newer type the Visible Implant alphanumeric (VIalpha).

This type of tag was developed in an attempt to combine the advantages of external tags with those of internal tags. It is applied in studies where a minimal disturbance of the fish is required. VITs are made of plastic strips and VIalpha are made of medical-grade silicone rubber often with the addition of fluorescent material. These tags come with printed information and placed for example on the cheek of brown trout (*Salmo trutta*), just behind the eye. They are most often used in research work where the institute carrying out the project also recovers tagged specimens, since tags may easily be overlooked. The use of

VITs has been described by Bisgaard & Pedersen (1991), Bergman et al. (1992) and Treasurer (1996). For further information on the use and applicability of VITs or (VIalpha) see the web-site of NMT (http://www.nmt.inc.com).

(a) Advantages

- All of the advantages of the internal and external tags apply to these tags except for their durability, which may be low.
- Tags may be read repeatedly without damaging or sacrificing the fish.
- Tags are simple and relatively inexpensive.

(b) Disadvantages

- Tag loss may be high.
- Tags can migrate in the fish to places where they are not visible.
- Transparency of the overlying tissue may change, causing the tag to become less visible with time.
- Application may be relatively slow requiring skill and special tag injection equipment.
- Tags may easily be overlooked, causing non-reporting of tagged animals by the recreational or commercial fishery - an obvious drawback.

4.3.6 Internal marks - externally and visibly detected

These are marks placed sub-cutaneously on fish in places where they are visible from the outside. The elastomer is an example of this type of mark.

In an attempt to combine the advantages of external marks with those of the internal marks, elastomers were developed. They are applied in studies where minimal disturbance of the fish is required. The marks consist of coloured and/or fluorescent plastic paint. They may be placed (for example) between the fin rays or at the base of the fins. Mostly they are used in research work where the institute carrying out the project also conducts recovery of marked specimens, since marks may easily be overlooked. Visible Implant fluorescent Elastomers are used to mark millions of Pacific salmon as well as shrimp and other aquatic animals. The use of elastomers has been evaluated by Godin *et al.* (1996) and Morgan & Paveley (1996). For further information on the use and applicability of VIEs see the web-site of NMT (http://www.nmt.inc.com).

(a) Advantages

- Marks are simple, inexpensive and are relatively easy to apply.
- The marks may be recognised repeatedly without damaging or sacrificing the fish
- They are suitable for many sizes of fish, even down to 10 mm length (Frederick, 1997)
- With suitable equipment, large numbers of fish may be marked
- If correctly applied good mark retention is achieved
- Individual or group identification is possible using different colours or mark positions

(b) Disadvantages

- Transparency may change causing the mark to become less visible with time
- Special mark injection equipment needed for large numbers

- Marks may easily be overlooked. As a consequence non-reporting of marked animals by the recreational or commercial fishery is an obvious drawback
- Special equipment such as UV-light may be necessary for detection

4.3.7 Genetic marks

Genetic marking is peripheral to the CATAG initiative. The use of genetic markers for identification purposes has been described by Hansen *et al*. (1995), Pella & Milner (1987), Lane *et al*. (1990), Galvin et al. (1995) and Fergusson *et al*. (1995). To withdraw genetic marks, only a sample of body tissue is needed for analysis. Individual recognition is described by Hansen *et al*. (1997). Practical guidelines to genetic marking may be found in Gharret & Seeb (1990).

4.4 GENERAL APPLICABILITY

Tagging or marking fish with ID tags or marks has wide applicability and is used to study population dynamics of fish stocks or populations. External and internal tags have been used in studies to determine growth (Francis, 1988), or to estimate von Bertalanffy growth curves in natural populations (James, 1991; Kimura *et al*., 1993). Such tags have also been applied for estimating post-release survival, migration and behaviour of released reared fish. European examples include work on salmon in the Baltic (Carlin, 1969) and cod in Norway (Svåsand & Kristiansen, 1990a, 1990b). Being cheaper than electronic tags (e.g. DSTs), some of these tags are ideal for preliminary experiments prior to the application of more costly tags, or they can be used in conjunction with electronic tags to indicate the presence of the latter. Furthermore, results of introductions, conservation of species, transfers and improvements of fish stocks or populations can be monitored and evaluated. Before embarking on a tagging or marking programme, it is important to assess the applicability of different types of tags or marks.

4.4.1 Types of studies

Examples of types of studies involving tags or marks include the following:

- Estimates of mortality from recapture rates, e.g. total, natural mortality, fishing mortality, tagging mortality
- Estimates of survival rates, e.g. after release of hatchery fish to the wild, escapees from fishing gear
- Study of migration patterns, e.g. research on spawning areas and migration in the wild
- Description of geographical distributions
- Studies of feeding behaviour, e.g. feeding areas and migration in the wild
- Studies of growth, e.g. growth patterns of individuals or groups of fish
- Management studies, e.g. effects of management decisions and measures taken to improve population strength
- Studies of harvest effects on population dynamics
- Studies on harvest patterns, e.g. effects of yield of harvest in different areas and periods
- Studies on fishery impacts or efficiencies, e.g. effects of types of gear used to harvest in different areas and at different periods
- Studies of the reliability of tagging methods, e.g. by applying more than one tag or mark at a time
- Studies of tag retention, e.g. double tagging

- Mixed tagging experiments, to study the relationship between recapture rates of different types of tags, or in conjunction with electronic tags to identify their presence

4.4.2 Limitations and restraints

Although tagging in most cases can be done without seriously affecting fish health and behaviour it must be remembered that no single type of tag or mark is perfect; each has its advantages and disadvantages as shown in section 4.3. In particular, external tags may cause health problems for tagged fish as the application implies penetration of the body and dangling tags may cause continuous irritation and access for microbial infections. The influence of tags on fish health, behaviour and growth is dealt with in section 4.4.3 (and more comprehensively in Chapter 7). Tags and marks may be lost or deteriorate during the period from tagging to recapture. Tag losses could result in data misinterpretation. Gathering of data may also be hampered by factors beyond the influence of the marker, such as low or irregular return rates from different fisheries. The fishery pattern (type, distribution, effort, etc.) in the release/recapture area may also influence the distribution of recaptures and thus bias results on migration or distribution. In order to obtain sufficient data for analysis, an adequate number of fish must be tagged or marked.

4.4.3 Influence on behaviour, growth and general health

Ideally behaviour, growth and survival of tagged and untagged fish are similar. While this may be true to many types of tags and marks, external tags especially may affect behaviour and survival. For example, fish with external tags may be more vulnerable to predation, or growth may be affected. By permanently penetrating the skin the tag may provide an access route for infection. Additionally, tags may become overgrown with algae, barnacles or mussels, adding weight to the tag and increasing drag. Tagging or marking of fish involves treatment and handling, which disturbs and possibly stress the fish. Careful handling procedures throughout the capture and marking process are of highest importance.

These questions are dealt with in detail in Chapter 7 of this report and on the CATAG web-site (http://www.hafro.is/catag) under ‘Welfare’.

4.5 SHELLFISH TAGGING

CATAG is primarily concerned with finfish. However, tagging is also of use for studies on shellfish, mainly crustaceans and to a lesser extent molluscs. It seems probable that the ease of attachment of DSTs to the hard shells of these groups will promote increasingly ambitious research. The information given below is introductory rather than exhaustive.

4.5.1 Crustaceans

Crustaceans, particularly crabs and lobsters, have been tagged for identification purposes at least since the 1930s (MacKay, 1942). Initially this was done on newly-moulted crabs and solely to determine migratory distances. Mostly these early studies used chicken tags or Petersen disc tags attached to the carapace by wires.

The major problem for all crustacean tagging is caused by moulting. At this time the exoskeleton splits along pre-determined fracture (‘suture’) lines and the soft animal emerges backwards, leaving the ‘old’ exoskeleton behind. Any tag must a) survive the moulting process, and b) not interfere with moulting itself. A simple method is to use v-notching of various parts of the anatomy (e.g. carapace edge, telson), but these marks will tend to disappear after one or two moults, and may not be evident to fishermen anyway.

During the 1950s 'suture' tagging was introduced in crab studies in North America and Europe (Harville & Verhoeven, 1978; Edwards, 1979). In this case two holes were drilled on the carapace suture line and stainless steel wire passed through the holes. Plastic Petersen button-type identification tags were attached by the wire. Mortality during the tagging process was low (<5%; Edwards, 1979), but the holes tended to enlarge with time, showing the characteristic blackness of damaged, necrotic crustacean exoskeletons. Laboratory and field trials showed that tags could be retained through moults, but experience indicates that positioning of holes must be very precise. This basic technique (but with replacement of steel wire by braided terylene) has been used ever since in crab studies, and has given good data for growth rates, but only in relatively large and robust crabs such as *Cancer pagurus*, *Cancer magister* or *Scylla serrata*. Smaller species (e.g. *Necora puber*) suffer much greater mortalities. The technique is also less suitable for population estimates because of the suspicion that tag loss rates are high (50+%?).

Crabs are also commonly tagged with claw tags. Originally these were discs attached around the base of one of the claws by stainless steel wire - nowadays nylon cable ties are used instead. This type of tagging can be used for short-term population estimates and for estimation of migration distances - the tags are always lost at moult.

New tagging methods are still being attempted in crustaceans, all aimed at solving the moult problem. In all cases, the method aims to attach tags to muscle rather than exoskeleton. This has been particularly successful in prawns, crayfish and lobsters, all of which have a large muscular abdomen, with relatively large arthrodial membranes between the abdominal plates. Floy® market three types of tag for these animals. Firstly, there are anchor tags that are injected into the arthrodial muscle and have a piece of monofilament connecting the anchor and an external piece of vinyl tubing. Barbed stainless steel or nylon T-bar anchors have been used. A more effective version that certainly survives moult is the 'streamer' tag, which passes through the abdominal musculature from side-to-side with two polypropylene streamers emerging on either side of the body. Anchor tags and streamer tags have also been used on crabs, but great care has to be taken over placement or damage can be done to the vascular system. Floy® also market 'spaghetti' tags for crabs - these are vinyl tubing loop tags that pass through muscle at the junction between carapace and abdomen.

Stock enhancement studies with crustaceans require tagging of large numbers of animals, and in most cases these tags must survive many moults. The most successful approach has been that used in hatchery-reared lobsters (*Homarus gammarus*) released into U.K. waters. In this case minute coded-wire tags were injected into the abdominal musculature of juveniles a few cm long. These have been found in adults recruiting to the fishery after several years (Bannister *et al.*, 1994). Larger individually-coded wires can also be used with adult crustaceans, but the risk of them entering the human food chain is usually too great. Chemical tagging (in this case by dye injection) has been used in penaeid prawns (Davenport *et al.*, in Press) to permit population estimates in mark and recapture trials.

Any tagging technique that requires surgical implantation would be unlikely to succeed - crustaceans have open blood systems and penetrations of the exoskeleton beyond small holes are almost invariably fatal because of blood loss or extensive necrosis. Most crustaceans also show marked agonistic interactions - fights between individuals are likely to dislodge external tags.

4.5.2 Molluscs

Tagging of shelled molluscs (mussels, oysters, scallops etc) is done rarely, though scallops have been tagged for growth studies in aquaculture. Tagging is simple - either holes can be drilled through parts of the shell (e.g. the 'ears' of scallops) and plastic tags attached by wires or cable ties. Alternatively, tags can be attached directly to the shell by adhesive (after abrasion to remove periostracum) - this approach has often been adopted in academic studies (e.g. Davenport, 1989).

4.6 REQUIREMENTS AND RECOMMENDATIONS

Protocols for optimal handling procedures throughout the capture, and marking process need to be made and updated for different species. National and international courses on tagging procedures are recommended. Recommendations on treatment of the fish are further discussed in Chapter 7.

There is a need for further studies on the impact of tagging and handling procedures and the tags themselves on growth, survival and behaviour especially when the objectives are to estimate the natural mortality, growth and migration patterns in natural populations.

While many of the problems mentioned in section 4.4.3 are often severe, many of these could be avoided by careful choice of tag or mark and after completion of feasibility studies.

Choice of tag or mark type should be made after a cost-benefit analysis of the individual method including the marking and recovery costs as well as the quality of data required.

Simple and cheap ID tags are recommended in preliminary studies to estimate potential return rates before embarking on studies using more sophisticated and expensive tags or marks.

Simple external ID tags or marks should be used to indicate the presence of internal tags or marks.

Simple ID tags or marks should also be employed in mixed tag experiments, but not only to indicate the presence of electronic tags. Programmes involving electronic tags should also incorporate fish tagged with simple tags or marks to provide better information on reporting rates than would be feasible if expensive electronic tags alone were used.

There is a need for further development of existing tag types. A particular concern is that fouling problems should be addressed - biofouling of tags may be a significant problem in tagging studies, but has been little studied.

There is a need for further development of tagging techniques to minimise handling and fish holding times. Development of reliable, user-friendly techniques for underwater or in situ tagging merit particular support.

When introducing new tagging methods, care needs to be taken to avoid loss of valuable data-time-series (historical data) collected by older techniques. To do this, comparative experiments should be conducted for a period sufficient to give confidence in the ability to cross-calibrate between the two techniques.

Double tagging experiments are recommended for comparisons of tag performance.

The value of tagging or marking is crucially dependent on how precise and comprehensive the information on the recovery is. The number of fish being tagged must be large enough to take into account the expected recapture, recovery or reporting rate. A number of measures could be taken to improve reporting rate. These include the following:

- Adequate rewards for returning the tag
- Advertisements to further stimulate reporting
- Direct communication with local fishermen
- Regular information bulletins on the progress of the project
- Prompt response to persons returning or reporting tags
- Anonymity should be guaranteed for those reporting on recaptures

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5. ELECTRONIC TAGS

5.1 INTRODUCTION

In recent years, the most significant advances in tagging and tagging methodologies have come about with the development of electronic tags (e.g. Stasko & Pincock, 1977; Priede, 1992; Arnold & Dewar, 2001; Arnold & Lundgren, 2002). The range and versatility of these tags has meant that new applications are constantly being discovered and the full benefits to be derived are barely being exploited at present. It is because of this that a significant amount of attention should be drawn to this area in future fisheries related studies. As electronic tagging techniques are constantly being developed and improved, consideration is given in the following section to current methodologies and progress with capture, handling and recovery of tagged fish. Particular attention has been paid to attachment methods, especially with regard to modifications to the normal behaviour of the fish that may make interpretation of data difficult to apply to whole populations. Apart from providing information on fish location and position in the water column, it is now possible using electronic tags to provide details of the immediate environment of the fish in real time and over long periods, thus allowing study of the factors which most influence their subsequent behaviour. Some of the recently developed electronic tags depend on recovery through commercial fisheries. For this reason information is presented on the approach to be taken when organising studies which require intensive and systematic tag recovery programmes.

To illustrate the enormous potential for fishery based applications that could be developed, specific examples of electronic tag application are given which have already provided significant input into fisheries related surveys and investigations of fish movements. Finally, a comprehensive examination is presented outlining the future developments needed to sustain necessary technological developments and to consolidate recent advances.

5.2 TAG AND SENSOR CLASSIFICATION

In recent years there has been a proliferation of electronic tag types and systems for tracking fish at sea and in freshwater. Many of these tags have been designed with specific applications in mind. The more generally applicable tags are described here together with their operational details. The list is not meant to be exhaustive but to give a broad overview of the tags that are most commonly used. Specific details on individual makes and manufacturers can be obtained from the CATAG website **(http://www.hafro.is/catag)**, which has links to most of the main manufacturers of electronic tags worldwide. A summary classification is given in Figure 5.2.1 and described below. In adopting it, we have taken a pragmatic approach and listed radio tags together with acoustic tags in order to emphasise common operational features, such as coding and programming. We think this will be more helpful to potential tags users than classifying radio tags with inductively-coupled tags which also transmit electromagnetic signals, albeit at a much lower frequency (Priede, 1992). Tag characteristics and typical dimensions are summarised in Table 5.1.

5.2.1 Inductively-coupled electromagnetic tags

5.2.1.1 Passive Integrated Transponding (PIT) tags

The PIT tag consists of a small glass-encapsulated electromagnetic coil and microchip that is inserted into the body cavity of a fish using a veterinary syringe. The tag is inert until it is activated inductively by a tag reader, which provides the power for the tag to transmit a unique alpha-numeric code. Typical systems provide the possibility of using billions of codes (Prentice et al 1990a, b). The tags are energised at frequencies of approximately 400 kHz generating a return signal of between 40 to 50 kHz. Tags can be decoded with a portable hand-held reader, which has a range of 10-15 cm. Automatic readers are also available with either a tunnel detector (up to 30 cm diameter) or a strip detector, which can be placed on the bed of a stream (up to 20 cm depth). PIT tags generally range from 11 to 28 mm in length and 2.1 to 3.5 mm in diameter.

PIT tags may last throughout the life cycle of their "hosts" and the tagging system allows rapid retrieval of transmitted information from large numbers of tagged fish. They can be detected and decoded in living fish in fresh and salt water, and they eliminate the need to anaesthetise, handle, restrain or kill the fish during data retrieval. Used with computer stations, they allow repeated identification and measurement of individuals within a population. As each PIT tag can carry a short unique code, it provides a good basis for many types of survey where the fish are able to come in close contact with detecting equipment. As the tag detection range is quite short, the principal disadvantage with PIT tags is the requirement for specialised fish pass facilities (e.g. raceways, bypasses, separators, and collection-diversion systems) which limit the applicability of the technique (Prentice et al 1990a, b).

5.2.1.2 Electromagnetic tags

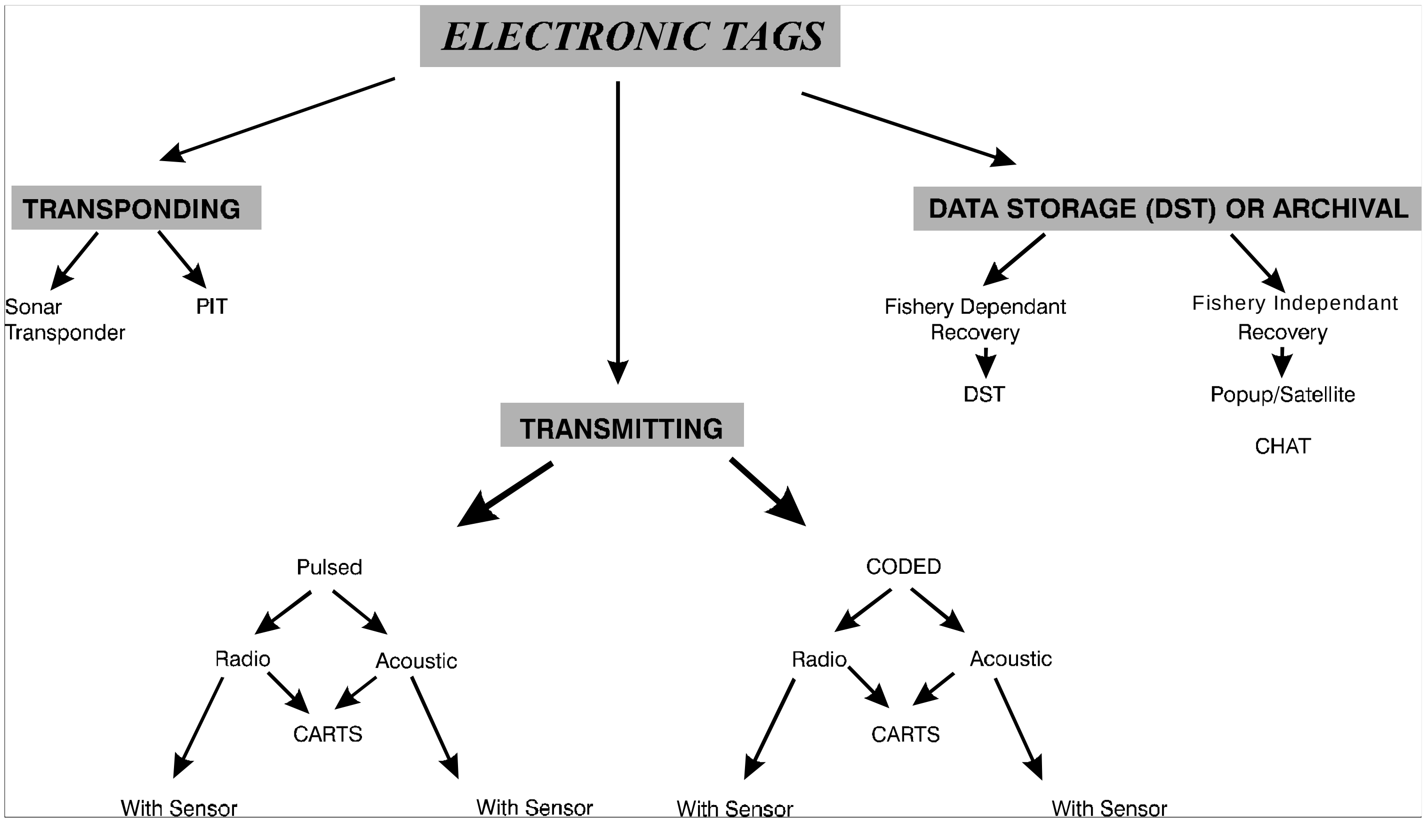
At frequencies below the VHF radio band (wavelength 1-10 m), antenna dimensions are too large to be useful for most animal telemetry (Priede, 1992). However, low frequencies have the advantage that the magnetic component of the electromagnetic wave penetrates seawater and solid rock to a significant degree (Dunbar, 1972), without the attenuation and reflection experienced by acoustic signals. Field strength decreases as the fourth power of distance, so inductive coupling can only be achieved over ranges of a few metres (Priede, 1992). This is sufficient, however, for the principal to have been applied successfully with slow moving, bottom-living crustaceans, using a series of detector coils placed on the sea bed and connected to an onshore monitor. The first systems were developed in Australia and tested on the rock lobsters *Jasus novaehollandiae* (Ramm, 1980) and *Panulirus cygnus* (Phillips *et al.*, 1984).

Subsequently a more robust and fully automated system (Jernakoff, 1987) was developed and used extensively to study the movements of *P. cygnus* in a shallow (<3 m) lagoon-like environment off the western coast of Australia (see Section 5.6.2.2). The system employed electromagnetic tags, which emitted a 31 kHz signal of 1.2 to 3.2 s duration, and were glued to the cephalothorax with epoxy resin. Fifty loop-antenna aerials made of double-insulated seven-strand copper cables (1.5 mm^2) were laid over an area approximately 100 x 160 m and held in position by steel tent pegs. The aerials were 12 x 12 m and were separated by a gap of 6 m. The tag detection distance was 6 m. Both aerials detected a tag between two loops and this information was used in determining the position of the lobster. A computerised system was used to record and decode information from up to 14 tags at any one time. The system sequentially scanned each of the 50 aerials every 10-min and tag signals were identified automatically.

A similar system (Collins, 1996; Collins *et al.*, 2000; Smith *et al.*, 2000), also based on Ramm's (1980) approach, has been used to study the behaviour of the European lobster, *Homarus gammarus* (see Section 5.6.2.2). The tags (40-mm dia. x 10 mm deep), which were glued to the carapace (70-136 mm), contained a transmitting coil, microcontroller, tilt switch and battery. Emitting 3 ms pulses at a frequency of 32.7 kHz, the tags were detected by 5-m diameter loops laid around an artificial reef and connected to a central receiver and

Tag type and Section Ref.	Description	Application	Diameter (mm)	Length (mm)	Weight (g)	Frequency	Pulse Rate bpm	Detection Range (m)	Fish Size Lower (cm	No. per Frequency	Attachment Area	Tag life (Days)	Available Sensors
5.2.1 Transponding Passive Integrated Transponder (PIT)	Transmits a binary coded signal when enegrised by a detector	Stock monitoring. Fish passage	2	10 - 12				30cms	18	>100	Internal, muscle	indefinite	No
Transponding acoustic	The tag contains an acoustic transmitter and transponding features. Ships sonar can trigg the transmission of an acoustic signal	Tracking of fish in the water column	1	5	4 (in salt water)	300 KHz		300	40	10	External	4	No
5.2.2 Transmitting Pulsed radio	Non-programmable Transmits a simple radio pulse at set intervals to a radio receiver	Tracking in freshwater. Migration studies	14 - 40	33 - 79	10 - 78	30-150 MHz	20 - 80	100m	18	10	External or internal	<1000	Temperature, activity
	Programmable Contains a programmable micro-chip The tags can be programmed to switch on at preset times. The signal is sent to a radio receiver	Tracking in freshwater. Migration studies	7 - 12	11 - 55	0.75 to 10	30-150 MHz	20 - 80	100m	18	10	External or internal	< 400	Temperature, activity, electromyogram
Pulsed acoustic	Non-programmable Transmits a simple acoustic signal to an acoustic receiver which then transmits a radio signal to a radio receiver	Tracking in fresh or saline water. Migration studies.	7 - 12	11 - 55	0.75 - 10	30-150 MHz	20 - 80	100m	18	10	External or internal	< 400	Pressure
Combined acoustic and radio (CART)	Programmable Contains conductivity sensor which can switch the signal transmitted from acoustic to radio allowing tracking in saline and freshwater bodies.	Tracking in fresh or saline water. Migration studies.	11	55	10	30-150 MHz	20 - 80	100m	18	10	External or internal	< 400	Conductivity
Coded radio	Contains a programmable micro-chip which can transmit a digitaly encoded radio signal at user defined intervals to a decoder/recorded	Tracking in freshwater. Microhabitat utilisation Fish entrainment behaviour	7 - 18	16 - 83	1.4 - 29	30-150 MHz	variable	100m		>150	External or internal	< 700	
Coded acoustic	Contains a programmable micro-chip which can transmit a digitaly encoded acoustic signal at user defined intervals to a decoder/recorder	Tracking in fresh and saline water, fish entrainment, micro-habitat utilisation,	8 - 18	16 - 70	0.4 - 16.6	30-150 MHz	variable	100m		> 150	External or internal	< 700	
5.2.3 Data Storage 1 **Recovery dependant** (DST or archival tag)	Tags which record information about the fishes surroundings on internal memory. The tags must be recovered in order to retrieve the saved information	Vertical and horizontal fish movements. Habitat preferences. Evironmental cues. Gear efficiency.	13 - 30	40 - 110	10 - 70						External or internal	>300	Depth, temperature, light, salinity,
5.2.4 Data Storage 2 **Recovery independent** Popup/Satellite Communicating history acoustic transponders (CHAT)	Tags which record information about the fishes environment on internal memory but which have the capability of transmitting this information to satellite (popup tag) or other remote receiving station (CHAT).	Migratory behaviour of highly migratory fish species and environmental factors during migration	4 32	18 150	65 190	401 KHz 27-33 KHz	1	1900 km	500 - 200 >100	>100 >100	External External	>300 500	Depth, salinity temperature, Depth, temperature,

Table 5.1. Summary information relating to electronic tags


ELECTRONIC TAGS
TRANSPONDING
Sonar Transponder
PIT
TRANSMITTING
Pulsed
Radio
Acoustic
CARTS
With Sensor
With Sensor
CODED
Radio
Acoustic
CARTS
With Sensor
With Sensor
DATA STORAGE (DST) OR ARCHIVAL
Fishery Dependant Recovery
DST
Fishery Independant Recovery
Popup/Satellite
CHAT

data logger on the seabed. The detection range of each loop antenna extended some 3-m beyond its perimeter and each tag was individually identified by its pulse rate (0.5-1 Hz). Lobster activity was quantified on a scale of 0-7 by counting the number of changes of state of the tilt switch inside the tag during each 10-min period and coding them on an exponential scale.

5.2.2 Continuously transmitting radio and acoustic tags

This is a large family of tags, which is increasing in size due to new developments for specific applications. These tags are larger than PIT tags and require an internal battery to power the transmitter and microchip (if present). The lifetime of the tag is a critical consideration in telemetry studies and depends on the trade-off between transmitter size, power supply, range and rate of the signals. Telemetry studies on free swimming fish are generally short-term studies ranging over periods of hours to months. Apart from pulsed and coded signals, which identify the individual fish, some tags also transmit data from physical or physiological sensors (Priede, 1992). Sensors can record depth, swimming direction and speed, or heart rate. The behavioural and physiological data sampled via transmitting tags can be used to study the activities of fish in relation to their immediate environment and also in relation to anthropogenic factors (fishing gears, dams, oilrigs, effluents etc). Microchip technology allows for specific instructions to be placed on some types of tag that allow the tag to be switched on or off under specified conditions (e.g. entry into freshwater). These features can be used to increase the longevity of the tags, or to transmit under certain environmental conditions. Accurate geolocation is possible by a variety of methods. The detection range, which may extend to a kilometer in some instances, is generally less than 100m. Attachment of the tag can be internal or external (see Section 5.4).

5.2.2.1 Pulsed tags

Radio and acoustic transmitting tags can transmit a simple pulsed signal at a selected pulse rate. Theoretically, large numbers of fish can be monitored simultaneously, using multiple frequencies or pulse rates. In practice, however, it is very difficult to distinguish more than four or five pulse rates on an individual frequency.

Radio tags, which can only be used in water of very low salinity, are useful in freshwater because radio waves are less affected by physical obstacles, turbidity, turbulence and thermal stratification than acoustic (non-electromagnetic) waves. Radio signals also radiate through the water surface and can be detected at great distances because there is little loss of signal strength in air (Priede, 1992). Receivers can be fitted in boats, aircraft or land-based listening stations (e.g. McCleave *et al.*, 1978; Solomon & Potter, 1988; Eiler, 1995). Radio tags operate at high frequencies (20-250 MHz), so there is little signal drift.

Acoustic tags are used in the sea because sound is transmitted over long distances in salt water, whereas radio waves are attenuated very rapidly (e.g. Niezgoda *et al.*, 1998). Frequencies of 30-300 kHz are used. Pulsed acoustic tags have been used to follow a number of species in the open sea, often using a simple receiving system comprising a directional hydrophone, a portable receiver and headphones (e.g. Stasko & Polar, 1973; Lawson & Carey, 1972; Holland *et al.*, 1985). This method provides only a rough indication of the position of the fish relative to the tracking boat. Accurate position fixing with a pulsed tag requires triangulation using an array of fixed hydrophones (e.g. Urquhart & Smith, 1992; Smith *et al.*, 1998c; O’Dor *et al.*, 1998; Cote *et al.*, 1998; Voegeli *et al.*, 2001).

(a) Non-programmable pulsed radio tags

Non-programmable transmitter tags are used to transmit a simple radio pulse at set intervals. They require radio receivers operating at 30-50 MHz frequency range to detect the signals.

(b) Programmable pulsed radio tags

Programmable microprocessor tags are used to transmit simple radio pulsed signals at user defined intervals. Specific on/off sequences can be set which can be useful for preserving the battery life of the transmitter. The tags can include sensors that measure behavioural and physiological variables, such as electro-myograph (EMG) (Demers *et al.*, 1996; Kaseloo *et al.*, 1996) and tail beat frequency (e.g. Young *et al.*, 1972; Voegeli & Pincock, 1981; Lowe *et al.*, 1998), which can be telemetered to the receiving station.

(c) Non-programmable pulsed acoustic tags

These tags telemeter a simple acoustic pulsed signal to an acoustic receiver. They are generally used in saline or semi-saline conditions, where radio signals cannot be transmitted. There is a limitation on the number of individual fish that can be identified as each receiver can only differentiate a single frequency.

(d) Combined Acoustic and Radio Tags (CART)

CART tags are hybrid tags combining components of both radio and acoustic tags that allow individual fish to be tracked between salt and freshwater (Solomon & Potter, 1988). A conductivity sensor is incorporated to detect the salinity of the water body around the fish and a microprocessor can automatically switch between acoustic transmission and radio transmission as appropriate (Deary *et al.*, 1998; Niezgoda *et al.*, 1998).

5.2.2.2 Coded tags

Coded tags operate by emitting a digitally encoded signal on specific radio and acoustic frequencies. Each signal can, theoretically, be unique. This offers the advantage that many individual fish can be tracked separately on a single frequency and that the information can be automatically recorded and downloaded to a PC. Coding has great potential for increasing data acquisition rates and increasing sample sizes in telemetry experiments. Digitally coded tags are also available (Cote *et al.*, 1998; Voegeli *et al.*, 1998), which allow as many as 170 tags to operate at one frequency (see also Section 5.7.3.2).

(a) Coded radio tags

These tags contain a programmable microprocessor and transmit a digitally encoded radio pulse at user defined intervals.

(b) Coded acoustic tags

These tags are similar to coded radio tags but transmit a digitally encoded acoustic pulse at user defined intervals. They are used for monitoring fish passage in marine and freshwater (Lacroix & McCurdy, 1996; Voegeli *et al.*, 1998).

5.2.3. Transponding acoustic tags

A transponding tag allows the position of a free-ranging fish to be fixed accurately relative to a research vessel (e.g. Greer Walker *et al.*, 1978). Transponding tags differ from other electronic tags in that they only transmit an acoustic signal when they receive an interrogation pulse from a sonar (e.g. Mitson & Storeton-West, 1971). Ultrasonic frequencies are produced by stimulating an annular ceramic transducer at its resonant frequency. Tag size is governed by the size of the transducer, whose diameter is inversely proportional to frequency (Priede, 1986). Range also varies inversely with frequency, so that, while a large diameter 30 kHz tag may have a range in excess of 1 km (e.g. Klimley *et al.*, 1998), a small 300 kHz tag usually has a range of less than 400 m (Greer Walker *et al.*, 1978). Frequencies of 34 to 50 kHz are commonly used for tracking large pelagic fish, while 60-80 kHz is commonest in coastal and estuarine waters (Priede, 1992). The higher frequencies (150 to 300 kHz) are used in freshwater, for studies where a small tag is required (Priede, 1992), or where specialised high-frequency imaging sonars are available (Arnold *et al.*, 1990). Transponding acoustic tags can be used to telemeter physical or physiological data by transmitting a second pulse and varying the delay between the two in proportion to the magnitude of the measured parameter (Storeton-West *et al.*, 1978; Pearson & Storeton-West, 1987; Mitson *et al.*, 1982).

5.2.4 Data Storage Tags (DSTs)

These tags, which are also known as archival tags, range from simple data loggers, capable merely of recording depth or temperature, to sophisticated programmable devices capable of providing a direct estimate of the geographical position of the fish at regular intervals over periods of many months. Developmental work over the last ten years has led to the production of a number of tags that are beginning to be used very successfully with free-ranging fish in the open sea. Tagged species have included tuna (Gunn *et al.*, 1994; Block *et al.*, 1998a, 2001a, b; Inagake *et al.*, 2001), Pacific salmon (Naito, 1997; Ogura, 1997; Ishida *et al.*, 1998; Tanaka *et al.*, 1998; Wada & Ueno, 1999; Walker *et al.*, 2000), Atlantic salmon (Sturlaugsson 1995; Karlsson *et al.*, 1996; Sturlaugsson & Thorisson, 1997; Sturlaugsson & Gudbjornsson 1997; Karlsson *et al.* 1999; Westerberg *et al.* 1999a & b), (sea trout (Sturlaugsson & Johannsson, 1996; Sturlaugsson & Gudbjornsson 1997), arctic char (Sturlaugsson *et al.*, 1998), cod (Thorsteinsson, 1995; Thorsteinsson & Marteinsdottir, 1998; Righton *et al.*, 2000, 2001a, 2001b), and plaice (Metcalfe *et al.*, 1994; Metcalfe & Arnold, 1997).

The most exciting and rapid advances in both technology and biology in recent years have been associated with data storage tags that can be programmed to record details of temperature, depth, salinity, pressure, light, chemical and physiological indicators at set intervals. Other sensors in development include tilt, heading and magnetic position fixing. Some of these tags can record data for up to five years and store this information for up to twenty years. However, in order to retrieve the information the tags must be recovered from the fish. Normally this involves establishing an intensive recapture operation, or relying on commercial or recreational catch returns. An external mark or tag is usually applied to the test animal to facilitate identification of fish carrying DST tags. Incentives (money, prizes) are often offered to improve the frequency of tag returns (see Section 5.5). Due to the high cost of production only relatively small numbers of animals have been tagged. However, the cost is offset by the enormous amount of data that can be generated from single tags on recovery.

Geolocation of fish may also be achieved by underwater light intensity measurements that are used to estimate times of sunrise and sunset (e.g. Hill, 1994; Gunn *et al.*, 1994; Welch & Eveson, 1999). These data are used, in turn, to calculate latitude and longitude using interactive software. An independent check on latitude can be obtained from the temperature measurements made by the tag (Block *et al.*, 2001b; Inagake *et al.*, 2001).

DST tags have been produced in a number of shapes and have been developed for applications with both roundfish and flatfish.

5.2.5 Remote data telemetry

Recent developments have included acoustic tags that telemeter stored data to remote receiving stations, instead of relying on recovery through commercial or recreational fisheries. To date, however, these tags have only been capable of transmitting relatively limited amounts of data and more progress has been made with tags that transmit data to polar orbiting satellites.

Advances in oceanic tracking have been possible with the development of the ARGOS data collection and location system (CLS), a joint venture between France (Centre National d'Etudes Spatiales - CNES) and the USA (National Aeronautics & Space Administration - NASA, and National Oceanic & Atmospheric Administration - NOAA). This provides complete world coverage with receivers on board NOAA satellites orbiting the earth in near-polar orbit at a height of 850 km (Taillade, 1992). The system uses UHF radio frequencies and its Doppler location system depends on a very stable transmitter frequency (401.650 MHz). The location of the platform transmitter terminal (PTT) carried by an animal is calculated from the shift in frequency of the transmitted radio signal as the satellite approaches and then moves away from the PTT (Harris *et al.*, 1990, Taillade, 1992). Accuracy of location improves with the number of successful 'uplinks' during each satellite overpass and Service Argos classifies the quality of location (class 1, 2 or 3) achieved with each fix. The implications of location accuracy for track reconstruction are discussed by Hays *et al.* (2001).

Until recently, the size of PTTs has precluded the use of the Argos system with all but the largest fish, and this difficulty has been compounded by the severe attenuation of UHF radio signals in salt water. Applications were therefore limited to large sharks, which surface sufficiently often to be detected by a passing satellite (see Section 5.4.2.1(a)). Recently, however, results have been obtained from North Atlantic bluefin tuna fitted with the first generation of 'pop-up' tags (Block *et al.*, 1998b; Boyan, 1998; Lutcavage *et al.*, 1999). These tags detach from the fish at a predetermined time and float to the surface from where they transmit to the Argos satellite (see Sections 5.4.2.3 and 5.7).

Combinations of transponding and data storage tags are being developed to increase the versatility of the applications. Communicating history acoustic transponding (CHAT) tags (Vemco Ltd., Nova Scotia, Canada) allow researchers to locate and track animals using transponding tags and retrieve data without recapturing the animal (Klimley *et al.*, 1998; Klimley & Holloway, 1999). The information is telemetered from the tag to a tracking receiver, or a fixed monitoring station, which can search for and locate any tag within range of the receiver, then store real time information to disk with GPS position. The receiving station can also send commands to the tag remotely to reset data recording intervals.

5.3 CAPTURE, HANDLING AND FISH RECOVERY

5.3.1 Introduction

Methods of capture and handling fish prior to, and during tagging, are of particular importance in ensuring that experimental fish are in good physical condition for laboratory or *in situ* experiments. Different capture and handling methods inflict different damages and stressors on the fish and different species have different tolerance for capture and handling. In addition, the vulnerability to handling may vary during different life stages. For example, salmonids, especially Atlantic salmon, vary greatly in their resistance to handling during their life span. While the fresh water related stages (parr, maturing and kelt stages) are less vulnerable, the skin of smolts, post-smolts and immature fish is very sensitive to handling. Atlantic halibut (*Hippoglossus hippoglossus*) are known to be difficult to handle without causing lethal damage (Midling, pers. com.), and several pelagic species such as herring (Clupeids) and mackerel (Scombrids) are similarly easily damaged (e.g. Wardle, 1968; Blaxter & Holliday, 1963).

This review of fish capture and handling methods in relation to electronic tagging is based on a selection of experiments mainly restricted to marine fish with emphasis on Atlantic species. Fresh water and non-Atlantic marine species are included where either the capture method or the physiological observations are of particular interest.

5.3.2 Damage during capture and handling

Most capture methods result in abrasion of the skin. The mucus layer protecting the epidermis and the scales is particularly delicate in most fish species. This layer protects the fish against fungal, bacterial and viral invasions and, together with skin and scales, provides a barrier against leakage or dilution of body fluids. An undamaged mucus layer is essential for the well being of the fish after capture. Damage such as scale loss and skin wounds will cause problems of increasing seriousness, depending on the degree of body cover lost. Prolonged struggles or swimming activity during capture leads to exhaustion, with subsequent conversion of muscle glycogen to lactate acid. In the case of severe exhaustion lactates are released into the blood stream from the muscles and cause lethal metabolic acidosis. The post-capture metabolism of accumulated lactates in the muscles will also lead to an elevated oxygen demand, which must be considered during subsequent transport and handling of the fish. Stress may also result in a reduction of immune responses.

A particular problem to overcome when working with physoclist (closed swimbladder) fish, like gadoids, is the expansion or reduction of the gas contained in the swimbladder if the external pressure changes. Physoclists can overcome this by absorbing or secreting the gas in order to keep neutrally buoyant. The compensatory mechanisms are, however, rather slow, and depend on both temperature and pressure (Harden Jones & Scholes 1985). Even relatively small involuntary upward movements can cause substantial swimbladder expansion, leading to rupture of the bladder and compression of internal organs (see section 5.3.3 and 7.4.6). The effects of decompression are a major cause of initial tagging mortality (Hislop & Hemmings, 1971) and physoclists must be brought slowly to the surface to avoid swimbladder damage and consequential and unwanted effects on behaviour.

Solomon & Hawkins (1981) and Wardle (1981) give an overview of the damage that may be inflicted on the fish during the capture and handling processes. The physiological and bacteriological processes set off by capture and handling will act in a similar manner after release back to nature. Experiences with methods used to capture fish for aquaria or aquaculture are therefore very relevant also in this context, even though they may not yet have been applied to electronic tagging.

5.3.3 Capture methods

The choice of a particular fishing method will depend on the species sought, fish density, location and possible legal restrictions. Solomon & Hawkins (1981) discuss some general advantages and drawbacks of various capture methods for obtaining good quality fish for aquarium use. Bottom *dragnets* (trawls, seines etc.) and midwater trawls, in which the fish is forced to swim with the gear during capture, may lead to exhaustion if towed too fast, or for too long (Hayes, 1983). The risk of skin damage and scale loss is always present, although this effect can be alleviated to a certain extent by using a lined codend. Despite these disadvantages, towed nets often are the only possible practical method. *Gillnets*, either stationary or drifting, enmesh the fish or entangle them and cause damage where the fish have been held, often by the head, the gills or the trunk. If enmeshed at the gill region, the fish may either suffocate or bleed to death. *Encircling nets* like purse seines have several advantages over gillnets, but if the catch is large, crowding during the final pursing may cause oxygen depletion and abrasions when the fish hit each other. Baited or unbaited *trapping gear* may be very effective (Hubert, 1983). The fish enter voluntarily and are seldom damaged or severely stressed. However, the fish may be damaged if other fish enter later, or when they are taken out of the trap. Solomon & Hawkins (1981) recommend that particularly delicate species are removed under water into a holding tank, or that the lower part of the trap is lined. In fresh water *electrofishing* (Reynolds, 1983) may prove effective and inoffensive because the fish recover quickly. However, Solomon & Hawkins warn against the possibilities of spinal fracture and haemorrhage that can be caused if the voltage is not properly adjusted. Other authors (see Section 5.3.4) have also observed such effects. *Angling and handline fishing* are singled out as methods with many advantages over other methods. Damage is often slight and confined to the jaws and can be further minimised by using barbless hooks (see Section 5.3.3.4). Struggling time can be reduced by using heavy fishing tackle. The disadvantage of angling is the low number of fish that can be caught. *Longlines, setlines and drifting lines* catch many more fish but have the disadvantage that the hook may be swallowed with the bait by many species.

In many experiments the descriptions of how the fish were captured and handled prior to electronic tagging are rather non-specific, often only stating which gear was used for capture. The time elapsed from start of capture to landing on deck, the method of handling the fish on board, or in the hatchery, and recovery times before tagging are often omitted. The most widely applied method for obtaining experimental fish from natural environment, however, seems to be to catch large numbers of fish, place them in a tank and, after an observation period of relatively short duration, choose perfect looking specimens for tagging.

5.3.3.1 Demersal fish and shellfish

Capture methods reported in electronic tagging experiments with demersal (bottom dwelling) fish have included: hook-and-line fishing for lingcod, *Ophiodon elongatus* (Matthews, 1992); handline fishing for cod, *Gadus morhua* (Arnold *et al.,* 1990; 1994); trawl fishing for plaice, *Pleuronectes platessa* (Greer Walker *et al.,* 1978; Harden Jones *et al.,* 1977; Metcalfe *et al.* 1993; Metcalfe & Arnold 1997) and cod (Engås *et al.*, 1991, Godø & Michalsen, 1997, 2000); gill nets for cod (Thorsteinsson, 1995; Thorsteinsson & Marteinsdottir, 1998); and seine netting for cod, and plaice (Isaksen & Midling, pers. comm.). Due to their robustness and economic importance cod have been the targets for many tagging studies.

Decompression of physoclists has commonly been dealt with by catching the fish at depths less than 10 m, or catching the fish with gear (e.g. pots, other cage-type gear, or hook and line) that enables the catch to be lifted slowly up to the surface. Tytler & Blaxter (1973) suggest a 5-hour decompression halt for gadoids for every 50 % reduction in external pressure. Engås, *et al.* (1991) captured cod by jigging in shallow water and let them recover in net pens for 3-8 days before tagging with hydroacoustic tags. Arnold *et al.* (1994) caught cod by rod-and-line or long-line in shallow water (< 8 m) being careful to bring the fish slowly towards the surface, the maximum pressure reduction always lying well below the 50% recommended by Tytler & Blaxter (1973). Fish were kept and fed in a large laboratory tank for several months until taken on board the tracking vessel, transported to the release site, tagged and released from cages.

Another method commonly used to reduce mortality caused by over-inflation of the swimbladder is to release the internal gas by puncturing the body wall and bladder with a hypodermic needle once the fish is on deck (Midling, pers. comm.; Olsen pers. comm.).

Gotshall (1964), who worked with blue rockfish (*Sebastodes mystinus*), reported positive effects of swimbladder puncture, as did Gitschlag & Renaud (1994), who investigated survival rates of caged and released red snapper (*Lutjanus campechanus*). Keniry *et al.* (1996), who conducted experiments on yellow perch, *Perca flavescens* collected at 10 and 15-m depths in Lake Michigan, reported similar benefits and also assessed the effects of decompression. Decompressed perch had higher survival than non-decompressed perch and, as would be expected, this effect was greater for fish caught at 10 than 15 m. Puncturing the swimbladder had a significant, positive effect on three-day survival; long-term survival was not affected.

There are no restraints on the speed at which demersal fishes without a swimbladder can be brought to the surface and flatfish like plaice and sole are relatively robust with respect to handling in general. The Lowestoft Laboratory has electronically tagged plaice since the early 1970s. Until recently the technique has been to select undamaged fish from trawl catches and return them to laboratory tanks until viability was confirmed (Greer Walker *et al.*, 1978; Harden Jones *et al.*, 1977; Metcalfe *et al.*, 1993; Metcalfe & Arnold, 1997). Recently fish have been tagged at sea with data storage tags immediately after capture to avoid disrupting natural patterns of movement and avoid problems with disease in the laboratory (Hunter, pers. comm.).

Other non-physoclist fish such as sea wolves (*Anarchicas lupus* variants), anglerfish (*Lophius piscatorum*) and halibut (*Hippoglossus hippoglossus*) are known to be difficult to handle without causing skin abrasions (Midling, pers. comm.). At the Dept. of Fisheries and Aquaculture, Fisheries Research Centre (FRC), Tromsø, northern Norway, where all these species have been captured and kept in conjunction with various fish holding experiments, the impression is that the grey wolf fish is best captured by Danish seine, while the spotted wolf fish is most easily taken in a trawl. If caught on hooks, *Anarchichas* risk excessive bleeding from the large arteries in the head and mouth region and need several weeks for adaptation (Midling, pers. comm.). Anglerfish are also difficult to handle without damaging the skin, although some individuals caught in a Danish seine survived in captivity for several weeks (Midling, pers. comm.). Lumpsuckers (*Cyclopterus lumpus*) are easily damaged in both the coastal and the pelagic phase, and require special observation when captured. Nets and trawl both cause lethal skin damage. Plaice and lemon sole on the other hand cause few problems and have been captured with seine net and transported with little mortality in special holding tanks (Midling pers. comm.).

In order to avoid adverse effects of capture and to secure observation of entirely natural food search and reactions to olfactory stimulants, Løkkeborg (1998) and Løkkeborg & Fernö (1999) set up experiments where cod were allowed to voluntarily swallow tags wrapped in various types of bait. This technique has also been applied with success to several deep-sea species, which are often stenothermal and stenohaline (Solomon & Hawkins, 1981), and could not otherwise be tagged because of the slow decompression rate and the time needed to get them to the surface. Grenadiers (*Coryphaenoides yaquinae, C. armatus*), deep sea eels (*Synaphobranchus bathybius*) and the deep sea gadoid (*Antimora rostrata*) have all been successfully tagged with acoustic tags after ingestion of bait hung beneath the cameras of a deep-sea lander (e.g. Armstrong *et al.*, 1991, 1992a; Bagley *et al.*, 1994; Priede *et al.*, 1990, 1994a, b, c; Collins *et al.*, 1998).

5.3.3.2 Shellfish

Shellfish have mostly been obtained by trapping the animals in pots or cages, or in some cases with tangle nets (González-Gurriarán & Freire 1994). Divers have been used at shallower depths. The risk of damage is small if the gear is carefully hauled; decompression is not a problem for shellfish. The attachment of tags is fast and the animals can rapidly be returned to their normal environment, if not tagged *in situ* by divers. Details of capturing and tagging Norway lobster (*Nephrops norvegicus* L.), European lobster (*Homarus gammarus*) and spider crab (*Maja squinado*) are given by Chapman *et al.* (1975), González-Gurriarán & Freire (1994) and Collins & Jensen (1992) and van der Meeren (1997), respectively.

5.3.3.3 Pelagic fish

Most pelagic species are susceptible to handling. As far as is known, the smaller schooling species (e.g. Atlanto-Scandinavian herring (*Clupea harengus* L.) and Atlantic mackerel (*Scomber scombrus* L.)) have not been used in electronic tagging studies so far. But as tags continually get smaller and sensors more varied the possibility of tagging these species increases and methods of handling will be of interest. Since 1968, the Norwegian Institute of Marine Research has been quite successful in tagging large numbers of mackerel and herring using conventional (internal) steel tags. Mackerel are caught by jigging, carefully unhooked and placed in tanks for observation prior to tagging. Bleeding or wounded fish are discarded (Myklevoll, 1994). Public aquaria, such as the North Sea Centre (NSC) in Hirtshals in Denmark regularly obtain these species for display in tanks. The NSC relies on professional fishermen, who use very fine meshed purse seines to catch schools of herrings and mackerel close to the coastline. Fish are transferred to holding tanks, and viable looking specimens chosen for transport to the aquarium. As mackerel are extremely sensitive to touch, great care has to be taken to avoid skin damage and this is achieved by only handling the fish when they are immersed in water. Herring are caught by similar methods as the mackerel (Flintegård, pers. comm.).

Special methods have been developed for capturing and tagging large pelagic species such as sharks, tunas, marlins and sailfish, which are difficult to handle and sedate on board a boat because of their size and strength. Pole and line fishing from vessels using lures with special barbless hooks is the main method of capture. The fish are handled rapidly without anaesthesia and care is taken not to cause skin damage by using soft plastic covered tagging or measuring cradles (Williams, 1992). Carey & Robison (1981) and Carey & Scharold (1990) carried out pioneering work to develop methods for handling and tagging swordfish (*Xiphias gladius*) and blue sharks, (*Prionace glauca*). Holland *et al.* (1990a, 1990b), tracked yellow and bigeye tunas and blue marlins (*Makaira nigricans*) caught by trolling and pole- and line fishing. The chosen tag attachment method enabled release of fish after approximately one minute out of water. Block *et al.* (1992a, b) caught blue marlins for tracking by trolling artificial lures with rod and reel from boats. Block *et al.* (1998a) have developed a successful method of capturing and handling Atlantic bluefin tuna (*Thunnus thynnus*) for use in archival tagging and acoustic tracking studies. The fish are caught by heavy tackle using circle hooks and bait presented in a chum stick (“chunk fishing”), a technique that allows chasing down the fish in order to keep fight times less than 15 minutes. The fish are taken on board a boat with specially designed leaders through a “tuna door” in the stern and tagged and released immediately. The method is suitable also for handling large individuals (> 50 kg) with low risk of damaging the fish. A similar approach has been used with southern bluefin tuna (Gunn *et al.* 1994).

Sharks lack a swimbladder and must swim to maintain position in the water column. Muscular movement assists in venous return of the blood and oxygenation at the tissue level is maintained in many by swimming at some optimum speed. Care is therefore needed when capturing and handling sharks to minimise struggling and the time for which the shark is restrained (Gruber & Keyes, 1981). Prolonged struggles affect blood serum protein deleteriously and accumulate lactates. Capture by trapping or trawling should therefore be avoided and Gruber & Keyes recommend the use of a handline. This method reduces the risk of injuring the mucous layer, skin and eyes and keeps the time for capture short. Nelson (1978), Carey *et al.* (1981) and Stevens (1996) give references to capture of shark species by handline or rod and line for subsequent electronic tagging.

5.3.3.4 Salmonids

Four main life stages of Atlantic salmon are recognised with different spatial distributions and different vulnerability to capture and handling. These stages must be considered separately in relation to the use of electronic tags (Anon, 1997).

Smolts: These fish are in transition from the fresh water phase to salt water tolerance and have started their down-river migration towards the sea. Wild fish (10 - 17 cm fork length depending on river environment and genetic origin) are generally too small to be tagged with electronic tags at present. Many experimenters have used hatchery fish instead, although smolts from wild stocks have been tagged where they are large enough to tolerate the application of the smallest available electronic tags. Tytler *et al.* (1978) used wild smolts caught in a trap in the river N. Esk. Holm *et al.* (1982) obtained a few wild fish from a fish trap in the river Imsa in southwestern Norway. After capture, the smolts were stored for 2 - 14 days in a hatchery trough before tagging; they were released within 24 h of tagging. Moore & Potter (1994) and Moore *et al.* (1990b, 1990c, 1992, 1995) used wild fish, which they caught in streams in Wales and southern England using fyke-nets and a keep box for the trapped fish. The fish were anaesthetised, tagged and put in oxygenated water for a recovery period of 30 - 60 min. before release into the river. Other techniques used for capturing wild fish for electronic tagging in rivers include electro-fishing and beach seining (Knutsson, unpublished). However fish traps and trap nets have advantages over electrofishing as trapping will capture only actively migrating smolts, while electrofishing takes all fish including those not yet in the active migratory phase (Anon, 1997).

Post-smolts are salmon in their first year after leaving fresh water. Depending on genetic origin and the time of capture after entering the marine environment, Atlantic salmon in this stage range from approx. 15-35 cm in length. Until recent years few captures of post-smolts had been made, but they are now regularly caught in surface trawls (Holst *et al.*, 1993; Hvidsten *et al.*, 1995). Trawl caught post-smolts lose 50 - 100% of their scales even in short tows (Holm *et al.*, 1998; Holst & McDonald, 2000; Hvidsten, pers. com.). Other reported capture methods include floating long-lines and drifting gillnets (Reddin & Short, 1991; Sturlaugsson & Thorisson, 1995), although none of these methods of capturing post-smolts has yet produced fish in a fit condition for tagging. Instead, most tracking studies have been performed with hatchery fish, or with wild fish trapped as smolts in freshwater (Moore *et al.*, 1995, 2000; Lacroix & McCurdy, 1996) and then released in rivers, estuaries, or fjords. Recently a device for obtaining post-smolts in viable condition from trawl catches has been developed and tested with promising results (0-6 % scale loss) (Holst & McDonald, 2000). Norwegian, Faroese and Icelandic research institutes plan to use the device in 2002 to catch post-smolts and grilse for a collaborative tagging project in the North Atlantic using data storage tags.

Adult stage - immature fish. Immature salmon (both one- and multi-sea-winter fish) are found in feeding areas in the open ocean. Handling must be done with great care as the risk of scale loss is substantial (Hansen & Jacobsen 1997). Adult immature salmon are occasionally caught by surface-trawling in the Norwegian Sea (Holm *et al.*, 1998), but this method is unsuitable for obtaining fish for electronic tagging because of the large loss of scales that occurs. Drifting gill nets have been used to catch salmon for tagging in the Pacific. Fish caught by long-line have been used for electronic tagging studies in the north Atlantic (Jákupsstovu, 1988) and experiences from a Carlin tagging programme in the Faeroes give valuable indications of how to handle the fish. The lines were patrolled constantly to remove hooked salmon. The fish were carefully lifted over the ship's side with a scoop-net and placed in a recovery tank where undamaged, viable looking fish were chosen for immediate tagging and release. It is sometimes more deleterious to remove a long-line than it is to leave it in the fish. Hansen & Jacobsen (1997) stress the importance of hook shape for ease of removal and recommend using non-galvanised material in case the hooks have to be left in place.

Adult fish - maturing salmonids and kelts: Maturing fish homing to their natal streams have been captured in coastal and estuarine waters using gear such as bag-nets, trap-nets, other fixed engines or beach seines. These methods are relatively harmless. In addition, the salmon are much more resistant to handling at this stage in their life history, as a result of physiological changes to skin and mucus, which occur in conjunction with maturation. Several authors (Westerberg, 1982a, b; Solomon & Potter, 1988; Potter *et al.*, 1992; Heggberget *et al.*, 1993; Smith & Smith, 1997; Sturlaugsson 1995; Sturlaugsson & Thorisson 1997; Karlsson *et al.*, 1996) have used fish obtained from trapping gear in the vicinity of the rivers to study various aspects of the homing behaviour of Atlantic salmon. Fish were tagged and released when they had regained their equilibrium after anaesthesia. Brawn (1982) caught Atlantic salmon with a mackerel net and lure in an estuary and kept them in cages for around 1 day prior to anaesthesia and tagging with acoustic tags. After tagging the fish were left in a cage for up to 1 day to recover. *Kelts* are post-spawning fish that will return to the sea. Like maturing fish, they are relatively resistant to handling because of the condition of their mucus during the winter, although they become sensitive prior to migration to sea when they become silvered (Sturlaugsson, J., pers. comm.) Where they are installed, fish ladders provide excellent facilities for capturing fish in rivers and good survival of ladder-caught adult Atlantic salmon and rainbow trout is reported by Peake *et al.* (1997a).

Fly fishing with barbless hooks has been used in rivers in south-east Iceland to capture anadromous trout (*Salmo trutta* L.) for tagging with data storage tags prior to seaward migration (Sturlaugsson & Johannsson 1996; Sturlaugsson & Johannsson, in press). Gill nets have been used to catch arctic char (*Salvelinus alpinus* L.) in lakes in northwest Iceland prior to tagging both anadromous and non-anadromous fish (Sturlaugsson *et al.*, 1998; Sturlaugsson, J., pers. comm.). In both situations anadromous fish were tagged under anaesthesia immediately after capture and released after a short period in an underwater cage. High growth and recapture rates were obtained with both methods of capture (Sturlaugsson, J., pers. comm.).

5.3.4 Handling and recovery

5.3.4.1 Anaesthesia

It is well known that anaesthetics cause physiological effects that can be measured as changes in levels of corticosteroid and other parameters (see Chapter 7), which in turn may lead changes in the behaviour of the fish for a varying time after sedation. On the other hand, the handling stress will be reduced under anaesthesia and tagging can be carried out more rapidly with less risk of the fish damaging themselves when trying to get loose. Anaesthesia and anaesthetics are discussed in chapter 7. Legal requirements are dealt with in Chapter 6.

Anaesthetics are easy to apply in the hatchery. Kreiberg & Powell (1991) identified the netting and capture phase of various hatchery operations as the major contributor to overall stress and developed a standard procedure for lightly sedating fish with metomidate before any major handling disturbance. They recommend this procedure for handling of all sensitive fish, such as chinook and other salmonids.

In field experiments, the ideal conditions for handling the fish cannot always be met. Setting up facilities for anaesthesia and recovery may be difficult because of spatial restrictions or poor weather at sea. The experimenter must then evaluate the relative difficulties of applying anaesthesia against possible trauma and damage caused by handling unanaesthetised fish, although legal considerations (see Chapter 6) may be paramount.

When electronic tags can be attached rapidly and non-intrusively, anaesthesia has often been replaced by simpler methods of keeping the fish quiet during tagging. Arnold *et al.* (1994) covered the eyes of cod with wet paper and Thorsteinsson (1995) used a similar method with the same species. Blindfolding is also commonly used when tagging adult salmon. These fish are relatively easily calmed if kept in their natural swimming position, for example in a moist handling cradle with the head covered with a wet soft cloth. Handling of unanaesthetised salmonids is, however, not recommended, because of the risk of scale loss and trauma, both internal and external (Sturlaugsson, 1995; Hansen & Jacobsen, 1997). McCleave & Arnold (1999) used a slurry of ice and water to anaesthetise yellow and silver eels (*Anguilla anguilla*) prior to tagging.

Anaesthesia has in general not been applied when tagging large pelagic species, such as tunas and sharks. The capture process is likely to be much more stressful and time consuming than attaching the tag, which generally only requires a minor incision. Instead, covering the eyes usually quietens the fish. Special devices to ease the process and minimise handling time have been developed by Block *et al.* (1992, 1998a), Carey & Robison (1981), Carey & Scharold (1990), Stevens (1996), Holland *et al.* (1990a; 1990b) and Williams 1992 (see Section 5.3.3).

5.3.4.2 Recovery from capture and handling

McCleave & Stred (1975), Moore *et al.* (1990a) and Lacroix & McCurdy (1996), among others, have investigated experimentally the effects of tagging and handling on salmonids using dummy tags. In most cases it was shown that the fish recovered quickly from the handling process.

Once the fish has been released it is difficult to assess the impact of the capture, handling and tagging process, although information from data storage tags may provide some useful indications. The various studies performed to estimate survival of fish escaping from fishing gear may, however, aid the assessment of short and long term effects of capture on the survival of electronically tagged fish.

A number of studies have been made on demersal fish escaping from codends of trawls, although estimates of mortality vary according to circumstance. Soldal *et al.* (1991) found no mortality of cod (*Gadus morhua*) and less than 10 % mortality of haddock (*Melanogrammus aeglefinus*) that were kept in cages anchored on the sea bed and observed for 12 to 16 days after escaping from the codend. Jacobsen *et al.* (1992) observed saithe (*Pollachius virens*) for 6-7 days by underwater television in cages drifting freely at 40-m depth. Only low mortalities were recorded from these fish, which had escaped from a trawl at 150-m depth. On the other hand, Sangster & Lehmann (1994) recorded 11- 52 % mortalities of haddock and whiting (*Merlangius merlangus)* escaping from codends when collected and stored in cages on the seabed for 60 days. No mortality was observed in the controls and there were no significant differences between the two species. In trawl simulation studies Soldal *et al.* (1993) and DeAlteris & Reifsteck (1993) recorded 100% survival of cod after escapement, while haddock suffered 10% mortality. Additional mortality occurred in all groups due to infection of wounds. Jónsson (1994) studied survival and scale damage of long-line caught haddock in aquarium after simulating escape through the meshes of cod-end; the survival rate in these experiments was only 30-50%.

The swimbladder of gadoids is observed to heal relatively rapidly. Experiments made at the University of Tromsø in the early 1980s (Olsen, pers. comm.) show that healing started 2- 3 days after capture in cod caught in a trawl at 100 m depth. Nevertheless, the use of fish with recently ruptured swimbladders should be avoided (Solomon & Hawkins, 1981), particularly if the aim is to use hydroacoustics to observe natural behaviour in the short term (Mohus & Holand, 1983).

The time the fish have been subjected to a fishing operation will also have consequences for tagging and must therefore be considered. After seven days of post-capture observation in cages Oddsson *et al.* (1994) recorded significant differences in survival of Pacific halibut (*Hippoglossus stenolepis)* subject to towing durations of 30 and 120 minutes.

The capture process affects small and large fish differently. Hansen and Jacobsen (1997) and Anon (1998a) found evidence of size dependent vulnerability to long line capture and subsequent handling in Atlantic salmon. Larger salmon had significantly better Carlin-tag recovery rates than smaller fish, which during tagging were observed to lose scales more easily than the larger ones. The deleterious effects of capture on small fish have also been demonstrated for other species. Soldal *et al.* (1991) examined scale loss of escaped cod and haddock compared to a control group. On average, less than 1% of the total body surface of cod was injured, while haddock, particularly those smaller than 40 cm, showed substantial scale loss and therefore greater mortality.

Harrell & Moline (1992) have assessed the effects of electrofishing. Striped bass (*Morone saxatilis*) captured by electrofishing showed significantly lower effects of stress and shorter recovery times than striped bass caught in gillnets. Dalbey *et al.* (1996) observed that rainbow trout (*Oncorhynchus mykiss*) suffered significantly more incidents of spinal injury if pulsed rather than smooth DC was used. The severity of injuries was increasing with increasing fish length and, although long term survival was not affected, 28% of the fish had markedly lower growth and condition.

Angling appears to be a good way of catching some species of fish. Pankhurst & Dedual (1994) found no mortality in rainbow trout as a result of capture or any of the handling protocols. In most fish initially elevated blood plasma levels returned to normal within 24 h of capture indicating that metabolic recovery had occurred.

Tytler *et al.* (1978) gave wild smolts a recovery time of 3 - 48 h after anaesthesia and tagging in a portable holding tank before transporting the tank to the release site, where they were given minimum one hour to adapt to local river conditions. Moore *et al.* (1990a) concluded that consideration must be given to a satisfactory recovery time before the fish are released from the controlled experimental conditions. Their results indicate that smolts can be safely released as soon as they are fully recovered from anaesthesia. Recovery from anaesthesia was judged to have occurred when full equilibrium was regained, and the fish reacted to external stimuli. Far better results have also been obtained for several Pacific salmonids (*Oncorhynchus* spp.) released immediately (e.g. Mellas and Haynes, 1985) instead of after prolonged recovery. Keeping wild salmonids for extended periods in tanks to recover after handling may give adverse results and may not improve fish survival (Nettles, 1983, in Moore *et al.*, 1990a).

In contrast, survival of hatchery fish appears to be improved by the provision of a recovery period after handling. Sharpe *et al.* (1998) studied the effects of various hatchery practices, including tagging and fin-clipping, on juvenile chinook salmon. No lethal effects were observed, and although indeed stressful, the physiological effects measured as elevated cortisol levels were of relatively short duration. Sharpe *et al.*, nevertheless recommend that fish to be released into a more challenging environment than a hatchery should be given a recovery time of at least 24 h. The work of Hansen & Jonsson (1988) supports this observation: the survival of 1 and 2-year old hatchery smolts was reduced if they were handled immediately prior to release for sea ranching. Of the various treatments given, dip-netting significantly reduced the survival of the younger smolts, although it did not affect the older smolts significantly.

5.4 TAG ATTACHMENT METHODS

5.4.1 Introduction

Electronic tags have been attached to fish both externally, in a variety of locations (Fig. 5.4.1, and internally, by insertion in the stomach or by surgical implantation in muscle or in the peritoneum (Figs. 5.4.1 and 5.4.2). There are advantages and disadvantages for each of these methods and choice depends on the type of tag, the type of fish and its lifestyle and the purpose of the research.

5.4.2 External attachment

Internal tagging is not feasible with flatfish, such as plaice (*Pleuronectes platessa*), which have a tightly coiled gut and a small peritoneum; for these species external tagging is essential. External tagging may also be desirable in other species for reasons of tag or data recovery, even though internal tagging may be possible biologically. External tagging is simpler and quicker than most internal tagging, avoids surgery and anaesthesia and may also entail a shorter refractory period. It may also be essential with sharks and large pelagic fish, such as tuna, marlin, and swordfish when it is not possible to catch the fish or bring it on board. External tags may be attached directly to the surface of the fish, or by a trailing lead that allows the tag to stream free when the fish is swimming. Tags have been attached dorsally, both anterior and posterior, dorso-laterally and ventrally. A few authors have used tags attached to the caudal peduncle, although this method is undesirable because it

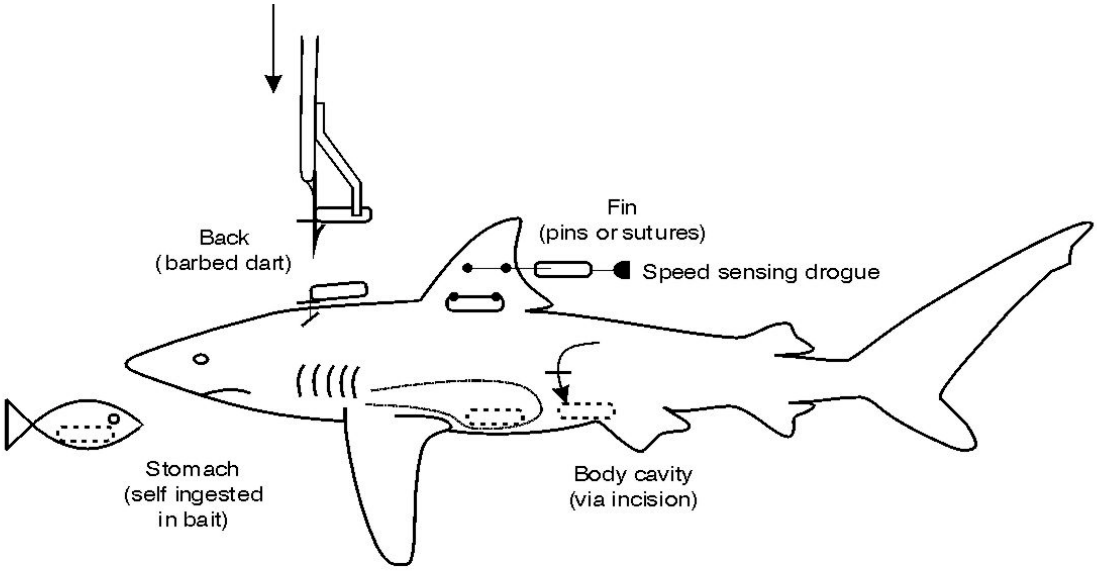


Figure 5.4.1 External and internal methods for attaching electronic tags to sharks (redrawn from Nelson, 1978). Application by barbed dart and self-ingestion are accomplished without capturing the shark.

interferes with swimming, particularly when the tag is mounted transversely to the flow (Carr & Chaney, 1977).

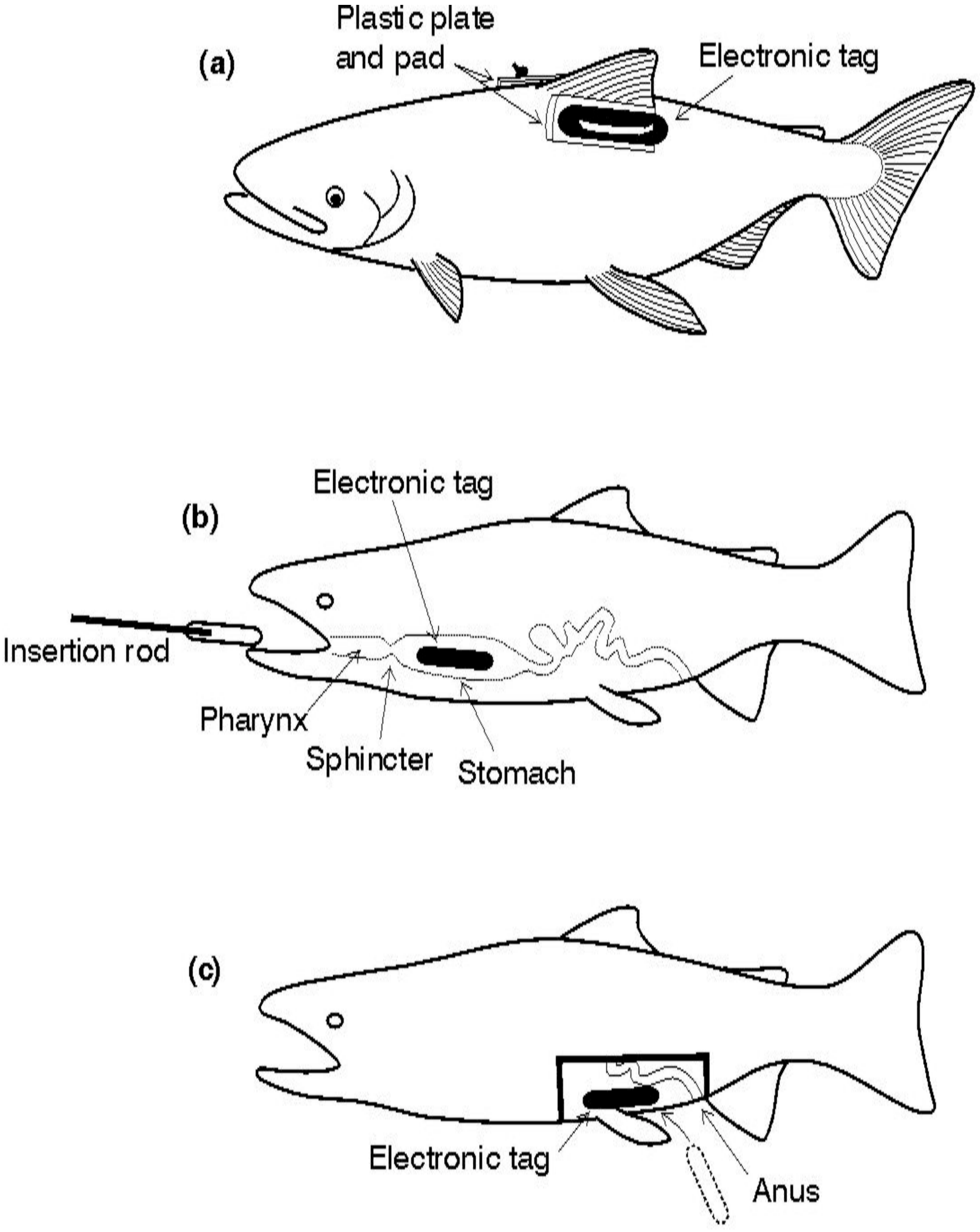


Figure 5.4.2 Methods of attaching electronic tags to salmonid fish: (a) external; (b) stomach; (c) peritoneum (redrawn from Mellas & Haynes, 1985).

5.4.2.1 Directly-attached tags

(a) Methods of attachment

Tags may be sutured directly to the body of the fish and this technique has been used with cod (*Gadus morhua*) to fasten ultrasonic transmitters to the dorsal surface ahead of the first dorsal fin (Mohus & Holand, 1983). Plaice (*Pleuronectes platessa*) have been tagged in a similar way with a transmitter fastened to the upper surface of the body (Mohus & Holand, 1983). Most external tags are, however, attached with fine wires or nylon cords, which pass through the body muscles and are attached to plastic discs or plates on the other side of the fish. The plate may be cushioned with foam to minimise scale damage.

One of the commonest positions for directly attached external tags is alongside the base of the dorsal fin (Fig. 5.4.2). Usually this involves a single tag on one side (e.g. Gray & Haynes, 1979; Mellas & Haynes, 1985), although some studies have used a pannier arrangement (Thorpe *et al.*, 1981; Greenstreet & Morgan, 1989) to equalise the load on the two sides of the body. Others have positioned the tag on the centre line immediately in front of the dorsal fin (Figs. 19 & 20 in Hallock *et al.*, 1970; Fig. 7 in Monan *et al.*, 1975). Typically, the tag is attached immediately below the dorsal fin (Fig. 5.4.3) with a plastic plate on the other side of the body to prevent the attachment wires cutting into the muscles. This arrangement has been used successfully to fit salmonids (*Salmo* and *Oncorhynchus* spp.) with radio tags (Gray & Haynes, 1979), and also with data storage tags (Sturlaugsson, 1995). A transponding acoustic compass tag has been fitted to salmon in a similar fashion, using a plastic plate on both sides of the fish (Potter 1985). Bradbury *et al.* (1995) describe an interesting variant of the one-sided tag layout, which involves two tubes mounted one above the other. The lower tube contains the transmitter, while the other is partially filled with water to make the unit neutrally buoyant. The transmitter can be replaced when its batteries are exhausted or exchanged for a dummy transmitter of identical size and weight, while the fish recovers from the tagging process.

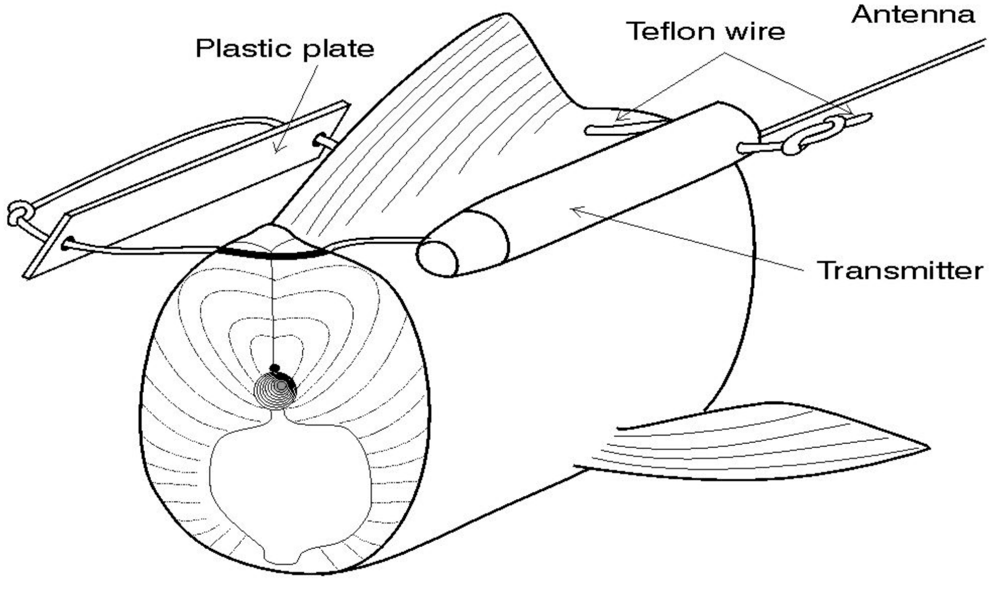


Figure 5.4.3 Attachment of a radio tag to an adult chinook salmon (*Oncorhynchus tshawytscha*), illustrating the typical method of attaching an electronic tag alongside the dorsal fin (redrawn from Gray & Haynes, 1979).

Cod have been fitted with acoustic tags in the same position (Arnold & Greer Walker, 1992, Arnold *et al.*, 1994), although with the tag attached more loosely to the fish. Plastic spaghetti tags (Fig. 4.1) were passed through the dorsal muscle at either end of the first dorsal fin, using a surgical needle, and the ends tied in a reef knot. A 300 kHz transponding acoustic tag was tied to the spaghetti tags using a nylon cord at each end of the tag. Tesch (1974) used a similar arrangement to fasten an acoustic pinger alongside the anterior end of the dorsal fin of eels (*Anguilla anguilla*), although in this case a single perlon thread was used and the tag was coated in balsa wood to make it neutrally buoyant.

Nylon cable ties have been used to attach ultrasonic transmitters to yellowfin (*Thunnus albacares*) and bigeye (*T. obesus*) tuna immediately behind the last dorsal fin, where the body slopes down to the caudal peduncle (Holland *et al.*, 1985). This method (Fig. 5.4.4) is probably only useful for large robust species. Tags mounted on king salmon (*O. tshawytscha*) in this position were not successful because the rear straps pulled out (Hallock *et al.*, 1970).

In recent years, the Lowestoft Laboratory has attached 300 kHz transponding acoustic tags to plaice using a light ‘saddle’ made from a single stainless steel wire, which is inserted through the ‘dorsal’ muscles (Fig. 5.4.5(a)). A numbered Petersen disc is fitted to the underside of the fish, the wire is cut to length to allow for growth and the end twisted to form two or three rings as with a conventional Petersen tag (Fig. 4.1). The acoustic tag is attached to the saddle by a nylon cable-tie and - as a safety precaution - a fine nylon cord is used to join the end of the tag to the top of the Petersen wire. This arrangement, which allows the tag to rotate a little, separates the tag from the upper surface of the fish and keeps the transducer clear of the sand when the fish buries into the bottom. A neoprene disc can be used to cushion the tag and protect the surface of the fish.

A similar arrangement was used to attach the Mk 1 Lowestoft Data Storage Tag (DST) to plaice (Metcalfe & Arnold, 1997). Two stainless steel wires were passed through small lugs on opposite sides of the circular tag and two Petersen discs were used on the under side of the fish (Fig. 5.4.5(b)). This system has been modified for the cylindrical Mk 3

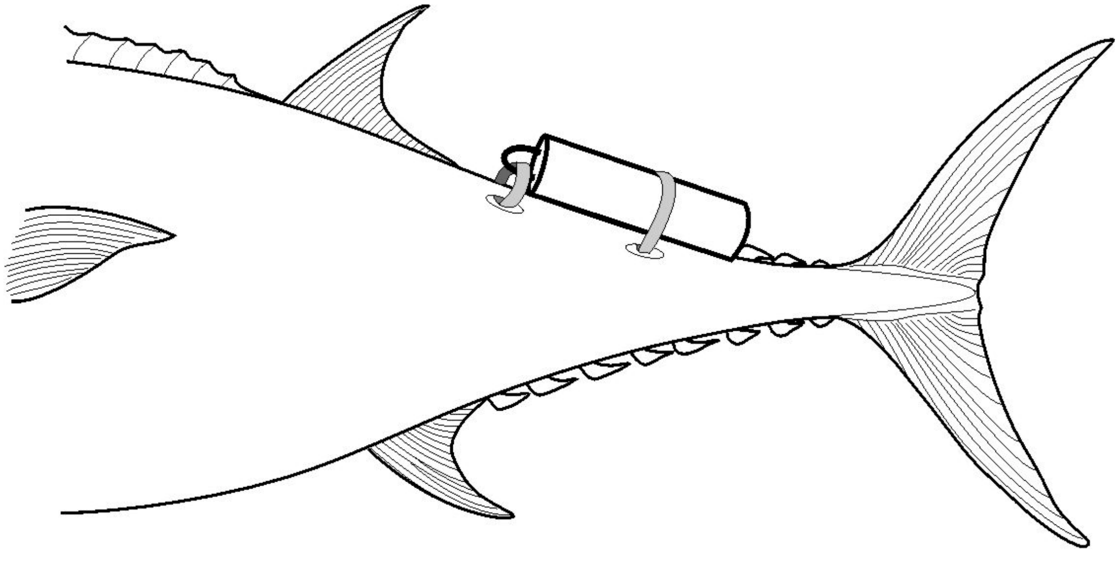


Figure 5.4.4 Attachment of an acoustic tag to the back of a tuna using two nylon tie wraps inserted through the dorsal muscles and pterygophores (redrawn from Holland *et al.*, 1985).

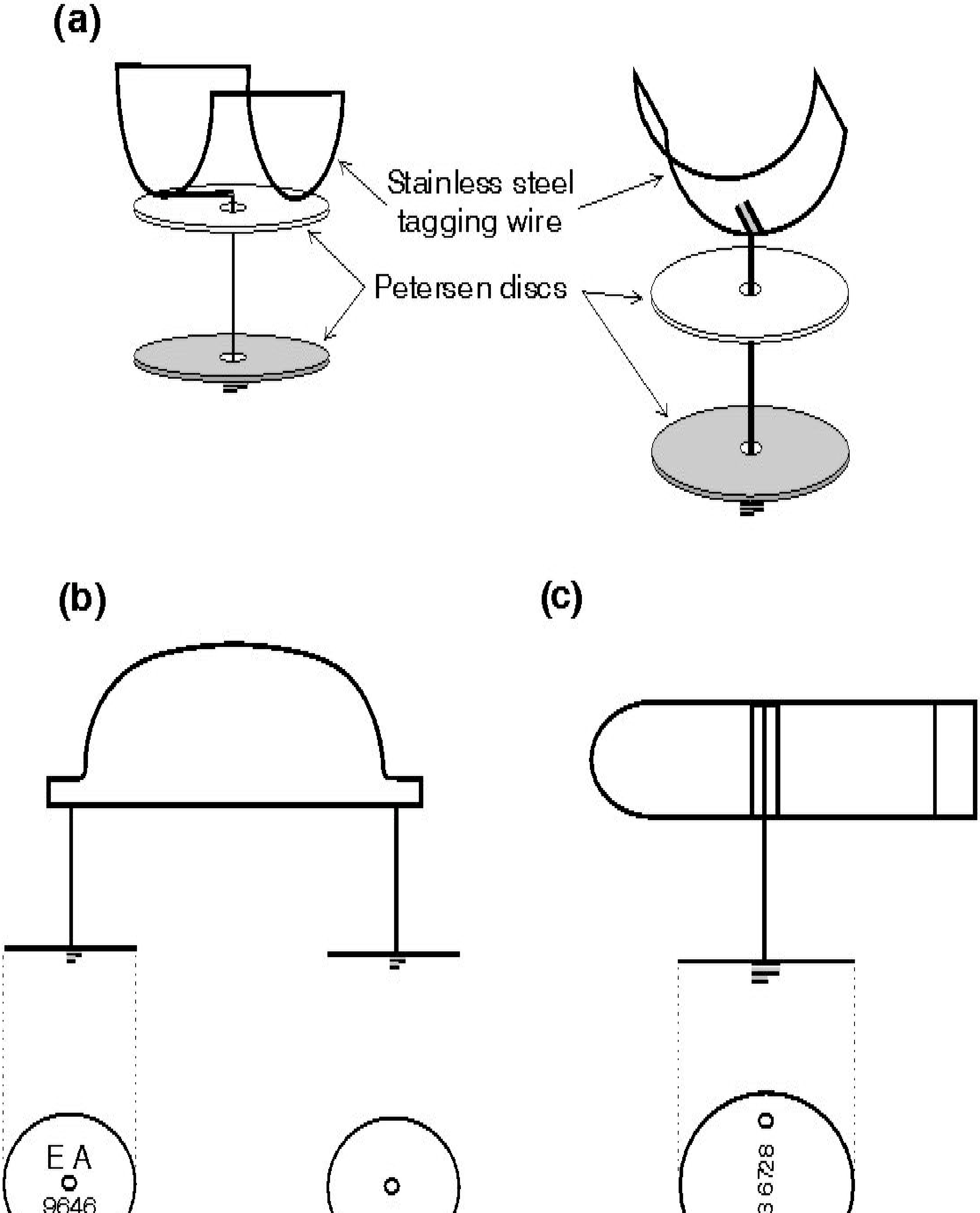


Figure 5.4.5 Methods used by the Lowestoft Laboratory (CEFAS) to attach electronic tags to plaice (*Pleuronectes platessa*), a typical flatfish: (a) wire saddle for a 300 kHz transponding acoustic tag; (b) attachment of a hemispherical data storage tag using two stainless steel wires and standard Petersen discs; (c) attachment of a cylindrical data storage tag with a single wire and a large Petersen disc.

DST. The wire passes through a rib moulded around the case of the tag and is held in position by a single large Petersen disc on the under side of the fish (Fig. 5.4.5(c)). The rib is flattened on the underside to allow the tag to rest on the surface of the fish and the Petersen disc has two holes. A similar arrangement was devised for a large acoustic tag that telemetered the compass heading of the fish back to the tracking ship (Pearson & Storeton West, 1987; Metcalfe *et al*. 1993). The Petersen wires passed through a small hole at each end of a flat plastic plate, which was glued to a tapered wedge on the lower surface of the tag; two standard Petersen discs were fitted to the under side of the fish (Fig. 2 in Mitson *et al*., 1982).

An unusual arrangement is possible with blue sharks, which often swim at the surface with the dorsal fin in air. The late Frank Carey of the Woods Hole Oceanographic Institution (WHOI) used a combined data logger and satellite transmitter to track the movements of three fish in the Gulf Stream from Cape Hatteras northwards. His design was based on a transmitter developed by the Sea Mammals Research Unit (Cambridge, UK). It consisted of two aluminium pressure tubes cast into a polyurethane saddle, which rested on the back of the fish, and a flange, which bolted through the dorsal fin. A 45 cm long streamlined mast raked back at the same angle as the leading edge of the fin carried a radio antenna at the top and a small propeller half way up its rear edge (Kingman, 1996).

(b) Problems

There are a number of well-recognised problems with tags that are attached directly to the body of the fish with two or more attachment points, as described above. These problems, which include chafing, abrasion and ulcerated wounds, also arise routinely with conventional tags and are discussed further in Chapter 7. Chafing may be avoided initially by cushioning the tag on a thin layer of high-density foam (Fig. 5.4.2(a)), but often, as the fish grows, the space between the tag and the body wall disappears and the tag grows into the flesh of the fish. To date, this has not been too much of a problem with electronic tags, because most radio and acoustic tags have only a limited life. It is likely to become much more of a problem in the future with the use of archival tags with potential lives of 10 to 20 years.

External tags can adversely affect various aspects of the behaviour and physiology of swimming animals, particularly if they have not been designed for minimal drag. There is scope for substantial improvement in this area, particularly when developing smaller tags (see Section 5.7.2.2). Shape needs consideration, as well as the method of attaching and mounting the tag. The work that has been done in recent years to improve the streamlining and positioning of tags on the backs of turtles (Watson & Granger, 1998) and penguins (Wilson *et al*., 1986; Gales *et al*., 1990; Culik & Wilson, 1991; Wilson & Culik, 1992; Culik *et al*., 1994; Bannasch *et al*., 1994) demonstrates the gains to be obtained from minimising tag drag.

5.4.2.2 Trailing tags

(a) Methods of attachment

For many years the Lowestoft Laboratory attached 300 kHz transponding acoustic tags to plaice and other flatfish using a nylon cord, which passed through the body of the tag just below the end cap, and was tied to the upper ring of a Petersen disc wire. This arrangement was very effective when the fish was in midwater. Flume studies (Arnold & Holford, 1978) showed that the tag streamed free of the body when the fish was swimming. On the bottom, the tag lay on the upper surface of the fish with the transducer close to the

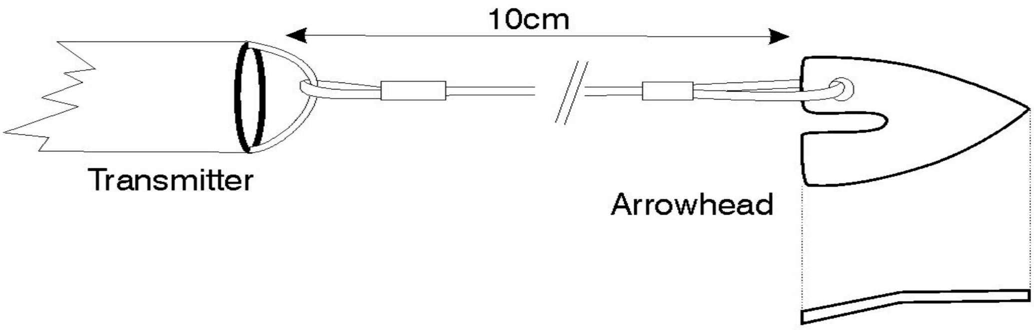


Figure 5.4.6 Tag attachment system for Pacific blue marlin. A stainless steel arrowhead is attached to the acoustic transmitter with a 10-cm length of monofilament (0.59 kg test) crimped at each end. The arrowhead has curved tines and a central notch to accommodate the prong of the applicator pole (redrawn from Holland *et al.*, 1990).

marginal (dorsal) fin. This was a poor arrangement when the fish was buried in sand, as the acoustic signal was often attenuated and difficult to detect. This problem was mitigated by the use of the saddle attachment described in section 5.4.2.1.

Similar single-point trailing attachments have been used with sharks (Fig. 5.4.1) and salmon (Yoza *et al.*, 1985; Ogura, 1997) and also to fasten positively buoyant data storage tags to the upper surface of cod just ahead of the first dorsal fin (Godø & Michalsen, 1997, 2000). In this case, the tags were attached in the same way as conventional Lea tags, using monofilament line inserted through the dorsal muscles.

Tethered tags require a strong permanent anchor point. With large free-swimming fish that cannot readily be captured, a dart with an arrowhead that resists extraction from the muscles is often used. Darts (Fig. 5.4.6) are commonly used with tuna, swordfish (Carey & Lawson, 1973, Carey & Robison, 1981) and marlin (Holland *et al.*, 1990a) and are applied with an applicator pole or harpoon (e.g. Chaprales *et al*, 1998). Another solution, which can be used when the fish is caught, is to place the dart in the muscles at the base of the second dorsal fin, so that the barb penetrates the bony extensions at the base of the fin rays (Williams, 1992). Titanium and nylon darts of this type (Block *et al.*, 1998a, b) have recently been developed in the USA for use with tuna and large billfishes (see Section 5.4.2.3).

(b) Problems

Trailing tags avoid many of the problems associated with close-coupled tags and, if properly designed, should produce limited drag. The original 300 kHz transponding acoustic tag developed at Lowestoft, for example, which had quite a high frontal drag coefficient (C_{D0} = 0.6), was shown to have little effect on the swimming performance of medium size plaice (*Pleuronectes platessa*, 36-52 cm) and cod (*Gadus morhua* 50-70 cm). The majority of these fish would have been slowed down by rather less than 5% and the extra power output required for a tagged fish to maintain the same steady speed as an untagged fish of the same size was shown to be about 3-5% (Arnold & Holford, 1978). Generally, however, little attention has been paid to minimising drag, either by optimising the shape of the tag, by or determining the optimal attachment point and tether length and this is particularly so for small and medium size fish. Pop-up satellite-detected tags, which are designed to be attached externally to large, fast-swimming pelagic fish, such as tuna and marlin, are different. The shape of the tag has been optimised in field and tank trials (Block *et al.*, 1998b; Arnold & Dewar, 2001). Designs are also available for a low-drag bomb-shaped towed body for use with swordfish and other fast pelagic species (Weihs & Levin, 1997).

5.4.2.3 Detachable tags

Pop-up tags were first developed by Nelson (1978), who used them to retrieve acoustic tags and also recover data by radio. Baba & Ukai (1996) describe a similar tag that will detach itself from the fish after a pre-set interval and float to the surface, from where it transmits a radio signal to an ARGOS satellite. A similar tag has been developed by Telemetry 2000 (Columbia, Maryland, USA). The satellite determines the pop-up position and the tag transmits a limited amount of stored data after it has reached the surface. Currently this consists of a set of average hourly or daily temperatures, distributed equally through the deployment, which can be up to 1 year in length. The tag, which is designed for use with large pelagic species, is too large (34 x 4 cm, 65-68 g) for use with most of the species exploited in European waters. However, it has been used successfully on bluefin tuna (*Thunnus thynnus*) in the North Atlantic (Block *et al*., 1998b; Boyan, 1998; Lutcavage *et al*., 1999) and less successfully in the Mediterranean (De Metrio *et al*., 1999, 2000). The tag is contained in a composite, positively buoyant, low-drag housing towed by a short (25-30 cm) leader attached to a tagging dart. The buoyancy is moulded to the rear of the tag, which floats vertically at the surface with a 16-cm aerial projecting vertically upwards above the surface. Prior to release, the tags, which are placed near the rear of the second dorsal fin, trail freely behind the fish with both tag and aerial horizontal.

The attachment dart, which is made of titanium (Block *et al*., 1998a) or medical grade nylon (Floy, Inc.), can be inserted in the dorsal muscle (Lutcavage *et al*., 1999) or at the base of the second dorsal fin, where it can be anchored through the bony projections and connective tissue radiating ventrally from the fin (Block *et al*., 1998a). Block *et al*. (1998b) caught large bluefin tuna on rod and reel with heavy tackle and tagged the fish on board a small angling boat. Lutcavage *et al*. (1999) caught large bluefin by rod and line, or purse seine, and tagged the fish in the water, using a custom-built applicator, or a harpoon (Chaprales *et al*., 1998). Lutcavage *et al*. (1999) and Block *et al*. (1998b) respectively report success rates of 85 and 95% for data retrieval from batches of 20 and 37 pop-up tags released on large tuna in the western North Atlantic.

External tags can also be deliberately detached to avoid adverse long-term effects of tagging, or to recover the tag before it stops transmitting. Osborne & Bettoli (1995) describe a positively buoyant tag assembly that detaches itself from the fish when the suture thread decomposes after a few weeks. Rewards are paid for returned tags, each of which can be reused several times. Different release times can be achieved through use of filaments with different rates of absorption Baras (pers. comm.).

5.4.3 Internal attachment

Internal tagging is only suitable for a fish with a large stomach, or space in the body cavity into which a tag can be inserted without impeding or damaging the internal organs. Internal tagging avoids the causes of tag loss associated with external tags and has a number of positive advantages, not least of which is the proximity of the tag to the centre of gravity of the fish. But the method is not suitable for all applications and may produce signal attenuation if acoustic tags are used with large fish. It is usually also necessary to mark the fish externally, so that fishermen are aware of the presence of the internal tag, if recovery of the tag is required.

5.4.3.1 Stomach insertion

The stomach is the natural location in which to impose extra mass on the fish and this may explain why the use of stomach tags is often very successful, particularly if tags have been ingested voluntarily by the fish.

(a) Voluntary ingestion

Some fish will ingest acoustic transmitters embedded in baits deployed close to the sea floor. This technique has been used to excellent effect to study the short term movements of grenadiers (*Coryphaenoides spp.*) and other abyssal demersal fish in the Atlantic and Pacific Oceans (Priede *et al.*, 1994a, b, c; Armstrong & Baldwin, 1990, Armstrong *et al.*, 1992b; Collins *et al.*, 1998). The work was done with Aberdeen University’s free-fall vehicle, AUDOS, using ultrasonic transmitters or transponders concealed in mackerel or squid bait. The baited packages were tied to a scaled cross in the field of view of a 35 mm underwater camera using fine thread. More bait was tied to the centre of the cross to help attract fish to the rig. Fish taking the baited tags triggered the camera and were subsequently identified from the processed photograph after the vehicle was recovered. The same technique has also been used with cod (Armstrong *et al.*, 1992b; Løkkeborg, 1998; Løkkeborg & Fernö, 1999).

(b) Forced ingestion

Forced insertion of a telemetry tag into the stomach is readily achieved with a glass or plastic rod or tube (e.g. Monan *et al.*, 1975), using glycerine as lubricant (Mellas & Haynes, 1985). This method of attachment (Fig. 5.4.2) is more commonly used with radio than acoustic tags and often involves an aerial wire fastened to the top of the mouth with a dart, or fed back through the gill slits and allowed to trail free in the water. Forced insertion is possible even with quite small fish and drinking straws have apparently been used to implant tags in the stomachs of 5-6 cm American shad. Insertion is easiest with a hollow tube fitted with a plunger (Fig. 7.5 in Nielsen, 1992). The tag is placed in the open end of the tube, flush with the end, and expelled when the plunger is depressed as the tube is withdrawn from the stomach.

5.4.3.2 Oviduct insertion

In salmonids and some other species, in which it is not connected to the ovary, it is possible to insert tags into the body cavity through the oviduct. Peake *et al.* (1997b) have recently shown that it is possible to insert dummy radio transmitters into Atlantic salmon (*Salmo salar*) in this way without affecting survival, behaviour or egg development, provided insertion is done prior to egg formation, or after the eggs have been shed. The leading end of the tag was tapered to assist insertion. The radio aerial was allowed to trail freely from the oviduct. Some fish expelled the transmitter via the oviduct within 7-13 days of insertion but Peake *et al.* (1997b) reported retention times of 60 days for salmon (~70%) that retained the tags for more than 14 days. Dissection showed that the tags were positioned well forwards of the internal opening of the oviduct at, or near the pelvic girdle. Tags were encapsulated in, and anchored by, a thin, transparent sheet of tissue. Similar trials with rainbow trout showed that reproductive success was compromised when the tags were inserted into fish with already developing egg masses. The technique may also be possible in female sturgeons (Acipenseridae), lungfish (dipnoans) and bowfins (Amia), which also shed eggs into the body cavity, and male hagfish and lampreys (agnathans), which similarly deposit sperm in the body cavity and have urinogenital ducts leading into the body cavity (Peake *et al.*, 1997b).

5.4.3.3 Intra-peritoneal surgery

Because of problems of regurgitation, abrasion and possibly predation, neither stomach tags nor external tags can offer long-term security of attachment. For long-term experiments, the solution is to insert the tag internally in the peritoneum. This has been done successfully over the last twenty years with a number of marine and freshwater species, both with and without the use of anaesthetics. Insertion need entail no more than making a small surgical incision in the body wall and the whole process can often be completed within a few minutes. Having had extensive experience of tagging several thousand southern bluefin tuna (*Thunnus maccoyii*), CSIRO has perfected the technique to the stage where a trained operator can insert an archival tag into an unanaesthetised fish in 50 s, a time that includes injecting antibiotics and suturing the wound (Williams, 1992). Surgery is, however, a delicate operation and field technicians need to be carefully chosen for their manual dexterity and seaworthiness in order to ensure the quality control vital for a successful tagging experiment (Gunn *et al*., 1994; Gunn, pers. comm.). Similar protocols have recently been described for cod (Thorsteinsson, 1995) and Atlantic bluefin tuna (Block *et al.,* 1998a). Longer surgical operations have been carried out equally successfully in the laboratory with both cod (Pedersen & Andersen, 1985) and rainbow trout (e.g. Kaseloo *et al*., 1996) using controlled anaesthesia. The advantages and disadvantages of anaesthetics are considered in Chapter 7, which also provides criteria for selecting the appropriate compound.

(a) Incision site and length

Once the fish is anaesthetised, an incision is made in the body wall with a scalpel blade. For some species, such as serrasalmids, which have a mid-ventral cartilaginous structure and long ribs, only one site is possible for the incision (Baras & Westerloppe, 1999). For other species there is a choice that can be made on the basis of a number of criteria, such as innocuousness, healing dynamics and minimum expulsion risk. Because the viscera lie in the dorsal part of the body cavity when the fish is turned upside down, mid-ventral incisions are unlikely to cause direct internal damage. They are thus more frequently chosen (e.g. Hart & Summerfelt, 1975; Bidgood, 1980) than lateral incisions, which may puncture the gonads and prove more difficult to close, because they involve a thicker body wall, longer healing times and lower survival rates. By contrast with mid-ventral incisions, lateral incisions also cause systematic damage to bundles of striated muscle, for which degenerative processes often outstrip tissue reconstitution (e.g. Roberts *et al*., 1973a, b, c; Knights & Lasee, 1996). However, lateral incisions can be advantageous because the transmitter exerts less pressure over tissues weakened by the incision (Tyus, 1988) and there is less risk of expulsion through the wound than with a mid-ventral incision.

In order to minimise the trauma to the fish, the duration of healing and the risk of expulsion of the tag through the wound, the surgical incision should be as short as possible. Key factors governing incision length are the diameter of the transmitter, its length and the flexibility of the fish body wall. The ratio of incision length to tag diameter is a convenient index. Feasibility studies (Baras, 1992; Baras & Westerloppe, 1999; Thoreau & Baras, 1997) indicate that a ratio of 1.4-1.5 is appropriate for catfishes, which have a flexible body wall. A ratio of 2.5 is more suitable for serrasalmids, which have a thick body wall and in which a lateral incision is unavoidable (see above). For most cyprinids, salmonids and cichlids a ratio of 1.6 to 1.8 is suitable (Baras, pers. comm.).

(b) Implant size and weight

There are finite limits on the size and weight of an implant, which are determined by the size and species of fish to be tagged. The relevant factors are considered in Chapter 7.

(c) Internal position of implant

Internal transmitters may move within the body cavity and cause a variety of damage, such as gonad alteration (Chamberlain, 1979), internal haemorrhage (Bidgood, 1980), bruised liver, eroded rectum (Schramm & Black, 1984), and puncture of the intestine (Baras *et al.*, in press). Tags should therefore be put in a position that offers the least probability of movement, such as over the pelvic girdle, and as far as possible from hazardous locations, such as the pericardium or the incision wound. Internal movements can be restricted by suturing the tag to the body wall and this technique works well with the Atlantic cod (Pedersen & Andersen, 1985) but not with channel catfish, in which it induces systematic expulsion (Marty & Summerfelt, 1986). An aerial or umbilical passing through the body wall can limit the movements of the tag inside the body, although the benefits of reduced movement are offset by a higher risk of bacterial infection in the incision wound. In species in which the implant becomes encapsulated by host tissues, tag movements are in practice often restricted to the first days or weeks after surgery.

(d) Closing the incision

Surgical incisions can be closed with absorbable or non-absorbable sutures or stainless steel staples. With larger fish (< 5 kg) it may be appropriate to close the incision with a double row of sutures, one each for the peritoneum and skin (Summerfelt & Smith, 1990). There are several common suture patterns, of which the ‘simple interrupted’ and ‘interrupted horizontal mattress’ sutures are the strongest and most suitable for closing the skin of fish. Each comprises a series of independent knots. The continuous suture, which involves less trauma, is suitable for soft internal tissue but is less secure than interrupted sutures because it has only two knots. The knot is the weakest point of a suture and if one knot becomes untied the entire suture will pull apart. Summerfelt & Smith (1990) give details of common sutures and knotting (their figures 8.2 to 8.4)

The commonest technique for closing abdominal incisions in fish is to suture at about 8 mm intervals with separate stitches right through the body wall (Hart & Summerfelt, 1975). For species with a rigid body wall or very thick skin, such as cichlids and catfish, round ‘atraumatic’ needles should not be used because their use may result in more damage and increase the time needed for tissue reconstitution (Baras & Westerloppe, 1999; Thoreau & Baras, 1997). There is a choice between absorbable (plain or chromed catgut) and non-absorbable (nylon or silk) filament. This often entails a trade-off between the risks of expulsion of the tag through an unhealed incision at the time the filament becomes dissolved and the risks of infection associated with a transcutaneous foreign body (Baras, 1992; Knights & Lasee, 1996). The removal of permanent suture filaments after the incision has healed may be advantageous, but fish have to be held in captivity for longer, and this is often detrimental to the fish or the experiment. Braided silk may be an undesirable suture material because fish have been observed to interfere with the healing process by grazing on stitches on which algae start to develop (Thoreau & Baras, 1997).

Suturing is time consuming and alternative methods of closing the wound may be desirable. Surgical staples can be used to close long incisions quickly (Mulford, 1984; Filipek, 1989; Mortensen, 1990) but necessitate the removal of more rows of scales than suturing and may render the fish more liable to fungal infection (Mellas & Haynes, 1985). They are also permanent transcutaneous foreign bodies.

Commercial grade cyanoacrylate adhesives, applied to the opposed edges of a blotted dry incision, enable the wound to close quickly and almost always suppress the inflammatory response at the incision site (Nemetz & MacMillan, 1988). However, they remain in place for a few days only and may result in more frequent loss of tags through the incision (Petering & Johnson, 1991). Baras & Jeandrain (1998) used cyanoacrylate to close incisions in European eels, for which suturing induces frequent necrosis of the body wall. They found, however, that the eels removed the adhesive within a few hours unless a biological bandage (a freshly cut fin fragment) was applied over the incision before the cyanoacrylate had dried.

A final option is to leave the abdominal incision open. This may cause ethical problems and favour bacterial infection, but it compares favourably with suturing in respect to survival, healing (Carmichael, 1991) and implant retention rate (Baras, 1992), especially for short incisions in small fish (Baras *et al.*, in press).

(e) Healing rates

Wound healing is a process of tissue reconstitution (Roberts *et al.*, 1973a, b, c; Marty & Summerfelt, 1986, 1990), whose dynamics are governed by factors, such as species, age, temperature and food availability that control fish growth. Fast-growing tropical fish heal incisions within less than two weeks (Baras & Westerloppe, 1999; Thoreau & Baras, 1997). Temperate species require four to six weeks (e.g. Pedersen & Andersen, 1985; Baras, 1992) and much longer at low temperatures (Ross & Kleiner, 1982; Knights & Lasee, 1996). Juvenile fish heal much faster than adults do. Wound healing in juvenile African cichlids and catfish (Baras *et al.*, in press; Baras & Westerloppe, 1999) and Atlantic salmon parr and smolts (Moore *et al.*, 1990a) occurs in 7-8 days and 14 days, respectively, equivalent to the resorption times of plain and chromed catgut.

5.4.3.4 Muscle implantation

To date most archival tag experiments with tuna have used tags implanted in the body cavity, although the NMT archival tag was originally designed for insertion in the dorsal muscles of tuna and billfish. A series of recent trials, using small (1-2 kg)_yellowfin tuna (*Thunnus albacares*) and 1/25 scale stainless steel models of the NMT archival tag has now, however, demonstrated that muscle insertion is a feasible alternative to peritoneal surgery (Brill, unpublished report).

5.4.4 Effects of electronic tags on fish behaviour and physiology

There have been a number of studies on the impact of electronic tags on fish behaviour and physiology since acoustic and radio tags first began to be used in the early 1970s. These are reviewed in Chapter 7 (Section 7.4).

5.5 RECOVERY OF DATA STORAGE TAGS (DSTs)

5.5.1 Publicity and rewards

In general, intensive tag recovery is not essential for either transmitting or transponding tags because these tags require specialised receivers. Research programmes are generally designed to ensure that the tagged fish are detected, either by placing receivers in strategic locations, or by actively tracking using mobile tracking equipment. However, tag recovery for data storage tags is essential as they do not transmit their position or information and each individual tag may contain an enormous amount of data. Despite this, few studies using electronic tags have directly examined whether the rate of recovery is sufficient to produce data which is representative of the problem being studied.

As the cost of each individual data storage tag is high, only a relatively small number may be used in any given research programme. This is offset by the amount of information that can be retrieved from even a few tags. The number of tags recovered will improve considerably with good publicity and reward systems in association with a good catch/stock scanning programme. Recovery programmes for data storage tags should therefore include:

- an investigation of the likely geographic area where tags will be recovered
- advertising the tagging programme in the appropriate area
- adequate tag scanning programmes and sufficient sample sizes
- simple recognition of tagged fish in samples from external tags or marks
- clear instructions to fishermen
- an incentive to declare tags and information.

5.5.1.1 Investigation of the likely geographic area of recovery

Generally, programmes involving DSTs take into account the probability of re-encountering tagged fish subsequently. In marine fisheries, the area of encounter is potentially vast but can be reduced significantly with backup information from catch data or conventional tagging studies. Pre-tagging surveys with conventional tags should be carried out to provide a rough estimate of where the electronic tags will be recovered and what the target fisheries are likely to be. Subsequently, standard fishing techniques can be applied to recover tags or catches can be scanned in a similar manner to conventional tags.

For migratory fish species, the area of encounter can be predicted more accurately if the migration routes are known and the fish can be intercepted at specific geographical locations at known points in the life cycle (Klimley *et al*., 1998). The tendency of many marine and freshwater species to home to specific spawning sites provides a good opportunity to tag and recapture spawning adults in the same location in successive years. This approach, which is likely to be particularly useful with anadromous fishes, such as Atlantic salmon, which home to their natal rivers with a high degree of accuracy, has already been applied to good effect with brown trout in Iceland. A large proportion (63 & 75%) of trout from Lake Thingvallavatn, which were tagged on their spawning grounds in the River Oxara in 1999 and 2000, were recovered in the same location during the following spawning season (Sturlaugsson, pers. comm.). Tagging of kelts (spent adults) in rivers prior to their return to the sea has been suggested as one way of providing information on oceanic migrations of salmon (Anon 1997, 1998b). An alternative is to tag large smolts in rivers prior to seaward migration (Anon 1998b) and a study of this type is planned in Iceland in 2002 (Sturlaugsson, J., pers. comm.).

5.5.1.2 Advertising the tagging programme

Initially, the objectives, tag type, secondary tag type (if used) and the rewards (if any) should be clearly advertised. Prospective individuals who are likely to recover tags or be aware of recovered tags (fishermen, fish processors, anglers etc) should be informed that tags of different types may be present in the fish they handle. It is important to emphasise the scientific value of the information contained in the tags (rather than the value of the tag itself), as well as the overall benefits of the data for protecting and possibly enhancing stock assessment and management.

Publicity can include:

Advertisements in national or local newspapers – if the tagging programme is locally based, it is probably best to advertise only in local papers to emphasise the probable recovery location of the tagged fish.

Posters – these should show the features which will identify a tagged fish (presence of an external tag, fin-clip, mark etc) and a clearly identified contact for return of the fish or the tag. Posters have been used extensively in conventional and electronic tagging studies and placed prominently in fish processors and fishing ports. A selection of typical posters advertising tagging programmes and rewards for recovery of various types of tags are included in the CATAG web-site (http://www.hafro.is/catag).

Public presentations – Experience has shown that direct interactions between scientists and commercial fishermen or the public improve the rate of recovery of tags and provide a more lasting impression of the objectives of the programme. Public presentations should be directed at fishermen and fishing organisations, processors, local representative groups and all users of the resource being studied.

Local interviews/contacts - again, direct contact with fishermen or other local contacts allows any queries to be dealt with expediently and creates a valuable dialogue between scientists and the public.

Subsequent reinforcement - reinforcing both the original message and the initial contacts has been shown to be effective in obtaining tags which might otherwise not be recovered, especially if tags may be recovered in more than one fishing season.

5.5.1.3 Tag scanning programmes and sample size

Even if the general area of encounter has been identified, there is still the problem of tag retrieval. For marine fisheries, where shoal sizes may be large relative to the number of tagged fish, large numbers of fish may need to be captured to ensure recovery of a single tag. In general then, marine tagging programmes are usually associated with commercial fisheries where large numbers of fish are available for examination. For anadromous fishes, recoveries can be made in drift nets, traps, and fish ladders or by angling and a systematic scanning programme at these recovery sites will greatly improve tag recovery.

Ideally, the entire catch should be examined for tags. If this is not feasible then a sufficient proportion of the catch should be examined. Numbers will depend on the estimated size of shoals, their temporal and geographic distribution and the number of tagged fish released initially. Significant improvements could be made if entire catches were routinely scanned for tags on board fishing vessels or in processing plants.

5.5.1.4 Simple identification of tagged fish in catches or samples

Clearly, catch scanning will only be effective if the tagged fish can be easily identified from non-tagged fish. This implies that a tag is clearly identifiable, or that the tagged fish is marked clearly with a secondary tag or mark. A message should be contained within the DST to inform the captor of the country of origin, tagging agency, the contact for tag return, information on rewards that may be available and any other instructions.

5.5.1.5 Clear instructions to fishermen and processors

Instructions on removing the tags and the procedures to be followed for recording relevant information, or retaining the fish, should be issued well in advance of the tagging period, and then reinforced while the fishery is taking place. For some research programmes, it may, for example be important to recover the carcass of the fish to investigate growth and condition, or determine whether spawning has taken place.

During intensive commercial fishing operations and in busy fish processing plants, retrieval of tags should not interfere substantially with routine processing, or interfere with commercial operations. If tag removal is simple, then more co-operation can be enlisted from fishermen or fish processors who are most likely to come into contact with tagged fish. This can be done on a contract basis or by organising a fee for tags recovered. In some instances, the time available to fishermen or processors to retrieve tags may be short, and it may be better to rely on trained technical personnel to scan landings and remove tagged fish.

5.5.1.6 Incentive to declare tags

The value of the data recorded by even a single DST is significant. There should therefore be a good incentive to return tags, particularly if tag recovery is dependent on commercial fishermen or processors. The following incentives have been used extensively in conventional tag recovery programme with varying degrees of success.

(a) Monetary rewards

This is a time honoured standard, although it is often difficult to decide on an adequate monetary reward. If the intention is to retrieve transmitting tags for re-use, the reward should be less than the cost of a replacement tag. For data storage tags the value must be decided in relation to the cost of the tagging programme, the value of the data and the effort needed to obtain tag recoveries, although this may be difficult to estimate in terms of direct cost benefit. By way of example, CEFAS and its European partners offer a reward of £25 (~40 Euros), payable in the local currency, for each data storage tag returned from cod, plaice or rays. In contrast, ICCAT offers a reward of $1000 (U.S.) for the return of each archival tag from its Atlantic bluefin tagging programmes (Prince & Cort, 1997). In Iceland, the Marine Research Institute offers a reward of 4000 kroner (~44 euros) for the return of each data storage tag, as well as 1000 kroner for the accompanying conventional tag (Thorsteinsson, V., pers. comm.). The Institute of Freshwater Fisheries offers the same reward for the return of each data storage tag and an extra reward of 500 kroner (~5 euros/ kg), if the fish is returned as well (Sturlaugsson, J., pers. comm.).

(b) Gifts

Gifts are often preferred as they are easier to administer and are often more acceptable, particularly if they have a high ‘popularity’ value. In many parts of the world institutes are moving towards offering T-shirts, sweatshirts, badges and peaked caps, all of which have a collectable appeal.

(c) Information

Often, the incentive to return tags can be increased if there is a corresponding return of information back to the individual recovering the tag, particularly if he/she is working within the fishing industry. Generally, the information would be in the form of an information leaflet outlining the objectives of the tagging study, information on the tagged fish that was recovered and information on the overall results of the programme.

(d) Recognition

Publication of a list of individuals who have recovered tags in an institute or fishing newsletter is often useful to advertise the tag programme and encourage tag recovery.

(e) Competitions and lotteries

As a general incentive, a lottery scheme can be a useful method to improve return rates for tagged fish. The names of people who have returned tags are entered into a draw and an overall winner, or winners, picked at random. This has the advantage that a substantially more attractive prize can be offered for the return of tags or tagged fish. A tag recovery lottery was carried out for a number of years by the North Atlantic Salmon Conservation Organisation to provide an incentive to fishermen to return conventional tags and improve the rate of tag return (NASCO, 1993). Iceland’s Institute of Freshwater Fisheries operates a lottery for the return of data storage tags (as well as conventional tags) from salmonid fish (Sturlaugsson, J., pers. comm.). In the UK, CEFAS has operated a lottery for fishermen who have returned tags deployed on plaice as part of an EC-funded research project on plaice in the North Sea (Metcalfe, pers. comm.).

5.5.2 International collaboration

Tagging programmes involving highly migratory fish species, or stocks that are exploited by several different national fleets, need special approaches for tag recovery. Again, a high degree of advertisement and publicity should be established between national co-ordinating agencies as outlined above. A separate reward scheme could be considered for tags returned from non-national fisheries.

The tagged fish should be readily identifiable to the captor, particularly if the fish has an internal DST. At the very least, a message should be contained within the DST to inform the captor of the country of origin, tagging agency, the contact for tag return and information on any rewards that may be available.

Considering the widespread use of conventional tags and the similarity of these tags being used internationally, it is recommended that a special conventional tag be used with fish containing internal electronic tags. These could be differentiated by colour, code or shape and should be advertised widely, both nationally and internationally as being specifically for this purpose.

Electronic mail and the World Wide Web should be encouraged as a method of advertising tagging programmes that have the potential to generate tag returns in international waters. The Web-site (http://www.hafro.is/catag) developed within this Concerted Action will provide an international forum for informing other agencies of ongoing or new tagging programmes and should go some way to stimulating co-operation in returning tags.

5.6 APPLICATION TO FISHERIES

Electronic tags are now being widely applied in many areas of fish biology and fisheries management. Generally, electronic tags are used to provide information that cannot be obtained using conventional tags. The main areas of application are given below with some specific examples quoted to illustrate the type of information that can be obtained from electronic tags.

5.6.1 Investigating fish behaviour in relation to fishing activities

5.6.1.1 Behaviour of fish in relation to vessels and gears

The examination of fish behaviour in relation to fishing vessels and fishing gear is one of the most important areas of application for electronic tags and one that is likely to develop significantly in future. Fish senses are highly developed and apart from sight and smell, fish can be extremely sensitive to even minute vibrations in the water or on the seabed. Electronic tags allow for real time tracking of fish or groups of fish and provide information on the reactions of these fish as the fishing vessels and gears are operating.

Telemetry studies in the late 1960s clearly showed that fish could detect and avoid fishing gear by sight and by other senses when light intensities were inadequate for the fish to see the gear. Shad (*Alosa sapidissima*) migrating up the Connecticut River reacted to drifting commercial gillnets at ranges of 1-2 m and few were caught (Leggett & Jones, 1971). Similar Norwegian studies have shown that cod (*Gadus morhua*) can detect and avoid a 30-m trawler approaching at a speed of 1-m s^{-1}. The fish reacted to the noise of the vessel at a range of 200 m and accelerated and swam out of its path when the range decreased to 100 m (Engås *et al.*, 1991). In more recent experiments, Norwegian fisheries scientists have made further observations of the reactions of cod to trawls using a fixed hydrophone array with radio-telemetry buoys to transmit data to a research vessel (Engås *et al.*, 1998). The system has also been used to investigate the reactions of edible crabs (*Cancer pagurus*) to baited pots (Skajaa *et al.*, 1998).

5.6.1.2 Improving fishing gear efficiency

There have been a number of specific studies to investigate the efficiency of fishing gears using electronic tags. In the 1970s, for example, the Fisheries Laboratory, Lowestoft (now CEFAS) in the UK carried out a major investigation to measure the efficiency of the Granton otter trawl on a flat sandy ground in the southern North Sea. The work was carried out over seven years and involved releasing several hundred plaice (*Pleuronectes platessa*) tagged with small transponding acoustic tags (Harden Jones *et al.*, 1977). One research vessel with a sector scanning sonar was used to observe the fish; a second vessel was used to tow the trawl. The results indicated that modifications of the gear could increase the efficiency of the trawl from 44% to 80% (Harden Jones & Arnold, 1982). These fishery-independent estimates of gear efficiency appear to be unique for finfish, although several studies have subsequently been undertaken with shellfish (see Section 5.6.2.2); more applications could be developed using the available technology.

5.6.1.3 Improving estimates derived from acoustic survey

Stock assessments of many fish species are now routinely carried out using acoustic technology. The results of these assessments are used to provide management advice for many of the most important marine stocks. However, validating the results of the acoustic trials is extremely time consuming and results in large expenditure of capital, ship's time and manpower. Specifically, biomass assessments from interpretation of the acoustic signals from shoals of fish may alter significantly during active migrating and feeding periods.

Electronic tags have been applied to investigate the accuracy of acoustic assessments for gadoid fishes. Biomass may be underestimated, if no account is taken of the reductions of 2-5 dB in average target strength (TS) caused by changes of attitude (pitch or tilt angle) of the fish (Foote, 1980), or changes in swimbladder volume caused by feeding or gonad maturation (Ona, 1990). Ultrasonic tracking studies in the southern North Sea have shown that cod are neutrally buoyant at the top of their vertical range but negatively buoyant on the seabed. These studies indicate that vertical migration may be accompanied by systematic and possible even larger changes in TS than those associated with feeding or gonad maturation (Arnold & Greer Walker, 1992). Negative buoyancy, which has also been demonstrated in northeast Arctic cod fitted with data storage tags (Godø & Michalsen, 2000), is accompanied by compensatory changes in attitude that may further reduce TS. Changes in tilt angle have not yet been measured successfully with electronic tags, although some trial experiments have been attempted in Norway (Michalsen, pers. comm.) and Iceland (Thorsteinsson, pers. comm.) using external attachment and surgical implantation, respectively.

Considering that acoustic data are now used extensively to provide information on biomass, applications that lead to improved efficiency and applicability of these estimates are essential.

5.6.2 Investigating fish migration, migration routes and distribution

5.6.2.1 Vertical and horizontal movements of oceanic fish

Although conventional tagging studies have provided much information on the extent of the migrations of many oceanic species, they can provide little information on behaviour or movement of the fish between tagging and recapture. Electronic tags are, however, now being used extensively to study both vertical and horizontal movements of a wide range of oceanic fish and to link behavioural changes with specific biological or environmental events. Acoustic tracking has been undertaken with salmon (*Onchorhynchus* spp.) and a number of large pelagic species such as tuna (e.g. Yuen, 1970; Block *et al.*, 1997; Josse *et al.*, 1998; Brill *et al.*, 1999; Dagorn *et al.*, 2000; Lutcavage *et al.*, 2000; Gunn & Block, 2001), billfish (Carey & Robison, 1981; Block *et al.*, 1992a & b; Brill *et al.*, 1993; Marcinek *et al.*, 2001) and sharks (e.g. Gunn *et al.*, 1999; Sundström *et al.*, 2001; Voegeli *et al.*, 2001). The tuna studies have included several investigations of behaviour associated with fish aggregating devices (FADs) (Holland *et al.*, 1990b; Cayré, 1991; Marsac & Cayré, 1998; Dagorn *et al.*, 2001).

Acoustic tracking has shown that large pelagic species - tuna, billfishes, sharks - exhibit a number of patterns of vertical migration, which appear to be associated with feeding, thermoregulation, or the avoidance of limiting oxygen levels. Some species, such as skipjack (*Katsuwonus pelamis*), yellowfin (*Thunnus albacares*) and giant bluefin (*T. thynnus*) tuna (Lutcavage *et al*., 1999) and blue marlin (*Makaira nigricans*) (Holland *et al*., 1990a), appear to be confined to the thermocline and the mixed surface layer of the ocean. These species swim nearer to the surface at night than by day. Others, such as the bigeye tuna *(T. obesus*), move rapidly up and down the water column apparently without regard for the thermocline. Bigeye forage in deeper, colder water by day, however, and need to make regular, rapid ascents back into warmer surface waters to recover lost heat (Holland *et al.*, 1992; Holland & Sibert, 1994). Swordfish (*Xiphias gladius*) also make extensive diel vertical migrations, swimming deep by day and coming near the surface at night. They appear to follow isolumes and have been recorded at midday depths of over 600 m in well-oxygenated water in the Atlantic (Carey & Robison, 1981; Carey, 1990). Some sharks also appear to follow isolumes (e.g. Nelson *et al*., 1997).

Blue sharks often break the surface with the dorsal fin and this behaviour allowed the late Frank Carey of the Woods Hole Oceanographic Institution (USA) to track several sharks directly by satellite. The transmitter (which was based on a design by the Sea Mammal Research Unit, Cambridge, UK) was bolted through the dorsal fin and carried a radio antenna on top of a long raked and streamlined mast (Kingman, 1996) (see Section 5.4.2.1 (a)). Three individuals were tracked over long distances in this way and their movements related to those of the Gulf Stream. A similar approach was adopted with whale sharks (*Rhincodon typus*) by Eckert & Stewart (2001), who used towed radio transmitters of three different designs, each attached to the shark by a monofilament tether and sub-dermal darts embedded close to the midline near the first dorsal fin. Direct satellite telemetry has limited application, however, because most species do not swim sufficiently close to the surface. Significant new discoveries are therefore more likely to come from the widespread use of other techniques, such as data storage tags (see Section 5.2.4), which have already been used with school sharks (West & Stevens, 2001), and pop-up satellite-detected tags (see Section 5.2.5).

CSIRO scientists from Hobart, Australia began an archival tagging programme to study the movements, behaviour and physiology of juvenile southern bluefin tuna (*Thunnus maccoyii*) in 1993 (Gunn *et al.*, 1994). Japanese researchers initiated a similar programme with juvenile Pacific bluefin (*T. orientalis*) in 1995 (Kittigawa *et al.*, 2000; Inagake *et al.*, 2001). North American scientists began two programmes in the western North Atlantic in 1996 and 1997. Large Atlantic bluefin tuna (*T. thynnus*) have been variously tagged with archival tags, single-point satellite-detected pop-up (PST) tags, or pop-up archival (PSAT) tags. The aim is to investigate migration and spawning site fidelity and test the current ICCAT management hypothesis that there are discrete eastern and western stocks (Block *et al.*, 1998a, b; Lutcavage *et al.*, 1999). Archival tags (Yamashita & Miyabe, 2000) and pop-up tags (DeMetrio, 1999, 2000) have also been used with Atlantic bluefin in the Mediterranean. Substantial progress has already been made with all three species (Gunn & Young, 2000; Kittigawa *et al.*, 2000; Block *et al.*, 2001a, b; Inagake *et al.*, 2001), which have been shown to make extensive feeding forays and rapid spawning migrations, some trans-oceanic in scale. Movements are related to oceanographic features and there are already sufficient data to show that bluefin tuna tagged off the east coast of the USA are vulnerable to fishing on both sides of the North Atlantic, with obvious implications for management. Gunn & Block (2001) and Arnold & Dewar (2001) provide more detailed summaries of recent progress.

Japanese studies with acoustic tags in the central Bering Sea and North Pacific indicate that the six species of Pacific salmon (sockeye, chum, pink, coho, chinook and steelhead) occur mostly in the upper 50 m of the water column, although making occasional forays to greater depths (150-200 m max.). Sockeye, pink, coho and steelhead are restricted to the top 10 m for over 70% of the time and chum salmon also swim near the surface; chinook salmon occur at depths of 20-40 m. Acoustically tagged individuals of these six species showed few regular patterns of vertical movement (Ogura, 1994, 1997; Ogura & Ishida, 1992, 1995). Seasonal and diel patterns of vertical movement were, however, recorded in other Japanese studies, in which chum salmon (*Onchorhynchus keta*) were fitted with timed data recorders (Ogura, 1997; Ishida *et al.*, 1998; Tanaka *et al.*, 1998). The fish were observed to swim consistently deeper by day than by night and seasonal differences in swimming depth were also apparent. The fish remained in cool, deep (100-200 m) water during autumn, but swam at shallower depths in winter after the surface waters had cooled down (Ishida *et al.*, 1998). Repeated diving in the top 60 m during the day was a pronounced feature of the behaviour of three chum salmon migrating from the Bering Sea - where 25 fish were tagged - to Hokkaido during the summer of 1998 (Wada & Ueno, 1999). The fish, which migrated distances of 2500 to 3000 km over periods of 47 to 77 days, remained near the surface at night, where they were probably feeding. Similar patterns of vertical movement have been deduced from long-term records obtained from eight individual Pacific salmonids tagged with small temperature loggers (Walker *et al.*, 2000). After an apparent refractory period of variable length, the records all showed large regular fluctuations in temperature consistent with the fish moving towards the surface at night, possibly to feed, and descending periodically to deeper, cooler water during the day.

5.6.2.2 Behaviour of shelf seas fishes

There has been a substantial amount of fish tracking work on the European continental shelf over the last 25 years, which has significantly advanced our understanding of the behaviour of free-ranging fish in the open sea. A wide range of species has been studied with acoustic tags. These include European eels (*Anguilla anguilla*) (e.g. Tesch, 1974; Tesch *et al.*, 1991; McCleave & Arnold, 1999), dogfish (*Scyliorhinus canicula*) (Greer Walker *et al.*, 1980), plaice (*Pleuronectes platessa*) (Greer Walker *et al.*, 1978; Metcalfe *et al.*, 1993), sole (*Solea solea*) (Greer Walker *et al.*, 1980; Lagardère *et al.*, 1988, 1990) and cod (*Gadus morhua*) (Hawkins *et al.*, 1974; Arnold, 1981; Arnold *et al.*, 1994; Godø, 1995; Svendsen, 1995). Some work has also been done with artificially matured European eels in the open ocean in an attempt to locate the spawning grounds in the Sargasso Sea (Fricke & Kaese, 1995) and similar experiments have also been attempted in the Pacific (Aoyama *et al.*, 1999).

Acoustic tags have been used in other parts of the world to investigate the local movements of various species of fish and shellfish. Research on finfish has encompassed several studies of cod (*G. morhua*) in near-shore waters in Newfoundland (Clark & Green, 1990; Wroblewski *et al.*, 1994, 1995, 2000; Green & Wroblewski, 2000). There have been similar studies of a number of other teleosts, including shad (*Alosa sapidissima*) (Dodson & Leggett, 1973, 1974), lingcod (*Ophiodon elongatus*) (Yamanka & Richards, 1993), yellowtail rockfish (*Sebastes flavidus*) (Pearcy, 1992) and deepwater rockfishes (*S. chlorosticus and S. paucispinis*) (Starr *et al.*, 2000). There have also been investigations of the behaviour of white goatfish (*Mulloides flavolineatus*) in a fisheries conservation zone in Hawaii (Holland *et al.*, 1993) and extensive studies of coral reef fish ecology in Australia (Zeller, 1997, 1998, 1999; Zeller & Russ, 1998).

Acoustic tags have also been used to study the behaviour of various species of crustacea (Lund & Lockwood, 1970; Monan & Thorne, 1973; Chapman *et al.*, 1975; Hernnkind, 1980; van der Meeren, 1997; Arnold *et al.*, 1990; González-Gurriarán & Freire, 1994; Freire & González-Gurriarán, 1998) and to investigate the reactions of crabs (*Cancer pagurus*) to baited traps (Skajaa *et al.*, 1998). There have also been studies of the behaviour of several cephalopods including ommastrephid (Nakamura, 1991, 1993) and loligid squids (O’Dor *et al.*, 1994; Sauer *et al.*, 1997) and *Nautilus* (Ward *et al.*, 1984; Carlson *et al.*, 1984). Electromagnetic tags, which have a much shorter detection range, but which avoid the attenuation and reflection to which acoustic transmissions are subject close to the seabed, have been used in a number of other studies. In Australia, for example, Jernakoff *et al.* (1987) used an automatic tracking system to track as many as 14 western rock lobsters (*Panilurus cygnus*) for up to 3 weeks and quantify their nocturnal foraging distances. Using the same system, Jernakoff & Phillips (1988) investigated the effect of a baited trap on the foraging movements of the same species; they also estimated the number of animals responding to the trap and compared the number of approaches with the number of animals captured. Similar studies have subsequently been undertaken in Europe, using a more advanced version of the Australian system (Collins, 1996; Smith *et al.*, 2000). These studies have investigated diel and seasonal patterns of activity of *Homarus gammarus* on an artificial reef (Smith I.P. *et al.*, 1998a & b, 1999), as well as catchability in traps (Collins *et al.*, 2000).

Data storage tags have been used extensively with demersal species in the eastern North Atlantic and adjacent seas to investigate vertical and horizontal movements of individual fish over much longer periods than can be achieved with acoustic tags. Rates of recovery have generally been high (> 40% in some instances) and the data have provided important new insights about seasonal distribution, as well as behaviour during feeding, migration and spawning (Arnold & Dewar, 2001). Most programmes have concentrated on plaice (*Pleuronectes platessa*) and cod (*Gadus morhua*), although there has also been some work with the thornback ray (*Raja clavata*) in the Irish Sea and Thames estuary (Arnold & Dewar, 2001; Buckley, pers. comm.) and the spider crab (*Maja squinado*) in Spain (Freire & González-Gurriarán, 1998; Freire *et al.*, 1999).

Extensive pressure recordings from plaice tagged with data storage tags in the North Sea have provided a way to investigate population distributions and mechanisms of horizontal migration, as well as seasonal patterns of vertical movement. Geographical tracks of individual plaice can be reconstructed over many months, from the vertical movements of the fish itself (Arnold & Holford, 1995; Metcalfe & Arnold, 1997), or hydrostatic data recorded when the fish remains on the seabed for one (~13 h) or more tidal cycles (Metcalfe

& Arnold, 1997; Metcalfe *et al.*, 1999). The reconstructed tracks have provided new information on the distribution of plaice populations in relation to known spawning grounds in the North Sea (Hunter *et al.*, 2001). The pressure measurements have shed new light on selective tidal stream transport (Greer Walker *et al.*, 1978), whose use appears to be restricted to areas of fast, directional tidal streams where the fish can save energy (Hunter *et al.*, 2001). Pressure data have similarly provided new information on the patterns of vertical movement of cod on Faeroe Plateau (Steingrund, 1999), at Iceland (Thorsteinsson, 1995; Thorsteinsson & Marteinsdottir, 1998), and off northern Norway (Godø & Michalsen, 2000), as well as in the North Sea and Irish Sea (Righton *et al.*, 2000, 2001a & b). Data from the North Sea show that some cod are sedentary for long periods during the summer (Righton *et al.*, 2000, 2001a & b). Rates of vertical movement recorded with data storage tags in the Barents Sea, Irish Sea and North Sea indicate that cod are negatively buoyant over much of their vertical range (Godø & Michalsen, 2000; Righton *et al.*, 2001b). These observations, which have important implications for target strength and acoustic surveys, agree with previous observations of acoustically tagged cod in the North Sea (Arnold & Greer Walker, 1992). Comparatively little has yet been learned from archival tag data about the horizontal migrations of cod. But investigations by the Institute of Marine Research in Reykjavik have shown that sexually mature cod tagged on the spawning grounds to the southwest of Iceland move off the continental shelf in early summer, descending to depths of 200-300 m and more. And the records of 11 tags, which spanned two successive spawning seasons, showed that the cod returned to the continental shelf between February and April the following year, remaining in shallow water for periods of 14 to 33 days. Most fish showed extensive vertical movements in deep water, but much reduced activity in shallow water during the spawning season (Thorsteinsson & Marteinsdottir, 1998).

5.6.2.3 Coastal waters and estuaries

In Europe, acoustic tags have been used to follow the movements of Atlantic salmon in coastal waters on their way back to spawn in freshwater. Tracking has been undertaken in UK (Smith *et al.*, 1981; Potter, 1985) and Swedish waters (Westerberg, 1982a & b; Døving *et al.*, 1985). The work has shown that adult salmon can maintain a compass course over quite large distances, irrespective of current or tidal stream direction (Smith *et al.*, 1981). It has also shown that salmon may exhibit diel vertical migrations swimming close to the surface during daylight, but descending to depths of as much as 40 m at night. Individual fish may also show large vertical movements near river mouths and it is suggested that this behaviour may be related to olfactory discrimination of fine scale hydrographic features during the search for the home stream (Døving *et al.*, 1985). The European salmon tracking work has been paralleled by similar work with Pacific salmon on the west coast of North America and also in Japan (for references see Arnold & Dewar, 2001; Arnold & Lundgren, 2002).

Data storage tags have been used on salmonids in Iceland since 1994 and in the Baltic since 1995, with recapture rates of 50 to 70% (Sturlaugsson, 1995; Karlsson *et al.*, 1996; Sturlaugsson & Thorisson, 1997; Westerberg *et al.*, 1999a; Karlsson *et al.*, 1999). The main aim of Icelandic work on Atlantic salmon (Sturlaugsson, 1995; Sturlaugsson & Thorisson, 1997; Sturlaugsson & Gudbjornsson, 1997) was to study the homing migration in coastal waters and the Baltic study (Karlsson *et al.*, 1996; Karlsson *et al.* 1999; Westerberg *et al.* 1999a & b) had similar aims. In Iceland returning salmon were captured and tagged in the estuaries of their home rivers. They were then transported to a number of release sites at distances of 25-420 km from the capture site by the shortest sea route. Some fish were released at sea at distances up to 200 km from the nearest shore and some salmon were tagged with ultrasonic tags as well as data storage tags (Sturlaugsson, J., pers. comm.). All these fish were thus repeating the final stages of their return migration from the sea to freshwater. In the Baltic, in contrast, salmon were caught at a variety of locations before they had returned to their spawning rivers; these fish were released at the capture location immediately after tagging. Both studies confirmed that migrating salmon swim within a few metres of the surface (≤2 m for 90% of the time), allowing satellite measurements of sea surface temperature (SST) to be used to deduce location and movement. Most salmon migrated close to the coast at Iceland and also in the Baltic. At Iceland depth and salinity measurements showed that some fish entered other estuaries and rivers before reaching their home river again (Sturlaugsson & Thorisson, 1997). At Iceland, although not in the Baltic, there was evidence of a diel rhythm of vertical movement in the sea. The fish swam deeper at night, although the majority of the deepest dives occurred around sunset and sunrise. Most dives were rapid and shallow, but some penetrated the thermocline (Sturlaugsson & Thorisson, 1997). The maximum recorded depths were 153 m (Sturlaugsson & Gudbjornsson, 1997) in coastal waters and 323 m in oceanic waters (Sturlaugsson, pers. comm.).

The Icelandic investigations also included studies of sea trout (*Salmo trutta* L.) (Sturlaugsson & Johannsson, 1996; Sturlaugsson & Johannsson, in press) and anadromous arctic char (*Salvelinus alpinus*) (Sturlaugsson *et. al.* 1998). Sea trout were caught and tagged in freshwater (see Section 5.3.3.4) in early May, using internal or external data storage tags and external conventional tags. In 1995 the electronic tags were programmed to record depth and temperature at intervals of 4 h for periods up to 4 months. This was sufficient to cover the remainder of the pre-migratory period in freshwater, the whole of the sea-going feeding migration (33 to 93 days), and a subsequent period after the fish had returned to freshwater. The data provided new information on growth, the timing of movements between fresh and saltwater, and vertical distribution in the sea. They showed that, like salmon, sea trout spend most of their time in the top of the water column (≤ 7 m for 91% of the time), with occasional deeper dives (Sturlaugsson & Johannsson, 1996; Sturlaugsson & Johannsson, in press).

A number of other studies (e.g. Moser *et al.*, 1991; Moore *et al.*, 1995; Lacroix & McCurdy, 1996; Moore *et al.*, 1998; Voegeli *et al.*, 1998; Lacroix & Voegeli, 2000) have used electronic tags to investigate the estuarine movements of salmon and sea trout migrating to sea at the end of the freshwater phase of the life history. Complementary studies have examined the upstream movements of adult fish returning from the sea. These studies have used chains of moored sonar buoys, which transmit a radio signal on receipt of an underwater signal from an acoustic tag. Radio transmissions from several buoys are received by an automatic listening station (ALS), which records the date and time at which each signal is received, as well as the identity of the sonar buoy and an audio recording of the pulse rate of the tag. The system has been used to track the movements of adult Atlantic salmon (*Salmo salar*) and sea trout (*S. trutta*) returning to spawn in freshwater (e.g. Potter, 1988; Potter *et al.*, 1992; Mee *et al.*, 1996) using CART tags (see section 5.2.3.1) inserted in the stomach (Solomon & Storeton-West, 1983).

5.6.2.4 Freshwater

Many important features of the migratory behaviour of anadromous and catadromous fish in freshwater have been elucidated with PIT tags (e.g. Prentice et al 1990a, b) radio tags (e.g. Solomon & Storeton-West 1983, Laughton & Smith 1992) or data storage tags. Specific studies have been carried out to investigate the movements of adult and juvenile fish in relation to fish passes, hydroelectric generation stations, barrages (e.g. Olsen *et al* 1990., Moore *et al.*, 1996) and a wide variety of man-made obstacles including thermal and chemical effluents. The effectiveness of hook and release (catch and release) of rod caught Atlantic salmon has been investigated as a conservation measure in many countries. Recent studies using radio tags have indicated that a large number of fish survive for several months after release and some of them spawn (Webb 1998). As a result, hook and release has been instigated as a management measure in many salmon rod fisheries in Europe, the USA and Canada.

Pressure sensitive radio transmitters have been used to monitor depth selection by rainbow and brown trout in lake systems in Montana USA (Williams & White 1990). Demers *et al.* (1996) used electromygram biotelemetry to determine the activity patterns of largemouth and smallmouth bass in the USA. Telemetry studies have been carried out to monitor the behaviour of important coarse fish populations in Ireland (Caffrey *et al.*, 1996; Donnelly *et al.*, 1998). In particular, the homing and territorial behaviour of pike (*Esox lucius*), tench (*Tinca tinca*), bream (*Abramis brama*) and rudd x bream hybrids has been described. These studies have shown that coarse fish will travel long distances to return to their own territory. Recent investigations have been carried out in Ireland to investigate multiple capture of coarse fish in competition stretches of important coarse angling venues and to assess the impact on the populations (Caffrey, *pers. comm.*) while the efficiency of migration of pike-perch through a bypass channel on the River Danube has been examined using radio tags (Schmutz *et al.*, 1998).

In addition to providing information on the behaviour of fish and their immediate environment during the sea-going phase of the life history (see Section 5.6.2.3), Icelandic data storage tag studies with sea trout (*Salmo trutta*) have also produced new information on rhythmic patterns of behaviour in freshwater during early summer, autumn and winter (Sturlaugsson & Johannsson, 1996). Similar studies with arctic char (*Salvelinus alpinus*), conducted annually since 1997, have given valuable information on the behavioural ecology of both anadromous and non-anadromous fish in freshwater (Sturlaugsson *et al.*, 1998). Data storage tags have also been used in freshwater to record the behaviour of non-migratory brown trout (*Salmo trutta*) throughout the year, as well as the migratory behaviour of Atlantic salmon. The brown trout studies, which were conducted in Lake Thingvallavatn, the largest natural lake in Iceland, provided detailed information on spawning and feeding. The Atlantic salmon studies, which were carried out in lakes and rivers, used double tagging, with data storage tags and radio transmitters attached to the same fish (Sturlaugsson, J., pers. comm.).

5.6.3 Assessments of predation and other multi-species interactions

Despite the significance of multi-species interactions, this area of fisheries biology and management is poorly described and understood. Most assessments are carried out on a stock by stock basis. Attempts to add extra parameters to account for interactions between stocks generally lead to extremely complex analyses and increased uncertainty in results. This is mainly due to the lack of reliable data on real rather than simulated interactions. Despite this, fishery scientists are becomingly increasingly dependent on the results of these analyses to provide advice to managers. Studies using electronic tags can be applied to describe real interactions and the scale on which these interactions occur.

5.6.3.1 Predation by other fish species

With the exception of deep-sea scavengers and some preliminary work with sharks (Klimley *et al.*, 1998; Goldman & Anderson, 1999) and tuna (Laurs *et al.*, 1977; Josse *et al.*, 1998), electronic tags have been little used to date to study feeding and predation of fish in the open sea. Aberdeen University (in the UK) has used baited acoustic tags (see Section

5.4.3.1) to study the foraging behaviour of grenadiers (*Coryphaenoides* spp.) and other deep-sea fish at various oligotrophic and eutrophic sites in the Pacific and Atlantic oceans (Priede *et al.*, 1990, 1994a, b, c; Collins *et al.*, 1998). Using this technique to measure times of arrival and departure of fish from the vehicle, it has been possible to show that grenadiers are active scavengers, which move independently of the abyssal currents. Population densities are higher at eutrophic sites than oligotrophic sites but - in accordance with optimal foraging theory - staying times are significantly longer at oligotrophic sites. Staying times also vary seasonally and appear to reflect seasonal variations in the supply of food reaching the ocean floor. Application of this technique might be expected to produce useful results in the study of multi-species interactions in shelf seas.

5.6.3.2 Interactions between fish and sea birds

Archival tags have been used to study the feeding ecology of oceanic sea birds alone (e.g. Tuck *et al.*, 1999) or in combination with satellite telemetry tags (e.g. Weimerskirch *et al.*, 1994). Foraging location has been provided by the satellite tag (e.g. Jouventin & Weimerskirch, 1990; Jouventin *et al.*, 1994), or by a light sensor in the archival tag. Foraging behaviour has been deduced from diving profiles (e.g. Wilson *et al.*, 1991) or recorded by an ingestible temperature sensor (Wilson *et al.*, 1992), which can be recovered by stomach flushing when the bird returns to the nest. These techniques have revealed quite a lot about seasonal and diurnal patterns of feeding activity in sea birds, which are known to prey on important commercial fish species and interact with fisheries. Important information has been obtained on rates of capture of individual prey items and the quantity of food ingested during foraging excursions (e.g. Bost *et al.*, 1997). Internal recorders have proved particularly useful by revealing characteristic patterns of temperature in the stomach (Weimerskirch & Wilson, 1992) or oesophagus (Charrassin *et al.*, 2000) following feeding.

Radio telemetry has been used to investigate the foraging activities of cormorants and shags (*Phalacrocorax* spp.), foot-propelled pursuit divers that feed on sandeels (*Ammodytes* spp.) and other marine fish, and do not range too far from their breeding colonies. Changes in signal characteristics indicate when the bird is at the colony or away feeding; breaks in signal transmission indicate when the bird is diving in pursuit of prey (Wanless & Harriss, 1992; Wanless *et al.*, 1993). Combined with automatic electronic balances, which measure adult body mass before and after a foraging trip (Grémillet *et al.*, 1997) it is now possible to measure daily food intake and foraging effort. This in turn allows calculation of catch per unit of effort, gross foraging efficient and parental investment at different breeding stages (Grémillet, 1997).

5.6.3.3 Interactions between marine mammals and fish

Telemetry investigations using electronic tags on seals in UK and Antarctic waters and whales in the Arctic, have enormous potential for investigating predation of marine mammals on fish and determining how feeding distribution compares with that of fish and fishing fleets (Harwood, 1992). The diving and foraging behaviour of grey seals (*Halichoerus grypus*) has been studied in the northern North Sea, using a combination of depth-telemetering acoustic tags, VHF radio tags, which transmit when the animal is on the surface, and satellite telemetry (e.g. Thompson *et al.*, 1991; McConnell *et al.*, 1992). Analysis of diet and dive data shows that grey seals feed almost exclusively on benthic or demersal fish, foraging exclusively on or near the seabed. Sandeels and large gadoids (cod, whiting, haddock, saithe and ling) dominate the diet. Off the east coast of England grey seals concentrate their foraging activities over areas of gravelly sand. Grey seals are observed to dive directly beneath dense assemblies of feeding seabirds - mostly gannets

(*Sula bassana*), kittiwakes (*Rissa tridactyla*), puffins (*Fratercula arctica*), guillemots (*Uria aalge*) and shags (*Phalacrocorax aristoteles*) - and may then be feeding on the deeper parts of shoals, or on predatory fish (Thompson *et al.*, 1991).

These mammalian studies emphasis the importance of understanding behaviour and spatial dynamics in any quantitative analysis of predator-prey interactions (Croxall *et al.*, 1985). They give some idea of what might be possible, if electronic telemetry was applied to investigating comparable fisheries problems.

5.6.4 Physiological ecology

Specialised sensors have been developed to monitor a variety of physical and physiological variables in free-swimming fish. Most been custom built for specific applications and few are available in commercially produced tags. EMG tags with radio transmitters for use in freshwater are an exception (e.g. Demers *et al.*, 1996; Kaseloo *et al.*, 1996).

5.6.4.1 Physical sensors

Direct measurements of swimming speed have usually been made with mechanical devices (e.g. wands, drogues or propellers), whose size has limited application to sharks (Nelson, 1976, 1978; Standora and Nelson, 1977; Sundström and Gruber, 1998), and large pelagic teleosts, such as tuna and marlin (Block *et al.*, 1992a, 1992b). The biomorph sensor used with brown trout (Young *et al.*, 1972) and the rolling ball device developed by SINTEF (Holand *et al.*, 1974; Holand, 1987) were exceptions. Non-mechanical tail beat frequency sensors have however, been developed for smaller fish (Stasko and Horrall, 1976; Ross et al, 1981; Voegeli and Pincock, 1981) and juvenile sharks (Lowe *et al.*, 1998). Recently, differential pressure measurements have been used to telemeter tail beat frequencies from European sea bass (*Dicentrarchus labrax*) (Aitken *et al.*, 2001; Webber *et al.*, 2001).

Mechanical compasses have been developed to record swimming direction in both large sharks (Nelson 1976, 1978) and small teleosts (Mitson *et al.*, 1982; Pearson and Storeton-West, 1987), such as salmon (Potter, 1985) and plaice (Harden Jones and Arnold, 1982; Metcalfe *et al.*, 1993). Other custom-built sensors have been developed to measure key environmental factors, such as salinity (Priede, 1982) and dissolved oxygen concentration (Priede *et al.*, 1988).

5.6.4.2 Physiological sensors

Many physiologiacal studies have involved acoustic telemetry of one, or more correlates of metabolism (Lucas *et al.*, 1993), such as heart or respiration rate (Oswald, 1978). Heart rate has been recorded in a variety of freshwater species, which have included salmon (Kanwisher *et al.*, 1974), trout (Priede and Tytler, 1977; Priede & Young, 1977) and pike (Armstrong *et al.*, 1989). In the sea, measurements have been made with plaice (Kanwisher *et al.*, 1974; Storeton-West *et al.*, 1978), sole and bass (Sureau and Lagardère, 1991), cod (Kanwisher *et al.*, 1974; Wardle and Kanwisher, 1974), mackerel (Kanwisher *et al.*, 1974), and lemon sharks (Scharold and Gruber, 1991). Tail beat frequency and measures of swimming speed (see Section 5.6.4.1) have also been used to estimate energetic costs and similar studies have been conducted with cephalopods, using acoustic tags to telemeter measurements of swimming jet pressure (e.g., Webber and O'Dor, 1986; O'Dor *et al.* 1994; Aitken *et al.*, 2000) .

Temperature has been measured in tunas to assess their capacity for thermoregulation and document the extent to which body temperatures are elevated above ambient (Carey & Lawson, 1973; Marcinek *et al.*, 2001). Similar studies have been carried out with other endotherms, such as swordfish (Carey and Robison, 1981), blue marlin (Block *et al.*, 1992a) and sharks (Carey *et al.*, 1982; Carey and Gibson, 1987; Lowe & Goldman, 2001). Using a combination of depth and muscle temperature transmitters, Holland and colleagues demonstrated that elevated body temperatures in bigeye tuna resulted from physiologically controlled short-term changes in whole-body thermal conductivity (Holland *et al.*, 1992; Holland & Sibert, 1994). Visceral temperatures have also been investigated in several species of sharks in relation to feeding physiology (Carey *et al.*, 1981, 1984; McCosker, 1987).

Behavioural activity has been investigated in a variety of marine and freshwater fish using electromyograms (EMG) recorded by acoustic (Rogers *et al.*, 1984; Wolcott & Hines, 1989; Dewar *et al.*, 1999) or radio (Demers *et al.*, 1996; Kaseloo *et al.*, 1996) telemetry tags.

5.6.4.3 Interactive tags

In addition to direct measurements of physical and physiological variables, there have been at least two attempts to investigate sensory physiology by altering the local magnetic field around a free-swimming fish. In each case a field generator has been combined with an electronic tag, such that the magnetic field could be switched on and off remotely under controlled conditions (Westerberg, 1982a; Yano *et al.*, 1996, 1997).

5.6.5 Aquaculture and sea ranching

Electronic tags have only been used in aquaculture relatively recently, with the application of fixed omni-directional hydrophone arrays to the problem of determining the position of fish within or around fish farm cages (Holand, 1987; Lagardere *et al.*, 1988; Bjordal & Johnstone, 1993). Recent studies have also begun to investigate how activity varies with social factors, such as fish density (Juell & Westerberg, 1993), and environmental factors (Lagardère *et al*., 1990). PIT tags have been used to monitor activity of fish at demand-feeders and investigate the effects of dominance hierarchies on feeding and growth rates (Brännäs & Alanärä, 1993). Some work has also been done on the application of heart rate transmitters in halibut (*Hippoglossus hippoglossus*) farming (Rabben & Furevik, 1993). Sea ranching applications are also recent and have been used in comparative studies of the local migratory behaviour of wild and farmed Atlantic salmon (Heggberget *et al*., 1993) and the extent of upstream migrations between ranched, escapee and wild salmon (Heggberget *et al*., 1996). Collins *et al.* (1997, 2000) discuss applications of tagging, tracking and telemetry in artificial reef research.

5.7 FUTURE APPLICATIONS AND DEVELOPMENTS

5.7.1 Introduction

Electronic tags have a major role to play in fisheries science in the next century and will provide solutions to many currently intractable problems. In recent years there has been a marked resurgence of interest in biotelemetry as newer equipment has become available and novel research possibilities have been created. The development of faster and cheaper microprocessors, coupled with the development of sophisticated software, means that complex algorithms can easily be incorporated into new tracking systems. New batteries, and smaller, more powerful and more efficient transmitters, have overcome many of the earlier problems of longevity and reliability. Data can now be recorded from a number of animals over long periods and many different kinds of environmental and physiological information can be obtained simultaneously. Furthermore, the continued refinement of surgical procedures and the development of new and safe anaesthetics have permitted an increase in the size and diversity of fish species that can now be successfully tagged.

This section sets out to identify the areas of research that are likely to benefit from the application of electronic tags, specify some relevant research objectives and identify the technical developments that are needed to realise them.

5.7.1.1 Migration and distribution

Because most conventional sources of data (surveys and simple tagging experiments) are biased by the distribution of fishing effort, good descriptions of migration and distribution are lacking for many commercially exploited species of fish in the open sea. This lack applies as much to demersal species, such as cod, in shelf seas, as it does to far-ranging diadromous species, such as salmon and eels, or other ocean migrants, such as tuna. Much less is generally known, though, about distribution and migration in the open ocean, and for many large pelagic species it is often not possible to provide a description of geographical distribution for all stages of the life history. This type of information is, however, essential for effective fisheries management and will be increasingly required as a result of the UN Agreement on Highly Migratory Species and Straddling Stocks and other initiatives. Knowledge is also required to understand ecological processes and how different species and size-classes of fish interact with one another. Similar arguments apply to vertical migration, which is a major feature of fish behaviour in most marine environments, and which appears to serve a number of different ecological functions.

Important objectives in this area of research include: describing migratory pathways and seasonal changes in vertical and horizontal distribution; identifying guidance mechanisms; and describing and understanding the functions of vertical migration. Major technical challenges are posed by determining geographical location, identifying the water mass (e.g. by temperature and salinity) in which fish are swimming, and recording orientation and swimming speed. Physiological measures of condition and reproductive state are also highly desirable.

5.7.1.2 Methods of estimating fish abundance

Fish behaviour strongly influences estimates of population abundance derived from static fishing gear, survey trawls, and acoustic instruments (echo sounders & sonars). It may bias results in a variety of ways, which may or may not be systematic. Fish that encounter the gear may avoid capture by reacting to individual parts of the gear or to the noise it produces. These reactions may vary with the size of the fish and ambient environmental conditions. ‘Natural’ behaviour, which governs horizontal and vertical distribution, determines the extent to which sampling gear encounters fish at all. For acoustic surveys changes in swimbladder volume or tilt angle, which occur naturally during vertical migration, or as the fish reacts to the noise of an approaching survey vessel, can cause major variations in target strength (TS) measurements and any estimates of abundance derived from them.

Research on ‘natural’ behaviour needs to focus primarily on the vertical and horizontal movements that determine spatial distribution and thus *availability* and *accessibility* (Anon, 1960; Harden Jones, 1974) to sampling gear. The rates and extents of such movements vary with both biological and environmental factors (e.g. light intensity, temperature and tidal currents) and the effects of these factors need to be determined. It is similarly important to determine how fish regulate buoyancy in relation to depth and how they compensate for negative buoyancy by tilting the body in the vertical plane. Static and mobile fishing gears work in different ways and studies of *vulnerability* (Anon, 1960;

Harden Jones, 1974) accordingly have different objectives for each type of gear. Static gears work by chance encounter (e.g. gillnets) or by attracting fish or shellfish from a distance with bait (e.g. pots and longlines) and an odour trail. For gillnets the research objective is to determine how fish move as they approach the net and how visibility of the net affects their avoidance reactions. For baited gear the aims are to define the shape and size of the odour trail in relation to the prevailing currents and the concentration of the olfactory stimulant, and to determine whether catch per unit effort is a reliable measure of population density. With towed fishing gear the principal objective is to study avoidance reactions and determine how capture efficiency differs between sizes and species of fish and varies with physical factors, such as temperature, light intensity and underwater visibility.

To meet these various objectives measurements are needed of one or more of the following physical quantities: noise, temperature, light intensity, turbidity, depth, rate of ascent or descent, tilt angle, swimming speed and reaction distance. In most cases the measurements must be made at the fish rather than at the research vessel and for some projects it may also be necessary to measure a physiological parameter, such as heart rate. Measuring and recording, or telemetering, these variables is difficult at present, particularly when real-time observations are needed for more than just a few fish at any one time.

5.7.1.3 Species interactions

Electronic tags have the potential to tell us a great deal about how and when fish eat and how much food they consume. Knowledge of the natural behaviour of free-ranging fish would provide a major impetus to the study of multispecies interactions and reduce the current over-reliance on theoretical models. It could also be used directly to correct or tune the multi-species VPA models used to provide advice for fisheries management. Improved knowledge of natural behaviour would advance our understanding of a number of important ecological processes, such as habitat selection (particularly important for small fish) and partitioning of resources between apparently sympatric species. For most marine species, habitat changes markedly as individuals grow from one size class to the next, alter their physiological optima, change their prey and become susceptible to larger predators. Changes usually occur in three dimensions, not just two. In addition to providing a better understanding of ecological processes, quantitative estimates of feeding rates in free-ranging fish would provide an important practical tool for interpreting gut content data collected during multispecies fisheries surveys. These data are currently difficult to interpret within the confines of existing knowledge, which is based almost entirely on laboratory studies.

Initially, any investigation of habitat selection and resource partitioning needs good descriptions of the horizontal and vertical distributions of the fish in question, by size and species. The second objective is to describe natural feeding behaviour and measure rates of encounter between predators and prey, rates of predator avoidance and feeding success. These quantities are needed to estimate costs of predator avoidance in relation to lost feeding opportunities. Locomotory costs are also important in establishing energy budgets and, in this area, measurements are needed of burst swimming speeds during predator escape reactions and cruising speeds during feeding. Direct measurements are also needed of basal metabolic rates and quantities of food consumed. There are major technical challenges in developing devices to measure and record these parameters.

5.7.1.4 Growth and reproduction

On-line estimates of growth and reproductive condition could be extremely useful both in understanding ecological processes and for practical applications, such as sea ranching and stock enhancement (see Section 5.7.1.5). In this context a thermal history of the fish throughout its time at liberty would be of great interest, particularly if temperature measurements recorded by data storage tags could be correlated with a direct estimate of growth rate from scales or otoliths. The identification of feeding locations in relation to the productivity of different water masses would also be highly informative. A measure of gonad fullness would aid studies of reproduction and a means of identifying specific spawning events could also be most useful. Tail beat frequency is a good correlate of spawning in salmonids (e.g. Johnstone *et al.*, 1992), as is the noise made by the fish when they cut redds in gravel spawning beds. Other species, such as cod and haddock, have a repertoire of sounds that they produce during spawning (e.g. Nordeide & Kjellsby, 1999). Biosensors in the blood would allow us to measure and record hormone levels and correlate them with different patterns of behaviour. This capacity would significantly advance our understanding of the links between physiology and behaviour. These requirements, which are to a large degree shared by the other research areas identified in this section, provide a major challenge for sensor development and miniaturisation.

5.7.1.5 Aquaculture, sea ranching and enhancement

Electronic tags have so far made a relatively limited contribution to aquaculture, although there is considerable scope to apply the technology to the investigation of a number of physical and biological factors that control production. The aquaculture industry should be encouraged to investigate these opportunities. Applications include feeding and energetic studies, which could serve as a useful precursor to similar studies with fish in the open sea (see Section 5.7.1.4). Studies of interactions of fish in rearing cages with predators or wild fish outside the cage would also be useful, as could a cheap identification tag that allowed escapees to be quickly and readily identified. Fish health is probably the highest priority in the fish farming industry and techniques for long-term monitoring of fish condition have considerable potential, particularly if data could be recovered regularly without removing the tag from the fish. Stress resulting from handling is obviously an important factor for fish kept at high densities and biosensors linked to data logging tags have considerable potential in this field, as they do, for example, in relation to studies of growth, migration and reproduction of free-ranging fish (see sections 5.7.1.1 and 5.7.1.4). Stress also arises in relation to slaughter and transfer between salt and freshwater.

Ranching and enhancement studies are concerned with where hatchery fish go in the wild and how they interact with wild stocks. Objectives are thus very similar to studies of migration and distribution in wild stocks and involve descriptions of local and migratory movements, geographical location, swimming behaviour and the measurement of appropriate environmental factors, as discussed in previous sub-sections.

5.7.1.6 Anthropogenic effects

Existing research has already identified the benefits of using electronic tags to study the impact of man-made structures on the distribution and abundance of fish. The construction of dams and other barrages in rivers has had a major impact on fish populations through disruption of migration and reproduction and electronic tags have been widely used to test the effects of mitigating measures, such as fish passes. They have been used less frequently to assess the impact of proposed structures before construction. This is an important area for the future, however, particularly in relation to the impending development of hydropower in big tropical rivers (e.g. in Southeast Asia), where large proportions of the human population depend on fisheries, and where most of the fish are highly migratory. There are similar opportunities in the sea in relation to policy decisions on the future of decommissioned oil rigs and studies to assess the uptake of pollutants by fish attracted to feed in the vicinity of drilling platforms (e.g. Soldal *et al*., 1998). Electronic tags offer an ideal way of studying local movements of fish in the neighbourhood of these and other structures (e.g. effluent discharge pipes) and also the migrations and seasonal movements that are capable of dispersing disease and pollutants over wide areas.

5.7.2 Biological improvements

Engineering will provide many of the technical advances needed to improve tag performance and reliability and this topic is discussed in section 5.7.3. Technology will not realise its full potential, however, unless biologists also make significant improvements to the way in which they capture and handle fish and attach tags. Some of these issues are addressed here; others are dealt with in Chapter 7.

5.7.2.1 Capture and handling fish

Reviews of the effects of capture, handling and tagging inevitably focus on the negative aspects of these procedures and tend to obscure the fact that, in many cases, it is already possible to obtain fish in excellent condition (see Appendix 1 of Chapter 7). Often, however, the relevant expertise is passed on by word of mouth and much useful knowledge never finds its way into the ‘grey literature’, let alone refereed scientific publications. There is a general need, therefore, for improved documentation of the various capture procedures and a codification of general principles. This clearly needs to be done in respect of each type of fishing gear (lines, trawls, traps etc.) and capture method. The incompleteness of existing information identified in section 5.3, however, means that there is also a need for systematic investigations to determine the effects of capture and handling on the condition and survival of different species of fish at various stages of their life history. While there is a general need for more research on the effects of these processes on commonly tagged fish in temperate waters, there is an even greater need for research on tropical species. Special attention also needs to be paid to methods of handling endangered species and delicate species or delicate life history stages.

During research, careful records must be kept of the size and condition of the fish, as well as environmental conditions, and any factors relevant to the specific method of capture. For trawls these factors include speed of towing, haul duration, and depth. The size and composition of fish catch is also important, as is the quantity and type of by-catch. By-catch can significantly increase mortality, especially in bottom trawls, where sharp objects such as shells and spiny fish and invertebrates can do a great deal of damage. Qualitative observations suggest that it is probably possible to define levels of debris in trawl catches above which it is not possible to use fish for tagging at all. Other, comparable constraints may apply in the case of line- and trap-caught fish.

Laboratory studies offer one way of recording mortalities and observing the condition of fish after capture, which is generally regarded as a more serious cause of damage than tagging. The fish must, however, be returned to the laboratory from sea and this process may exacerbate any problems caused during capture. It may therefore be better to make the observations at sea using cages to monitor condition and survival, as described in section 5.3.4(b). Further work of this type should be encouraged, even though it is not easy to do for logistic reasons. A third option is to obtain information from electronic tags, which may reveal how long fish exhibit atypical behaviour after tagging and release before resuming natural activities such as migration and spawning. Acoustic tags (Candy *et al.*, 1996; Candy & Quinn, 1999; Pepperell & Davis, 1999) and data storage tags (Wada & Ueno, 1999; Walker *et al.*, 2000) can both be used for this purpose. Confirmation of spawning can also be obtained by recovery of the carcass of the tagged fish, which can also reveal the state of any wounds associated with tag attachment. Pilot projects with dummy tags are recommended before starting DST tagging programmes as they can clarify the effects of capture, handling and tagging on the fish and indicate the expected recovery rates of the electronic tags.

While systematic studies of the effects of conventional methods of capture are essential, encouragement should also be given to the adoption of new, less traumatic approaches where the fish are tagged underwater. Baited tags, which have been used on a range of species (see Section 5.4.3.1), allow the fish to ingest a tag voluntarily without being caught. This could clearly be advantageous in many situations, although there is limited control over the size, or even species, of fish that is caught and an individual fish may ingest more than one tag. Tagging underwater, which has had only limited application to date (e.g. Gitschlag, 1986), may eventually become a routine way of avoiding the problems of catching fish with closed swimbladders. The cost and logistics of deploying teams of scuba divers makes it impractical at present. One commercial company is, however, developing an automated device capable of withstanding depths of 1000 m and able to automatically tag large numbers of fish of different types and sizes. If successful, such a device would revolutionise the whole process of tagging fish at sea.

5.7.2.2 Design and attachment of external tags

Weight, which is an important consideration in the design of electronic tags, is discussed more fully in Chapter 7. The main design aim is to minimise the ratio of tag weight to fish weight by reducing the weight of the tag in water. In many cases it is possible to increase the volume so that the tag becomes neutrally buoyant and imposes no extra weight on the fish. Slight positive buoyancy may actually be advantageous, provided the increase in tag volume does not result in excessive drag.

For external tags, drag, which is a function of shape, is generally more important than weight and should be minimised wherever possible. Although some progress has recently been made with hydrodynamic designs of pop-up tags for use with bluefin tuna (Block *et al.* 1998b; Lutcavage 1999), there have been very few similar studies with other externally attached tags. Systematic studies are therefore urgently needed to devise the most appropriate hydrodynamic shape for the tag and, perhaps more importantly, the best position of attachment on the fish. Sensor design and attachment must be included as an integral part of this programme, which requires assistance from hydrodynamicists and access to flumes for work with swimming fish. Some idea of the improvements that can be expected from a programme of this type can be gained from the work done with penguins (e.g. Wilson & Culik, 1992; Culik *et al.*, 1994; Bannasch *et al.*, 1994) and turtles (Watson & Granger, 1998) (see also Section 5.4.2.1). Significant advances have been made with these groups by matching the shape of the tag to the morphology of the animal and this approach should be adopted with fish. One possibility worth considering would be to design a blister shaped tag that would be equally streamlined in all directions and could be used with flatfish.

Fish with external tags may be more prone to predation than untagged fish and the shape and colour of the tag may influence the risk of predation. Some species of fish use sexually selected traits (for example coloured or swollen body parts) as signals during mating rituals, which could - theoretically - be confused by the presence of an external tag. Both subjects should be studied and tag designs modified in the light of findings.

Tag loss is a common problem with electronic tags and there is a clear need to develop more permanent methods of tag attachment, particularly for DSTs, which potentially have a life of ten years or more. The development needs to be done in conjunction with the hydrodynamic investigations identified above and with full consideration of welfare implications. The problem of tag loss is unlikely to be solved completely, however, and an alternative solution may be useful in tracking studies where the fish may not move for long periods. Stationary tag signals are difficult to interpret in this situation and it would be useful to be able to distinguish between a tag that is still attached to a live fish and a tag that has fallen off, or is attached to a dead fish. A tag that could differentiate between these situations – with an internal accelerometer or other sensor – would be a useful development.

5.7.2.3 Swimming performance and behaviour

In addition to developing new attachment procedures there is a need to develop challenge tests to evaluate how tags modify the normal behaviour and responsiveness of the fish. To date the most commonly used challenge test is the comparative swimming trial. This has been used successfully to evaluate various attachment techniques, using both critical swimming speed and fatigue trials (e.g. Moore *et al.*, 1990a; Anderson *et al.*, 1997; Colavecchia *et al.*, 1998; Beddow & McKinley 1998, 1999; Peake *et al.* 1997a). There is clearly scope for significant development in this area and one approach is to use physiological sensors to record the recovery of fish from tagging (Anderson *et al.*, 1998) as a step in developing standard procedures for commonly tagged species. Tags that measure muscle activity (EMG) and heart rate are commercially available and are already suitable for this purpose. Existing techniques are probably not suitable for long-term measurements in the open sea, however, without significant further development and one of the main challenges for the future will be to devise ways of recording ‘natural’ behaviour and physiology without resorting to invasive surgery.

5.7.2.4 Representativeness

As discussed in more detail in Chapter 7, concern is growing about the welfare of experimental animals. Experimental procedures are strictly regulated and authorities in most countries are increasingly scrutinising the number of experimental animals used in individual studies. In this context, electronic tags – particularly data storage tags - have the great advantage over simple identity tags that much more information can be gained from fewer fish over much longer periods. Concomitantly, it becomes more important to demonstrate that results from a relatively small number of tags are representative of the whole population. One way of doing this is to use large numbers of identity tags (see Chapter 4) in parallel with electronic tags. Another very effective approach is to predict the behaviour of the population from the electronic tag observations and test the prediction by independent means. This method has been used to demonstrate the importance of selective tidal stream transport in the life cycle of plaice (*Pleuronectes platessa*) in the Southern North Sea and eastern English Channel. The phenomenon was first demonstrated with a small number of acoustically tagged fish; its importance to the population at large was confirmed by a series of comparative fishing experiments with large midwater trawls (Harden Jones *et al.*, 1979; Arnold & Metcalfe, 1996).

5.7.3 Engineering developments

Major advances in the research areas identified in section 5.7.1 will depend to a large extent on improvements in the design and performance of electronic tags. The most important of these are telemetry tags that transmit more data over longer ranges and data storage tags that can record more information and store it for longer periods. Individual coding and remote, fishery-independent data retrieval are also becoming increasingly important. Improvements in telemetry may come from smaller, more powerful tags. More sophisticated retrieval of data from noisy backgrounds may, however, offer a more effective solution by avoiding the need to increase the transmitting power of the tag. A significant reduction in the cost of tags, particularly data storage tags, would provide a major impetus to the use electronic tags and would see them used to solve a wider range of fisheries and ecological problems. Cheapness, however, conflicts with the need for devices that are both smaller and more sophisticated. Technological factors that will affect the development of better and cheaper tags are considered in this section.

5.7.3.1 Tag performance

(a) Size

The development of significantly smaller tags is an almost universal requirement, although small tags currently have some disadvantages, such as reduced life and increased weight in water. They may also be harder to find when the fish is recaptured. Smaller tags are, however, needed for use with smaller fish, especially juveniles, and more compact circuits are required to allow greater sophistication within the same space. Successful development of smaller tags will depend primarily on the availability of smaller electronic components, batteries and sensors. At present most microsystems are built from a large number of components, none of which are tailor-made for the needs of wildlife telemetry. Integrated circuits may perform more functions than are actually required in the specific tag application, consuming more current than necessary and reducing battery life. One solution might be to develop custom-built integrated circuits, although costs would be high because of the need to manufacture these devices in sufficiently large quantities to justify development. Another option would be to use custom-built silicon chips for whole tags, although with continuing advances in microcontroller technology this approach is not likely to be cost effective. A prime requirement is to use small batteries and to do this it is necessary to minimise power consumption. Greatest reductions in power consumption are likely to be achieved by the use of quick response sensors that can be switched on for short periods only and can be sampled within a few milliseconds of being switched on.

(b) Life and memory size

Telemetry tags often only require a relatively short life measured in days rather than months. Most biological cycles are seasonal, however. The majority of data storage tags therefore need to be able to record several items of information for at least a year and store the data for several years to maximise the chances of capture and tag recovery. The use of flash memory, with an expected life of 10-20 years, overcomes the need to provide power for long-term data storage but, as more sensors are included, tags will need progressively more memory. Certain applications, such as the investigation of spawning site fidelity will require tags that record data for several years in succession and tags of this capacity will be needed for many applications with large pelagic species that range extensively through the oceans. Data management will also be important to ensure that best use is made of the available memory, either through data compression or intelligent data recording (e.g. by not recording new data until a sensor reading changes significantly).

(c) Batteries

Tag size and life is currently determined largely by the size of batteries, which will continue to be a limiting factor for the foreseeable future. Silver oxide cells offer a number of important advantages, such as the ability to deliver a high peak current (8 mA) for a short period from a small cell. Lithium cells are unable to do this and have other technical disadvantages, such as a tendency to passivation, which often leads to premature tag failure. They do, however, operate over a much wider temperature range (-30° to >100° C) than silver oxide cells (-2° to 65° C) and most battery development is now devoted to lithium cells.

5.7.3.2 Tracking systems

(a) Short-range systems

Fixed arrays of hydrophones are currently used to investigate the movements of fish or shellfish static in the vicinity fishing gear (e.g. Løkkeborg, 1998; Løkkeborg & Fernö, 1999). Similar techniques have been used to study the effects of dams and barrages on the passage of fish in rivers (e.g. Russell *et al.*, 1998). The simple systems used to date have depended on three or four hydrophones anchored several hundred metres apart in a triangular pattern with a maximum effective range of about 1000m. Early systems depended on electric cables to bring data ashore. More recently data has been sent by radio telemetry to the shore or to a research vessel and this development has allowed these systems to be used in the open sea. Fish are tagged with acoustic transmitters and their position estimated from the time of arrival of the sound pulses at each of the hydrophones. The depth of the fish is measured with a pressure sensitive telemetry tag. Traditionally each tag has worked on a different frequency and up to 10 tagged fish have been kept under surveillance at any one time. Recently new systems have become available that use binary codes – pseudo random (PN) numbers – to code the tag signals (Cote *et al.*, 1998; Voegeli *et al.*, 1998). This development allows the arrival time of the signal to be measured much more accurately and also enhances the signal to noise ratio. The resulting coding gain provides increased range, allows the tags to operate in noisier environments and can track up to 212 fish simultaneously on a single acoustic frequency. There is no restriction on the number of hydrophones and the operating area can be readily increased to match the type of investigation to be undertaken. These developments are to be encouraged because they will also open up the possibility of investigating predator-prey behaviour in the open sea in a cost-effective way.

(b) Long-range systems

Fixed arrays of acoustic listening stations on the seabed have been used with great success in the North Atlantic to monitor ocean currents by recording the tracks of neutrally buoyant SOFAR floats. A similar system would be highly desirable for use with highly migratory oceanic fish. Unfortunately, the SOFAR system operates at low frequencies and the transmitters are far too large to be used on any fish. The receivers of the RAFOS system, which operates on the same principle, but in reverse with fixed transmitters and mobile receivers, are also too large for use with fish.

Fisheries research vessels undertaking regular trawl surveys or acoustic surveys might be used as mobile listening stations. Sonars could be used to search for acoustically tagged fish and it might be possible to recover stored data using a sonar or hydrophone. The concept could be tested with single frequency tags designed merely to record the presence or absence of fish. Even with this simple configuration, however, it would be necessary to released very large numbers of tagged fish, given the depth of the sea, the power of existing acoustic tags, the range of existing sonars and the limited width of search swath that could be achieved.

5.7.3.3 Physical sensors

(a) Temperature

Thermistor technology is well developed and small beads are readily available. Calibration and stability are not a problem. The main difficulty is to avoid spuriously high readings when the tag is heated by sunlight and the thermistor is mounted inside the tag. The problem is probably soluble using a miniature thermistor bead coupled as closely as possible to the water.

(b) Pressure

Small electronic sensors are available that are capable of measuring pressure at depths in excess of 3000 m. They are suitable for use with most adult fish but smaller devices are needed for use with juveniles. Lower prices would also be desirable. Technically there are a number of problems, including zero drift, undesirable variation in sensitivity between individual devices and variation in output (offset voltage) with temperature, all of which create problems for accurate calibration.

(c) Light

A number of data storage tags incorporate sensors that measure ambient light intensity and are used to estimate geographical position. Some tags use large area (5-10 mm^2) silicon diodes, either singly or joined together; others use a point source diode and a separate collector with a light pipe to focus the light on the diode. These devices are fairly sensitive and can detect light down to about 300 m in clear oceanic water. They can satisfactorily measure light levels around dawn and dusk when the fish is swimming near the surface. They are not sensitive enough, however, for fish that dive to greater depths at dawn and dusk, or swim consistently well below the surface. Greater sensitivity is required for these applications and switched mode operation is desirable to avoid excessive power consumption. This requires the development of high input-impedance amplifiers with fast settling times to cope with the behaviour of the sensor at low light levels. The frequency response of existing semiconductor sensors is also not ideal, peaking as it does at approximately 900 nm. Devices with maximum sensitivity in the range 450-550 nm would provide greater sensitivity for most marine applications, except turbid coastal waters, whose peak transmission may be as high as 600 nm.

(d) Salinity

One DST available on the market can measure salinity. This tag, which has been used to study movements of adult salmonids in the sea (see Section 5.6.2.3), can identify whether the fish is in fully saline water, has entered an estuary, or has returned to freshwater. Much greater sensitivity is needed, however, before it will be possible to use DSTs to identify the type of water in which a fish is swimming in the open ocean from the relatively small differences in conductivity.

(e) Tilt angle

One commercially available DST can measure tilt angles in the range ±40° from horizontal with a resolution of <5°, using a mechanical sensor. These tags have been used in the Barents Sea to investigate the attitude of free-swimming cod in relation to vertical migration and target strength (TS). Sampling rates are rather low, however, in relation to the problem and a sampling interval of the order of 1 s would be desirable for this type of research. It would also be desirable to use an electronic sensor with an increased angular range and a resolution of <1°. To achieve this resolution in practice and make reliable measurements, however, it would be necessary to develop a much better system of tag attachment and this is a significant challenge for the biologists.

(f) Speed and acceleration

Direct measurement of swimming speed is currently difficult. Most devices (e.g. turbines, hot films, electromagnetic sensors, Doppler shift instruments) that have been used are either too large, too vulnerable, too unstable, or consume too much power, to be of practical use, except with very large fish (e.g. Lowe *et al.*, 1998). An alternative approach might be to measure speed indirectly through tail-beat frequency, although further research is needed to fully elucidate the relationship between the two quantities in many species of fish. Another approach could be to measure acceleration, which, if sufficiently accurate, might open up the prospect of reconstructing through-water movements of the fish by inertial navigation techniques. Small low-power accelerometers would, however, be required and there would probably be difficulties in operating them for sufficiently long periods to sample the movements of the fish adequately.

(g) Activity

For a number of applications, it may be sufficient to record activity rather than speed or acceleration. This approach has already been adopted with spawning Atlantic salmon using an electrolytic tilt sensor inside the fish (Johnstone *et al.*, 1992) or an EMG sensor (Økland *et al.*, 1997). A similar approach may be useful in other situations.

(h) Compass heading

Miniature magneto-resistive devices are now available that are capable of resolving the compass heading of a fish to <1°, provided the sensor can be kept within a few degree of horizontal. Fish rarely swim in this fashion, however, and an accurate electronic compass requires the output of the compass sensor to be corrected for pitch and roll. Accelerometers that measure pitch and roll are now available in miniature form and an electronic compass would seem to be a realistic development goal in the near future.

(i) Magnetic field sensors

Geomagnetic sensors could be useful in helping to determine the geographical position of oceanic fish that migrate large distances to feed and spawn, particularly if combined with light-based or other methods of geolocation. Such devices might be less useful in shelf seas, where fish generally cover shorter distances during migration. Small low-power devices capable of measuring the total intensity of the local magnetic field of the earth would be appropriate, if they existed, and magneto-optical devices might be able to provide a solution. An alternative approach would be to use a sensor capable of measuring magnetic dip, for which suitable magneto-resistive devices already exist. As with an electronic compass sensor, however, measurement will be complicated by the need either to provide a stable platform or to compensate for movements of the fish in all three dimensions.

(j) Sound

Sound recordings require a large amount of memory. A typical CD of classical music, for example, can use 650 Mbytes. Simple calculations show that even with a limited bandwidth (e.g. 10-40 Hz) and 4-bit analogue to digital (A-D) conversion, a miniature recorder is impractical for the present, except possibly for use with very large pelagic species of fish, or sea mammals.

5.7.3.4 Physiological sensors

Surprisingly little physiological research has yet progressed to the stage where it is possible to envisage worthwhile programmes with free-ranging fish in the open sea. In most cases, even with relatively simple subjects (e.g. the relationship between swimming speed and tail-beat frequency) a substantial amount of laboratory research is still an essential pre-requisite. There are a few areas, however, where some progress could be made fairly soon. The most obvious of these is feeding, where the ability to record feeding patterns and rates of food intake in the sea would significantly advance our knowledge of predator-prey relationships and where some work has already been attempted. Cardiac output and EMG are others.

(a) Mechanical feeding sensors

A simple design for a mechanical jaw angle sensor for use with sharks was proposed in the late 1970s but apparently not used. The device consisted of two rods sutured to the upper and lower jaw and connected, respectively, to the case and rotor of a miniature one-turn trimpot (Nelson, 1976, 1978). More recently, progress has been made in Denmark with the development of a mechanical probe to detect food intake in free-swimming cod (Lundgren, pers. comm.). The probe consisted of a piezoelectric film encapsulated in a sheath of silicon rubber, which was surgically implanted and attached to the wall of the oesophagus. A device of this type will provide information about when and where fish eat and the frequency of ingestion. Coupled with a strain gauge the device might also provide an estimate of the size of individual food organisms. Further development work is required in this area. An alternative approach might be to measure changes in pressure in the buccal cavity with a differential pressure sensor. This technique would require only minimal surgery and might therefore be more appropriate for use with free-ranging fish. Patterns of buccal pressure will clearly vary, however, with the mode of food ingestion and not much is yet known about this subject except for fish that feed by suction.

(b) Physiological sensors

Mechanical sensors may not offer the best long-term solution to recording feeding events and a radically different approach might be to measure one or more of a variety of physiological parameters that should change predictably following feeding. Stomach, or visceral, temperature is one possibility, especially in warm-blooded fish. Some encouraging advances have recently been reported with Southern Bluefin Tuna (Gunn *et al.*, 1994; Gunn *et al.*, 2001) and there may be scope to pursue the idea with other species, including possibly some poikilotherms. Heart rate, blood flow, gut pH, bile colour and blood chemistry are other options; they would also be relevant to studies of bioenergetics, stress and the reactions of fish to changes in the surrounding environment.

Physiological sensors will increasingly be needed to measure the responses of fish to environmental changes induced by anthropogenic activities, as well as performance under natural conditions. Existing techniques, such as EMG (e.g. Beddow & McKinley, 1998, 1999; Dewar *et al.*, 1999) and heart rate monitors, can already be used in these areas, although there are limitations to the usefulness of both. EMG can be used to measure metabolic expenditure when swimming behaviour dominates but not when the fish is resting during recovery from a stressful event. Heart rate measurements, which can be used during both types of event, do not give a true measure of metabolic activity because of changes in stroke volume, which occur in many species. A sensor that could record both heart rate and stroke volume and provide a measure of cardiac output would be a big step forward.

In addition to sensors to measure the physiological state of the fish, there is a continuing need to for more sensors to monitor the surrounding environment. Depth, temperature and conductivity sensors have all been incorporated in transmitting or recording tags but information is now needed on the chemical environment as well (Brodeur *et al.*, 1999). Sensors are required to measure quantities such as pH, chlorine and ammonia and these factors must be monitored at the same time as the physical measurements. There is therefore a continuing drive to develop a range of smaller, more accurate devices that can be assembled in small multi-function tags. A variety of devices exist to measure these quantities, including electromagnetic sensors, thin-film electrodes and biosensors. But most have so far only been used under controlled conditions in the laboratory and substantial research programmes are required to transfer the technology for use with fish that will be allowed to range freely in the wild. Animal welfare considerations will be extremely important in this context (see Chapter 7).

5.7.3.5 Remote data retrieval

Remote data retrieval is already possible in certain situations. In freshwater, for example, signals from radio tags can be detected by mobile receivers in aircraft or by fixed detectors on the riverbank. Fixed listening stations can in return relay information to the laboratory by radio or telephone. A similar approach can be adopted with acoustic tags if the fish are within a short distance of a hydrophone on a moored or drifting buoy, which converts the acoustic signals into radio signals before transmission.

(a) Remote radio telemetry

Satellite data recovery is currently possible with pop-up tags that detach from the fish at pre-programmed times and float to the sea surface (see Sections 5.4.2.3 and 5.6.2). Second generation pop-up tags that are capable of measuring several physical quantities and have substantial data storage capacity, have recently become available and are already producing valuable new data (e.g. Block *et al.*, 2001a, b; Marcinek *et al.*, 2001). Pop-up satellite archival tags (PSAT) are currently available from two US manufacturers, Microwave Telemetry and Wildlife Computers, based in Columbia, Maryland and Redmond, Washington, respectively.

The size of satellite tags is unlikely to decrease much in the short-term, however, and pop-up tags are unlikely to be suitable for use with the small to medium sized fish found in European waters until use can be made of cellular phone systems. Rapid advances are currently underway in this field and several worldwide systems are under development, each of which will employ 60-80 satellites. A number of problems need to be solved before the prospect becomes a reality, however. These include miniaturising the phone and the pop-up system and providing enough power to transmit to the satellite against a background of increasing radio noise, especially in heavily populated areas. The service provider will have to agree to this use of the network. There may also be problems of data corruption when information is transferred between satellites and lack of cover over the open ocean at some times. Developing a miniature pop-up system is likely to be difficult, as is provision of sufficient battery power. Phone miniaturisation may not be a problem if manufacturers develop a single chip for the purpose in response to the very high demand for cellular phones.

(b) Remote acoustic telemetry

Recovery of data by an acoustic link demands a lot of power, is slow and is limited to short range. It is also susceptible to multi-path reflections, which can corrupt the data. Acoustic data recovery is thus best suited to situations where fish regularly and reliably return to a known position or remain within the vicinity of a sonobuoy for a sufficiently long period (Klimley *et al.*, 1998; Klimley & Holloway, 1999; Voegeli *et al.*, 2001). Communication history acoustic transponding tags (CHAT tags, see Section 5.2.5) tags are beginning to show interesting results (Klimley *et al.*, 1998). Recovery of large amounts of data from data storage tags may be possible via sonobuoys or static listening stations (Fig. 5.7.1), if fish can be induced to stay close to the hydrophone for as long as it takes to download the data. Alternatively, it may be possible to recover the data in limited (say 100k) blocks by sending a command signal to the tag by a low power radio link when the fish is in the immediate vicinity of the hydrophone.

5.7.4 Costs of production and sustaining development

The wildlife telemetry market is small compared to the mobile telephone market, for example, and has not benefited from mass production. High prices of existing electronic tags are preventing realisation of the full potential of the technology and ways need to be found of reducing costs. This may be possible in some areas such as aquaculture, where mass markets may become feasible. There are proposals, for example, in Scandinavia that consideration should be given to individually marking all cultivated fish to provide a quality assurance system for the aquaculture industry, and to facilitate the identification of fish that escape to the wild. Electronic tags similar to PIT tags would be ideal for this purpose but would need to be quicker to insert and cost less per tag in order to be a viable and cost effective possibility. The aquaculture industry could also benefit from the use of electronic tags to monitor the health and condition of stocks, without the need for handling or otherwise interfering with the fish. Similar possibilities may also exist in relation to cheap unsophisticated tags capable of worldwide use for a range of very simple applications. This approach will, however, not satisfy most of the research objectives defined in section 5.7.1, for which advanced devices are needed. Thus, whilst mass markets may become possible for some applications, development costs are likely to remain very high and continued public funding and pre-market investment will be essential to ensure rapid and sustained development of new technology.

5.8 RECOMMENDATIONS

Due to the limitations of conventional tagging methods, electronic tags will play an increasing role in fishery science and management in the next century. In the following section the requirements and recommendations for maintaining progress in this field are identified.

1. Large-scale systematic studies are required to describe and understand the migrations and movements of commercially exploited species of fish. These should include juvenile stages of the life history as well as adult fish. Particular attention should be paid to the interaction between behaviour and the physical environment, with special emphasis on the role of currents as transporting or guiding agents.
2. Reactions of fish to research vessels and survey trawls can seriously bias fishery-independent estimates of abundance and systematic investigations of these effects should be encouraged. Similar studies should be made of the ‘natural behaviour’ of fish beyond the influence of the vessel and should include systematic investigation of vertical migration and distribution in relation to swimbladder function, depth of neutral buoyancy, body attitude and acoustic target strength.
3. Investigations of predator-prey interactions should have a high priority. Studies should include direct measurements of feeding rates of free-ranging fish in the open sea to provide independent validation of existing inputs to multi-species VPA models, as well as prey selection.

4. Studies of the physiology of free-ranging fish should be encouraged in order to understand how behaviour changes in response to condition and reproductive development. Direct measurements of growth in relation to temperature and food availability are highly desirable.
5. The aquaculture industry should be encouraged to investigate the use of electronic tags to monitor the health and condition of stocks without the need for handling or other interference.
6. Consideration should be given to mass marking all cultivated fish stocks to provide a quality assurance system for the aquaculture industry and to facilitate the identification of fish that escape to the wild. Encouragement should be given to the development of electronic tags for this purpose.
7. A number of investigations have demonstrated the benefits of using electronic tracking systems to evaluate the environmental effects of man-made structures such as barrages, dams and oil rigs. Further application of these methods should be encouraged.
8. Systematic studies are needed to improve methods of tag attachment (both external and internal) and to minimise the effects of electronic tags on behaviour and swimming performance of fish. Underwater tagging is an attractive possibility, particularly for deep-water species and other species with closed swimbladders. Shared protocols are needed for standard tags and commonly tagged species.
9. Independent testing should be encouraged to evaluate whether data obtained from relatively small numbers of fish are representative of whole populations.
10. Technological advances should be aimed at producing smaller tags with longer life, more memory and increased operating range.
11. Further improvements are needed to systems for tracking or monitoring large numbers of individually identifiable fish. These should include improved coding systems, increased detection ranges and better software for processing and interrogating data.
12. Sensors need to be smaller and able to record a wider range of physical and physiological variables. The important physical variables include tilt angle, compass bearing, magnetic field strength, magnetic dip, tail beat frequency and swimming speed or acceleration. The important physiological variables include heart rate and cardiac output, feeding rate, growth rate, gonad development, and related levels of enzymes or hormones in the blood.
13. More reliable methods of estimating the geographical position of fish tagged with data storage tags are needed and their development should have high priority. Investigations should include both direct (e.g. geomagnetic sensors) and indirect methods (e.g. sequentially released pop-up satellite tags).
14. The development of better systems of fishery-independent data retrieval should be encouraged. These should include data transmission via satellites or cellular telephone systems and fixed and mobile acoustic listening stations.
15. Mass markets may become possible for some applications (e.g. mass marking of cultured fish) but continued public funding and pre-market investment are essential to rapid and sustained development of new technology.

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6. LEGISLATION

6.1 INTRODUCTION

All forms of fish tagging involve invasive processes, though tagging is usually much less stressful than the capture process. Detrimental effects on fish are undesirable scientifically - no-one wishes their data collection to be compromised because the tagged fish do not behave normally, or have features of physiology or biochemistry that make them unrepresentative of the background population. However, a further problem of invasive procedures is that there may be conflict with public opinion, ethical committees or legal statute. Furthermore, even if scientists are not subject to ethical/legal constraints in their own countries, there can be impacts upon their ability to publish work - many scientific journals are now unwilling to publish studies that involve procedures or experiments that would not be legal in the country of publication.

6.2 FISH TAGGING AND THE LAW GOVERNING VIVISECTION

6.2.1 Background

Many countries have laws that control or prohibit ‘vivisection’ (dissection or other painful treatment of living animals for purposes of scientific research; Oxford English Dictionary). In the early 19th century, public movements developed to oppose cruelty to animals (particularly horses, cattle and dogs) and common laws to prohibit cruelty to domestic or wild animals by private citizens have been on the statute books of most European countries for many years. Legislation controlling experimental work on animals dates from the late 19th century, when physiological experiments upon live animals became common. Almost without exception, such legislation was initially aimed at protecting higher vertebrates, especially mammals - until 1986 the existing antivivisection legislation in the UK required experimental animals to be kept ‘warm and dry’!

1986 was a crucial year in the vivisection legislation of most European countries, because it coincided with the promulgation of a Directive by the Council of the European Communities (86/609/CEE). Directives are not laws, so there is no European vivisection legislation actionable in European courts. However, directives require Member States to enact national legislation. Directive 86/609/CEE is extremely detailed and will not be described here because of its lack of direct legal force. However, its aim was to avoid inhumane treatment of non-human vertebrate animals.

Substantial opposition to scientific experiments upon animals has developed during the past 30 years, particularly in the USA and Western Europe. As with most political movements, this opposition encompasses many levels of opinion. At one extreme, a large fraction of the public of several European countries opposes routine regulatory experiments to test cosmetic compounds upon animals. Many such people are in favour of responsible experimentation for biological/medical research, and are only concerned with protection of mammals (and perhaps birds). At the other extreme are a variety of militant ‘animal-rights’ organisations who oppose all experiments upon animals and are prepared to move outside the law to achieve a cessation of experimentation, even to the extent of damaging property, intimidating scientists or using physical violence. Most animal-rights organisations are particularly interested in protecting mammals or birds, and opposition to vivisection is associated with initiatives to ban hunting of wild animals and prevent intensive farming of poultry, pigs, cattle and fur-bearing mammals. However, such organisations have also targeted fish experiments, intensive aquaculture and angling, although to a limited extent so far - the most prominent organisation at present is PISCES (see http://w.w.w.envirolink.org/orgs/pisces), which specifically identifies fish-tagging as 'an extremely traumatic experience'.

Fishing itself (whether commercial or recreational) was for long not regarded as involving cruelty, basically because it was believed that fish could not feel pain. However, in recent years the fishing industry has attracted adverse international comment for practices now deemed cruel (e.g. careless handling of discards, removal of sharks' fins from living animals), while anglers have been castigated for use of barbed hooks and (especially) fish as live bait (illegal in several countries). The Royal Society for the Prevention of Cruelty to Animals (RSPCA) is a British institution, but with a high international profile. In 1994 it published a report 'Pain and Stress in Fish' (prepared by S C Kestin of Bristol University) that concluded, *inter alia*, that:

- All the fundamental structures and modulation processes necessary to achieve a perception of pain are present in fish
- Fish rapidly learn to avoid painful experiences, sometimes performing elaborate processes, or depriving themselves of food for extended periods of time to do so

This report has attracted much attention - and a summary of it is in the top ten Internet web sites displayed by several search engines in response to the search string 'fish+tagging', even though tagging itself is not considered in the report! It is now routinely invoked in critical comment upon fishing and fish farming.

6.2.2 Legal control of tagging

It should be noted that even the most recently-introduced legislation was drafted more than a decade ago, when fish tagging was largely carried out for identification and involved external tags or minute injected tags; the drafters were not specifically aware of Data Storage Tags (DSTs) and the increasing use of internal tags. Tagging was not generally used in aquaculture at that time either, so the use of tagging on fish farms is not identified separately. Within Europe, the legal position of fish tagging is very variable and there is no pan-European law (beyond the 1986 86/609/CEE directive regarding humane treatment of laboratory animals). The following sections are distillations of national legislation, most of which either directly reflects the provisions of the EU Directive or hybridises those provisions with earlier laws:

6.2.2.1 Austria

Austrian legislation makes no mention of fish tagging and was primarily developed for medical experiments with mammals.

Permission for experiments which go beyond conventional agricultural or veterinarian treatment are regulated by the Tierversuchgesetz 1988.

Only institutions with special licences are allowed to have experiments conducted on their premises.

Performance of surgery on vertebrates is restricted to staff with veterinary, medical or pharmacy qualifications, plus those biologists with special knowledge.

Experiments are controlled by the Ministry of Science & Transport which has set up a commission to control permissions. The commission works without official rules.

Impact of tagging legislation: considerable: current experience is that permission for surgically-implanted tags is unlikely to be given.

6.2.2.2 Belgium

Belgian legislation, which is aimed primarily at mammals and birds makes no direct mention of fish tagging. .

Legislation applies whenever surgery is used, and theoretically applies to all tagging.

The Ministry of Agriculture issues licences to directors of laboratories and licences for projects. An appointed national ethics committee decides on the acceptability of projects.

The performance of a project is under the scrutiny of an expert local veterinarian.

Highly detailed reporting forms are filed annually.

Impact of tagging legislation: considerable, tightly controlled.

6.2.2.3 Denmark

Danish law was last revised in 1993. As with most European legislation, it was primarily designed to apply to mammals.

As far as tagging is concerned, marking fish with external tags requires a licence from the Ministry of Justice. The Animal Experiment Inspectorate deals with tagging permissions and control. Permission is given to a person (or group) for a set number of years and for tagging a maximum number of fish per year. The person who has the licence must be present during tagging (but need not perform the operation him/herself). Premises and people are inspected and each tag has to have a tag journal. Logbooks detailing tag type, no. of fish, purpose of experiments, mortalities, when and where fish were released are kept and reported yearly to the Inspectorate

Tagging that requires surgery (e.g. intra-peritoneal tags) is controlled by a similar system, but obtaining a personal licence requires extra scientific/veterinary qualifications, plus a training course for recent recruits to tagging.,

Very recently, interpretation of the law in Denmark has changed following deliberations of a Commission. From 1st January 1998, permission will not be needed for external tagging associated with identification and monitoring purposes. This ruling is retroactive. However, strict legislation will still apply to invasive procedures.

Impact of tagging legislation: considerable, tightly controlled, but recently relaxed for the bulk of tagging operations.

6.2.2.4 Finland

Current Finnish legislation dates from 1986 (Lahteensmaki, 1987) and is fairly typical of recent law in European countries and stems from the European Council Directive on the protection of vertebrates. It has the following features:

Licenses (issued by Provincial Administrative Boards) are required by establishments carrying out experimental work on vertebrates.

Only those whose qualifications are recognised by the Ministry of Agriculture and Forestry are permitted to carry out research.

Researchers have to produce research plans (which become public documents) to obtain a project licence.

Procedures are classified (two classes); fish tagging would generally fall into the second class, where permissions are more readily granted.

Impact of tagging legislation: In practice no licences are required for routine tagging operations for monitoring populations. However, within the Finnish Game and Fisheries Research Institute there is a standing committee on animal experimentation, which controls most of the tagging carried out in the country. The committee is supervised by a Provincial Administrative Board Committee which requires an application for all tagging activities except mass tagging methods like painting and fin-clipping. The aim is to ensure that tagging operations are appropriate and carried out by competent personnel.

6.2.2.5 France

Legislation dates from 1987, but does not specifically address fish tagging. It has the following provisions:

Invertebrates, embryos or vertebrates not suffering pain are not covered by legislation.

Local or general anaesthesia is required for work on vertebrates that are liable to suffer pain, except when the anaesthesia is more detrimental to the animal than the experiment itself.

If anaesthesia is not used, the number of experiments must be minimised, and only one procedure may be carried out on an individual animal.

Authorisation for experiments is provided by the Ministry of Agriculture. Permits are given for 10 years, with automatic renewal if experiments continue.

Experimenters should be a veterinarian, medical doctor, pharmacist or qualified at BSc, MSc or PhD level in the biological sciences, or have equivalent experience.

There is a wide range of procedure requirements, but these are applied flexibly to different types of animals.

Experimenters must show evidence of having undertaken training courses in surgical and prophylactic procedures.

6.2.2.6 Germany

Straightforward tagging for identification is not controlled by legislation. However, if surgery is required, then permission for projects is required and operators need to have suitable qualifications and training.

Impact of tagging legislation: considerable as far as procedures governing surgery are concerned.

6.2.2.7 Greece

Greece has no laws governing vivisection; fish tagging is subject to no rules whatsoever. However, government authorities expect workers to be guided by international humanitarian practice. Effectively this is a self-regulatory regime.

Impact of tagging legislation: None.

6.2.2.8 Ireland

Ireland’s basic legal framework in this area is the 1876 Cruelty to Animals Act (which was drafted when Ireland was part of the U.K.). This act issued licences to people to carry out procedures provided they were suitably qualified. It has been updated by EU legislation (Directive 86/609/EEC) and annual returns are required. Identificatory/external tagging (‘routine husbandry’) is excluded from control.

Impact of tagging legislation: considerable as far as procedures governing surgery are concerned.

6.2.2.9 Italy

From 1992 a law based on an EU Directive (86/609/CEE) was introduced:

The law governs 'the protection of animals used for experimental aims or for other scientific topics', but this is primarily aimed at laboratory work upon laboratory-reared mammals.

Experiments can only be done in authorised laboratories and require permissions from the Italian Health Ministry and local authorities.

Experiments on wild animals are allowed, after specific request, only to a few scientific institutes for study and research aims, but it is necessary to demonstrate a value to conservation, and also that it is impossible to use animals reared in the laboratory.

Technically, therefore, tagging should involve legal control. In practice this is ignored in the case of small, common fish (Fabi, pers. comm.) but is more likely to be taken seriously in the case of tunas or other large pelagic fish.

Impact of tagging legislation: unclear at present - limited tagging is taking place in Italy.

6.2.2.10 Netherlands

Not available

6.2.2.11 Norway/Iceland

Norway and Iceland have virtually the same legislation; the Norwegian one is described:

The 1974 Animal Welfare Act (supplemented by the provisions of the EU Directive 86/609/CEE) applies to live mammals, birds, reptiles, amphibia, fish and crustaceans.

It applies generally to the public, and is not specifically aimed at controlling scientific experimentation.

Animals must be treated well so that there is no risk of causing them unnecessary suffering.

Inspection by police, animal welfare committees and official veterinarians may be carried out at any time.

A person carrying out biological research must have a special licence, granted by a committee.

From July 1998 researchers must attend mandatory 3-week courses, organised by veterinary colleges.

No specific mention is made of fish tagging, and tagging operations are not subject to reporting.

Iceland differs from Norway in the following ways:

An Animal Welfare act (1994) applies;

researchers do not need licences;

there is no requirement at present for training.

Impact of tagging legislation: in both countries there appears to be no impact of legislation on recognised types of fish tagging.

6.2.2.12 Portugal

There is very limited general legislation in Portugal affecting fish tagging.

Impact of tagging legislation: negligible.

6.2.2.13 Spain

There is very limited general legislation in Spain affecting fish tagging.

Impact of tagging legislation: negligible.

6.2.2.14 Sweden

The Swedish Animal Welfare Act ('Djurskyddslag', no. 1988/534) with a recent amendment of 25 February 1998 (no. 1998/56) is now very similar to the EU-Directive (86/609/EEC). Certain experiments are **exempted**: 1) experiments on invertebrates; 2) minimal and simple operations; and 3) bird-ringing.

Tagging operations that involve surgical treatments are subject to the following regulations:

Operators must be licensed, as must each experiment. The Ministry of Agriculture controls licensing through an Ethics Committee (there are 6 committees within Sweden).

From 31 December 1994 operators must take part in 3-week courses which have a fixed curriculum (including: laws & regulations governing animal experimentation; ethics; biology and care of animals; familiarity with current types of experiment; alternatives to use of animals).

Experimenters must be veterinarians, or have close links with veterinarians.

At the end of a procedure, a veterinarian shall decide whether slaughter is necessary (and what humane method should be used).

All procedures have to be reported; reports have to be held for at least 3 years at the place of experimentation; records must be open for inspection at any time.

Impact of tagging legislation: considerable, tightly controlled, requiring specific permission. At the time of writing, attempts are being made to obtain exemptions. For example, it is hoped that exemption will be granted for Carlin tagging performed to follow the effects of Water Court decisions on salmonid smolt releases, and also for adipose fin cutting of smolt reared for harvest purposes.

6.2.2.15 United Kingdom

The U.K. appears to have the most detailed legislative control of animal experimentation (The Animals (Scientific Procedures) Act 1986) in the EU at present:

U.K. law applies to all non-human vertebrates, plus the common octopus; it is quite likely that advanced crustaceans (e.g. crabs/lobsters), will be added to the list in the next few years. As far as fish and amphibians are concerned, the law does not apply to larval stages - the Act only applies when the animals can feed independently. Tagging larval fish by any means (e.g. tagging by fluorescent dye, genetic tagging) is therefore outside legislative control.

Experimentation requires site, personal and project licences, all of which must be sought from the Home Office.

Establishments and programmes are subject to unannounced inspection at any time by Home Office Inspectors.

Regional Home Office Inspectors (registered medical or veterinarian practitioners) advise on projects, not only on the basis of the humane nature of experiments, but also on the scientific validity of project plans. They are prepared to balance stress against the benefits of a programme (cost:benefit analysis) but are equally prepared to turn down a programme they perceive as trivial.

There are highly detailed descriptions of categories of experiments and specific duties described for experimenters.

Experimental procedures have to be reported annually in detailed returns to the Home Office for national published statistics.

Tagging purely for identification, and which causes ‘only momentary pain or distress’, or for ‘routine husbandry’ is not covered by legislation (i.e. it can be freely undertaken). Tagging for forward stock assessment falls into this category. Tagging conducted at sea outside the 12-mile limit of territorial waters is also deemed not to be controlled by legislation.

Tagging carried out for ‘scientific reasons’ (as judged by a Home Office Inspector) requires Personal and Project Licences. This means that most data storage tagging will require anaesthesia, and will certainly do so if tags are implanted surgically.

Holders of licences have to possess appropriate scientific qualifications and new holders now have to undertake training courses. These are expensive and largely aimed at laboratory mammalian practice and the maintenance of proper animal houses, although there are also modules dealing with fish or farm animals. None of the training specifically addresses fish surgery or tagging procedures.

From 1st April 1999, each institution carrying out procedures under legislation will be required to have an internal *ethical review process* in place to consider, advise and control such procedures. This is in addition to existing external controls.

Impact of tagging legislation: considerable, tightly controlled.

6.2.2.16 U.S.A.

The USA is outside the remit of CATAG, but has state (rather than federal) laws governing tagging that are similar to the more stringent ones obtaining in Europe. A particular legal problem has surfaced recently - sport freshwater anglers are starting to conduct informal tagging operations of their own. This illegal practice, which interferes with legitimate fish management research, has the potential to spread throughout Europe. Tagging guns and tags are now available cheaply through mail order catalogues and there are already instances of game fishermen using tags in Denmark. This a grey area of law, although in Iceland sports fishermen routinely (and legally) move and tag sea-ranched salmon. Fin clipping is also quite common in Belgian freshwater systems.

6.2.3 Tagging of organisms other than fish

Tags are applied routinely to shellfish, marine mammals and turtles. *De facto*, bird-ringing (including that applied to marine birds) is also a form of tagging. Broadly speaking, shellfish tagging is not covered by legislation anywhere in Europe, though there are signs that higher crustaceans (crabs, lobsters) may be incorporated into more rigorous legislation (e.g. in the UK), and in principle crustaceans could be covered by Norwegian/Icelandic legislation. Marine mammals are covered by the same legislation as that applied to fish (i.e. with national differences) - a controversial area is the propriety of using hot-iron branding for seal identification. Interesting there is little objection to freeze branding, although tissue effects are indistinguishable (Feydak, personal communication).

The legal status of turtle-tagging and bird-ringing make an interesting comparison with fish-tagging. Both activities are seen as almost entirely beneficial (despite increasing evidence of high tag-loss rates in turtles), and it is common for nationals of one European country to conduct ringing or tagging in another (relatively unusual in fish tagging, save in large co-operative programmes). Generally turtle-tagging and bird-ringing are treated as husbandry or monitoring practices not covered by vivisection legislation. However, they are not outside legal control.

Most European countries with nesting turtles require taggers to have permits from relevant authorities (e.g. Department of the Environment in Cyprus - the only part of Europe to have substantial populations of both green and loggerhead turtles), principally because all sea turtle species are endangered, and therefore subject to international law (e.g. CITES). However, there appears to be no distinction between tagging for identification purposes, and the use of electronic tags, such as DSTs and satellite tags.

Bird-ringing is regulated, but generally by NGOs rather than government departments. In most European countries it is illegal to catch (as opposed to shoot!) wild birds, while many species (e.g. raptors) are protected by national legislation. Bird-ringers are licensed, and the licensing procedure requires training, usually of considerable duration before ringers may act independently. In the U.K. bird-ringers have to obtain licences from the Joint Nature Conservation Council, but the licensing is delegated to the British Ornithological Trust (another NGO.

Tagging of invertebrates (shellfish) is subject to no legal controls at present.

6.2.4 Tagging, the food chain and European law

Anaesthesia during tagging procedures has the potential for contaminating fish tissues with chemical residues. If the fish are of fishable size and are released into the environment after tagging, then there is a possibility that such residues might reach humans via consumed fish. In addition it is feasible that materials used for prophylaxis (disinfectants, antibiotics) could also contaminate fish. A separate issue concerns the release of chemically-tagged fish into the environment, though so far this seems not to have been considered because chemical tagging has been a mass tagging process applied to immature (and hence unfishable) fish.

As far as anaesthesia is concerned, the USA Food & Drug Administration (FDA) technically permits only one anaesthetic to be used on fish that are subsequently released into the environment (MS222^{TM} = tricaine, 3-amino benzoic acid ethyl ester methanesulphonate). However, clove oil is also legal because the FDA recognizes it a ‘generally recognized as safe’ substance (GRAS) rather than an anaesthaesthetic. The FDA also requires that fish are not released into the environment until 3 weeks have elapsed since anaesthesia, though again clove oil-anaesthetised fish appear to be exempt. In the UK, the Medicines (Restrictions on the Administration of Veterinary Medical Products) Regulations 1994 governs this area, and again only MS222 is permitted. However, in this case, the fish only have to be held for 10 days before release (it is generally agreed that all residues have disappeared from fish by around 24 hours after anaesthesia). The degree to which similar legislation exists in other European countries is unclear. But at present there is no system of enforcement or control, so it is important that scientists releasing fish after anaesthesia or prophylaxis should behave in a responsible fashion (‘self-regulation’).

6.3 REQUIREMENTS AND RECOMMENDATIONS

DG VI, XII, XIV could be asked to examine the possibility that fish tagging should be treated separately from experimentation on animals. At a minimum, it would help if a consistent approach was adopted throughout Europe to tagging used for identification only (in fisheries and aquaculture operations) - this is exactly analogous to identifying cattle or pets by external tags/pit tags, and should not be subject to vivisection legislation. **It is should be noted that the evidence collected by CATAG has already led Denmark to change its application of legislation in this fashion.**

Fish tagging practitioners should all be required to undergo training. Current legislation often requires experimentation licence holders to undergo generalised training in the legality of various procedures and holding techniques, but surgical procedures on fish are very different from those used on terrestrial mammals.

All efforts should be made to avoid chemical residues associated with the tagging process reaching the human food chain.

6.4 REFERENCES

a) List of acts on animal experimentation in the European Union

Belgium: Arrêté Royal du 14 novembre 1993 relatif à la protection des animaux d'expérience (based on Belgian Law from 14 August 1986 on Animal Welfare, European Law from 1991 on the protection on Vertebrate Animals and on the directives of the ECC from 24 November 1986 on the consistency between European regulations on Animal experimentation 86/609),

Finland:

Finnish legislation on animal protection and experimental work on vertebrates consists of the following laws and acts:

1.Law On Animal Protection, Eläinsuojelulaki 247/1996

2. Act On Animal Protection, Eläinsuojeluasetus 396/1996

3. Act On Animal Experimentation, Asetus koe-eläintoiminnasta 1076/1985. This is partly changed by act 395/1996

4. Decree of Veterinary Division in Ministry of Forestry and Agriculture on classification of animal experiments, Maa- ja metsätalousministeriön päätös tieteellisten eläinkokeiden luokituksesta 447/1986

5. Introductory Act On European Convention For The Protection Of Vertebrate Animals Used For Experimental And Other Scientific Purposes, Asetus kokeellisiin ja muihin tieteellisiin tarkoituksiin käytettävien selkärankaisten eläinten suojelemiseksi tehdyn eurooppalaisen yleissopimuksen voimaansaattamisesta 1360/1990

Germany: Erste Gesetz zur Ænderung des Tierschutzgesetzes vom 12-08-1986, Bundesgesetzblatt Teil I vom 22-08-1986 Seite 1309.

Spain: Real Decreto numero 223/88 de 14-103-1988 relativo a la protection de los animales utilizados para experimentacion y otros fines científicos, Boletín Oficial del Estado numero 67 de 18-03-1988 Pagina 8509.

France: Décret 87-848 du 19 octobre 1987 pris pour l'application de l'article 454 du code pénal et du troisième alinéa de l'article 276 du code rural et relatif aux expériences pratiquées sur les animaux.

Greece: Décret présidentiel du 12-04-1991, FEK A numéro 64 du 03-05-1991 Page 1061.

Ireland:

1. The Cruelty to Animals Act of 15-08-1876.

2. EC (Amendment of the Cruelty to Animals Acts of 1976) Regulations of 1994, Statutory Instruments Number 17 of 1994.

Italy:

1. DM 27/01/1992 - Attuazione della Direttiva n. 86/609/CEE in materia di protezione degli animali utilizzati a fini sperimentali o ad altri fini scientifici

2. Circolare 05/05/1993 - Decreto Legislativo 27 gennaio 1992, n. 116, articoli 8 e 9, concernenti deroghe agli articoli 3 e 4.

3. Circolare 22/04/1994 n. 8 - Applicazione del Decreto Legislativo 27 gennaio

1992, n. 116, in materia di protezione degli animali utilizzati a fini sperimentali o ad altri fini scientifici.

Austria: Bundesgesetz vom 27 September 1989 über Versuche an lebenden Tieren (Tierversuchgesetz 1988)

Portugal: Decreto-lei numero 129/92 de 15-06-1992., Diario da Republica I Série A, numero 153 de 06-07-1992 Pagina 3197.

United Kingdom: The Animals (Scientific Procedures) Act 1986 (subsequently amended by three Statutory Instruments).

b) Journals/Reports

Lahteensmaki, V., 1987. Legislation dealing with animal experimentation in Finland. *Animal Technology,* 38: 229-233.

Kestin, S.C., 1994. Pain and stress in fish. RSPCA

c) Websites

http://w.w.w.envirolink.org/orgs/pisces/pain.html

http://w.w.w.envirolink.org/orgs/pisces/welfare.html

http://www.dnr.state.oh.us/odnr/wildlife/news/archive/enforce/ap421.html

7. FISH WELFARE AND HEALTH IN RELATION TO TAGGING

7.1 INTRODUCTION

All forms of fish tagging involve invasive procedures, first by capture itself. Externally-fixed, or superficially-injected tags breach the skin and musculature, while internal tags (whether mounted in the stomach or peritoneal cavity) normally involve either force feeding or surgery (though some tags can be ingested voluntarily in food/bait). Use of anaesthesia may itself alter body biochemistry (e.g. MS222 use causes elevated serum cortisol levels in coho salmon; Strange & Schreck, 1978). All types of tags have the potential to cause health problems for fish subsequent to the tagging process itself. There may be disturbances of physiological function, or more subtle behavioural or immunological effects.

7.2 ANAESTHESIA

7.2.1 Introduction

Rendering fish quiet (sedation) or unconscious (anaesthesia) is crucial to several aspects of fish tagging. Summary sheets at the end of this section are intended to help operators choose and use anaesthetics: they are also readily downloadable as OHP slides. More information about anaesthesia may also be gained by interrogating the WELFARE database**.** Operators should be aware that there are legislative implications of use of anaesthetics on fish that are to be released to the wild because of the perceived risk of chemical residues reaching humans through the food chain (see Section 6.2.4).

7.2.2 Anaesthesia

A variety of handling methods have been applied during the tagging process, ranging from use of blindfolding in calming fish, to full anaesthesia involving continuous irrigation of the gills with fresh or seawater containing diluted anaesthetic agents.

Under anaesthesia, handling stress will be reduced and tagging can be accomplished more rapidly without risk of the fish hurting themselves when trying to escape. Although the use of anaesthetics in some cases may be unwanted due to their detrimental effects on the physiology and behaviour of the fish, considerations of animal welfare will in most cases prohibit tag attachment to unsedated fish if surgery is involved.

7.2.3 Choice of anaesthetics

Different handling procedures demand different anaesthetic approaches. Light anaesthesia (=sedation) is defined as ‘reduced activity and reactions to external stimuli’, and is sufficient for procedures such as transport or weighing of fish. Full anaesthesia can be defined as ‘loss of consciousness and reduced sensing of pain, loss of muscular tonus and reflexes’ and is needed when surgical procedures are applied (McFarland, 1959).

The behavioural changes occurring in fish passing through sedation to full anaesthesia were classified by McFarland (1959). There are 4 stages with subclasses ranging from normal (stage 0), where the fish reacts to external stimuli and where the muscular tonus and swimming ability is normal, to the stage of total physiological collapse (stage IV), where gill movements have stopped and which in a few minutes will lead to heart failure. In a tagging context, the stages where the fish is in a state of light/deep anaesthesia (stages II and III) are of greatest relevance, as the animal is then insensitive to pain caused by the attachment of transmitters or data storage tags.

Choice of sedatives/anaesthetics must be based on the species to be tagged, the number and size of fish involved, and the duration of the operation in question. Water temperature and chemistry have also to be taken into consideration when choosing the method. Lastly, the work often has to be done under primitive field conditions without accurate control of concentrations and exposure times. An anaesthetic with a good safety margin between effective anaesthesia and irrevocable collapse is essential in such circumstances.

7.2.4 Categories of methods

(a) Physical sedation methods

Physical sedation can be obtained by rapid lowering of temperature or by electric shock. The former method is mainly applicable for transportation (c.f. Ho & Vanstone, 1961). Coldwater adapted species, and marine fish require lower temperatures for sedation than warm water species and freshwater fish (Chung, 1980). Water cooling can also be used in conjunction with other anaesthetics (e.g. Benzocaine) but the dosage must then be reduced by about 30% (cf. Ross & Ross, 1983). Electroanaesthesia has a number of advantages such as rapid immobilisation of fish, no need for chemicals, rapid regain of consciousness and low costs (Madden & Houston 1976, Gunstrom & Bethers 1985, Tytler & Hawkins 1981; Cowx & Lamarque, 1990; Cowx, 1990). But these are outweighed by the fact that the method cannot be used in saline water, and the danger of using inappropriate voltage levels, which may give severe physiological stress responses in experimental fish (Shreck *et al.*, 1976) due to hypoxia. There are also significant risks to experimenters, principally from electric shock. In the U.K. the National Rivers (NRA) issued a safety Code of Practice in 1995.

(b) Chemical sedation and anaesthesia

Chemical sedation is distributed to fish in liquid dilutions of varying strengths depending on the agent used. The sedative is inhaled by the fish and diffuses across the gill epithelia. In minor quantities it can also diffuse into the fish via the skin - this may be a particularly significant route in scaleless fish with well-vascularised skins. Since these chemicals are absorbed and excreted predominantly via the gills, fish with a large surface of gill ephithelium for a given body weight (e.g. salmonids) require lower doses of anaesthetics than fish (e.g. eels) with relatively smaller epithelial surfaces (Ross & Ross, 1983). Other factors affecting the absorption and excretion of chemicals are the relationship between the surface of the gill epithelium and the body volume, thickness of epithelium, type of anaesthetic, dosage and temperature.

All known anaesthetics have unwanted side effects. Most of them are barbiturates, which lead to unconsciousness, inhibition of the sensing of pain and loss of muscular tonus and reflexes. The most important complication connected with all forms of chemical anaesthesia is hypoxia due to reduced respiration and vascular activity. This leads to physiological changes in the blood (e.g. lowered pH), hypotonia (= reduced blood pressure), raised blood glucose, blood lactate and haematocrit (Tytler & Hawkins, 1981). In addition to physiological deterioration of blood parameters, hypoxia can cause brain damage, which interferes with directional orientation (Taylor, 1988), or alters temperature preferences (Goddard *et al.*, 1974).

Widely used anaesthetics of the barbiturate group are:

MS 222- Tricaine methane sulphonate

Chemical name: ethyl- amino- benzoatemethanesulphonate. MS 222 (trade name) is probably the most widely used fish anaesthetic world-wide, and there are numerous studies on the physiological effects of this agent (e.g. review by Bell, 1987). It is a crystalline powder easily dissolved in fresh and seawater. The recommended dosage for anaesthesia is 50- 100 mg/ l (Klontz 1964; Ferreira et al., 1979). It should be observed that MS222 becomes toxic in seawater exposed to sun (Bell, 1987). MS222 gives an acid solution and a dosage of 75 mg l^{-1} can cause the pH to fall to 4.0 in soft water (Wedemeyer, 1970). This effect can, however, be mediated by adding 5- 6 ml saturated (10%) solution of $NaHCO_3$ to 1 litre of 100 mg l^{-1} solution of MS222.

Benzocaine

Chemical name: Ethyl-p-aminobenzoate. This chemical is also very widely used in fish anaesthesia. It is chemically close to MS- 222, both being derivatives of p-aminobenzoic acid. Benzocaine is a white crystalline powder, which is insoluble in water and has to be dissolved in ethanol in a ‘master solution’ of 1 g l^{-1} 96% alcohol. The master solution should be stored in a dark bottle, and has a life of up to a year. The recommended dosage is 2.5 ml of this master solution to 10 l of aerated water. With this dosage the animals should be immobilised in 2 - 5 min. and the recovery time will be 5 - 15 min. Benzocaine gives a neutral solution (Egidius, 1973). The time to obtain anaesthesia was observed to take 1.5 min longer time for trout (*Salmo trutta*) and 3 min longer for pike (*Esox lucius*) in 7°C water than at 12 °C (Dawson & Gilderhus, 1979). According to Wedemeyer (1970) a comparison between Benzocaine and MS-222 as anaesthetics for salmonids was slightly in favour of Benzocaine as less metabolic change was observed. More recent studies by Soivio et al. (1977) showed few differences between the two; both caused hyperglycaemia. However, benzocaine caused somewhat lesser hyperglycaemia than MS-222. With the exception of occasional allergic reactions, health hazards to humans are not normally recorded with the use of benzocaine (MND, 1986).

Chlorbutanol- Chlorbutol- Chorethone- Acetochloroform

Chemical name: Chlorbutanol. Although classified as a safe anaesthetic for fish (Johansson, 1978), it has not been widely used outside Scandinavia due to health hazards to humans connected with its use. Inhalation of larger quantities may cause unconsciousness, it can also irritate human skin and eyes. Chlorbutanol (Cb) is a crystalline colourless powder that has to be dissolved in ethanol. The usual base solution is 30 g to 100 ml 96% ethanol, and the dose 10 ml base- solution to 10 litres aerated water. Johansson (1978) states that the time for falling into stupor and wakening is inversely dependent to the water temperature, the higher the temperature the lesser the time needed for sedation. The dosage varies somewhat with the size and species of fish but is considered sufficient when the fish rolls on it side after 3-5 min. Chlorbutanol gives a light anaesthesia, but it is normally sufficient when the fish only needs to be handled for a short time handling, such as in tagging (Johansson, 1978; Horsberg & Høy, 1989). Chlorbutanol is considered a safe anaesthetic for fish, although a study by Hansen and Jonsson 1988 showed an 87 % reduction in return rates of Atlantic salmon (*Salmo salar*) smolts anaesthetised before release in comparison with untreated fish. Chlorbutanol has also been tested on Atlantic halibut (*Hippoglossus hippoglossus*), but with a dosage of 50 ml base solution dissolved in 10 l water. The smallest fish are most rapidly sedated; they also have the shortest recovery time.

Methomidate chloride

Methomidate is a hypnotic (sleeping-agent) and not a barbiturate. It therefore causes less depression of respiration than MS-222 or Benzocaine. This may lead to fewer and less serious side-effects. Methomidate is water-soluble. Mattson & Riple (1989) report an effective concentration of 5 mg l^{-1}. Methomidate was tested on rainbow trout in the early

1980s by Gilderhus & Marking (1987), and showed in these tests to give a relatively long wake-up time and also some mortality after treatment. However, during the late 1980s this anaesthetic has been tested with good results for handling salmonids and other fish in culture, such as cod and halibut at the Department of Aquaculture, Institute of Marine Research, Norway, (Mattson & Riple, 1989; Huse, pers. Comm.; Furevik, pers. comm.). From 1992 onwards methomidate has been the only anaesthetic used at the Dept. of Aquaculture (Holm, pers. comm.); the only negative feature is the high cost of the product.

Quinaldine

Quinaldine is not easily soluble in water, and is also reported to be irritating to human skin and mucus membranes. Quinaldine-sulphate does not have these negative effects, but gives an acid solution, and must therefore be buffered with sodium bicarbonate (Blasiola, 1977). It has been used in acetone solution for the capture of intertidal fish living in rock pools. Reports that it may be carcinogenic currently restrict use.

Propanidide

In a 5% solution this chemical is water-soluble. *Propanidide* seems to have few physiological side effects, and can be used both for short- and long-duration anaesthesia. The main reported asset of this anaesthetic is that it does not reduce the ventilatory rate of the fish (Ross & Ross, 1984). The blood-circulation can also remain unaffected as reported by Veenstra et al. (1987) from studies of *S. fontinalis* embryos and 7 days old alevins of amargosa pupfish (*Cyprinodon nevadensis amargosae*). It has also been tested on carp (Jeney *et al*., 1986) rainbow trout and smolts of Atlantic salmon and sea trout (Siwicki, 1984) with good results.

Clove oil

Chemical name: eugenol (4-allyl-2-methoxy-phenol). Recent experiments (Anderson et al., 1997) have shown that clove oil is just as effective an anaesthetic for both juvenile and adult rainbow trout (*Oncorhynchus mykiss*) as MS-222. Munday & Wilson (1997) report excellent results with clove oil on *Pomatocentrus amboinensis* and recommend its use in preference to quinaldine. Clove oil does not affect swimming performance and it also provides swift induction and recovery from anaesthesia. It is regarded as a GRAS (‘generally recognised as safe’) substance by the US Federal Drugs Administration (FDA) and is suitable for use in field studies where immediate release of the fish into the food chain is required. Anderson *et al*. (1997) have shown that concentrations of 20-40 and 100-120 mg/l will induce light and heavy anaesthesia, respectively. At a concentration of 120 mg/l induction times are significantly faster than MS-222 for both juveniles and adults. At a concentration of 40 mg/l there is no difference for juveniles but induction times are significantly faster for adults. Recovery times for adult fish are rather longer than MS-222 at the higher concentration but no different at the lower concentration.

7.2.5 Information sheets

Downloadable information sheets that will assist in the choice of anaesthetics for specific purposes have been prepared; they are displayed in Appendix II (7.10) of this chapter and are also available on the CATAG web site (http://www.hafro.is/catag).

7.3 EFFECTS OF CONVENTIONAL TAGS ON FISH

Consideration of conventional tagging (including procedures such as fin-clipping) will be given here. Generally such tagging procedures are innocuous and there is little or no stress to fish beyond that involved in capture and handling (e.g. chinook salmon, *Oncorhynchus tshawytscha*, Sharpe *et al.*, 1998; see also Gjerde & Reftstie, 1988, Hansen, 1988). The main problem associated with tags is that of pathological lesions caused by tagging or fin clipping (Roberts *et al.*, 1973a, b, c; Morgan & Roberts, 1976), or indeed any breach of fish skin. Such lesions may be subject to secondary infections and are likely to cause effects on growth rate and reproductive performance. Uncontrolled infections may well be a source of mortality, but it seems probable that this is very rare.

Adipose fin clipping (commonly performed on Pacific salmon) may be detrimental because there is some evidence that these fins are secondary sexual characters, which perform an important function in mate selection.

Most tagging experiments are based on the assumption that the behaviour, growth and survival of tagged fish is similar to that in untagged fish and that data generated from these studies is unaffected by the type of tag used or the tagging procedure implemented. Few studies have been carried out to assess the impact of simple external tags on the behaviour of fish (e.g. Lewis & Muntz, 1984; McFarlane & Beamish, 1990), probably because they are difficult to design and carry out. Furthermore, tag effects are sometimes examined under controlled laboratory experiments, which often provide conditions different from the natural environment.

While many of the internal tags or marks may have minimal or negligible effect on the behaviour of marked fishes (Buckley & Blankenship, 1990), external tags may affect the behaviour of tagged fish. Small individuals may have problems with relatively large tags and the application of the tag may cause problems, such as wounds around the attachment. External tags may effect feeding or evasive behaviour and the fish may therefore be more vulnerable to predation. Especially in demersal fish, tags may become overgrown with algae and/or mussels, becoming heavier and more cumbersome. An external tag that has not been anchored firmly into the muscle may continue to irritate the fish, preventing the wound from healing causing a chronic wound.

Growth of sablefish, *Anoplopoma fimbria*, was found to be affected by the tag or tagging procedure in a comparison of wild, tagged fish with untagged fish (McFarlane & Beamish, 1990), using size at known age data. Thus, extrapolating growth information from tagged fish resulted in altered estimates for mortality and mean age at maturity for this species. On the other hand, no effect on growth was observed in similar studies with Arctic char (*Salvelinus alpinus*) (Berg & Berg, 1990).

Carlin tagging and fin clippings are commonly used in studies on salmon or trout migration, survival or growth. Saunders & Allen (1967) showed negative effects of this tagging method on survival of Atlantic salmon, *Salmo salar*, implying that mortality estimated from tagged salmon smolts would result in an underestimation of the survival rates to adults. This was confirmed in later studies on the same species by Isaksson & Bergman (1978) and Hansen (1988). The increased mortality was attributed to handling, anaesthesia and marking of fish. Carlin tagging was found to have a higher impact on survival than fin clipping, although the latter was not without impact, probably due to stress from handling and anaesthesia. In a laboratory study on snapper (*Pagrus auratus*), no effect of dart tags on survival or growth was observed on three length sizes of fish during a one-year period (Quartaro & Kearney, 1996).

All tagging or marking of fish involves treatment, which disturbs the fish and may stress or harm the fish. Careful handling procedures throughout the capture and marking process are of highest importance. Physiological research has shown fish to be stressed for a prolonged period after handling; for example, levels of lactic acid may be elevated for more than 24 hours after stressing the fish at certain temperatures (Wendt 1965, 1967; Wendt & Saunders, 1973). Histopathological studies on the effects of Disc-dangler tags on Atlantic salmon (Morgan & Roberts, 1976) revealed that external tags of these types can leave severe traumatic wounds which may lead to secondary infection. The incomplete healing of the integument during the life of the fish may affect the normal behaviour of the fish and result in biased estimates of biological parameters.

A possible (and virtually unstudied) effect of all types of external tagging (whether conventional or with electronic tags) is that tags may become fouled, causing enhanced drag, so disadvantaging the fish. Anecdotal evidence has been collected during CATAG of the existence of such fouling (e.g. by barnacles and seaweed) but more investigation is needed. In particular, it would be desirable if systematic fouling trials could be conducted on tags and tag materials - it is quite possible that fouling could be a source of unremarked mortality of tagged fish.

7.4 EFFECTS OF ELECTRONIC TAGS ON FISH

7.4.1 Introduction

Electronic tags have become commonly used during the last decade to monitor movements, activity, physiological responses and reaction to a number of environmental variables in many fish species in natural environments (review in Lucas & Baras, 2000) as well as in aquaculture environments (Baras & Lagardère, 1995). The area of electronic tags is in rapid development, and since the start of fish telemetry (see Malinin & Svirskii, 1972; Stasko, 1975, for a historical perspective) these tags are used by an increasing number of teams and researchers, in an increasing number of species, most of which have never been tagged before (Baras, 1991; Priede & Swift, 1992; Baras & Philippart, 1996; Lagardère et al., 1998; Moore & Russell, 2000). Implicit in these studies is the usual assumption that the tag and the tagging procedures have no significant effect on the data collected. Whereas some authors found no difference between tagged and untagged fish in terms of behaviour, growth or physiology (e.g. Hinch *et al.*, 1996), other studies have documented adverse effects that are dealt with here. Furthermore, only a very small proportion of tagging studies have investigated the actual adverse effects of tagging, and effects on behaviour or physiology have been investigated far less frequently than direct, 'obvious' effects on survival, anatomy or pathology (see Figure 7.1).

A future goal should be to ensure that the effect of the tag and the tagging procedures on the animals used in any project are studied before this type of assumption can be made

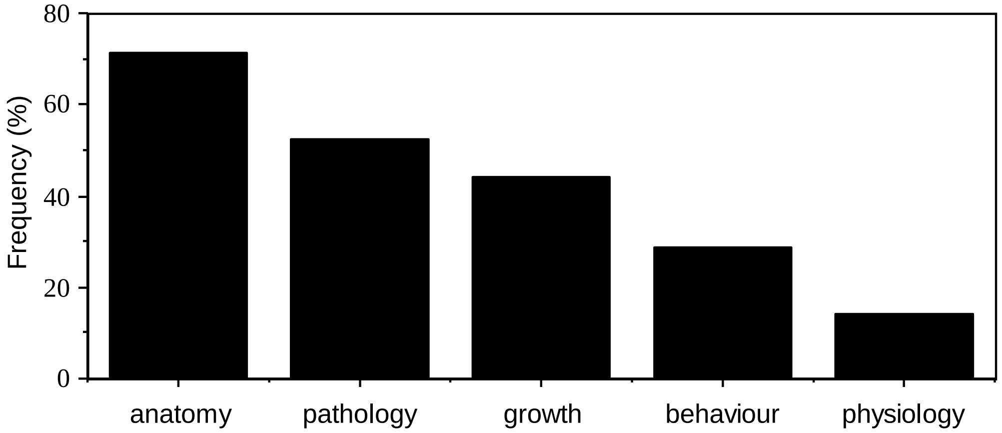

Figure 7.1. Proportion of tagging feasibility studies where the effects of tags or tagging procedure on anatomy, pathology, growth, behaviour and physiology were investigated.

with confidence. Furthermore, because electronic tags and tagging techniques are developing rapidly, the need to document modifications of behaviour from newly developed techniques needs to be emphasised. This should be done, not only to secure the welfare of the animals, but also to avoid biased data collection due to decreased performance, altered behaviour or elevated stress level in the fish.

The present review focuses on the effects on fish of tagging and carrying electronic tags. Because of their larger size and mass, telemetry (radio and acoustic) and data storage tags (DST or archival tags) are considered separately from other electronic tags, such as passive integrated transponder (PIT) tags, and from conventional tags (see Section 7.3). The main results from studies dealing with the effects of radio and ultrasonic transmitters in fish are summarised in Appendix I (7.9) of this chapter. Additional, more detailed information can be found in the WELFARE database on the CATAG web site (http://www.hafro.is/catag).

7.4.2 Survival

For ethical considerations, cost effective research and reliable statistical analyses, it is crucial that fish survive the tagging procedure and that neither the tag nor the tagging procedure influence the survival rate of the fish, either during the time of the study or later. Survival rates evaluated in telemetry or DST tagging studies ranged from 20 % one month after tagging (grass carp *Ctenopharyngodon idella*, Schramm & Black, 1984) to 100 % 30 months after tagging (blue tilapia *Oreochromis aurens*, Thoreau & Baras, 1997), both derived from captive studies. Because of differences between the procedures used by different authors (e.g. threads for attachment, coating, tag size, anaesthetics, temperature) and because not all factors likely to influence mortality are systematically investigated, or mentioned in feasibility or field studies, it may be difficult to draw general trends. Different fish species or life history stages may also have different resistances to handling or pathological outbreaks. However, the analysis of the CATAG fish WELFARE data base provides evidence that gastrically-inserted transmitters are less prone to cause the death of fish, compared with externally- attached or intraperitoneally-inserted transmitters (Figure 7.2). Surgical procedures are often deemed to be the most invasive ones, since they require deep anaesthesia, longer handling, opening of the body cavity and insertion of a foreign body inside the fish. But carefully evaluated procedures tailored to the species of interest are

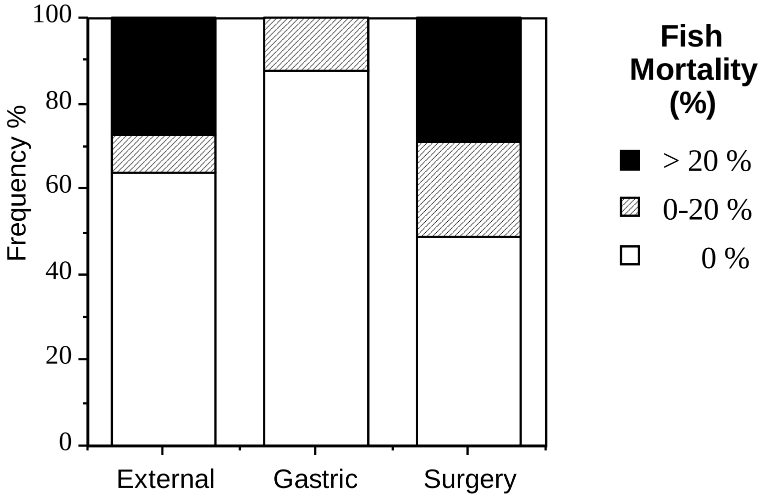

Figure 7.2. Proportion of telemetry studies reporting variable rates (0%, <20%, 20%) of fish mortality depending on attachment procedure.

frequently reported to cause no additional mortality compared with controls.

Mortality of internally-tagged fish takes place most frequently within the hours, days or weeks following tagging, as a result of wound infection, blockage of gut transit or damage to internal organs. Wood *et al.* (1983) reported that 40 % of tagged rainbow trout *Oncorhynchus mykiss* died within 12 hours following 6 min of intensive exercise, probably because of acidosis. Similarly, most cases of mortality of surgically-implanted fish took place before the fish had healed their incisions and recovered physical integrity and osmotic balance (within 4 days to 7 weeks, depending on species and ambient temperature). In contrast, deaths of externally-tagged fish rarely take place within the first days or weeks. External tag attachment involves progressive, or chronic lesions to muscular tissues, in which degenerative processes exceed by far the capacity for tissue repair (Roberts *et al.*, 1973; Birtles *et al.*, 1995; Knights & Lasee, 1996). Adverse effects thus accumulate over time and can be exacerbated by exposure to increased water velocity, which increases the drag on the tag. These problems can, however, be postponed depending on the time interval between the moment of tagging and the time of the year when the fish moves into a faster flowing environment. Externally-attached tags or trailing antennas may become entangled in vegetation (e.g. Chinook salmon, *Oncorhynchus tshawytscha* Adams *et al.*, 1998). This can cause tag shedding or fish mortality.

7.4.3 Retention

Tag shedding or expulsion has been reported for all three major attachment procedures (externally-attached, intragastrically-inserted, intraperitoneally-inserted), as well as for oviduct insertion, which has recently been evaluated in salmonids (Peake *et al.*, 1997). Generally, shedding has been reported more frequently, and shedding rates found to be higher for gastrically-inserted tags than for external or intraperitoneal tags (Figure 7.3), and this contrasts with the mortality rates inherent in these three procedures. This section will concentrate on shedding or expulsion mechanisms, and conditions that increase the propensity of fish to shed tags. Details on tag shedding rates in different species or life stages can be found in the WELFARE data base.

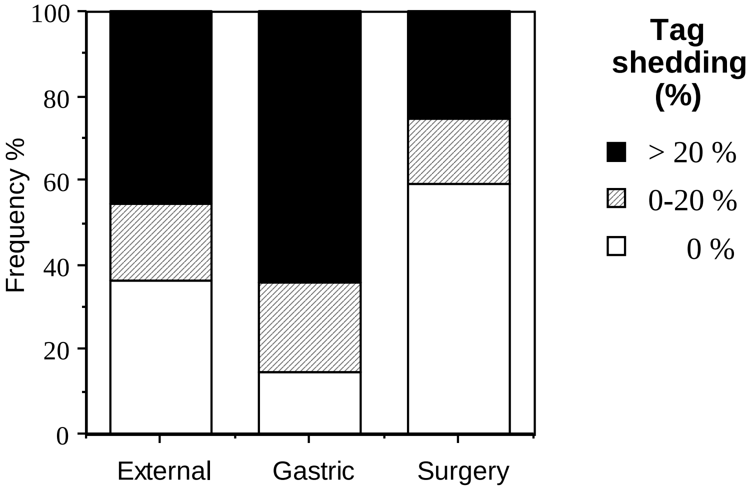

Figure 7.3. Proportion of telemetry studies reporting variable rates (0%, <20%, 20%) of tag shedding depending on attachment procedure.

a) Shedding of externally-attached tags

Externally-attached transmitters can be programmed to be shed by fish on purpose, by using absorbable attachment threads such as catgut, or by use of pop-up technology (Block et al., 1998; Lutcavage et al., 1999). Tags fixed by non-absorbable threads are supposed to remain attached to the body of the fish, but shedding has been frequently reported (Figure 7.3), as exemplified by tags attached at the base of the anal fin of yellowtail, *Seriola quinqueriadata*, that were shed on average 8 days after tagging (Ichihara *et al.*, 1972), or by tags attached dorso-laterally to lake whitefish, *Coregonus clupeaformis* (Bégout *et al.*, 1998). The main causes invoked were untied knots (e.g. barbel, *Barbus barbus*, Baras, 1992; dace, *Leuciscus leuciscus*, Beaumont *et al.*, 1996) or deep cuts in the dorsal musculature caused by attachment wires (e.g. lake whitefish, Bégout *et al.*, 1998) as a result of drag. The use of cyanoacrylate adhesive at the time of tagging can secure knots. Attachment plates frequently used in side-saddle harnesses reduce the extent of cuts and subsequent shedding rates (e.g. < 5 % after three months in yellow perch, *Perca flavescens* and < 5 % after 37 d in black bass, *Micropterus salmoides*; Ross & McCormick, 1981; 0 % after 45 days in white perch, *Morone americana* and rainbow trout, *Oncorhynchus mykiss*, Mellas & Haynes, 1985). However, harnesses may cause erosion of scales and muscles in the long run, and eventually promote microbial infection and death of tagged fish. Similarly, more secure knots may untie later, and possibly at different times, and thus cause the fish to drag the tag at the extremity of the attachment wire (Beaumont *et al.*, 1996). This almost certainly modifies fish behaviour. Feasibility studies with externally-attached transmitters have rarely lasted more than 90 days, and it is thus uncertain whether tags may be retained for long periods, especially for side-saddle harnesses, which may strongly interfere with growth, and cause deep cuts to the fish musculature.

(b) Regurgitation and egestion of gastrically-inserted tags

Transmitters in bait, that are voluntarily ingested by fish, have never been reported to damage the digestive tract of the fish (Armstrong et al., 1992), whereas damage to the oesophagus was observed when transmitters were inserted with a plunger (McCleave & Horrall, 1970; Solomon & Storeton-West, 1983). Stomach-inserted or ingested transmitters may be lost through regurgitation (vomiting) or egestion (defecation). Regurgitation rates and delays between ingestion (or insertion) and regurgitation vary greatly, depending on the fish species and the relative size of the tag (Moser *et al.*, 1990; Nielsen, 1992). Regurgitation rates generally increase as relative tag size increases (Nielsen, 1992). Small tags, in contrast, may be lost through egestion (Baras, 1992). Some species are known to regurgitate transmitters more frequently than others (Table 7.1). Recently, Marmulla &

Regurgitation unlikely		**Regurgitation likely**	
Alosa sapidissima	(American shad)	*Catostomus commersonni*	(white sucker)
Anguilla rostrata	(American eel)	*Esox lucius*	(northern pike)
Ictalurus nebulosus	(brown bullhead)	*Gadus morhua*	(Atlantic cod)
Morone chrysops	(white bass)	*Katsuwonus pelamis*	(skipjack tuna)
Morone saxatilis	(striped bass)	*Oncorhynchus kisutch*	(coho salmon)
Oncorhynchus gorbuscha	(pink salmon)	*Oncorhynchus mykiss*	(rainbow trout)
Oncorhynchus keta	(chum salmon)	*Perca flavescens*	(yellow perch)
Oncorhynchus nerka	(sockeye salmon)	*Salmo salar*	(Atlantic salmon)
Oncorhynchus tshawytscha	(Chinook salmon)	*Salmo trutta*	(brown trout)
Salvelinus namaycush	(lake trout)	*Stizostedion canadense*	(sauger)
Thunnus thynuus	(bluefin tuna)		

Table 7.1. Fish species with high and low potential for retaining gastrically-inserted transmitters. (after Nielsen, 1992; adapted from Stasko & Pincock, 1977, and others).

Ingendahl (1996) suggested that the mode of capture influenced the propensity of salmonids to regurgitate tags: sea trout captured with electric fishing in rivers regurgitated sooner and more frequently than those captured by netting.

(c) Expulsion of surgically-implanted transmitters

By contrast with terrestrial vertebrates, fish maintain near-neutral buoyancy. They have not developed their abdominal region to cope with gravity effects like these induced by negatively-buoyant transmitters or tags, and this may account for the relatively frequent expulsion of implants by fish. Early implant exit may take place through the incision before healing is completed and is generally a consequence of loose suturing. Implants may be expelled later, either through the incision, through an intact part of the body wall, or through the intestine (channel catfish, *Ictalurus punctatus*, Summerfelt & Mosier, 1984; rainbow trout, *Oncorhynchus mykiss*, Lucas, 1989; Atlantic salmon smolts, *Salmo salar,* Moore *et al.*, 1990; vundu catfish, *Heterobranchus longifilis*, Baras & Westerloppe, 1999). All three modes of exit share a common mechanism, which consists of the encapsulation of the implanted tag by proliferating granulation tissue consisting of collagen and myofibroblasts (Marty & Summerfelt, 1986, 1990). The contraction of myofibroblasts adds to the gravity pressure exerted by the transmitter over the fish tissue, and forces the implant through the route of least resistance. During the transintestinal expulsion process, the implant capsule adheres to at least two points of the intestinal peritoneum, as well as to the parietal peritoneum. The resulting rigidity interferes with the movements of the intestine during digestion and causes the dislocation of the muscular layer of the pyloric intestine, allowing the implant to pass into the lumen of the intestine and thence to be transported by reflex peristalsis to the anus.

Encapsulation is a classical body reaction and has been observed with all coatings assayed to date, and this suggests that the expulsion process is not specific to coating (Baras *et al.*, in press). Further, no anal or body wall exit was observed in some species like blue tilapias (*Oreochromis aurens*) which encapsulated implants almost systematically (Thoreau & Baras, 1997). It is worth emphasising that not all fish species encapsulate tags, and the propensity for expulsion is thus species-dependent, especially for transintestinal expulsion, which seems specific to siluriform species (channel catfish, *Ictalurus punctatus,* Marty & Summerfelt, 1986; vundu catfish, *Heterobranchus longifilis,* Baras & Westerloppe, 1999). Factors that promote the expulsion of implanted tags include the position of the tag and tag: fish size ratios. Positioning the implant far from the incision, either through a plunger or using a shielded needle technique, minimises the risk of pressure over this weakened tissues and promotes long term retention of the implant (Ross & Kleiner, 1982; Baras & Westerloppe, 1999). Incidence of rejection of transmitters through the body wall, or incision site, seems to increase with transmitter size (channel catfish, *Ictalurus punctatus*, Summerfelt & Mosier, 1984; Chisholm & Hubert, 1985; Marty & Summerfelt, 1986; rainbow trout, *Oncorhynchus mykiss*, Chisholm & Hubert, 1985). Large transmitters are, however, less likely to enter the intestine and be expelled by peristalsis (Lucas, 1989; Baras & Westerloppe, 1999). Bleeding during surgery favours the formation of clots and adhesions (Rosin, 1985) which are involved in the encapsulation and expulsion processes. Similarly, factors that promote the invasion of the body cavity by microbial organisms, such as external whip antennas of radio transmitters, or permanent suture materials, also increase the risk of expulsion (Baras *et al.*, in press). In this respect, braided suture filaments were recently shown to cause more frequent transintestinal expulsion in vundu catfish, *Heterobranchus unifilis,* than monofilaments (Baras & Westerloppe, 1999), essentially because the former provide a larger surface for the settlement of micro-organisms than the latter. Prophylaxis and use of antibiotics may thus be extremely advantageous to minimise or prevent tag expulsion.

Although transmitter loss is undesirable scientifically, it should be noted that transmitter expulsion does not necessarily lead to subsequent mortality or morbidity (channel catfish, *Ictalurus punctatus,* Marty & Summerfelt, 1986; rainbow trout, *Oncorhynchus mykiss,* Lucas, 1989; Atlantic salmon smolts, *Salmo salar*, Moore *et al.*, 1990; vundu catfish, *Heterobranchus longifilis,* Baras & Westerloppe, 1999).

7.4.4 Infections and wounds

Fish with externally-attached and surgically-implanted transmitters may have infections and wounds at the attachment points and the incision (e. g. yellow perch, *Perca flavescens,* Ross & McCormick, 1981; white perch, *Morone americana*, Mellas & Haynes, 1985; barbel, *Barbus barbus,* Baras, 1992; bluegill, *Lepomis macrochirus,* Knights & Lasee 1996; European eel, *Anguilla anguilla*, Baras & Jeandrain, 1998). In freshwater, especially at higher temperatures, fungus infection may be a problem, especially for salmonids (rainbow trout, *Oncorhynchus mykiss,* Lucas, 1989; Kaseloo *et al.*, 1992; Chinook salmon, *Oncorhynchus tshawytscha*, Adams *et al.*, 1998), but these infections are not specific to external wounds, since they were also observed in salmonids with gastrically-inserted transmitters, possibly as a consequence of handling (Solomon & Storeton-West, 1983). Infections are enhanced by the presence of permanent transcutaneous bodies (Roberts *et al.*, 1973) such as the threads of externally-attached transmitters, permanent suture material or externally trailing antennas of radio tags. Similar problems are also encountered frequently for gastrically-inserted transmitters with trailing antennas that cause abrasion of the mouth corner (e.g. Chinook salmon, *Oncorhynchus tshawytscha,* Martinelli *et al.,* 1998). Threads of external transmitters or heavy tags, as well as suture materials, can also cause deep cuts into the muscles and skin (yellowtail *Seriola quinqueradiata* Ichihara *et al.,* 1972; barbel, *Barbus barbus,* Baras, 1992; lake whitefish, *Coregonus clupeaformis,* Bégout *et al.,* 1998). These cuts promote further infection of the fish by microbial organisms (bluegill, *Lepomis macrochiris,* Knights & Lasee, 1996), or cause the tissue to become necrotic and prevent normal healing (rainbow trout, *Oncorhynchus mykiss,* Kaseloo *et al.,* 1992; bluegill, *Lepomis macrochiris,* Knights & Lasee, 1996; European eel, *Anguilla anguilla*, Baras & Jeandrain, 1998). Fast flowing environments, which increase the drag of externally-attached tags, can cause abrasion of the skin beneath the tag, or the foam pad on the side of the fish. These abrasions can eventually cause microbial invasion (white sucker, *Catostomus commersoni*, Lonsdale & Baxter, 1968; yellow perch, *Perca flavescens*, Ross & McCormick, 1981; hybrid bass Yeager, 1982; barbel, *Barbus barbus*, Baras, 1992; sea bass, *Dicentrarchus labrax*, Claireaux & Lefrançois, 1998). The severity of wounds is often worse in cryptic or highly structured environments, in which externally-attached tags can become entangled in surrounding vegetation, or torn by rocky substrata (yellow perch, *Perca flavescens,* Ross & McCormick, 1981; Atlantic salmon, *Salmo salar* smolts, Nettles & Gloss, 1987; Chinook salmon, *Oncorhynchus tshawytscha*, Adams *et al.*, 1998).

Internally positioned transmitters can cause wounds too, either during inserting, or later, as a result of movements of the tag inside the fish. Plungers used to insert intragastric tags may damage the stomach or the oesophagus (cutthroat trout, *Oncorhynchus clarki*, McCleave & Horrall, 1970; sea trout, *Salmo trutta*, Solomon & Storeton-West, 1983). Scalpels may puncture viscera or ovaries, especially when making incisions laterally to the midventral line (grass carp, *Ctenopharyngodon idella*, Schramm & Black, 1984; Baras *et al.*, in press). Surgically-implanted transmitters may move inside the body cavity and cause various types of damage such as alterations to gonads (Chamberlain, 1979), internal haemorrhages (rock bass, *Ambloplites rupestris*, Bidgood, 1980; carp, *Cyprinus carpio,* Otis & Weber, 1982; Mortensen, 1990), bruised livers or erosion of the rectum (grass carp, *Ctenopharyngodon idella*, Schramm & Black, 1984), necrosis of the pelvic girdle (bluegill, *Lepomis macrochirus*, Prince & Maughan, 1978) or rupture of the body wall or intestine prior to expulsion (channel catfish, *Ictalurus punctatus*, Marty & Summerfelt, 1986; rainbow trout, *Oncorhynchus mykiss*, Lucas, 1989; vundu catfish, *Heterobranchus longifilis*, Baras & Westerloppe, 1999). Attempts have been made to suture implanted transmitters to the body wall in order to prevent movement inside the body cavity and consequent damage to viscera. However, these attempts have produced highly variable results depending on species. Petersen & Andersen (1985) succeeded while tagging Atlantic cod, *Gadus morhua*, whereas transmitters sutured to the body wall of channel catfish *Ictalurus punctatus* were almost systematically expelled (Marty & Summerfelt, 1986).

Most damage can be prevented, or alleviated, by tailoring the attachment procedure to the species of interest and prevailing environmental conditions. Adjustments include tag size, shape, length and coating, tag positioning, attachment threads (external tags), incision site and closing material (intraperitoneal tags), and use of appropriate prophylactic measures (see Summerfelt & Smith, 1990; Baras *et al*., in press).

7.4.5 Effects on growth and feeding

Depressed growth rate, or weight loss of fish has been observed frequently after tagging, but with variable extent and duration, depending on fish species, life stage and attachment procedure. Growth is an integrating variable of fish physiology and behaviour, and impaired growth may thus be the consequence of habitat change, depressed mobility or competitive ability, difficulties in recovering buoyancy, change of social status, increased energy expenditures or reduced appetite.

The degree of stomach fullness is a well-known factor that regulates the appetite of fishes. Feeding can be terminated by a full stomach (Toates, 1981) and gastrically-inserted tags may induce similar reactions. The problem does not arise with adult salmonids and other species that do not feed during spawning migrations. Tags affect food intake in proportion to the tag:fish weight ratio, although it seems likely that this effect is governed by the relative volumes of tag and stomach. Moser *et al.* (1990) observed that tag ratios less than 4.5 % did not affect feeding and growth of juvenile coho salmon, *Oncorhynchus kisutch* whereas higher ratios (4.5-14.5 %) reduced the feeding rate. Similarly, Armstrong and Rawlings (1993) reported that Atlantic salmon (*Salmo salar*) parr did not feed after the insertion of transmitters into their stomachs. Adams *et al.* (1998) and Martinelli *et al.* (1998) observed that gastrically-inserted transmitters averaging 4 and 6% of the body weight of juvenile Chinook salmon, *Oncorhynchus tshawytscha,* impaired their growth over longer periods than tags inserted into the peritoneum. However, not all species seem to be affected in the same way, since the food intake of Atlantic cod, *Gadus morhua*, is not modified after gastric-insertion of transmitters. Whether abrasion of the corner of the mouth, which is frequently observed in fish tagged with transmitters involving the external antenna trailing from the mouth (e.g. Chinook salmon, *Oncorhynchus tshawytscha*, Martinelli *et al*., 1998), affects the feeding rate or growth of the fish, is uncertain.

No long term effects on feeding and growth have been found in studies with surgically-implanted transmitters in muskellunge (*Esox masquinongy*; Crossman, 1977), channel catfish (*Ictalurus punctatus*; Summerfelt & Mosier, 1984), Colorado squawfish (*Ptychocheilus lucius*; Tyus, 1988), razorback sucker (*Xyrauchen texanus*; Tyus, 1988), juvenile Atlantic salmon (Moore *et al.*, 1990) and rainbow trout (Lucas, 1989; Martin *et al.*, 1995). However, studies where growth was investigated at shorter time intervals provided evidence that the growth of surgically-tagged barbel (*Barbus barbus*, Baras, 1992), vundu catfish (*Heterobranchus longifilis*, Baras & Westerloppe, 1999) or blue tilapia (*Oreochromis aureus*; Thoreau & Baras, 1997) was impaired over the first few post-tagging days, but was then compensated for by higher than normal growth rates. Growth rate returned to normal again when the surgical incisions had healed. Factors invoked included partly excessive tag ratios that restricted access to food resources, or feeding subordinated to untagged individuals that appeared dominant at feeding time (bluegill *Lepomis macrochirus*, Knights & Lasee, 1996). During the transintestinal expulsion process in catfishes, tags may also cause a transient blockage of food, of which the duration is uncertain, but is apparently long enough to depress the growth of the fish.

The effects of external tags on feeding and growth rate have also been investigated, but essentially during short or mid-term feasibility studies. No effects were found in yellow perch (*Perca flavescens*; Ross & McCormick, 1981), dace (*Leuciscus leuciscus*; Beaumont *et al.*, 1996) or lake whitefish (*Coregonus clupeaformis*; Bégout-Anras *et al.*, 1998), whereas externally-tagged largemouth bass (*Micropterus salmoides*) showed lower predation rates on minnows (Ross & McCormick, 1981), and barbel (*Barbus barbus*) carrying external dummy tags lost weight over several weeks after tagging (Baras, 1992). Similarly, the feeding rates and growth in parr of Atlantic salmon (*Salmo salar*) was affected by external tagging, and growth impairment was proportional to the tag ratio (Greenstreet & Morgan, 1989). In contrast to intraperitoneally-implanted transmitters, the effects of external tags on growth and feeding may be progressive and increase in the long run, essentially because of permanent wounds, and generally deeper cuts to the musculature as time goes by. Side-saddle harnesses are also deemed to interfere mechanically with the growth of the fish but no study has evaluated this problem over long periods.

7.4.6 Effects of tags on behaviour

The effects of tags and tagging procedure on fish behaviour or physiology have been relatively poorly documented, essentially because these aspects have rarely been investigated during feasibility studies (see Figure 7.1). Reasons for this include the difficulty of measuring physiological variables accurately in live fish without causing additional interference, and the discrepancy between experimental environments used in feasibility studies and wild environments. Furthermore, changes in behaviour can be more discrete and last for shorter periods of time, and thus be far less obvious to detect than mortality, tag shedding or reduced growth.

(a) Buoyancy and posture

With few exceptions (e.g. tunas or catfishes), teleost fish maintain reduced body density by adjusting the volume of their swim bladder. Many fish with swim bladders are negatively buoyant over much of the water column, only approaching neutral buoyancy at the top of their vertical range (Blaxter & Tytler, 1978; Harden Jones & Scholes, 1985; Arnold & Greer Walker, 1992). The swim bladder is said to have a volume of about 5 % of fish volume in marine fishes, and about 7 % in freshwater fishes, though these are theoretical values and real data are much more variable. More importantly, the swim bladder has an adjustment capacity of about 25 % (Alexander, 1966; Bone & Marshall 1982). This adjustment capacity permits the fish to cope with increased mass, such as that caused by negatively-buoyant eggs or tags. Physostomatous fish such as salmonids or anguillids possess a connection between the swim bladder and the gut, and can refill their swim bladder by swallowing air. The connection is absent in the vast majority of teleosts (physoclistous fish), in which gas exchange takes place via the *rete mirabile* (Bone & Marshall, 1982).

This anatomical difference implies that physostomes can regain near-neutral buoyancy more rapidly than physoclists after attachment of a negatively-buoyant transmitter or DST, provided they can access the surface (e.g. Atlantic salmon, *Salmo salar*, Fried *et al.*, 1976). Physoclistous percids remain on the bottom until sufficient gas is secreted, whereas cichlids or centrarchids like the bluegill (*Lepomis macrochirus*) increase their fin beat frequency to create the upward force necessary to reach shallow depths where they can achieve neutral buoyancy (Gallepp & Magnuson, 1972). Similarly, blue tilapia *Oreochromis aureus* take about 72 hours to compensate for the negative buoyancy and slight postural disequilibrium caused by implantation of a transmitter which adds 0.9 % to their body mass (Thoreau & Baras, 1997). Swimming compensation may also take place in physostomatous fish denied access to the surface (Fried *et al.*, 1976), and in negatively-buoyant fish like scombrids or thunnids, which swim continuously to avoid sinking and for which adding weight implies faster swimming.

Tagging thus imposes temporary or permanent constraints on fish bioenergetics, of which the energetic cost has rarely been quantified, but is presumably directly proportional to the tag:fish weight ratio. This accounts partly for the observation that most fish carrying tags representing more than 1.75-2.00 % of their body weight in water show deviant behaviour subsequent to tagging, whereas minimal or zero effects are observed for lower ratios (e.g. McCleave & Stred, 1975; Greenstreet & Morgan, 1989; Moser *et al.*, 1990; Kaseloo *et al.*, 1992; Voegeli *et al.*, 1998). More adverse effects of capture and release procedures can theoretically take place when fish are captured in deep water and transported to the surface for tagging, as this rapid change of depth can damage the swim bladder (see Chapter 5).

(b) Swimming performance and energetic expense

As mentioned earlier, negative buoyancy induced by tagging may cause the fish to increase its fin beat frequency to compensate for added mass, regardless of the attachment procedure. However, additional specific adverse effects may originate from the procedure itself. Externally-attached tags are usually positioned further from the centre of gravity of the fish than internally positioned tags. Because of this they are more prone to cause permanent or temporary postural disequilibrium and irregular swimming (e.g. Atlantic salmon *Salmo salar,* Thorpe *et al.*, 1981; largemouth bass *Micropterus salmoides,* Mellas & Haynes, 1985; dace *Leuciscus leuciscus*, Beaumont *et al.*, 1996). Drag resistance of externally-attached tags varies depending on transmitter bulk and shape.

Swimming performance may be affected by the presence of a transmitter, which is especially important to consider when dealing with migratory species, such as salmonids, and active pelagic species, such as scombroids. Drag resistance of externally-attached transmitters is the most obvious cause of reduced swimming capacity, but large internal transmitters may inhibit swimming movements, reducing available power. Other effects of transmitters that reduce the health of the fish and/or increase the energy demand, will also combine to affect swimming performance.

Externally-tagged rainbow trout have been shown to exhibit lower exhaustion times than other tagged groups or control fish (Mellas & Haynes, 1985). In another study of rainbow trout, two types of externally-attached transmitters raised both tail beat frequency (TBF) and opercular beat rate (OBR), but a transmitter consisting of two packages mounted symmetrically on either side of the body affected TBF and OBR least (Lewis & Muntz, 1984). In a study of Atlantic salmon smolts, critical swimming speeds were lower in fish with external transmitters (McCleave & Stred, 1975). Drag measurements of external transmitters in a flume indicated that the extra power output required for tagged plaice (*Pleuronectes platessa*) and cod (*Gadus morhua*) to maintain the same steady speed as untagged fish was between 3 and 5 %, which in this study was considered negligible (Arnold & Holford, 1978). In a field study of adult chinook salmon (*Oncorhynchus tshawytscha*), upstream migration in a river was successful in externally-tagged fish, which migrated at the same speed as control fish. In contrast, most of the fish with surgically-implanted transmitters were not able to pass a dam, and eventually migrated downstream (Haynes & Gray, 1979). No effects of the transmitters on swimming performance were detected in swimming tests of juvenile Atlantic salmon with surgically-implanted transmitters, white perch (*Morone americana*) with surgically-implanted, externally-attached and gastrically-inserted transmitters, and rainbow trout (*Oncorhynchus mykiss*) with surgically-implanted and stomach-inserted transmitters (Mellas & Haynes 1985; Moore *et al.,* 1990).

Studies dealing with swimming performance of tagged fish demonstrate that the effects vary considerably. Swimming performance seems least affected when transmitter size and volume are as small as possible in proportion to fish size (e. g. McCleave & Stred, 1975).

(c) Effect on social behaviour and interactions between species

The effect of tagging or tag presence on predation risk has rarely been investigated in feasibility or field studies. Because of the difficulty in recovering neutral buoyancy, or because of reduced swimming capacities, fish tagged with electronic tags may be more vulnerable to predation than untagged fish (Jolley & Irby, 1979; Ross & McCormick, 1981; Eiler, 1990). External tags may also make tagged fish more easily detected by predators, and it is thus recommended that external transmitters are camouflaged to reduce their visibility (Ross & McCormick, 1981). Similarly, handling or tagging procedures may affect the social status of the fish. Surgically-tagged Guadeloupe bass (*Micropterus treculi*) showed less social tendencies than untagged fish (Manns & Whiteside, 1979; Manns, 1981), and externally-tagged yellowtail (*Seriola quinqueradiata*) showed depressed social behaviour over the first hour after tagging (Ichihara *et al.*, 1972). In other circumstances, tagging did not modify shoaling or schooling (e.g. Baras, 1997). With respect to species exhibiting territorial behaviour or social hierarchy, occasional changes of social status were observed in rainbow trout (*Oncorhynchus mykiss*) carrying tags in their stomach (Mellas & Haynes, 1985), whereas surgery was not enough to cause reversal of a well established hierarchy, either in brown trout (*Salmo trutta*; Baras *et al.*, in prep.) or rainbow trout (*Oncorhynchus mykiss*, Swanberg & Geist, 1997). However, similar status changes were also seen in fish that had only been handled, suggesting that this adverse effect did not originate from tagging, but from the capture and handling procedure (Baras *et al.*, in prep.). It is strongly suggested that such adverse effects on fish behaviour must also be considered when tagging fish with conventional tags or PIT tags.

Considering the various adverse effects of tagging and their dynamics, the risk of predation or change of social status is highest during the post-tagging hours or days for all attachment procedures, then vanishes when wounds have healed. Exceptions to this rule of thumb are mainly concerned with external transmitters, for which adverse effects can cumulate over time. This applies particularly to spawning behaviour, and it is generally recommended that fish are not tagged during the reproductive period (Winter, 1996). Fish are deemed to be more delicate at this time (Økland *et al.*, 1996) and there is a higher risk of damaging the enlarged gonads of females when implanting tags in he body cavity (Bidgood, 1980; Schramm & Black, 1984). However, adverse effects of tagging mature fish are not systematically observed and some species spawn successfully less than one week after abdominal surgery and transmitter implantation (Baras, 1995). Similarly, most studies where the gonadal development of fish with surgically- implanted tags has been evaluated show little or no difference from controls (Moore *et al.,* 1990, 1994; Martin *et al.,* 1995; see parallel with PIT tags in Baras *et al.,* 2000). There may even be advantages in tagging mature individuals of species like the vundu catfish, *Heterobranchus longifilis,* in which enlarged gonads may prevent transintestinal expulsion of tags (Baras & Westerloppe, 1999).

(d) Mobility and habitat selection

There are a few studies of the effects of tags on mobility and habitat selection in artificial rivers (e.g. brown trout, *Salmo trutta*, Baras *et al.*, in prep.), or culture tanks (e.g. blue tilapia, *Oreochromis aureus*, Thoreau & Baras, 1997). Most tag-induced biases have, however, been reported from field studies. Irregular swimming, erratic movements and apparent disruption of surface avoidance behaviour have been reported in several species (Guadeloupe bass, *Micropterus treculi*, Manns & Whiteside, 1979; largemouth bass, *Micropterus salmoides*, Mesing & Wicker, 1986). Hypoactivity of newly tagged fish is most frequent (e.g. rainbow trout, *Oncorhynchus mykiss*, Zimmermann, 1980; blue tilapia, *Oreochromis aureus*, Thoreau & Baras, 1997), as well as increased downstream movements of upstream migrants (Chinook salmon, *Oncorhynchus tshawytscha*, Haynes & Gray, 1979). However, post-release hyperactivity has been observed too (Atlantic cod, *Gadus morhua*, Hawkins *et al.*, 1974; Lake whitefish, *Coregonus clupeaformis*, Bégout-Anras *et al.*, 1998). Further, both hypo- and hyperactivity have been observed in the same species (Thoreau & Baras, 1997), and this makes it difficult to determine whether these were just normal changes in the activity level of the fish, or actual perturbations resulting from the tagging procedure. Similarly, both upstream and downstream movements were observed in sick brown trout, *Salmo trutta*, that died eventually, and long downstream movements were observed in healthy individuals (M. Ovidio, unpublished data).

This variability considerably limits the relevance of behavioural criteria, essentially because the behaviour of the fish prior to tagging is generally unknown. Hence it is suggested (Lagardère *et al.*, 1996; Baras *et al.*, in press) that these criteria would be best used within a framework of individual modes, for an *a posteriori* determination of when the fish stopped behaving normally.

(e) Additional perturbations of behaviour

The use of electronic tags in fisheries is deemed to minimise the subsequent stress of recapture that is frequently encountered in conventional tagging studies. However, radio or acoustic telemetry frequently implies that the fish is tracked from the banks of a river, or from a tracking boat in lakes or at sea, and this may cause temporary perturbations of fish behaviour. Vibrations on river banks during tracking can cause fish to move away from the noise source, or to dive in deeper water (Baras, unpublished). Similar behaviour was reported for European eels (*Anguilla anguilla*); these do not change swimming direction, but dive to greater depth when a boat approaches within 10 m, then regain their original depth after the boat has passed (Westerberg, 1983). Boat engines are extremely noisy and can be detected at distances of hundreds of metres by several fish species, including Atlantic cod *Gadus morhua* (Stasko & Buerkle, 1975). Whether all fish change their mobility pattern at the approach of a boat is uncertain. Stasko & Pincock (1977) stated that pink salmon (*Oncorhynchus gorbuscha*), Chinook salmon (*O. tshawytscha*), American eel (*Anguilla rostrata*), white bass (*Morone chrysops*) and largemouth bass (*Micropterus salmoides*) were apparently not affected, while reactions had been reported frequently in dusky shark (*Carcharhinus obscurus*), white marlin (*Tetrapturus albidus*) and in some cases in sockeye salmon (*O. nerka*) and Atlantic salmon (*Salmo salar*). Avoidance reactions of marine fish to research vessels and fishing gear are discussed in some detail in Miston (1995)

7.4.7 Effects of tags on physiology

Although the physiology of newly tagged fish has rarely been investigated, one aspect of this problem has already been addressed indirectly in section 7.3.3.f., which deals with the physiological changes (i.e. increased gas exchange or increased rates of fin movement) that may be needed to compensate for the added mass of the tag.

Surgically-tagged fish with open incisions may experience difficulty in maintaining their osmotic balance, and their physiology may thus be affected for a variable period, whose length will depend on the capacity of the fish to repair tissue. This period is likely to last at least until the incision is filled with connective tissue (2 days to several weeks, depending on species, age and temperature; see Anderson & Roberts, 1975; Baras *et al.*, in press). It should be complete once the epidermis has been reconstituted over the incision area. However, these aspects have never been investigated in detail, and it is also uncertain whether quicker ways to close the incision, such as use of cyanoacrylate adhesives, minimise the problem (Nemetz & MacMillan, 1988; Petering & Johnson, 1991; Baras & Jeandrain, 1998). Similarly, the effects of chronic lesions caused by the threads of external tags on osmotic balance are unknown.

There is little doubt that infections, haemorrhages or damage to organs due to erosion by the tag, or the tag expulsion mechanism, affect fish physiology too, but the extent of these perturbations has rarely been measured during tagging feasibility studies. Martinelli *et al.* (1998) provided evidence for reduced levels of plasma proteins in newly tagged Chinook salmon (*Oncorhynchus tshawytscha)* that lasted for at least 5 days in surgically-tagged fish, and at least 21 days in fish carrying transmitters in their stomachs. These changes were deemed to reflect reduced food intake. Claireaux and Lefrançois (1998) measured metabolic rates of externally-tagged Atlantic cod (*Gadus morhua)* and sea bass (*Dicentrarchus labrax)* and found that these were substantially higher than in untagged fish, although they estimated that the impact of tag carrying was low with respect to the metabolic capacities of these two species.

7.4.8 Effects of PIT tags

Because of their small size (11 x 2.2 mm in diameter, 70 mg in the air and 40 mg in water), there is a low probability that PIT tags cause a major interference with fish life processes (Nielsen, 1992), and this is indeed the case in husbandry management programmes where the technique is used (Jenkins & Smith, 1990; Poncin *et al.*, 1990). Short term effects of PIT tagging have been noticed while tagging broodstock, but these are mainly a result of capture and handling (Baras & Westerloppe, 1999).

However, precisely because of their small size, PIT tags can be applied to small juvenile fish (Prentice *et al.,* 1990; Peterson *et al.*, 1994; Ombredanne *et al.*, 1998), which may thus be confronted with problems similar to those encountered in telemetry studies with adult fish, where transmitters are implanted into the body cavity. These include difficulties in buoyancy compensation, reduced access to food and slower growth over the first post-tagging days when using tags of such a size that the tag:fish weight ratio in air exceeds 3% (Nile tilapia, *Oreochromis niloticus*; Baras *et al.*,1999; perch, *Perca fluviatilis*; Baras *et al.*, 2000). Similar but less severe effects were noticed in fish with lower tag ratios (Baras *et al.*, *op cit.*; Baras & Westerloppe, 1999). Ombredanne *et al.* (1998) also reported depressed growth of brown trout (*Salmo trutta*) parr after PIT tagging, but the extent of growth depression was comparable with that observed after adipose fin clipping alone. As for most other tags implanted surgically, normal growth resumes when the incision has healed. Healing is usually achieved in less than 14 days (salmonids; Prentice *et al.*, 1990), and sometimes as fast as 7 days (catfishes; Baras & Westerloppe, 1999), either because the incision is small compared with those used for telemetry tags, or because the fish are younger and have greater capacity for wound repair. In contrast to salmonids, the healing rate in small juvenile perch and tilapia is faster when the PIT tag is inserted manually through an incision made with a scalpel than when using conventional injectors (Baras *et al.*, 1999). The latter procedure also causes much higher mortality rates than the former, and this contrasts too with young salmonids, for which injectors are usually efficient and innocuous.

The relative inadequacy of injectors in tilapia or perch smaller than 10 g is due to the difficulty of controlling the penetration of the hypodermic syringe following piercing of the body wall. This is much more rigid than in salmonids, for which the injector was originally developed.

PIT tags are encapsulated in inert glass, which has few adverse effects on fish tissues, even several years after implantation. Plastic tips covering PIT tags further limit their propensity to migrate through muscular tissues, causing further damage. Probably for these reasons, the retention of PIT tags is usually extremely high (92-96 % in juvenile snapper, *Pagrus auratus*, Quartaro & Bell, 1992; 96.6 % in juvenile *Salmo trutta*, Ombredanne *et al.*, 1998; 99-100 % in Chinook salmon, *Oncorhynchus tshawytscha*, Prentice *et al.*, 1990; 100 % in largemouth bass, *Micropterus salmoides*, Harvey & Campbell, 1989). By analogy with observations in studies where sutured and non sutured incisions were evaluated (Baras *et al.*, 1999; Baras *et al.*, in press), it is likely that most tags were lost via the incision before the wound had healed. As observed for telemetry transmitters, PIT tags remained free in the body cavity of some species (Salmonids: Prentice *et al.*, 1990), whereas they frequently became encapsulated in others (Cichlids; Baras *et al.*, in press a; Percids; Baras *et al.*, in press b; Clariids; Baras & Westerloppe, in press). Though encapsulation was frequent in these species, no single tag expulsion was observed in juvenile tilapia or perch, at least when the incision had been closed by a single stitch. Some catfishes, however, expelled the tag through the intestine, as observed for electronic tags in adults (Baras & Westerloppe,1999).

Effects of PIT tags on physiology and behaviour have rarely been investigated. Jenkins & Smith (1990) found no adverse effect of PIT tagging on spawning in breeders of red drum (*Sciaenops ocellus*) and striped bass (*Morone saxatilis*), and PIT tagging juvenile tilapia did not prevent their sexual maturation and breeding (Baras *et al.*, in press). Similarly, no difference was observed between the development of gonads or accumulation of abdominal lipid reserves in PIT tagged and untagged juvenile perch (Baras *et al.*, 2000). No effect on swimming stamina or stride efficiency was found in PIT tagged juvenile Chinook salmon and rainbow trout (Prentice *et al.*, 1990), but signs of negative buoyancy were observed in juvenile perch and tilapias where tag ratios were higher than 3 %.

7.5 CONCLUSIONS

1. Tagging fish with electronic tags can generate numerous biases, the extent of which and duration of varies between species and environments. However, successes have been associated with attachment procedures tailored to the species of interest during the course of feasibility studies.
2. Scientists using electronic tags are increasingly selecting surgical techniques, mainly because adverse effects decrease over time. Surgery, however, involves longer training and more practice than is required for other attachment procedures.
3. In all tagging studies, attention should be paid to the size of the tag since excessive added weight is the most widely cited adverse bias. The tag:fish weight ratio should be kept low and drag, too, should be minimised when external tags are used. Research programmes should also be tailored to the capacities of the fish instead of imposing constraints that cannot be overcome by the fish, except after an adaptive process, whose duration exceeds that of the study.
4. Fish species have anatomical, physiological and behavioural peculiarities that make them unique, and it is thus worthwhile designing a feasibility study before implementing any field research, both for animal welfare reasons and reliability of results.
5. Increasing attention should be dedicated to lesser studied factors, such as

attachment threads, closing material, tag shape and coating, pre- and post-operative care and confinement, since these may condition the actual success of tagging, and duration of post-tagging perturbation.

6. Identifying the duration of the post-operative perturbation is a sensible goal in any feasibility study, especially since electronic tags can now be programmed to transmit or collect data after delayed starts. DSTs can also be used to record post-operative effects, and thus observe directly how long the process lasts.

7.6. EFFECTS OF TAGS ON ORGANISMS OTHER THAN FISH

An exhaustive review of this topic is outside the remit of CATAG, but a few points are worth making. Tagging of marine mammals and birds (particularly seals and penguins) is common. Metal flipper tags are usually used for identification and are attached without anaesthetic. Tagging by hot-iron branding is still extensively used (e.g. on elephant seal pups; Feydak, personal communication). Though frowned upon ethically or for reasons of animal welfare, it is an extremely useful technique because the brands are readable after many years, whereas metal tags are lost. Satellite tags have been applied to both seals and penguins and are usually attached to fur or plumage by adhesives. This involves anaesthesia in seals (because they cannot be conveniently and safely immobilised in any other way). This anaesthesia may involve double administration of anaesthetics, first by darting to capture the animal concerned, secondly by administration of spinal anaesthesia during the tag attachment process. Care has to be taken to ensure that darted animals do not reach the water before capture; drowning is a significant risk.

Marine turtles have largely been tagged with flipper tags for identification. Tag loss rates are high and holes in flippers made during tagging may be susceptible to fungal infection. Satellite tags have also been attached to sea turtles. These cause minimal problems for the hard-shelled green, loggerhead, ridley and hawksbill turtles, other than increasing drag resistance (and presumably energy expenditure), but there are special problems with the large leatherback turtle *Dermochelys coriacea*. Satellite tags cannot be attached by adhesives because of the leathery, oily nature of the carapace and plastron. Early trials with towed tags, or tags attached by webbing harnesses failed with some mortalities (unacceptable in an endangered, protected species). Current satellite tagging with this species involves the fitment of plastic-protected harnesses with biodegradeable portions that allow the harness to be lost after some weeks or months.

Crustaceans have been tagged at least since the 1930s. Originally, tags were attached to crabs and lobsters to establish distances of migration and metal (later plastic) tags were simply wired through holes in the shell. These holes often enlarged and showed signs of infection. The main problem for crustacean tagging is to attach a tag that remains on the animal when it moults. Wired tags had to be very carefully placed along moult lines on the carapace to achieve this. Modern tags (lobster tags, spaghetti tags, streamer tags) are generally attached to the animal by piercing muscles, often with barbed anchors, or passing tags through the abdominal musculature from one side to the other (See Chapter 4 for more detail). Access is through arthrodial membranes, not the hard shell. If this is done effectively, the tags usually survive moulting. However, there are some reports of growth after moult being distorted by poorly-placed tags. No welfare problems have been reported from lobster stock enhancement programmes involving injection of coded-wire tags into the tail musculature of juvenile lobsters.

7.7 REQUIREMENTS AND RECOMMENDATIONS

All tagging procedures should aim at minimising short-term pain and stress to fish, and should avoid, as far as possible, causing long-term deterioration in health.

Planning of new tagging trials on familiar species should always involve full consideration of existing data on procedures, to ensure that mortalities, ill-health and tag losses are minimised. Laboratory feasibility studies to establish effective procedures on new species should ideally precede full field trials.

Fish tagging practitioners should all be required to undergo training Current legislation often requires experimentation licence holders to undergo generalised training in the legality of various procedures and holding techniques, but surgical procedures on fish are very different from those used on terrestrial mammals.

Anaesthesia should be used to minimise pain and trauma, save in circumstances where anaesthesia itself is more detrimental to fish.

All efforts should be made to avoid chemical residues associated with the tagging process reaching the human food chain.

Discussions amongst CATAG participants suggest that low temperatures may be effective in having an anaesthetic-like effect, at least in some fish species. Where such procedures are legal, it has sometimes been found that survival of surgical procedures is better when fish are kept cold during surgery than if they are anaesthetised. It is recommended that research (including neurophysiological investigations) be carried out to evaluate whether lowered environmental temperature is a humane approach to support of tagging operations involving surgery. It is appreciated that such research would have to encompass warm-temperate fish, as well as cold-water species. In addition, the long-term consequences of cold-exposure would also require study.

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Species	**Tagging method**	**Transmitter Mass and size**	**Observation**	**Number of fish (fish size)**	**Observation period**	**Results**	**Reference**
Atlantic sailfish (*Istiophorus platypterus*)	Externally attached		Field	8	2 h 56 min-28 h 21 min	Seven fish survived. One fish sustained severe eye injury and was killed by a shark 6 h 25 min after release	Jolley & Irby (1979)
Atlantic salmon - juveniles (*Salmo salar*)	Surgically-implanted	1.3 g	Laboratory	5 tagged parr (127-172 mm), 5 tagged smolts (122-189 mm), 5 sham-tagged (surgery carried out, but no trans-mitter inserted) and controls	3-150 days	No significant effects of tagging on growth, feeding or swimming behaviour in either parr or smolts. Recovery from the surgical implantation was rapid and total, infection was absent and physiological processes such as smoltification and maturation of testes in precocious parr were unaffected. Expulsion of the transmitter through the body wall occurred in a number of fish without adversely affecting the animals.	Moore *et al*.,, (1990)
Atlantic salmon -parr (*Salmo salar*)	Externally attached	2.7 g in air, volume 0.4 ml, density 6.7 g/ ml	Laboratory	50 fish with ultrasonic tags, 50 fish with Carlin tags and 50 controls.	17 April – 7 May	Attachment of transmitter significantly affected the growth rates of the fish. Fish less than 160 mm in length lost weight and showed no change in length. Fish over 160 mm in length put on weight, however less than the controls. For fish between 160 and 180 mm in length, the increase in length and weight was significantly smaller in tagged fish than in untagged fish. For fish over 180 mm in length, no difference could be detected in the length gains between tagged and untagged fish, while the increase in weight was smaller in tagged fish than in controls.	Greenstreet & Morgan (1989)
Atlantic salmon -parr (*Salmo salar*)	Inserted in stomach	0.8-0.9 g, 12.5 x 9 x 4.5 mm	Laboratory tanks	8 tagged and 9 controls	Eight days	Three of the fish regurgitated the transmitters. The proportion of fish that fed was significantly higher in the control group compared with the tagged group. No food was eaten on day 1 or 8 by test fish that retained the transmitters. Food was also eaten by some fish that had rejected the tags.	Armstrong & Rawlings (1993)

7.9 **APPENDIX I**. Summary of main results from studies dealing with effects of

Species	**Tagging method**	**Transmitter Mass and size**	**Observation**	**Number of fish (fish size)**	**Observation period**	**Results**	**Reference**
Atlantic salmon - smolts (*Salmo salar*)	Externally attached and inserted in stomach	Different sizes: 1.25-3.94 g in water, 4.00-6.67 g in air	Laboratory	In total 190 tagged, 79 sham tagged and 55 controls (< 20 cm)		Effects of transmitters on stamina were measured. Critical swimming speeds were similar for fish in control groups and two of the groups with internal transmitters. The widest internal tag (19 x 10 cm) caused a significant decrement in swimming performance. Externally placed transmitters caused a decrease in swimming speed compared with untagged fish.	McCleave & Stred (1975)
Atlantic salmon - smolts (*Salmo salar*)	Inserted in stomach	4.0 g in water, 5.6 g in air, 33 x 8 mm	Laboratory	In total 149 tagged fish and 152 controls (about 20 cm)	Up to 24 hours	The tagged fish were able to compensate for negative buoyancy induced by the tag if permitted to fill their swim-bladders by gulping air. Smolts denied access to the water surface after tagging never regained buoyancy. It is recom-mended to be aware of behavioural effects caused by negative buoyancy for 2-8 hours after tagging and release.	Fried *et al.*,, (1976)
Atlantic salmon (*Salmo salar*)	Inserted in stomach	10-16 g in water, (0.2-0.4 % of the fish weight in air), 6.5–9.6 x 1.9 cm	Field	40 (3-6 kg, 67-84 cm fork length)	21 June – 8 November	Five fish regurgitated the transmitter soon after release. Two salmon were recaptured 32 and 42 days after tagging and release. Neither showed ill effects from carrying the trans-mitter.	McCleave *et al.*,, (1978)
Bass -juvenile (*Dicentrarchus labrax*)	Surgically-implanted		Laboratory			Tagging had minimal effects on the subsequent survival and behaviour	Moore *et al.*,, (1994)
Bluegill (*Lepomis macrochirus*)	Inserted in stomach	3.38 g, excess mass in water of 2.76 g (2.4 % of the fish's mass)	Laboratory	50 tagged , 22 sham handled and 94 controls (ca 130 g)		Effects of negative buoyancy was studied. The fish required about 300 min to reach hydrostatic equilibrium when adjust-ment proceeded within 0.5 m of the surface. Before neutral buoyancy was reached, pectoral fin movements increased. Longer times are required for deeper releases.	Gallepp & Magnuson (1972)

ultrasonic and radio transmitters on fish.

Species	Tagging method	Transmitter Mass and size	Observation	Number of fish (fish size)	Observation period	Results	Reference
Bluegill (*Lepomis macrochirus*)	Surgically-implanted	2.81 g, 2.0 x 1.0 x 0.5 cm	Raceway	40 tagged and 40 controls (mean mass 133 g)	8 weeks	Mortality, adverse morphological effects, altered behaviour and limited healing in bluegills suggest that implanted transmitters impaired their health, especially at higher temperatures.	Knights & Lasee (1996)
Carp (*Cyprinus carpio*)	Surgically implanted and inse-rted in stomach		Field	1 implanted and 1 in stomach	7 weeks	Tagged fish kept on having high moving ability and did not appear affected by handling stress	Steinbach (1986)
Channel catfish (*Ictalurus punctatus*)	Surgically-implanted	Small: 36.4 g Large: 72.8 g both 19 x 90 mm	Pond	21 with small tags, 18 with large tags, 20 controls, 20 sham-implanted (mean 3.64 kg)	Average 112 days	Surgical implantation of transmitters did not increase mortality or decrease growth. 25 of 35 fish lost their transmitters. Retention rate of small transmitters was significantly greater than that of large transmitters.	Summerfelt & Mosier (1984)
Channel Catfish (*Ictalurus punctatus*)	Surgically-implanted	Large: 20 x 87 mm, 2.0 % of fish mass Small: 15 x 57, 0.5 % of fish mass	Laboratory	74 (0.7-5.2 kg)	23 days	Within 23 days, two fish died and 39 fish expelled their transmitters. Tissue reactions and number of incision exits were significantly greater with transmitters of 2.0 % of body mass than with transmitters of 0.5 % of body mass.	Marty & Summerfelt (1986)
Chinook salmon (*Oncorhynchus tsawytscha*)	Externally attached and surgically-implanted	Large: 68 g in water, 11.5 ± 0.4 x 2.7 cm Small: 34 g in water, 7.9 ± 0.4 x 1.9 cm	Field	In total 39 with external tags, 24 with internal tags and 64 controls (65-103 cm long, 1,4-12,7 kg)	During three migration periods	During upstream migration travel times and percent returns did not differ between externally-tagged fish that retained their transmitters from point of release to upstream trapping facili-ties. Externally-tagged fish that lost their transmitters moved upriver more slowly than the controls, although percent returns were similar. Most internally tagged salmon eventually mig-rated downstream. Of those migrating upriver, none crossed the first trapping facility 6.5 km upriver form the release site.	Gray & Haynes (1979)

Appendix I continued.

Species	Tagging method	Transmitter Mass and size	Observation	Number of fish (fish size)	Observation period	Results	Reference
Cod (*Gadus morhua*)	Externally attached	8.26 g in air, 4 g in sea water, 5 x 1 cm	Laboratory/ field	(50-70 cm)		Based on drag measurements in a flume, the extra output required for tagged fish to maintain the same steady speed as untagged fish was between 3 % and 5 %. and to maintain the same constant rate of acceleration less than 1 %. They concluded that the swimming performance of cod observed by sector-scanning sonar in the southern North Sea was unlikely to have been affected in any significant way by the addition of a tag.	Arnold & Holford (1978)
Cod (*Gadus morhua*)	Inserted in stomach	5 g in water, 56 x 16 cm	Laboratory	10 tagged (985 g), 10 controls (940 g)	35 days	The transmitters did not seem to affect food intake or feeding behaviour. More than half of the salmon regurgitated the transmitter during the first 7 days of the experiment.	Lucas & Johnstone (1990)
Coho salmon (*Oncorhynchus kisutch*)	Inserted in stomach	20 g , 6.5 x 2.0 cm (some larger transmitters, 8 mm long, used in one year)	Field	186 (405-725 mm)	1984-1987	61 salmon were not detected upriver from the release site. Some fish left the river. Some fish died because of predation or handling. Predators were observed in the vicinity of the tagging site, and tagged fish were susceptible to predation. The standard transmitter used did not appear to have any adverse effects on the salmon, although some problems were ex-perienced with the larger transmitters.	Eiler (1990)
Colorado squawfish (*Ptychocheilus lucius*)	Surgically-implanted	< 1 % of the body mass of the fish	Field	97		Results from field studies 1978-1985. No transmitter expulsion was detected. Growth rates of 14 recaptured fish did not differ from 59 nonimplanted dangler-tagged fish of the same size. There was no difference in mortality between implanted and dangler-tagged fish.	Tyus (1988).
Crownose ray (*Rhinoptera bonasus*)	Externally attached		Laboratory			Wing-beats/s was used as a measure of energy expenditure. Transmitter attachment had no immediate effect on ray swimming behaviour below a transmitter-to-ray mass ratio of 0.03.	Blaylock (1990)

Appendix I continued.

Species	**Tagging method**	**Transmitter mass and size**	**Observation**	**Number of fish (fish size)**	**Observation period**	**Results**	**Reference**
Dace (*Leuciscus leuciscus*)	Externally attached	2.31 g in air, 0.9 g in water, 2.0 x 0.9 x 0.8-0.9 cm	Semi-natural conditions	7 tagged and 19 controls (< 300 mm)	One experiment of 6 days and one of 10 weeks	By the second day, the behaviour of the tagged fish appeared normal and they were integrating with the rest of the shoal. Median condition factors of tagged fish did not differ from those of untagged fish over a 10-week period. Results from field studies in River Frome indicate that release method affect the behaviour. Fish released immediately after tagging often moved significant distances soon after release, while fish allowed to acclimatise for 24 h and released remotely from a holding cage, did not exhibit such behaviour.	Beaumont *et al.*,, (1996)
Lake Ontario brown trout (*Salmo gairdneri*)	Externally attached and surgically-implanted		Field	8 externally 25 implanted	Spring and fall	Transmitter attachment related mortality was 0 and 32 % (externally and surgically-tagged, respectively)	Nettles *et al.*,, (1983)
Largemouth bass (*Micropterus salmoides*)	Externally attached	Different types: 5.1-10.5 g in air, 3.3-7.0 g in wa-ter, tag weight in water 1.5-2.5 % of fish mass.	Pond			The feeding rate of tagged largemouth bass was lower than that of untagged fish over a 3.5 week period. It was concluded that weights of external transmitters in water should be less than 1.5 % of the fish weight.	Ross & McCormick (1981)
Largemouth bass (*Micropterus salmoides*)	Surgically-implanted		Hatchery pounds and laboratory	10 tagged and 10 controls + 8 fish for buoyancy compensation tests		No differences in swimming movement or catchability between transmitter and control fish. All fish were observed feeding and spawning. Negative buoyancy of the transmitters affected bass temporarily, and fin beats increased only during the time it took the fish to adjust to the effect of the transmitter.	Crumpton (1982)
Muskellunge (*Esox masquinongy*)	Surgically-implanted		Field	5	6-11 days	No apparent effect of tagging on equilibrium, swimming or feeding. No apparent abnormally high amount of movement immediately after release.	Crossman (1977)

Appendix I continued.

Species	Tagging method	Transmitter mass and size	Observation	Number of fish (fish size)	Observation period	Results	Reference
Plaice (*Pleuronectes platessa*)	Externally attached	8.26 g in air, 4 g in sea water, 5 x 1 cm	Laboratory/ field	(36-52 cm)		Based on drag measurements in a flume, the extra output req-uired for tagged fish to maintain the same steady speed as un-tagged fish was between 3 % and 5 % and to maintain the same constant rate of acceleration less than 1 %. It is conclu-ded that the swimming performance of plaice observed by sector-scanning sonar in the southern North Sea was unlikely to have been affected by the addition of a tag.	Arnold & Holford (1978)
Rainbow trout (*Oncorhynchus mykiss*)	Surgically-implanted		Laboratory			Transmitter mass caused a highly significant decrease in spontaneous activity and avoidances/pursuits, while transmitter length decreased spontaneous activity only. The operation itself did not perturb the animals.	Zimmermann (1980)
Rainbow trout (*Oncorhynchus mykiss*)	Externally attached	Mk V tags: single package. Mk VI tags: two packages of equal size mo-unted symmetrically on each side of the fish. Both: 1.55 g in air, volume 0.78 ml, density 1.99 g/ml	Laboratory	8 fish with Mk V tags, 4 fish with Mk VI tags and 8 controls (length 11.5 ± 0.5 cm)		Effects on tail beat frequency (TBF) and operculum beat rate (OPB) of rainbow trout was measured at different swimming speeds. Both types of transmitters raised both TBF and OBR. The symmetrical tag affected the behaviour less, especially at low swimming speeds, even though the relative drag was greater by this transmitter.	Lewis & Muntz (1984)
Rainbow trout (*Oncorhynchus mykiss*)	Surgically-implanted	Large: 2.2 g in air, 13 x 19 mm Small: 1.0 g in air, 10 x 16 mm	Aquarium	15 with large transmitters and 15 with small transmitters	165 –175 days	Eight fish died during the experiment. Eight fish with large transmitters expelled the transmitter 42-175 days after implantation. Five fish with small transmitters expelled the transmitter 86-175 days after implantation.	Chisholm & Hubert (1985)

Appendix I continued

Species	**Tagging method**	**Transmitter mass and size**	**Observation**	**Number of fish (fish size)**	**Observation period**	**Results**	**Reference**
Rainbow trout (*Oncorhynchus mykiss*)	Externally attached, surgically implanted and inserted in stomach	3.0 ± 0.2 g, 2.9 ± 0.2 x 1.0 cm	Laboratory	80 (24.5-30.5 cm, 168-372 g)	2 weeks observation in tanks, followed by swimming tests.	Only one fish changed dominance rank after tagging. Externally-tagged fish had significantly lower exhaustion times in swimming tests than the other tagged groups and controls. Reduced feeding resulting from stomach insertion was not evident.	Mellas & Haynes (1985)
Rainbow trout (*Oncorhynchus mykiss*)	Surgically-implanted	1-1.6 % of the body mass of the fish, 12.5 x 48 mm	Laboratory	21 tagged, 5 sham-implanted and 8 controls (mean mass 327-392 g)	7 months	No significant difference in mortality or growth occurred between control, sham-implanted and implanted groups. Transmitters became encapsulated by connective tissue. Three fish expelled transmitters via the body wall.	Lucas (1989)
Rainbow trout (*Oncorhynchus mykiss*)	Surgically-implanted	10 g, 13 x 50 mm	Pond	10 tagged fish and 10 controls (mean fork length 351 mm)	47 days	Study close to spawning time. All fish survived and no transmitter expulsion appeared. There were no differences in weight, condition factor, or gonad development between tagged fish and controls.	Martin *et al.,,* (1995)
Rainbow trout (*Oncorhynchus mykiss*)	Surgically-implanted	2.6 g in air, < 2 % of fish mass	Laboratory	11 tagged and 8 controls (240-290 mm fork length)	7 days	Studied effect of transmitters on social interactions. Dominant fish with dummy transmitters retained their rank and showed no differences from control fish in amounts of agonism and interaction time with subdominant fish.	Swanberg & Geist (1997).
Razorback sucker (*Xyrauchen texanus*)	Surgically-implanted	< 1 % of the body mass of the fish	Field	9		Results from field studies 1978-1985. No transmitter expulsion were detected. Growth rates of 2 recaptured razorback suckers did not differ from 39 nonimplanted dangler-tagged fish of the same size. There was no difference in mortality between implanted and dangler-tagged fish.	Tyus (1988).
Rock bass (*Ambloplites rupestris*)	Externally attached and surgically-implanted	9 x 40 mm and 11 x 34 mm	Laboratory			Studied effects on equilibrium and feeding. Rock bass did not seem suitable for internal tagging of the sizes used because of the shape and size of the fish.	Chamberlain (1979)

Appendix I continued.

Species	**Tagging method**	**Transmitter mass and size**	**Observation**	**Number of fish (fish size)**	**Observation period**	**Results**	**Reference**
Sauger (*Stizostedion canadense*)	Surgically-implanted		Experimental channels	21 x 2		All specimens which survived to the end of the experiment lost weight; the effect on growth was considered inconclusive. There did not seem to be any relationship between survival and sex or size and the implanted dummy transmitters.	Wrenn & Hackney (1979)
Smallmouth bass (*Micropterus dolomieu*)	Externally attached and surgically-implanted	9 x 40 mm and 11 x 34 mm	Laboratory			Effects on equilibrium and feeding by tagging was studied. It was concluded that for short term tracking (1-2 days), external transmitters in front of the dorsal fin appear best. For long term tracking, internal transmitters seem best.	Chamberlain (1979)
Sockeye salmon (*Oncorhynchus nerka*)	Inserted in stomach	20 g , 6.5 x 2.0 cm (some larger transmitters, 8 mm long, used in one year)	Field	398 (405-670 mm)	1984-1987	68 salmon were not detected upriver from the release site. Some fish left the river. Some fish died because of predation or handling. Predators were observed in the vicinity of the tagging site, and tagged fish were susceptible to predation. It was concluded that the standard transmitter used did not appear to have any adverse effects on the salmon, although some problems were experienced with the larger transmitters.	Eiler (1990)
Sockeye salmon (*Oncorhynchus nerka*)	Surgically-implanted		Field	168	Spawning season	Radio transmitters were more stressful to fish than the application of Petersen disks. No evidence that such stress would result in immediate mortality, would impede the fish's ability to migrate to the spawning grounds, or cause the fish to drop out of the study area.	Schubert & Scarborough (1996)
Tilapia (*Oreochromis aureus*)	Surgically-implanted		Aquaculture tanks	39 (4 with motion sensitive transmitters)	Up to 30 months	One fish died. With one exception, all fish retained their transmitter until the end of the study. No infections. Low level of activity 12-24 days after surgery, however, the fish maintained their normal diurnal activity rhythm pattern. Suggested that tilapias need 3-4 days to completely compensate the negative buoyancy resulting from anaesthesia and tagging.	Thoreaux & Baras (1997)

Species	**Tagging method**	**Transmitter mass and size**	**Observation**	**Number of fish (fish size)**	**Observation period**	**Results**	**Reference**
White crappies (*Pomoxis annularis*)	Surgically-implanted	Small: 3 g in water, 8 x 40 mm Large: 4 g in water, 16 x 37 mm	Field	37 (265-327 mm, 315-530 g)	April - October	Recaptured fish were in good condition, the incisions were healing well and the fish had fed while carrying the transmitter.	Guy *et al.*,, (1994)
White perch (*Morone americana*)	Externally attached, surgically-implanted and inserted in stomach	3.0 ± 0.2 g, 2.9 ± 0.2 x 1.0 cm	Laboratory	100 (19.0-31.5 cm, 106-635 g)	Swimming tests. 17 of the fish held for 45 days in aquarium afterwards	There was no significant difference in exhaustion times among tagged fish and controls. Reduced feeding resulting from stomach insertion was not evident.	Mellas & Haynes (1985)
Yellow perch (*Perca flavescens*)	Externally attached and surgically-implanted	9 x 40 mm and 11 x 34 mm	Laboratory			Studied effects of tagging on equilibrium and feeding. Concluded that for short term tracking (1-2 days), external transmitters in front of the dorsal fin appear best. For long term tracking, internal transmitters seem best.	Chamberlain (1979)
Yellow perch (*Perca flavescens*)	Externally attached	Different types, 5.1-10.5 g in air, 3.3-7.0 g in water, weight in water 1.5-2.5 % of fish weight	Pond			Tagged fish were more susceptible to predation and more sensitive to environmental stress than were controls. Feeding and respiration rates were similar among tagged and control groups over a 6-week period. It was concluded from the results that weights of external transmitters in water should be less than 1.5 % of the fish weight.	Ross & McCormick (1981)

7.10 APPENDIX II. DOWNLOADABLE INFORMATION SHEETS

Description of the ideal anaesthetics
(modified after Marking & Meyer, 1985, in Summerfelt & Smith, 1990)

a) Induction < 15 min, and ideally < 3 min
b) Recovery < 5 min
c) No toxicity for fish, and large tolerance margins for concentration
d) No persisting effect on fish physiology and behaviour
e) Fast excretion and/or catabolism, leaving no residues in fish tissues
f) No acclimatory or cumulative effects
g) No danger for operators
d) Easy preparation
i) Low Cost

Indicative list of the cost (1998 levels) of the main anaesthetics used in fish tagging. The cost of 1 litre of anaesthetic solution is calculated for cyprinid species at 15°C.

Compound	Presentation	Cost (ECU, VAT excl.)	Cost per litre of anaesthetic solution (ECU, VAT excl.)
Amobarbital	Powder	312 / 50 g	0.94
Benzocaine	Crystals	91 / kg	0.01
2-phenoxy-ethanol	Liquid	25 / l	0.01
Quinaldine (90 %)	Liquid	96 / l	0.03
Quinaldine sulphate	Powder	114 / 25 g	0.11
Tricaine	Crystals	180 / 100 g	0.18
Xylocaine (lidocaine)	Powder, Crystals	111 / 250 g	0.11

Tentative key for decision making when choosing between anaesthetics for fish handling and tagging

Criteria

1. Fish destined (C) or not destined (N) for consumption by humans
2. Deep anaesthesia required (D) or sedation only (S, e.g. weighing)
3. Natural environments (M), or experimental facilities, aquaculture (A)
4. High or low volume of anaesthetic solution requested (H / L)

Anaesthetics, in decreasing order of preference

(*) = expensive, (#) = difficult to implement

CDMH: Tricaine (stock solution)

CDML: Tricaine (stock solution) (*), Hypothermia(#)

CDAH: Tricaine (crystals), Hypothermia

CDAL: Hypothermia, Tricaine (crystals) (*)

CSMH: Tricaine (stock solution), Carbon dioxide (#), Electrical anaesthesia (DC)

CSML: Electrical anaesthesia (DC), Tricaine (solution stock) (*), Carbon dioxide (#)

CSAH: Tricaine (crystals), Carbon dioxide

CSAL: Electrical anaesthesia (DC), Carbon dioxide, Tricaine (crystals) (*)

NDMH: 2-phenoxy-ethanol, Hypothermia, Tricaine (stock solution)

NDML: 2-phenoxy-ethanol, Hypothermia, Tricaine (stock solution) (*)

NDAH: Tricaine (crystals), 2-phenoxy-ethanol, Hypothermia

NDAL: 2-phenoxy-ethanol, Hypothermia, Tricaine (crystals) (*)

NSMH: 2-phenoxy-ethanol, Quinaldine sulphate, Tricaine (stock solution), Carbon dioxide, Electrical anaesthesia (DC)

NSML: Electrical anaesthesia (DC), 2-phenoxy-ethanol, Quinaldine sulphate, Tricaine (stock solution) (*), Carbon dioxide (#)

NSAH: 2-phenoxy-ethanol, Quinaldine sulphate, Tricaine (stock solution), Carbon dioxide, Electrical anaesthesia (DC)

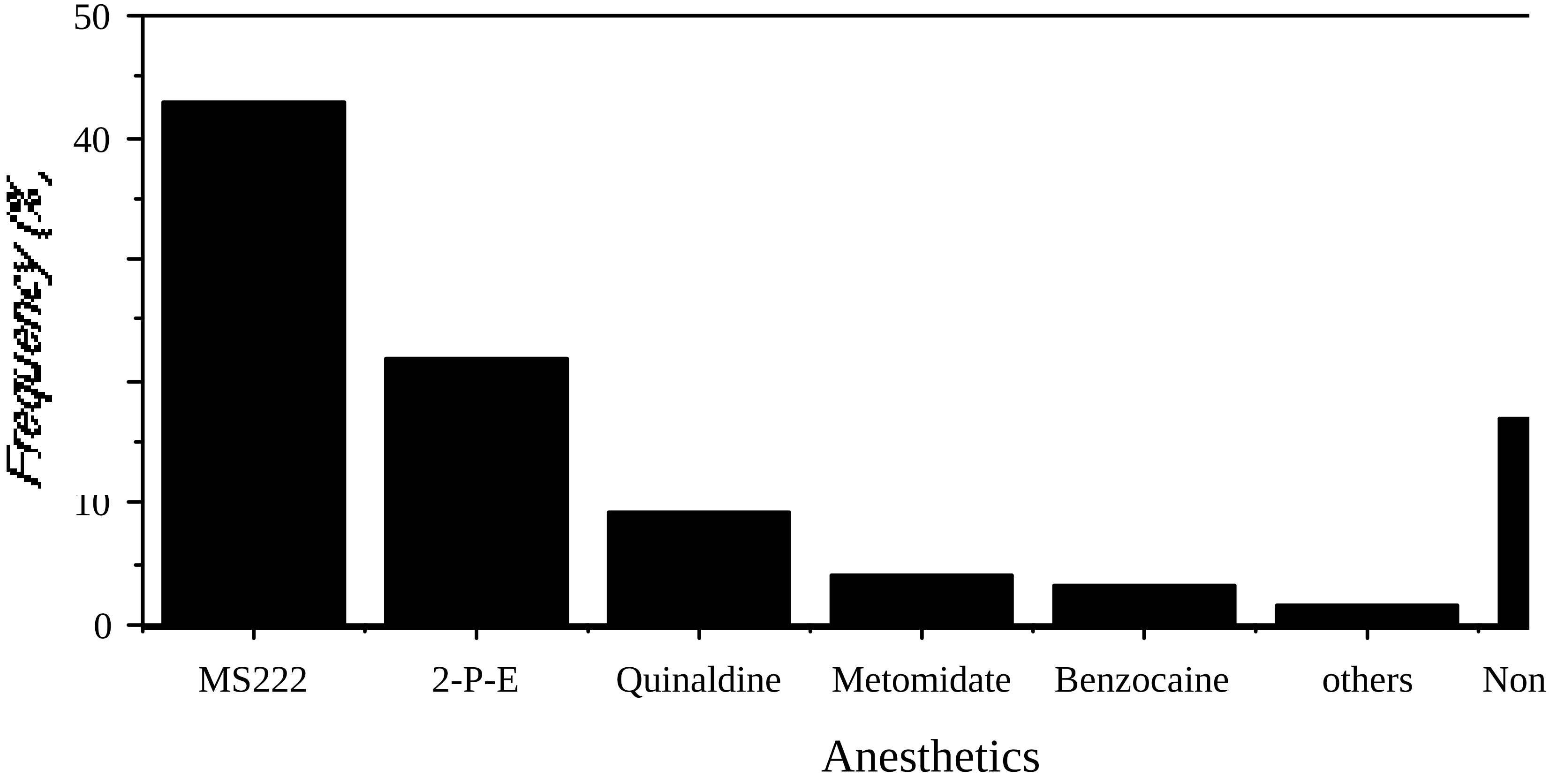
NSAL: Electrical anaesthesia (DC), Carbon dioxide, 2-phenoxy-ethanol, Quinaldine sulphate

Typical concentrations of tricaine and 2-phenoxy-ethanol recommended for deep anaesthesia

(for deep sedation about half the dose is required)

C (cold water, 5-15°C), T (temperate water, 10-25°C), W (warm water > 25°C)

Species	Family	Env.	Tricaine (mg / l)	2-phenoxy-ethanol (ml / l)
Salmo salar (Atlantic salmon)	Salmonidae	C	25	0.20-0.40
Oncorhynchus sp. (Pacific salmons)	Salmonidae	C	40-60	0.20-0.30
Gadus morhua (cod)	Gadidae	C	50	??
Thymallus thymallus (grayling)	Thymallidae	C	50-70	0.25
Oncorhynchus mykiss (rainbow trout)	Salmonidae	C	60	0.30-0.40
Salmo trutta (brown trout)	Salmonidae	C	50-75	0.20-0.30
Brycon moorei (dorada)	Characidae	W	80-100	0.40
Perca fluviatilis (Eurasian perch)	Percidae	T	90	0.40
Oreochromis niloticus (Nile tilapia)	Cichlidae	W	100	0.40
Piaractus brachypomus (colossoma)	Serrasalmidae	W	100	0.40
Prochilodus magdalenae (bocachico)	Curimatidae	W	100	0.40
Barbus barbus (barbel)	Cyprinidae	T	100	0.40
Leuciscus cephalus (chub)	Cyprinidae	T	100	0.40
Morone saxatilis (striped bass)	Percichtyidae	T	100	??
Cyprinus carpio (common carp)	Cyprinidae	T-W	100-150	0.35-0.60
Lepomis macrochirus (bluegill)	Centrarchidae	T-W	150	??
Carassius auratus (goldfish)	Cyprinidae	T-W	150-250	> 0.40
Clarias gariepinus (catfish)	Clariidae	W	120-300	0.40-0.60
Anguilla anguilla (European eel)	Anguillidae	C-T	250-500	0.80-1.00



Use of anaesthetics in fish telemetry tagging procedures

Usual name	TRICAINE	Exact name	3-amino benzoic acid ethyl ester methanesulphonate
Synonyms:	Tricaine methanesulonate, salt of methanesulphonate, metacaine, MS-222TM, FinquelTM		
Conditioning:	- crystals highly soluble in water (1 g / 9 ml) - stock solutions short term)		
Conservation:	- Opaque bottle, stored at low temperature (crystals) - Freezing (stock solution)		
	:Typical concentrations	Salmonids	25-60 mg / l
		Cyprinids	80-150 mg / l
		Cichlids, Characids	± 100 mg / l
		Catfishes	100-250 mg / l
		Eels	_ 250 mg / l
Drawbacks:	- Affects the olfactory epithelium (channel catfish) - Acid solution, which can affect the motility of spermatozoa, and cause respiratory stress - High cost		
Toxicity	- non mutagenic - No specific toxicity at the concentrations above		
Permanence, legal aspects:	- Insignificant residues after 24 h - 21-d delay between anaesthesia and consumption (FDA)		
Suggestions	- Add sodium bicarbonate (NaHCO3) before anaesthesia to buffer the anaesthetic solution (about 250 mg de NaHCO3 for 100 mg of tricaine) - Do not buffer a stock solution before storage(inactivation)		

Usual name	2-PHENOXY-ÉTHANOL	Exact name	1-hydroxy-2-phenoxyetane
Synonyms:	Ethylene glycol monophenyl ether, phenoxetol, phenoxethol, beta-hydroxyethyl phenyl ether, phenyl cellosolve		
Conditioning:	- Dense (1.1 g / l), transparent liquid, with low solubility in water (27 g / l) but high solubility in alcohol		
Conservation:	- Opaque bottle		
	:Typical concentrations	Salmonids	0.2-0.4 ml / l
		Cyprinids	0.3-0.8 ml / l
		Cichlids, Characids	± 0.4 ml / l
		Catfishes	0.4-0.8 ml / l
		Eels	0.8-1.0 ml / l
Drawbacks:	- Irritations of epithelial tissues - Little margin between induction and toxicity in salmonids		
Toxicity	- Damages the liver and kidney at subletal doses in mammals, and possibly in fish - Acute toxicity in some species		
Permanence, legal aspects:	- unknown - not approved for fish food (FDA)		
Suggestions	Prepared syringes for use in natural environments		

Usual name QUINALDINE Exact name 2-methylquinoline

Synonyms: none

Conditioning: - Transparent liquid, with low solubility in water but high solubility in organic solvents (alcohol, acetone)

Conservation: - Opaque bottle and cap (oxidation by air and light)

Typical concentrations:

Salmonids	5-12 mg / l
Cyprinids	2,5-20 mg / l
Cichlids, Characids	20-40 mg / l
Catfishes	30-?? mg / l
Eels	?? mg / l

Drawbacks:
- long delay between immersion and injection
- fish still sensible to tactile stimuli
- no action at pH < 6.0
- irritation of epithelia of operators
- strong, persistent odour
- strong inter individual variability of responses to anaesthesia

Toxicity
- increases with water temperature and alkalinity
- suspected as carcinogen for operators (larynx, pharynx)

Permanence, legal aspects:
- no residue in fish muscles after 24 h
- accumulation in adipose tissue
- not approved for fish food (FDA)

Suggestions
- solutions (60 % acetone, 40 % water) are highly stable, even in the long run
- elimination of tactile reflexes by a preliminary injection of a relaxing compound (gallamine triethiodide, pancurorium bromide,…)

Usual name QUINALDINE SULPHATE Exact name Quinate

Synonyms: No usual synonym

Conditioning: - Light yellow crystalline powder, with high solubility in water

Conservation: - Opaque bottle and cap (oxidation by air and light)

Typical concentrations:

Salmonids	25-40 mg / l
Cyprinids	< 75 mg / l
Cichlids, Characids	15-60 mg / l
Catfishes	?? mg / l
Eels	?? mg / l

Drawbacks:
- inconvenience typical of acid solutions (see Tricaine)
- fish still sensible to tactile stimuli
- irritation of epithelia of operators

Toxicity
- increases with water temperature and alkalinity
- suspected as carcinogen for operators (larynx, pharynx)

Permanence, legal aspects:
- no residue in fish muscles after 24 h
- not approved for fish food (FDA)

Suggestions
- buffer the solution prior to use (see tricaine)

Usual name	BENZOCAINE	Exact name	Ethyl aminobenzoate
Synonyms:	*p*-aminobenzoic acid ethyl ester, 4 aminobenzoic acid ethyl ester, ethyl-*p*-aminobenzoate		
Conditioning:	- Powder with low solubility in water but high solubility in organic solvents (acetone, alcohol)		
Conservation:	- Opaque bottle and cap (oxidation by air and light)		
	:Typical concentrations	Salmonids	25-50 mg / l
		Cyprinids	25-150 mg / l
		Cichlids, Characids	25-100 mg / l
		Catfishes	?? mg / l
		Eels	?? mg / l
Drawbacks:	- High variability of delay between immersion and induction depending on fish size and water temperature - Long recovery, especially in warm water species		
Toxicity	- increases with water temperature increase - No specific toxicity at the concentrations above		
Permanence, legal aspects:	- variability between species, accumulation in muscles - not approved for fish food (FDA)		
Suggestions	- buffer the solution prior to use (see tricaine)		

Usual name	CARBON DIOXIDE	Exact name	Carbon dioxide
Synonyms:	CO2, Carbonic acid, carbonic gas, carbonic anhydride		
Conditioning:	- non combustible gas non combustible, stored at -35°C (solid), or as sodium bicarbonate (NaHCO3, powder); dissolved in water (6.75 %), with addition of sulphuric acid (3,95 %) to obtain the desired concentration in carbonic acid, at a pH in between 7 and 9		
Conservation:	- no particularity for bicarbonate - low temperature for CO2		
	:Typical concentrations	Salmonids	150-650 mg / l
		Cyprinids	150-650 mg / l
		Cichlids, Characids	?? mg / l
		Catfishes	?? mg / l
		Eels	?? mg / l
Drawbacks:	- mainly used for sedation - risk that the operator looses conscience at _ 10 % CO2 in the air - risk inherent to the use of sulphuric acid - risk inherent to the use of low temperature for solid CO2 - hard to obtain deep anaesthesia, and to maintain the oxygen level		
Toxicity	- risk inherent to hypercapnia in fish, especially with respect to osmoregulation		
Permanence, legal aspects:		- No permanence - approved for fish food (FDA)	
Suggestions	mixing O2 and CO2 in pressurised cylinders to obtain stable concentrations		

8. DATA ANALYSIS AND MODELLING

8.1 INTRODUCTION

Quantitative analysis of fish tagging results has a 100 years history, going back to the first calculations done by C.G.J. Petersen during the 1890s. Petersen (1896) founded the basic theory behind most developments in the use of fish tagging for estimating exploitation rates and population abundance. Since then, many new and improved tagging techniques have been developed, and the analysis and modelling of tagging data has evolved along with new demands and possibilities.

In order to meet the objectives of *mass tagging studies* (systematic tagging in large enough numbers to secure quantitative treatment), adequate tools are needed to handle the large amount of data generated from the recaptures. Similarly, new developments in electronic tags, particularly the fast evolving utilisation of data storage tags (DST), mean that large amounts of data can be obtained on each tagged fish and its environment. In both cases, appropriate models and statistical techniques are crucial in order to make the best use of the available information.

Traditionally, many tagging programmes have been carried out without definite goals and hence without a well-considered experimental design. Some have simply sought to provide qualitative information on distribution patterns and migration routes. Such programmes have sometimes been continued for many years to maintain a time series, without reconsidering whether the scientific objectives of the programme are being met. The costs of catching fish for tagging is often high, due mainly to the cost of employing vessels, and tag recovery programmes may also be expensive. The effectiveness of tagging programmes is dependent on the quality of both of these phases and great care must be taken in planning to make best use of available resources. The tagging programme must be carefully planned in order to ensure that the tagged fish are representative of the population. Similarly the recovery programme must obtain representative samples of the fishing mortality of the population. Modelling and analysis tools can be used at all stages of a tagging programme (planning, design, quality control, analysis of results) to improve efficiency and reduce costs.

Two basic goals are to:

- Optimise strategies of tagging experiments
- Extract maximum information from tag recapture data

In the following sections, methodologies applied in the analysis of tagging data will be highlighted (without giving a complete review) under the following headings:

- Experimental design
- Estimation of abundance and mortality
- Modelling of fish behaviour, movement and migration
- Methodologies used for other animal groups.

The last point includes a brief inspection of modelling and analytical tools utilised for other groups of animal (reptiles, birds and mammals), bearing in mind that these approaches may be of direct relevance to fish tagging studies.

8.2 CURRENT METHODOLOGY

8.2.1 Experimental design

Substantial errors can be introduced at several stages of tagging experiments. The limited use of tagging in evaluation of commercial fish stocks in the EU at present is closely linked to the uncertainty associated with such data. It is therefore of major interest to highlight these questions and look at potential solutions for the future. The errors associated with the design of tagging experiments that permit quantitative data treatment fall into three categories:

- Errors associated with the non representative distribution of tags in the population (release errors)
- Errors due to effects of tags, or tagging, on the survival or behaviour of the fish (tagging mortality, tag losses, increased predation)
- Errors due to non representative sampling and/or reporting occurring in the recapture phase (recapture errors)

In addition, an area of growing importance is the design of experiments employing electronic tags and the analysis of the results. This area includes the treatment and analysis of data telemetered through a difficult physical environment from an acoustic transponding tag. Also, time series of data from DSTs need careful handling related to data quality and data refinement. In addition to these new problem areas, experiments with electronic tags are susceptible to the same errors as traditional tagging.

Consequently, the success of any kind of quantitative treatment of data from tagging - conventional as well as electronic - depends on the quality of the preparatory work done prior to, in particular in formulating clear, specific goals and setting up a corresponding experimental design. A proper experimental design is the only way to avoid the numerous pitfalls and to minimise the effect of the described errors.

Although different problems affect different types of tag or tagging method, the data from all studies need careful scrutiny before the final analysis is undertaken. The overall goal of modelling work connected to this process is to control data quality, improve consistency and fill gaps and holes in broken time series.

(a) Release errors

In order to meet the objectives of any tagging study, it is important to ensure that the release programme is well planned. Where large numbers of fish are tagged for assessment purposes, it is important to distribute the releases in the population so that the distribution of recaptures does not diverge from the general assumptions in the analytical models that are used. For example, efficient design of the release programme to comply with initial goals and assumptions might be achieved by combining information about the distribution pattern of the population with data from the commercial fishery and previous tag recovery records. Commonly, the rate of exploitation (u) (the fraction of the fish in a population that is caught at a given time) is assumed to be equal to the relationship between number of recaptures (R) and marked fish (M):

$$U=R/M=C/N \qquad (7.1)$$

which again is equal to the relation between the population catch or sample (C) and (N) (see Ricker, 1975; Burnham *et al.*, 1997 for details). However, it is essential that the distribution of the tagged individuals in the population does not reduce or increase the probability of catching marked fish relative to unmarked ones. This can be achieved either by intrinsic mixing of individuals in the population or by distributing tagged individuals in the population in space and also over time. Special attention has to be paid to sampling when designing a tagging programme for studying the effects of sea ranching or cultivation in rivers or lakes (see e.g. Svåsand, 1990; Vreeland, 1990).

In many cases, practical considerations in the tagging phase preclude choosing the optimal experimental design. Further, incomplete knowledge about the structure of fish stocks may prevent an optimal release design being created. Commercially important fish populations, marine as well as anadromous and fresh water species, are often structured both geographically and intrinsically (by size, year class, etc.). This has to be taken into account in the design of tagging experiments by distributing the tagged fish proportionally to geographic and demographic properties of the stock. Numerically this means e.g.

$$M_{ij}= \sum_{ij} M \,(N_{ij} / \sum_{ij} N \qquad (7.2)$$

where M_{ij} is the number of released fish of age i in area j and N_{ij} is the sub population size at age i in area j. M and N are the total and tagged population sizes. The tagging programmes on Norwegian spring spawning herring (Hamre, 1989) and Northern cod (Taggart *et al.*, 1995) are examples of marine stocks where the population structure is taken into account when designing tagging releases. Some of the problems caused by improper or unbalanced release design can be compensated for in a thorough sampling of recaptures and will be dealt with later.

Intuitively, the precision of assessments from tag recoveries will be dependent on the number of releases. It should, however, be kept in mind that most models rely rather on the number of recaptures to determine the precision of the estimates. Consequently, based on actual or assumed recapture rates, simulation studies can be run to estimate the number of releases needed to obtain a certain precision (Xiao, 1996a).

A special concern is related to the number of releases of electronic tags. High price limits the number of releases. Also, the size of tags often makes it necessary only to select larger fish for tagging. In addition, survival may be size dependent (see Chapter. 7). Hence, particular attention should be paid to the design of such experiments when data are to be analysed with the aim of supplying information on population or sub-population properties.

(b) Tagging mortality, tag losses

Tagging mortality and tag losses represent a special challenge during numerical treatment of tagging and recapture data. In most cases capture and tagging are very stressful for the fish and can affect survival in the tagged population (tagging mortality, Ricker, 1975). More seriously for modelling and calculations, there is a high risk of varying tagging mortality among releases caused by variation in the capture situation. Fish can be caught at different depths, under different weather conditions and at different times of year and these factors may affect their survival. Reduced survival compared to assumptions leads to underestimates of recaptures and hence rates of exploitation (eq. 7.1) in experiments conducted for stock assessment purposes.

Year	1	2	3	4
1	R_{11}	R_{12}	R_{13}	R_{14}
2		R_{22}	R_{23}	R_{24}
3			R_{33}	R_{34}
4				R_{44}

Tag loss, by a variety of methods, can seriously affect assessment results from tag-recapture experiments. Fish can shed tags, and external tags can be lost after becoming entangled in fishing gears during capture. Further, an external tag may alter the appearance and/or behaviour to potential predators with subsequent effects on recapture and survival probabilities (Svåsand & Kristiansen, 1990). If the releases do not satisfy assumptions on representativity related to the whole population, the recaptures may give misleading results (Turner, 1986).

In systematic tagging programmes, where mass tagging occurs, for example, routinely every year, the effects of tagging mortality can be estimated through comparison of rates of survival during the first and subsequent years. For example, if the rows in the table below represent the release year and columns the recapture year, an analysis comparing returns (R) for different tagging groups between different years may give valuable information about losses due to tagging.

To exploit such possibilities, systematic and long term tagging programs are needed. Varying fishing mortality and tagging mortality make such approaches difficult in practice. A special model (Hamre, 1980) was used to quantify variation in tagging mortality from year to year by means of such information. If the tags are lost due to shedding, predation or other mortality caused by tagging, the effects can also be studied in so-called "dead recovery experiments" where information from tags recovered from dead individuals is used in separated or combined analysis with data from living individuals (Seber, 1970; Lebreton *et al.*, 1995, Program MARK-http://www.cnr.colostate.edu/~gwhite/mark/mark.htm).

Mortality and tag losses during tagging might also be a serious problem for experiments designed to study and model fish distribution and migration. Loss of tags has been studied for a lot of tag types and species through experiments employing tags with secondary marks. In such tests the fish are doubly identified by a second tag, or by a combination of marking (e.g. finclipping) and tagging (Ricker, 1975; Xiao, 1996b). Reports over time give information on rates of tag loss in the experiment. The tagging mortality might be size and/or sex specific, and thus lead to inaccurate behaviour models. Particular emphasis should be paid to this problem when data from large electronic tags are used in modelling. These tags potentially expose the fish to a higher risk of dying due to tagging (e. g. of health causes), by entangling in fishnets, or by predation. These effects are discussed in details in chapter 5.

In some cases, the effects of tagging on the behaviour and survival of fish and the impacts of tag losses on assessments can also be addressed by developing methods that ignore data or results that are affected. Thus, in the case of tracking studies using electronic tags, data collected in the first few hours or days might be ignored in any analysis because the behaviour of the fish may have been affected by the handling or tagging procedures. Similarly fish can be released sometime prior to the period of interest. For example, in studies of salmonid smolts passing through estuaries, Moore *et al.* (1995) caught and tagged the fish in freshwater days or weeks before they were expected to emigrate through the estuary. The run-reconstruction model (see Lassen *et al.*, 1988; Potter & Dunkley, 1993; Rago, *et al.*, 1993) adopts a different approach. By back-calculating the stock size from the surviving spawning stock, tagging mortality and tag loss, which are believed mainly to occur soon after release, can be ignored.

(c) Recapture errors

There are two types of errors that can lead to biased or imprecise estimates in population studies based on tag-recapture data:

Recovery reporting errors - Recaptures are normally reported by commercial fishermen or obtained in automatic screening systems in association with production lines, or special sampling arrangements. Errors may arise from mechanical inefficiency of automatic registration systems, or from human mistakes in recording position, measuring fish length etc., or simply by irregular reporting by the fishermen. To minimise the effect of such errors in the recovery database, simple automatic control routines can be applied when entering information on, for example:

- position – by controlling/excluding reports from 'on land' locations, which might be processing sites or simply erroneous position records
- time – by controlling/excluding recaptures reported before release or those resulting in unrealistic migration distance/speed based on the reported time at large
- size - by controlling/excluding recaptures that give unrealistic length/weight increments

It is, however, essential that any exclusion or correction of data does not introduce any kind of bias in the database. For example due to the normally quite imprecise reporting of stock parameters, a slight negative growth report shortly after release may occur with the same probability as a similar positive growth.

Assumption errors - Recoveries recorded from catches not representing the population may seriously bias stock assessment studies based on these data. Similarly, low quality of catch statistics may introduce serious errors in population estimates, if it is assumed that the population/catch ratio equals the tag/recapture one. As an example for the general assumptions needed for modelling, the following are required for to use the Brownie models (Brownie *et al.*, 1985):

1. the tagged sample is representative of the tagged population
2. there is no tag loss, or it can be accounted for by double tagging
3. survival rates are not influenced by tagging
4. the year of tag recovery is correctly tabulated
5. the fate of each tagged fish is independent of the fate of other tagged fish
6. all tagged fish within a tagged cohort have the same annual survival and recovery probabilities in a given year
7. the survival and recovery probabilities do not depend on the age of the animal
8. the forces of instantaneous natural and fishing mortality are additive and independent
9. natural mortality is constant within a year (no seasonal variation) and between years
10. fishing mortality for a user group is constant for the period of the year that the fishery is operating
11. tagging takes place over a short period

(d) Electronic tags

In addition to the errors and problems described above, analyses of electronic tag data require special attention to quality control and data manipulation. Relatively few tags are normally released compared to conventional tagging experiments, while thousands of data points can be collected from each tag instead of just one. When results are scaled up to the population level it may be difficult to balance the detailed information on the individual level with the variability shown between tags. In other words, particular attention should be paid to the number of recaptures when making inferences about population behaviour from data from individual fish.

The database from electronic tags is particularly vulnerable to technical failures, or errors, if it is not properly calibrated and controlled. Due to the high value of each individual fish, realistic calibration of each tag and sensor is needed. Normally this is done by the producer, but in many instances it can also be easily tested as part of the tagging protocol. For example, tags with temperature and depth sensors can be attached to a Conductivity, Temperature, Depth (CTD) profiler after recording has started and exposed to realistic fish depths and temperatures before the fish is tagged and released. After recovery the CTD measurements and the DST recordings can then be compared or contrasted with original calibration (K. Michalsen, Institute of Marine Research, Bergen, pers. comm.). Similar procedures can also be applied to returned tags to test for drift in accuracy of recordings over the whole period for which the tag was at liberty.

DST data can be corrupted as a result of malfunction of sensors occurring periodically, or at a certain moment during operation. General screening of data is therefore important and such examinations should consider *abrupt*, as well as *gradual*, changes towards unrealistic values from the sensors.

DSTs are often larger than conventional tags and special attention therefore should be paid to effects this might have on recapture results. Stress from a higher drag and entanglement in fishing nets may change behaviour, as well as reduce the number of recorded recaptures. In such cases double tagging combining conventional and electronic tagging may be useful (see e.g. Thorsteinsson, 1995).

8.2.2 Assessment of abundance and mortality

Although many tagging studies have been conducted in the past, relatively few such studies are currently being used in the assessment of European fish stocks, and tagging data are utilised in only a small number of ICES stock assessments. To a large extent this reflects the high cost of tagging studies and the difficulty of addressing the problems outlined above. However, the situation contrasts with that in the Pacific, where tagging is applied much more widely and is an integral part of assessments of tuna and salmonid stocks. The difficulties of developing and improving approaches have been exacerbated by the fact that many assessment studies have only been reported in the grey literature. Nevertheless, examples exist which demonstrate the applicability of tagging for operational management. For example, the Norwegian spring spawning herring assessment utilises Virtual population Analysis (VPA), a common assessment method exploiting commercial catch by cohort as a basis for quantifying fishing and natural mortalities. For this assessment tag recovery data are used as an input to tuning the VPA (Anon., 1998). Also, the estimation of exploitation rates for certain North Atlantic and Baltic salmon stocks in marine fisheries is based largely on coded wire tag (CWT) or Carlin tag recovery data (Anon., 1991; Anon., 1995a; Anon., 1995b). Some examples of tagging programmes that have been used to monitor features of importance to management (e.g. exploitation, population distribution and mixing) are given in Table 8.1.

(a) Models

Assessment models utilising tagging data are usually developed to estimate stock abundance and this leads on to methods for estimating mortality (i.e. changes in abundance). Much literature appears on these subjects, and a range of approaches has been proposed for improving basic mark-recovery estimates. Ricker (1975) presented an extensive review of methods to estimate abundance and mortality parameters. A series of approaches are described, beginning with studies which employ one release of tagged fish followed by recaptures in a single period (e.g. Petersen method) to models based upon multiple releases and recapture periods.

Various approaches are proposed for dealing with the biases discussed in preceding sections (e.g. differential tagging mortality, non-random distribution of tags, etc). Multiple tagging studies may be based upon two (e.g. Ricker, 1975), three (Bailey method, e.g. Fairfield & Mizroch, 1990) or four and more (Jolly-Seber method, e.g. Kunzlik *et al.*, 1986) release and recapture periods. There is an extensive literature on the latter group of models, which has been summarised by Brownie *et al.* (1985). The method has been used in a wide range of fishery assessments, including reservoir fish populations (Hightower & Gilbert, 1984) and Pacific salmon (Law, 1994).

There have been other developments to estimate area or fishery based harvesting. Brooks *et al.* (1998) have extended models to estimate fishing mortality separately for a commercial and a recreational fishery harvesting the same salmon stock.

An alternative approach has been developed for estimating levels of exploitation of Atlantic salmon stocks in sequential fisheries, which operate through their lives in the sea. These models, referred to as run-reconstruction models, back-calculate the number of fish from a stock (e.g. a river) that were alive at earlier stages in the life cycle using an estimate of the returning spawning stock (Lassen *et al.,* 1988; Potter & Dunkley, 1993; Rago *et al.*, 1993). CWT or Carlin tag studies are used to estimate the numbers of fish removed by fisheries and hence the levels of exploitation of the extant stock (i.e. all fish of a single cohort that are alive wherever they are). The run-reconstruction approach has been further developed, in part using the results from the tagging studies, to estimate the stock abundance for large stock groupings (e.g. North American and North East Atlantic). It has also been used to propose preliminary stock conservation limits (Potter *et al.*, 1998, in order to provide advice to the North Atlantic Salmon Conservation Organisation (NASCO).

In studies of diadromous fish, stocks can often be sampled at more than one point on their migration route (e.g. when migrating downstream). Similarly, downstream migrants can be trapped, marked, and then released upstream of the trapping site; they can then be resampled as they pass the trap site for a second time. This technique may provide an opportunity for making mark-recapture estimates using the Petersen method, but the estimate may be biased if both the sampling sites are selective. This problem may be reduced by employing Schaefer's (1951) stratification method, which has been used to enumerate salmon smolt runs from tagging data from the River North Esk in Scotland (Shearer, 1992).

Many tagging studies have been carried out to assess the distribution of various fish stocks or to estimate the stock composition by origin in different areas. In the case of Atlantic salmon, the fact that fish from both North America and Europe migrated to West Greenland was demonstrated by tagging studies (e.g. Anon., 1991), although the composition of the stock in that area is now determined by scale analysis or genetic methods. Tagging studies have been conducted on mackerel in the north-east Atlantic to describe geographical distribution and migration (Iversen & Skagen, 1989). The results of these tagging experiments have been used in the consultations between Norway and the European Union to determine the proportion of the stock which should be apportioned to different areas of jurisdiction, and to distribute quotas by country (S. Iversen, Institute of Marine Research, Bergen Norway, pers. comm.).

(b) Limitations and problems

Currently, tagging experiments are not extensively used to assess stock abundance or mortality largely due to the cost and the practical difficulties related to tagging a representative sample of the stock and obtaining unbiased recovery data. In addition to the general problems highlighted in Section 8.1, there are specific problems associated with assessment studies. The major commercially exploited fish stocks are usually very large and distributed over a wide area. This means that tagging studies require marking very large numbers of fish on the one hand and on the other that good co-operation is achieved with fisherman to find and report marked fish (Hilborn & Walters, 1992). In the past, tagging experiments have often failed because too few fish have been tagged, or because fishermen and other members of the industry have been reluctant to report recoveries.

This problem further emphasises the need to ensure that the objectives of tagging experiments are clearly spelt out and that preliminary modelling is used to determine that tagging and recovery programmes are likely to generate statistically meaningful results. Furthermore, it is important to ensure that at least as much effort is put into the tag recovery programme as the original tagging. This may include extensive advertising of rewards and explaining to fishermen the benefits of reporting recaptures.

Table 8.1. Examples of tagging experiments being used to assess abundance, mortality or stock identity of commercial fish stocks

Tagging method	**Analysing method**	**Stock**	**Reference**	**Application**
Internal /metal	Ricker, Jolly –Seber Mortality	Norwegian Spring Spawning Herring	Hamre (1989)	Results input in tuning of VPA
Internal /metal		Western Mackerel	Hamre (1980)	Migration models
Coded Wire Tag (CWT)	Run-reconstruction	Atlantic salmon	Potter and Dunkley (1993); Rago *et al.* (1993)	Estimation of exploitation
Carlin	Run-reconstruction	Baltic salmon	Anon, 1995a (ICES)	Estimation of exploitation by area
CWT	Brownie method	Pacific salmon	Brooks *et al*. 1998	Estimation of exploitation by fishery
Carlin	Schaeffer	Atlantic salmon	(Shearer, 1992)	Estimation of smolt runs
External	New exploitation models	Northern cod	Myers *et al*. 1994, 1996	Exploitation,

Tagging programmes may also depend upon reliable catch records, for example by scaling tag recoveries to the level of the recorded catch. In such circumstances it is important that the catches are reliably reported both in quantity and by location. Otherwise any conclusions drawn from tagging studies may be similarly biased.

In the case of salmon run-reconstruction models, an important element is the estimation of the returning spawning stocks. The difficulty of counting upstream migrants in large rivers tends to limit the use of this approach to smaller systems. These tend to support stocks which return mainly as one-sea-winter fish and thus make it difficult to obtain information on multi-sea-winter stock components. Cost effective methods for river monitoring are therefore required. The approach also depends upon estimates of tag reporting rates, which can often only be approximated.

8.2.3 Modelling of fish behaviour, movements and migration

Fish populations have over time developed favourable migration patterns, which in the long term secure advantageous circumstances for survival, recruitment and growth. Although migration and dispersal is not totally under the control of the individual fish, it is fundamentally driven by behaviour that puts (or maintains them) in advantageous circumstances with respect to population survival. However, the movement of individuals in the same environment will not necessarily be identical and this is an important factor to consider when developing fishery models based on tagging results. Whilst random movements undoubtedly occur, fish orientate to a variety of directional stimuli and dispersion cannot generally be considered as simple diffusion. Movements within a specific area may be influenced by many factors, which include the physical environment, food availability, predator avoidance, pollution and so forth.

Modelling of fish behaviour, movements and migration has to a great extent been a theoretical exercise, which tries to synthesise available knowledge and information into a dynamic framework. Because of the very manifold nature of biological processes in nature and the complex interaction between fish and their physical and biological environment, such models become complex and dependent on difficult parameterisation and/or strong assumptions. Such models often suffer from lack of realism because of a lack of adequate data. As a result they are often only used for simulation purposes rather than as operational tools for fish stock assessment and management. This type of modelling suffers further from a lack of understanding of the basic biological processes and motivation behind fish movement and the dynamics in these processes. Recent technological developments including new electronic tags, new software and faster data processing capabilities have opened new possibilities for filling these gaps. There is, however, a demand for new analytical approaches which are constantly being developed and modified according to new achievements in technology and knowledge. These may in future improve the interaction between theoretical developments and practical application. For example the use of multiple tag types or combined methodologies may be necessary to fully develop models for future fisheries applications.

8.2.3.1 Large scale models

Large-scale models refer here to approaches that cover broad scale movements of populations without emphasis on individual behavioural patterns. Significant contributions to our understanding of large-scale fish migrations have come from conventional tag and recapture experiments. With improvements in electronic devices, and particularly the fast evolving utilisation of data storage tags (DST), a much larger quantity of data on individually tagged fish has now become available which can be related to the position of the fish. These tags are now commonly used for fish migration studies. However, the quality of the data generated from all electronic tags should be assessed and the suitability of analytical procedures critically examined.

Apart from general analyses of tag recoveries and related data, there are two major categories of mathematical models that are applicable to the study of large scale animal movements - here called *differential diffusion models* and *random walk models* (Okubo, 1980). The main difference between the two methodologies is that the first add parameters to the equations, making them larger and more complex. These models consider entire populations. Probability models, on the other hand, modify the existing probabilities as a function of multiple interactions.

(a) Differential diffusion models

This category includes models that use differential calculus to solve diffusion equations. Joseph & Sender (1958), Ozmidov (1958), Bowles et al. (1958) have developed the theory of diffusion based on differential calculus. Only Ozmidov’s solution is suitable for describing oceanic diffusion.

Salvado (1993) developed an approach to the understanding of animal motions and migrations from the empirical Green Function. This was based on the development of a point source solution of the differential field equations resulting in a one parameter model, which would be applicable to fisheries simulations based on tagging results.

(b) Random walk models

This group of models is based on probability functions. Despite their implicit insensitivity to environmental conditions, they are used in fisheries assessment (Jones, 1959, 1976; Mullen, 1989) to describe fish dispersion and local population dynamics (Okubo, 1980).

To add realism and a more directional spatial displacement to diffusion models based on probability functions, there has been an effort to incorporate into their design ecological controlling functions in the form of spatially-explicit and temporally articulate probability distributions (DeAngelis & Yeh, 1984; Marsh & Jones, 1988). Introduction of these "biased" rules to modify movements of fish implies complex decision-making on the part of the organism. In fact, some of these more sophisticated probability models can produce accurate simulations of an organism's response to heterogeneous environmental conditions (Saila & Shappy, 1963; Kareiva & Shigesada, 1983; Pulliam *et al.*, 1992). Schaefer et al. (1961) and Bayliff (1979) have described approaches based on quantitative analyses. These analyses which use measures of directional and random movements developed by Jones (1959, 1976) are suitable only for random or simple directional movement.

Darroch (1961) and Arnason (1972, 1973), in their statistical works on analysis of movement data, examined spatially stratified capture recapture models, but under the condition of multiple recaptures. A limitation in these studies is the assumption of equal probability of the capture in all areas, which is unlikely considering the nature of commercial fisheries where tag recoveries are made.

Burnham *et al.* (1997) considered traditional models and approaches of mark-recapture studies on spatially structured problems with unequal fishing effort in the spatial strata. Adopting a Markovian movement model, Ishii (1979) simulated the movement of tagged fish and used non-linear minimisation techniques to determine the movement probabilities that optimise the difference between observed and expected number of recoveries in each spatial area. Ishii's model included parameters such as natural mortality, and tag shedding. Later Sibert (1984) included natural mortality, fishing mortality, and movements between two countries in his analyses, which used tagging data to determine mortality rates and exchange rates between the two countries. Ishii and Sibert used the method of the least squares to estimate the parameters involved in their models.

Schwartz (1988), and Schwartz & Arnason (1990) described the extension of this approach to the statistical analysis of mark-recapture data, using explicit multinomial probability functions. Movements of fish were calculated from differences in stock structures between censuses by Schnabel (in Ryan, 1990) using multiple-mark-recapture studies. Hilborn (1990) developed a model that adopted the maximum likelihood method based on the Poisson distribution and presented a general method for the analysis of movement data from tag returns. This method was based on an extension of the generalised linear model approach adopted from Cormack (1981).

Mullen (1989) suggested combining differential and probability models by using an approach based on the variable coefficient of diffusion model, in which the local environment affects local population dynamics by creating unique diffusion coefficients for each spatial co-ordinate. Mullen's coefficient of diffusion was based on a simple bio-economic model taken from Clark (1985). With the inclusion of this coefficient of diffusion, many variables such as the foraging mechanism can be included in the model.

8.2.3.2 Small scale behaviour models

Behavioural models can be considered on a smaller scale than migration models as they tend to describe more localised movement. Computer simulations can provide a good approach for stochastic investigation of animal movements. These simulations require an abstraction of actual animal motion into certain elements, for instance, speed, direction, activity, and rest periods, and an evaluation of the statistical distribution of each of these processes. For this purpose, the assumed relations may be based on actual data, or on theoretical considerations. The required distributions and algorithms can then be programmed into a computer to simulate animal motion. The result is then compared with data to test the applicability of the model; if necessary the model can be modified.

Various forms of animal movements have been described (Fraenkel & Gunn 1961which can be simulated. These are:

- *Orthokinesis* - movement in which step length is a function of the stimulus intensity.
- *Klinokinesis*: - the probability of an animal changing its direction in the space.
- *Tropotaxis*: directed movement on a stimulus gradient,

Other processes influencing population ecology (growth, death, predation, competition, etc) can be added to develop a more complete model of fish behaviour. A number of models have been developed but they have normally no direct reference to tagging and will thus not be dealt with in any detail here (an overview with references is given at the CATAG web site http://www.hafro.is/catag). These models facilitate simulation based on modelling of various kineses and taxes and demonstrate potential individual movement in a variable environment based on motivation and behavioural features (see e.g. Rohlf & Davenport, 1969; Neill, 1979; Okubo, 1980).

The development of sophisticated electronic tags and telemetric procedures allows for tracking of individually marked animals. Coupled with simultaneous measurements of environmental factors and physiological data there is an inestimable potential for discovering important processes affecting fish populations. The fact that many individuals may be tracked simultaneously may improve the quality of the results and lead to better reproducibility. Thus, new electronic tags can become important in validating and developing the theoretical modelling summarised above toward the development of important scientific and management tools.

Keleher, *et al.* (1985), carried out radio tagging to study the behaviour and movements of Pacific salmon species in relation to environmental influences and used the *t-test* to compare movements between species. Separate regression analyses were also developed to relate daily distance travelled to the cumulative precipitation (an indicator of stream flow) of a lake system.

Binkley (1976) presented several mathematical techniques for examining circadian rhythms data that allow the significance of a periodogram peak to be tested. These include:

- Average curves
- Enright’s formulation of the Whittaker periodogram
- Autocorrelation
- Power spectral analysis

In order to establish circadian characteristics, Schulz and Berg (1992) applied the χ^2 periodogram test (Sokolove & Bushell, 1978), based on Enright’s method (Enright, 1965) to analyse the daily activity data derived from ultrasonically tagged brown trout in Lake Constance, Switzerland. The coherence of barometric pressure and migration activity was tested with general linear models. Additionally, mean swimming activity, swimming depth and temperature were calculated for day (light intensity > 1 lux) and night (light intensity < 1 lux), and tested with *t-tests*. Swimming activity during the day (*foraging behaviour*) was significantly higher than at night in most experiments. Cyclic features in fish behaviour data such as diurnal and tidal patterns have also been studies with circular statistics by e.g. Batschelet (1981) and Moore and Potter (1994).

Greer Walker *et al*. (1980), Arnold *et al.* (1994), Arnold & Holford (1995), Arnold & Metcalfe (1995), have studied migratory behaviour of fish in the North Sea by means of data from electronic tagging. A variety of behaviours shown during the tracking suggests some kind of *cues* or *clues* to which the fish might respond under different conditions (Arnold & Metcalfe, 1989; Arnold *et al.*, 1994). Direct observation of behavioural pattern of plaice in relation to tidal current by means of acoustic tagging experiments, initiated development of a migration model using tidal stream vectors calculated from the British Admiralty tidal data. The basis for the approach was obtained by observing the heading of the fish and its speed through the water compared to measurements of tidal stream vectors made with current meters (Arnold *et al.*, 1994). By using vertical migration data from data storage tags Arnold & Holford (1995) were able to predict the rates and scale of horizontal movements and demonstrate that the model is able to estimate the recapture position of the tagged fish with remarkable precision in some circumstances. This work might serve as an example of the potential success by combining information from new electronic tags with physical models in testing behaviour and migration hypothesis.

Migratory behaviour of fish results in temporal changes in the spatial distribution of biomass and is influenced by prey availability, vulnerability to predation, accessibility to fishing gear, and exposure to environmental conditions. The migration route may vary from year to year in response to changing climatic conditions, or environmental factors. The influence of the environment on the fish behaviour has been discussed by Harden Jones (1968), Laevastu & Hela (1970), and Neill (1984). Random walk models have been used in order to model simple movement of fish. DeAngelis & Yeh, (1984) used a *biased random walk* adopting a hypothetical oceanic coastal region, with environmental heterogeneity built into the model to simulate a realistic situation.

8.2.3.3 Limitations and problems of tagging studies

(1) The general lack of an experimental design is a serious deficiency in many tagging surveys; it can undermine the relevance of the data collected and the analytical procedures

(2) The number of fish to be tagged is often based on economic considerations rather than on the basis of ensuring good representation. This has a direct bearing on the type of analyses that can be performed and the confidence limits that ca be achieved

(3) Release times and conditions are difficult to standardise in tagging studies.

(4) Many studies incorporate the results of all recaptures regardless of how much time has elapsed since the release of the tagged animals. There can be problems in interpretation of recovery data from fish that have been at liberty for different periods of time

(5) The influence of environmental factors on tag recoveries and return rates is poorly understood

(6) The availability of data for analyses can be affected by the rate of reporting of recaptured fish by commercial or recreational fishermen

(7) Results can be seriously confounded by even slight uncertainty in recapture data, lapses in time series, misclassification or mis-reporting of information

(8) Data interpretation from DST tags can be compromised by local events (e.g. localised temperature effect) or anomalies, which make comparison with data from other sensor sources with different resolution less accurate

(9) Specific problems arise with the application of electronic tags that may be affected by radio or acoustic interference

(10) Data quality problems caused by environmentally induced background noise or disturbances

8.2.4 Review of analytical methodologies used for other animal groups

Tagging studies of migration and behaviour are not exclusive to fish and many applications developed for other species have been and can be adapted for fisheries related work. Models have been developed describing the behaviour of seals, birds, turtle, sharks, insects and mammals and there are many novel analytical approaches, which may be applicable to fisheries studies. A significant number of computer simulations are available particularly for studies relating to animal behaviour which could be adapted for fish behaviour.

There are several examples of experiments on other species that have been adapted for fisheries work. Dodson & Dohse (1984), for example, adapted a model of directional bias based on olfactory mediated conditioning to study the homing behaviour of American shad (*Alosa sapidissima*) in the Connecticut River.

Random search has been proposed as a possible mechanism for homing. Whilst a completely random search would appear to be unlikely as a factor in homing, the possibility has been examined by a number of workers. Wilkinson (1952) first demonstrated that random search explained some observed phenomena associated with bird homing. Since then Jones (1959) and Saila & Shappy (1963) have proposed the idea that random search combined with a small amount of directional orientation (possibly of olfactory nature) can theoretically provide reasonable homing results in fish. Wilson & Findley (1972) showed that experimental data on bat homing could be interpreted in terms of the random search hypothesis. All of these studies suggest that random search cannot be excluded as a possible homing mechanism.

Movements of animals within the home range can be considered to be a stochastic process in space, as for example a random walk. However, the walk is not purely random but it must be regarded as a biased walk (Holgate, 1971). That is, the probability of taking a step toward the centre of activity of the home range is greater than moving away from the centre. This kind of *random walk*, is called *centrally biased* (Okubo, 1980).

In a random walk, movement is assumed to be discrete. In the limit of increasingly smaller steps, however, the differential equation for probability becomes a generalised diffusion equation describing continuous movement. Then, in the limit, the discrete equation converges to the following equation:

$$\partial S / \partial t = \omega^2 / k \, \partial (x S) / \partial x + A^2 T / m^2 k^2 \, \partial^2 S / \partial x^2 \qquad \textbf{(8.2.4.a.3)}$$

called *Fokker-Plank's equation for the Ornstein-Uhlenbeck process* (Uhlenbeck & Ornstein, 1930; Wang & Uhlenbeck, 1945). Both equations consider the same concept, but the differential one is much more convenient to handle analytically.

Dunn & Gipsen (1977) and Dunn (1978) have proposed a multivariate centrally biased diffusion process as a useful model for the study of home range. The model is characterised in terms of some typical descriptive properties of home range, such as activity centre, activity radius and distributions of turning angle and displacement. An extension of this approach was carried out to test for territorial interaction between two or more individuals in the case of deer, coyote and birds using telemetry data (Okubo, 1980).

Siniff & Jessen (1969) simulated the movement of an animal in its home range on the basis of telemetry data for red foxes (*Vulpes fulva*), snowshoe hare (*Lepus americana*), and raccoons (*Procyon lotor*). The telemetry data were obtained from the University of

Minnesota's Cedar Creek automatic tracking system, which continuously monitors the movements of animals carrying miniature radio transmitters (Cochran *et al.*, 1965).

Korschgen *et al.* (1996) used radio-tracking data to investigate the magnitude, timing, and causes of mortality of the canvasback duckling (*Aythya valisineria*) from hatch to fledging at the Agassiz National Wildlife Refuge (NWR) in north-western Minnesota. The survival rate was estimated with the *Kaplan-Meier non-parametric estimator* (Kaplan & Meier, 1958) and the Weibull survival parametric model. The resultant plots of log{-log[S (t)]} against log (time) from the Kaplan-Meier procedure were generally linear, indicating that a Weibull survival model would adequately fit the data. The LIFETEST module of SAS (SAS Inst. Inc., 1989) was used to fit the Kaplan-Meier curves and the LIFEREG module of SAS (SAS Inst. Inc., 1989) was used to compute estimated parameters of the Weibull survival model. In general, parametric models provide more precise estimates of survival (Miller, 1983; Klein & Moeschberger, 1989).

Otis (1994), in his studies on wood duck (*Aix sponsa*) populations, developed a statistical methodology for computing optimum allocation of banding effort to examine which two banding periods per year were more appropriate**.**

French and Reed (1989), French *et al.* (1989) developed a simulation model of seasonal migration based on daily movements of fur seal (*Callorhinus ursinus*). This migration model is useful both in understanding the movements of fur seals and in identifying where they are vulnerable to impacts following interaction with the results of man's activities. The model has been used to estimate impacts resulting from hypothetical oil spills in the Bering Sea. The model could also be used to estimate impacts of other localised pollutants or entanglement in marine debris. VHF, ultrasonic tags and satellite-link transmitters have been used to study distribution and movements of grey seals (Hammond *et al.,* 1993). System Argos provides access to information on the location of the transmitted signals and their quality, and any other data that have been transmitted. Information on locations and tracks is cross-referenced to other data to indicate periods of foraging and other behaviours (Thompson *et al.,* 1991).

8.2.5 Population parameters and species interaction

Populations are susceptible to changes in their physical and biological environment that may affect their productivity. Climatic changes my lead to variation in stock parameters and the appearance and disappearance of prey and predator species - caused by man or nature - may profoundly affect harvest levels. Representative pictures of these variations are difficult to monitor, and tag-recapture programmes might in future improve studies, particularly if new technology is fully utilised.

(a) Population parameters

During the past 30 to 35 years, much literature has appeared on the estimation of population parameters based on capture-recapture sampling. Burnham et al. (1997) has considered the general theory for the analysis of multiple interrelated release-recapture data sets. Starting from statistical concepts, they have considered the following relevant points:

- protocols for studies with a control and one treatment
- theory for studies with two or more treatments
- the importance of replication
- the properties of procedures
- the importance of planning the experiments

Burnham *et al.* adopted Maximum Likelihood Theory to estimate survival rates, components of variance, and non-linear regression to estimate values for the Von Bertalanffy model of growth parameters (Green *et al.*, 1990).

The dispersal of animals can be classified as random dispersal or density dependent dispersal, which is particulalry important in relation to *population dynamics* (Ito, 1975). The relationship between animal dispersal and population density has been studied extensively with insects (Okubo, 1980). Morisita (1950) ascertained a relation between animal dispersal and population density in natural populations of water striders. Similar relations were also recognised in experiments with aphids (Ito, 1952) and rice weevils (Kono, 1952), from which it was concluded that for each species there is an associated population pressure that enhances population dispersal. Later Morisita (1954) attempted to quantify this population pressure by experimentally releasing ant lion larvae (*Glenuroides japonicus*) from a point and observing their dispersal. The movement pattern of individuals was classified as one of two types:

- individuals which dug holes in the vicinity of the realise point (normal individuals)
- individuals that dug holes after having travelled large distance from the release point (abnormal individuals)

Morisita’s empirical formulae appear to be of general applicability in describing the time variation of the variance for insect dispersal from a point source and may possibly be applicable to fish under some circumstances.

The relationship between population density and dispersal behaviour is significant when viewed from the standpoint of social processes in communities (Ito, 1961) and Andrewartha and Birch (1954) also assign great importance to dispersal as a reaction to crowding. Overpopulation does not necessarily lead to dispersal, however. A unique characteristic of the Regional Organism Exchange (ROE) model (Reyes *et al.*, 1994) is the combination of the migration equation with more classical population parameters (Hardin, 1960).

(b) Interaction between species

It is well known that in a real ecosystem the importance of interactions between all the species cannot be overlooked, in particular in the case of predator-prey relationships. One method to estimate the various contributions of stock compositions to multiple and mixed stock fisheries is to measure differences in natural biological characteristics such as age composition, egg diameter, and parasites. Mark-recapture studies can also provide information on the stock composition of the catch. Monte Carlo methods are adopted to evaluate changes in variability and bias caused by changes in tagging rate, catch sampling rate, catch level, stock abundance in the fisheries, and distribution of stocks across fisheries. The overall variability in the Monte Carlo estimates can be surprisingly high and depend principally on variation in tag recovery and distribution of probability of harvest across the species and catch strata.

Random walk models do not normally take into account interactions between individuals and species (Schwarz & Poland, 1975), although exceptions exist (see e.g. Shigesada & Teramoto, 1978). This mathematical model of advection and diffusion can explain the spatial distribution of animal populations that are principally controlled by interference between individuals and other environmental conditions. The formulation is based on the assumption that animals move under the influence of the following fundamental forces:

- a dispersive force associated with random movement of animals
- an attractive force, which induces directed movement of animals toward favourable environments

- population pressure due to interference between individual animals

The DYNUMES model of Pola (1985) is a numerical simulation model of fish migration in the eastern Bering Sea. This multi-species, numerical ecosystem simulation model has a spatial resolution of 63.5 km. Migrations are simulated by redistributing the biomass over the grid and primed by biological and environmental factors such as temperature. In this model the redistribution of biomass for both types of migration is computed using a finite difference advection equation (Laevastu, 1976).

8.3 REQUIREMENTS AND RECOMMENDATION

8.3.1 Experimental design

(a) Release errors

Representative distribution of tags in the population is essential for stock assessment studies. This can be obtained either by mixing of tags through migration and movements or through a systematic design for the release program. The extent of the problem may be species or stock specific and thorough population studies are needed for designing proper tagging experiments

> *Recommendation*: Work is required to develop and use methodology (e.g. simulation studies) to optimise the design of tagging experiments. The goal is to achieve an unbiased estimate with a specified level of precision.

(b) Tagging mortality, tag losses

Variations in tagging mortality rates and tag losses can seriously bias population studies and should be taken into account in data analysis. Tagging methods that have less effect on the health and behaviour of the fish are desirable.

> *Recommendation*: Experiments should be undertaken to identify the effects of tagging on fish before undertaking large-scale tagging operations. Development of tagging methods less harmful for the fish (e.g. underwater tagging) is required.

(c) Recapture errors

Full and precise information on the recaptures is required to achieve the desired results. Most assessment models rely on detailed catch statistics to upgrade recapture results to population estimates.

> *Recommendation*: Tagging programmes should be widely advertised. The validity of recapture data should be controlled by developing and using control routines in the recapture database. Improvements should be made to the precision of catch statistics used in conjunction with tagging data.

8.3.2 Requirements related to assessment of abundance and mortality

(a) Mass tagging

The precision of the assessment results obtained from tagging studies is dependent mainly upon the number of tags recovered. One way to improve precision is therefore to increase the number of tagged fish released, but this may increase the costs of the programme unacceptably. Clearly, the development of alternative methods for mass-marking large numbers of fish, preferably with less effect on individuals, would be advantageous. Mass marking (adipose finclipping and/or coded wire tagging) of salmonid smolts has been shown to be practical with the recent development of an automatic smolt tagging machine (http://www.nmt-inc.com).

> *Recommendation*: Consideration should be given to the development of mass marking methods to achieve more precise population assessments. The use of genetic and chemical marks, which may be introduced, or which may occur naturally in populations, should also be considered.

(b) Recovery

In the past many studies have underestimated the importance of maximising the recovery of tagged fish.

> *Recommendation*: The development of new marking methods must clearly give considerable attention to optimising recovery programmes and to methods of improving public awareness of the benefits of such programmes. In the case of genetic and chemical marks, it may be possible to develop mass-screening methods.

(c) Guidelines for modelling

Whilst there is an extensive literature on modelling and assessment methods, there is no up-to-date and user-friendly guide to recent developments in the field.

> *Recommendation*: The preparation of guidelines on theoretical approaches and assumptions in modelling would encourage the use of modelling methods in stocks assessment and help to ensure a higher standard of work in many areas. Such guidelines should include advice on the use of sensitivity analyses in developing project proposals and analysing results.

(d) Catch statistics

Catch statistics provide a major input to many models and particular efforts are therefore required to ensure that these reflect, as accurately as possible, the true size and distribution of fishing mortality and landings.

> *Recommendation*: Work is required to further assess methods for estimating the accuracy of reported catch data and levels of non-reporting.

(e) Freshwater survey methods

Assessment modelling for fish stocks in freshwater may be restricted by the difficulties of surveying large river systems. In the case of salmon this makes it difficult to model stocks which have a high proportion of multi-sea-winter returns. Studies of species that only occur in large systems (e.g. sturgeon) or that have different types of populations in rivers of different sizes (e.g. salmon) are desirable.

> *Recommendation*: More work is required to address the problems of surveying fish stocks in large rivers utilising the potential of modern tagging techniques.

(f) Population structures

In the past, many assessment methods have ignored the effects of population and sub-population structures. However, there is an increasing awareness that such structures may be important in the biology of certain species.

> *Recommendation*: There is a need to conduct genetic and other studies to describe the role of population and sub-population structure for particular species. Modelling of fish behaviour, movement and migration.

8.3.3 Modelling of fish behaviour, movement and migration

(a) Cost efficient development

More extensive international co-operation is needed both to avoid repetition of experiments that have already been already done and to promote wider programmes of research to obtain global results. The establishment of a Web Page within this field could be a useful development.

> *Recommendation:* Develop an international network to co-ordinate effort within modelling in tagging through a Concerted Action and/or development of a Web Page solution (e.g. through further development of the CATAG Web Page).

(b) Model validation and experimental design

> *Recommendation:* Existing models need to be reviewed and sensitivity analyses carried out to establish the range of accuracy of models based on tagging programmes, particularly where specific fishery advice is being given (ICES, NASCO, ICCAT etc.). Experimental design must take specific analyses and models into account.

(c) Migration and behaviour

Data storage tags provide large amounts of information on the behaviour of individual fish and their immediate environment. Such data can fuel the development of a new generation of migration and behaviour models, which have great potential for improving stock assessment and management.

> *Recommendation*: Encouragement should be given to the development of individual behaviour based models using information from well-designed data storage tag experiments, integrated where possible with data from traditional mark-recapture experiments.

(d) Pollution – migration and behaviour

Knowledge about effects of pollution on fish behaviour, migration and mortality is scarce. In future such information will be important for evaluating the impact of pollution on fish stocks.

> *Recommendation:* Dedicated models describing the behaviour of populations in relation to pollution need to be developed as a tool for monitoring effects of pollution on marine life and as a way of predicting potential impacts of large-scale marine developments prior to their establishment.

(e) Data Fusion

Electronic tags can provide environmental, geographical, and physiological information regarding the fish and its environment. Electronic tags, in particular DSTs, can offer data on the dynamics of physical processes that are fundamental to studies of migration and behaviour. Environmental monitoring and modelling approaches to treat such data are well established. Methods which co-ordinate and integrate data from tagging and environmental data in a systematic and coherent way (data fusion) are essential to exploit existing models, develop new approaches and maximise the benefits of expensive tags. Such work will also be important for geographical positioning of tagged fish in a monitored environment.

> *Recommendation:* Develop methodology for data fusion as tool to derive maximum benefit from electronic data storage tags. This requirement applies to environmental data (e.g. temperature, light, primary productivity, ocean currents) obtained from satellites, marine surveys, observation buoys or by other means.

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9. FUTURE

9.1 PERSPECTIVES

Tagging is a long-established tool in biology, and is economically valuable for European aquaculture, fish husbandry, stock assessment and fisheries management, as well as for commercial enterprises that provide tag technology. Traditional methodology is dependent on catching and handling fish before release and recovering a proportion of the tags through commercial and recreational fisheries. Challenges to the use of these procedures include substantial uncertainty about the survival and welfare of the fish and recovery of reliable data. There are also doubts as to whether data obtained from a relatively small number of individuals are representative of the population at large. Quantitative use of tagging data therefore requires a set of assumptions, which are difficult to control. Technological, biological and mathematical developments considered in this Concerted Action will help to meet these challenges. In any case, it should be recognised that tagging can provide assessments that are independent of many of the serious problems associated with other methods. Tagging is also an obvious tool in aquaculture and ranching programmes, where strict control of the cultured population is essential to avoid adverse affects on natural populations.

Investment in new development has been limited, probably because of the uncertainties associated with traditional tagging methods. Electronic tag technology generally has a limited market due to restricted application of this technology to date. Public funding and pre-market investment are therefore essential to rapid and sustained progress. Modern technology has already opened up exciting new possibilities by developing: (a) sophisticated electronic tags which can collect large amounts of data on individual fish over long periods; (b) small ‘smart’ tags for mass tagging; and (c) automatic tagging techniques, which may remove substantial uncertainty connected with fish survival and welfare. Because of the pace of technological developments in IT, microelectronics and nanoengineering, it is impossible look beyond a technical horizon 3-5 years away. As discussed in the previous chapters, the full potential of these new developments has yet to be recognised. Despite this under-utilisation, these techniques already have the potential to collect information far more economically than is feasible by conventional means. To elevate tagging to the status of a reliable and recognised tool for collecting quantitative fish population assessment data, as well as detailed biological and behavioural information, an integrated and aimed investment programme is needed over a period of at least 5 years. Retention and expansion of the tagging network established during CATAG is also highly desirable for maintaining momentum, ensuring efficient utilization of limited development costs, and establishing technological standards in this field. From a European perspective it should also be noted that tagging is much more widely employed in northern Europe than in southern Europe or the associated Atlantic islands. Positive action is needed to encourage tagging initiatives in these southern ecosystems.

9.2 RECOMMENDATIONS/REQUIREMENTS

CATAG participants have identified many areas of tagging applications, methods and technologies that need stimulation and financial support. The following recommendations have the highest priority. More detailed recommendations may be found at the end of each of the chapters produced by the four working groups.

9.2.1 Communication and training

- The CATAG website should be maintained and developed, as an educative as well as a research tool. This will require funding, and it is recommended that the EU considers means by which this support might be provided
- Workshops are needed to encourage exchange of ideas amongst oceanographers, fisheries biologists, engineers and veterinary scientists
- Practical training courses for fish tagging, handling and anaesthesia are required

9.2.2 Technological improvements

- Data storage tags need more memory and longer life; PIT tags need more range. Sensors need to be smaller and able to measure a wider range of variables (including physical data such as compass heading, tilt angle and acceleration and biological parameters such as growth and feeding rates and blood hormone levels)
- More reliable methods of estimating geographical position for fish fitted with data storage tags are urgently required. Indirect methods (e.g. sequentially released pop-up tags) and direct methods (e.g. geomagnetic sensors) need to be investigated, further developed and tested
- Automated mass tagging and in *situ* submerged tagging (especially for deep-water fish) are both highly desirable technologies requiring further development to improve efficiency and quality of assessments
- Development of tags to collect information about feeding rates and prey preferences for fish predators should have a high priority as part of developing an ecosystems approach to fisheries management

9.2.3 Biological improvements and fish welfare

- Evaluation of the effects of capture stress, handling and pre-release treatment of tagged fish, together with systematic study of the effects of tags upon fish behaviour and swimming performance should be given a high priority
- Tagging methods, including use of novel anaesthetic procedures (e.g. hypothermia), should be evaluated and optimised. New techniques should ideally be preceded by effective feasibility studies
- Improvements in anti-fouling and anti-inflammatory performance of tag materials are needed

9.2.4 Data collection, handling and modelling

- It is recommended that user guidelines be established for theoretical approaches and assumptions in modelling. Clarification and quantification of underlying assumptions in quantitative application of tagging data (e.g. about tagging mortality, tag shedding, mixing of tagged and untagged populations) is required
- Development of techniques of data fusion (combining data from tags, scientific surveys, fisheries and environment [GIS systems]) should have a high priority. Further, encouragement should be given the use of this type of information for the development of individual based models in fisheries science

9.2.5 Legislation

Tagging for husbandry should be removed from legislative control and not require expensive and unnecessary training of operators. EU harmonization of legislation and its implementation is highly desirable.

10. THE CATAG WEBSITE (http://www.hafro.is/catag)

Welcome to CATAG web-site

Concerted Action for Tagging of Fishes

CATAG

- Improvements in tagging methods for stock assessment and research in fisheries

This web-site is being maintained by Marine Research Institute - Iceland

Supported by the European Commission

10.1 WEBSITE FUNCTIONS

10.1.1 To reflect the work of the CATAG group

The CATAG group collaborated for 30 months with the objective of improving methodologies used in tagging experiments for use in fisheries research and fish stock assessment. The results have been disseminated in reports to the EU, a special scientific report for publication and the website **http://www.hafro.is/catag** which provides access to all of this material (including the final report in html form).

10.1.2 To provide practical information on tagging or marking of fish

The participants in CATAG have considerable expertise in all aspects of tagging, reinforced by their network of European colleagues and collaborators. This information has been categorized and made available on the website. CATAG participants have used their knowledge to disseminate practical instructions in easily accessible form. In addition, users of the website are provided with access to details of commercial equipment suppliers, usually reached via hyperlinks.

10.1.3 Provision of tools for scientists using tagging experiments for fisheries research

Several databases and collated sources of information are mounted on the website with the express intention of facilitating scientific research. These include descriptions of the most-frequently used mathematical models that incorporate results from tagging programmes. There is also a database of ongoing tagging experiments to help researchers avoid duplication and seek cooperation. Detailed evaluation of anaesthetics and surgical procedures employed in the use of electronic tags is given in the Welfare database. Legislative implications of tagging work with fish are considered on a country-by-country basis to ensure that scientists are aware of their legal obligations.

10.1.4 To provide a communication platform or pathway

The website includes a database of contacts, made up of a list of people who have been connected in any way with the CATAG project or its website. This growing list is in the form of an ORACLE database located at, and supported by, the Marine Research Institute at Reykjavik. The database can be searched for institutes, names of contacts, communication details and fields of scientific interest. There is an entry form attached to it so that new contacts can be added at any time. On the website there is also a conference board which permits on-the-Web discussions.

10.1.5 To educate

The WorldWideWeb is now an established teaching medium with no rules about who may access it or download material from it. The CATAG website delivers publicly available information that may be used by schoolchildren, tertiary students, professional fishermen, amateur anglers, legislators or expert researchers alike. Some of the information may also be useful to scientists for whom tagging itself is of marginal interest. However, a particular educational requirement is that those who become involved in tagging programmes should first undergo training (this is already a legal requirement in some countries within the EU as far as fish welfare is concerned). The website provides a good forum for the organisation of such courses and has much relevant study material online.

10.2 WEBSITE STRUCTURE

The web-site structure is self-explanatory to those who access and browse it, but a brief overview of its features is given here. Below is a hierarchical list of headings and heading subdivisions that outlines the structure of the web-site:

- **About this web-site**
    - **What this web-site provides**
    - **About the CATAG project**
    - **Responsibility**
    - **Construction**
- **Tags and tagging**
    - **Tag and mark types**
        - **External tags**
        - **External marks**
        - **Internal tags**
        - **Internal-external marks**
        - **Electronic Tags**
        - **Genetic Marks**
    - **Tagging methods manual**
        - **Some descriptions of tagging methods**
    - **Applications, analysis and modelling**
        - **General concerns**
        - **Applications**
        - **Data analysis and modelling**
    - **Database of tagging experiments**
        - **Entrance page for survey and survey-database**
            - **Search**

            - **Submit a form (questionnaire)**
            - **Help on filling out the form/questionnaire**
    - **Search facilities for recaptures**
        - **Entrance page for search facilities (Tags released - by institutes)**
    - **Recommendations made by the CATAG-group**
        - **Future scenario and recommendations (From chapter 9 final report)**
        - **Recommendations from group A, working on conventional tags and tagging**
        - **Recommendations from group B, working on electronic tags and tagging**
        - **Recommendations from group C, collecting information on legislation in Europe**
        - **Recommendations from group C, working on welfare of fish on tagging experiments**
        - **Recommendations from group D, working on data analysis and modelling**
- **Legislation concerning tagging or marking of fish**
    - **Legislation and tagging (from chapter 6 in final report)**
- **Contacts**
    - **Project participants.**
    - **Contacts. (A database of names of scientists and institutes who have been in contact with CATAG project).**
        - **Contact database - entrance page**
            - **Search**
            - **Add a new contact**
            - **Help**
- **Producers and suppliers**
    - **Producers and suppliers in the field of tagging or marking**
- **Health and welfare**
    - **Health and welfare (of fish in tagging or marking experiments)**
        - **Health, behaviour and welfare documents (from CATAG report)**
        - **Tables of results from studies**
        - **Database on welfare**
- **Reference section**
    - **Reports of the progress of the CATAG-Project (1997-2000)**
        - **i) Abstract of the Midterm Report May 1998**
        - **ii) Consolidated Midterm Report May 1998**
        - **iii) Final report of CATAG to the EC, Abstract (Downloadable)**
        - **iv) Final report of CATAG to the EC, Executive summary**
        - **v) Final scientific report of CATAG to the EC (Downloadable)**
    - **Some international reports and presentations of interest**
        - **i) International Council for the Exploration of the Sea (ICES), papers and reports.**

11. Annex 1: Alphabetical list partners in FAIR CT.96.1394 CATAG

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Þessi listi er einnig á Netinu
(This list is also on the Internet)

http://www.hafro.is/Timarit/fjolr.html

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