Potential use of biotelemetry in tropical continental waters

Charles H. Hocutt (1), Scott E. Seibold (2),
Roman V. Jesien (1)

ABSTRACT

Biotelemetry technology has been used extensively to research fisheries and wildlife management issues in the Northern Hemisphere, but has been virtually ignored as a tool by freshwater and anadromous fisheries managers in Africa. Radiotelemetry, particularly, has several advantages over conventional tagging programs as a means to gather life history information on targeted species, e.g. home range patterns, migratory habits, seasonality of behaviour, homing instinct, preferred spawning or foraging areas, or response to natural or man-related alterations in the environment. Notably, telemetry-tagged fish do not have to be re-captured to obtain valuable behavioural data in a relatively short period of time. This paper discusses the prospects of use of biotelemetry as a research and management tool, and notes the limitations of the technology. Examples are drawn from the literature and personal experience. It is viewed that the promotion of this technology in Africa will significantly enhance data gathering efforts on representative species.

KEYWORDS: Behaviour — Biotelemetry — Fisheries — Home range.

RÉSUMÉ

LA BIOTÉLÉMÉTRIE DANS LES EAUX CONTINENTALES TROPICALES

Les techniques de biotélémétrie sont largement utilisées dans les études sur les pêches ou la gestion de la faune sauvage dans l'hémisphère nord, mais ont été particulièrement ignorées par les gestionnaires des pêcheries anadromes continentales en Afrique. La radiotélémétrie, en particulier, présente certains avantages par rapport aux techniques classiques de marquage pour collecter des informations sur le comportement d'espèces cibles, comme par exemple la distribution de l'habitat, les migrations, la saisonnalité du comportement, les zones d'alimentation ou de ponte, ou bien la réponse à des modifications naturelles ou artificielles de l'environnement. En particulier, la télémétrie de poissons marqués n'impose pas la recapture des individus pour obtenir des données de comportement sur une période assez courte. Cet article présente les possibilités d'utilisation de la télémétrie comme outil de recherche et en donne les limites. Les exemples sont issus de la littérature et d'une expérience vécue. Le développement de son utilisation pourrait améliorer la collecte de données concernant un certain nombre d'espèces.

MOTS CLÉS : Comportement — Biotélémétrie — Pêcheries — Territoire.

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(1) *University of Maryland Eastern Shore, Princess Anne, MD 21853, USA.*
(2) *Posthumously.*

INTRODUCTION

Knowledge of the life history and home range requirements of resident and migratory fishes is a priority need to establish effective management strategies of a fishery to insure its sustainability. This is a critical issue in Africa and other tropical regions where indigenous communities often live at the subsistence level, and rely either directly or indirectly on the local fishery as a means of supplementing their income or protein requirements.

Conventional tagging programs, although valuable in their own way, often require long-term tagging/large scale efforts of literally tens of thousands of fishes to be an effective measure of a species' habits. High technology hydroacoustic surveys (MacLennan and Simmonds, 1992) are particularly valuable in determining stock concentrations, with inferences on standing crop; however, the technology is limited in discerning migratory behaviour unless labor intensive, and phenomena such as home range, homing, and annual iteroparity can not be addressed at all. Biotelemetry offers an extremely viable option of monitoring target fish species in African waters to study their daily and seasonal behaviour, or to evaluate their migration patterns and home range requirements.

Much of the experience with biotelemetry in the Northern Hemisphere and on the African continent has been with terrestrial wildlife species (Kenward, 1987; Priede and Swift, 1993), such as black bear (Craighead *et al.*, 1971) and lion (Van Orsdol, 1982). However, the use of telemetry in aquatic applications was being considered by the late 1950s. Trefethen (1956) and Johnson (1960) pioneered the application of biotelemetry to aquatic organisms, employing ultrasonic techniques, while MacKay (1964) was apparently the first researcher to use radiotelemetry. The available literature on aquatic biotelemetry has steadily increased, with reviews being provided by Stasko and Pincock (1977), Winter (1983), Baras (1991), Priede (1992) and Baras and Philippart (1994).

Telemetry has been used in recent years in North America to explore a number of fisheries research questions, relative to species-specific management strategies or the influence of environmental variables on their behaviour. By way of example, Summerfelt, Mosier (1976) and Dudley *et al.* (1977) employed telemetry to track striped bass *(Morone saxatilis)* to their spawning grounds. Coutant and his co-workers employed similar techniques to examine the thermal requirements of striped bass in Tennessee reservoirs (Coutant, 1985; Coutant and Carroll, 1980; Cheek *et al.*, 1985). Spigarelli *et al.* (1983) correlated movement of brown trout *(Salmo trutta)* to depth, velocity and temperature gradients. Seibold (1992) evaluated the homing behaviour of largemouth bass *(Micropterus salmoides)* displaced from their site of capture during fishing tournaments. There are countless other examples on the employment of biotelemetry in fisheries research in developed countries involving numerous species with Emery and Wydoski (1987) and Baras (1991) listing about 1,100 references on more than 100 species. However, Hocutt (1989a, 1989b) and his student Mabaye (1994) have been the only scientists to demonstrate that the technology has equal value for assessing basic fisheries management issues in sub-Saharan Africa.

The purpose of this presentation is to promote the use of telemetry technology as a tool for use by fisheries investigators in sub-Saharan Africa, and other tropical regions. An overview of biotelemetry technology is presented, including methodologies, application procedures, advantages and limitations. The discussion considers applications in both fresh and brackish water environments.

BIOTELEMETRY

There are two generally-recognized methodologies employed for studying aquatic animals *in situ*, radiotelemetry and ultrasonic techniques, although variations of each have been used as conditions dictate.

Radiotelemetry

Advantages

The application of radiotelemetry to the study of aquatic vertebrates lagged ultrasonic technology (Trefethen, 1956). However, the advantages (Annex 1) of radiotelemetry over ultrasonic techniques are sufficiently numerous that the latter methodology is now virtually limited to conditions of study where high water conductivity/salinity or great depths interfere with radio-wave transmission and reception (Stasko and Pincock, 1977; Solomon, 1982).

Major advantages of radiotelemetry include (1) the receiver and antenna can be located entirely in air, including use on airplanes or for detection through ice in temperate zones; (2) radio-signals are virtually unaffected by turbulence, algae, or macrophytes in the water, which cause dramatic decay or interference with sonar signals; (3) the higher radio-frequencies permit a wider bandwidth for information retrieval, as well as facilitating the identification of a particular transmitter where several are used; and (4) radio-tags have lower power consumption, thus allowing smaller lighter packages with longer life. There have been significant advances in battery life, electronic technology, and attachment procedures in recent years, to the point that larger species may carry transmitter packages with life spans greater than two years (e.g. HOCUTT *et al.*, 1990).

The feature of being able to track radio-transmitters through surface-based receivers can not be overemphasized. This permits the rapid covering of a very large area when aircraft are employed for tracking; additionally, the transmission of radio signals through air (as opposed to water) facilitates reception due to the nearly direct line between antenna and receiver (GILMER *et al.*, 1981). Even boat-based tracking is significantly facilitated by this capability, which considerably reduces time, manpower and financial constraints. This is opposed to tracking acoustic transmitters which can require one to become completely stationary with boat engines cut off prior to being able to make an accurate directional heading. However, it should be noted that there is likely to be serious attenuation of radio signals in areas of dense vegetation mats, floating islands, circuitous meanders of the river channel, inundated forest floodplains, dense forest canopies, and montane reaches where signals are reflected by landscape topography, as can be encountered in tropical countries.

Although a major disadvantage of radiotelemetry is that the technology is ineffective in saline waters, HOCUTT *et al.* (1990) demonstrated that it could be used successfully to research the behaviour of anadromous striped bass on the freshwater component of their home range. Similarly-designed studies have applicability in African coastal waters, since the freshwater environment represents the most crucial habitat to formulating a management strategy of anadromous fishes, i.e., the habitat critical to reproduction. There is little literature documenting the affects of conductivity/salinity on radio-frequency transmission/reception; however, our experience indicates that 800-1,000 μmhos represents a threshold of effectiveness for transmitters operating in the 48-52 MHz band.

FREQUENCIES

The radio frequency of 104.6-105.0 MHz has been allocated for use on aquatic organisms in the United Kingdom (SKIFFINS, 1982), but there have been trials to shift the frequency band down to 49 MHz (ARMSTRONG *et al.*, 1988). In North America, radio-transmitters for fish commonly operate in the 30-52 MHz range; while these frequencies are not as acceptable to interference as higher frequencies, common domestic cordless telephones operate at the same frequency. Higher wave lengths such as 148-150 MHz attenuate more rapidly in water than lower wave lengths, but broadcast further in air, hence they are used more often for terrestrial wildlife research (WHITE and GARROTT, 1990). Radio-transmitters operating at 48-52 MHz at modest depths (<5.0 m) and conductivity (<200 μmhos) normally can be received up to 2 km by a boat-based receiver, or 5 km from an airplane. If designing a study, some African catchments provide the conditions for use of higher wave lengths, i.e., relatively shallow depth, low conductivity, and the lack of radio-transmission "noise" common to urban areas.

Higher frequencies have the advantage of smaller reception antennas for the same gain. For instance, a yagi directional antenna of 10 decibel (dB) gain is 5.2 m long at 50 MHz, but only 1.7 m long at 150 MHz (BURCHARD, 1989). This is an important consideration whether using a boat, vehicle or airplane-mounted receiving system.

Radio-transmitters typically operate at a particular frequency with a specific pulse rate, e.g., 48.230 MHz at 50 pulses per minute. However, if a large number of animals are tagged, scanning time of all the frequencies being searched for can be reduced by 50 % simply by having two fish on the same frequency, each at a different pulse rate, e.g., 50 and 70 pulses per minute. One manufacturer of radio-tags (Lotek Engineering, Inc.) reports that it now produces transmitters with encoded signals that permits the tracking of about 200 individuals on the same frequency. This is very important if tracking a large number of fish by airplane given the rate of speed of travel, and the prospect of missing a fish if frequency scanning is required.

Ultrasonic technology

STASKO and PINCOCK (1977) thoroughly reviewed acoustic telemetry, and the technology remains basically the same (BAGLEY, 1992). Ultrasonic telemetry is based on the fact that low frequency sound travels for substantial distances underwater, with range of tags being up to 1,000-1,500 m. Tags usually operate at frequencies of 40-300 kHz and have a life of about 1 year. Fish are typically tagged on the same frequency, and are distinguished by the pulse rate assigned to a particular individual, e.g., on three pulses and off three pulses. This last factor means that the number of fish that can be effectively tagged on any given frequency is limited, which in turn might restrict study objectives. Reception can be reduced by temperature-induced refraction, hence time of day; thermoclines; salinity gradients and chemoclines; depth; vegetation including plankton patches; turbulence and air bubbles; extraneous noise; and physical obstacles. Additionally, a hydrophone coupled to a receiver is required for signal detection, eliminating rapid tracking either by boat or airplane. The major advantages are that acoustic systems operate in marine/brackish water conditions and have greater depth ranges that radio-transmitters. BAGLEY (1992) summarized the state-of-the-art for monitoring deep-sea fish using transponding tags, which are activated upon receipt of a ship-based interrogating sonar. MACLENNAN and SIMMONDS (1992) provide detailed information on signal propagation, absorption and scattering of acoustic signals.

Hybrid systems

"Hybrid" tags combining both ultrasonic and radio transmission capabilities have been developed in the United Kingdom (ARMSTRONG *et al.*, 1988; SOLOMON and POTTER, 1988), thereby permitting the tracking of fish in both brackish and fresh water environs. This has particular utility for diadromous species which move from one salinity regime to another, e.g., to spawn. Optionally, larger specimens could be dual tagged with both types of transmitters, but this would double the equipment cost of a study.

Satellite telemetry

Satellite tracking, a form of radio-tracking, was first applied to black bear (CRAIGHEAD *et al.*, 1971) and elk (CRAIGHEAD *et al.*, 1972). Since that time, transmitters have become significantly smaller and lighter in weight, and have been used on a number of species including birds, terrestrial mammals, cetaceans, sea turtles and sharks, using the TIROS/ARGOS satellite system (WHITE and GARROTT, 1990). From satellite telemetry, the term "platform terminal transmitters", or PTT tags, was coined. However, satellite position data is not without its limitations, and may be inconsistent if not inaccurate (LOTEK, 1990). Additionally, satellite systems *per se* have little application at this date for fisheries studies unless used in concert with fixed position receiver/transmitter packages, perhaps similar to the system used by O'DOR *et al.* (1989) for snow crabs (*Chionoecetes opilio*).

PROSPECT OF THE USE OF BIOTELEMETRY IN DEVELOPING COUNTRIES

The results of HOCUTT *et al.* (1990) have direct bearing on this presentation. They reported a >40 % return rate of radio-tagged anadromous striped bass to their spawning grounds in Chesapeake Bay tributaries (USA) after one year at sea, as compared to less than a 5 % return rate of over 100,000 adult striped bass in a conventional tagging program conducted over a six-year period along the Mid-Atlantic Coast of North America. This led the authors to conclude "... that biotelemetry represents a technological advance over conventional mark-recapture programs, i.e., an individual does not have to be recaptured, only detected" to provide valuable migratory information.

From a developing country context, conventional tagging of fishes has often been totally ineffective producing no tag return information. The ineffectiveness of conventional mark-and-recapture programmes can be attributed to any of several reasons (on a case by case basis), such as : (1) the long distance of the fisheries staff away from the waters being researched; (2) the lack of qualified staff to conduct labor intensive, and extensive, mark-and-recapture studies; (3) the dearth of information, and hence a lack of understanding, of the daily and seasonal behaviour of target species influencing their home ranges; (4) a void of knowledge on the relationship of environmental parameters, such as flooding, on the longitudinal, lateral or vertical migration of fishes, and their seasonal activity centers; (5) the risk of capture of tagged fishes in subsistence/artisanal fisheries, combined with the illiteracy of indigenous persons to assist in tag return information; and (6) the changing priorities of fisheries administrations, often dictated by the political or economic climate, which do not permit the continuity required for detailed longer-term investigations.

Conventional tagging programs definitely have value for addressing certain fisheries management/research needs; however, despite sharing some of the constraints noted above, biotelemetry offers several distinct advantages for developing countries (Annex 2). For instance, in telemetry studies (a) manpower requirements and time are minimized to provide valuable information on the migratory habits and ecology of targeted species; (b) fewer individuals need to be tagged to obtain robust data since they need only to be detected, not recaptured; and (c) the wealth of data which can be obtained from tracked fish is limited only by the time a researcher can spend tracking on a day-to-day basis, while conventionally tagged fish usually provide information only on time at large and place of recapture. For these reasons, the employment of biotelemetry has great potential for addressing fundamental questions about the ecology and life history requirements of many species in Africa and other tropical waters. The primary disadvantages are the initial cost of telemetry equipment, the expense of aerial surveys if required, and the need for one or two specially-trained individuals; however, these concerns might be outweighed by either (1) the urgent need for specific data requirements, or (2) the availability of donor funding.

In summary, telemetry is not a new technique *per se*, with its first fisheries application dating to the mid-1950s; however, its use in fisheries studies in less developed countries (LDCs) is virtually non-existent. The research of HOCUTT (1989a, 1989b) and MABAYE (1994) established the efficacy of employing telemetry to fisheries studies in sub-Saharan Africa. Elsewhere, MOCHEK *et al.* (1990) used telemetry in Peru, and Orstom scientists are mounting a major program in French Guiana. Considering the relative ease of learning the technology application, and the (often) immediate need for life history information on tropical fishes, the promotion of the telemetry for use in tropical waters is strongly recommended. This latter point is pertinent, given the accelerated environmental alteration being experienced in many emerging nations (HOCUTT *et al.*, 1992a), and the consequential need for species-specific data on a short-time scale.

TECHNICAL PROCEDURES

A growing concern over the care and welfare of animals, especially mis-used and abused primates and other mammals, led to the passage of the Animal Welfare Act (Public Law 89-544, as amended 94-279) in the USA and the development of guidelines for the care and use of animals in laboratory research (USDHHS, 1985). Although the use of animals in field research places different constraints on the researcher, guidelines have none-the-less been developed for fishes and other aquatic vertebrates (ASIH, 1987a, b; SCAW, 1988). The presentation of protocols for the capture and handling of wild and laboratory experimental animals is an expected portion of proposals which seek donor funding in the USA. While similar guidelines are largely lacking for developing countries, and apart from the moral and professional obligations involved, it is imperative that animals employed in telemetry studies be subjected to minimal trauma. For this reason, researchers should follow appropriate guidelines and procedures for handling fishes.

Anesthetics

An excellent review of anesthetics for fishes is presented by SUMMERFELT and SMITH (1990), and condensed here. Over 50 different chemicals and drugs have been used as fish anesthetics, but many are in disuse due to certain undesirable properties such as being carcinogenic, having side effects, or having too slow a reaction time. By 1986, only one of these was registered for use on food fish by the USA Food and Drug Administration : Finquel™, a registered form of tricaine. However, this does not prohibit the use of other drugs or chemicals as anesthetics on non-food fish and in research.

The most popular chemical in use in North America is tricaine, also commonly known as MS-222™, Metacaine™ and tricaine methane-sulfonate in addition to Finquel™. Other popular anesthetics for surgery are benzocaine, quinaldine, and quinaldine sulfate; tricaine, secobarbital and Amytal Sodium™ are commonly used for fish transport (SUMMERFELT and SMITH, 1990). A common anaesthesia used for aquaculture and fisheries applications in Europe is 2-phenoxy-ethanol, which is relatively inexpensive, a consideration for developing countries. Some researchers, including ourselves, have used a tricaine/quinaldine (or quinaldine sulfate) solution as an anesthesia, which has a synergistic effect (GILDERHUS *et al.*, 1973). Tricaine tends to block reflex action, while fish can tolerate quinaldine for longer exposures (SCHOETTGER and STEUCKE, 1970).

Six stages of anesthesia are generally recognized that range from Stage 1, Light Sedation : slight loss of reaction to external stimuli, to Stage 6, Medullary collapse : opercle movements cease, followed by cardiac arrest (JOLLY *et al.*, 1972). The intermediate stages are Stage 2, Deep Sedation; Stage 3, Partial Loss of Equilibrium; Stage 4, Total Loss of Equilibrium; and Stage 5, Loss of Reflex Reactivity. Transport and immobilization of fishes usually is facilitated by applying an anesthetic in sufficient concentration to achieve Stage 2, while surgical operations are conducted at Stages 4-5.

The concentration and induction time for each drug to cause sedation or complete anesthesia will vary by a number of factors, including species, size of specimen, density of fish in holding tank, oxygen concentration, water temperature and perhaps conductivity. Recovery time from anesthesia is influenced by the same factors, and as a general rule is proportional to the induction time.

For African researchers, appropriate anesthetics and their concentrations need to be researched for target species; the only known work is that of FERREIRA *et al.* (1979, 1984a, 1984b). HOCUTT (1989a, b) used a concentration of 6.0 mg.l^{-1} (1:166,667) quinaldine for *Clarias gariepinus* and *Tilapia rendalli*. However, SADO (1985) observed that tilapia were very tolerant of quinaldine, requiring concentrations of 25-50 mg.l^{-1} to achieve sedation and partial loss of equilibrium, and 50-1,000 mg.l^{-1} for complete anesthesia. SMIT *et al.* (1979) suggested that a 50 $mg.l^{-1}$ dosage of MS-222 would not be harmful to *Oreochromis mossambicus*. By way of a elementary guide, SUMMERFELT and SMITH (1990) noted that the following concentrations for some of the more common drugs which have been used for North American species : MS-222, 15-500 $mg.l^{-1}$ (1:66,000 — 1:2,000); quinaldine, 2.5-40 $mg.l^{-1}$; quinaldine sulfate, a more soluble form of quinaldine without several of the limitations (15-60 $mg.l^{-1}$); and benzocaine (15-200 $mg.l^{-1}$).

Fish capture and immobilization

Fish collecting should be performed to minimize physical and physiological stress to the specimens. Such collecting procedures might include hoop nets, baited traps and seine nets. Angling tackle has its value for certain species, but might result in lactic acid stress. Gill nets are an efficient gear for many species if they are set for short durations to reduce scale loss, abrasion and asphyxiation. Upon capture, fish should be placed in a holding tank with a concentration of anesthesia of choice to ensure either deep sedation if the specimens are to be returned to a processing area, or total loss of equilibrium/loss of reflexive ability if the tag is to be immediately attached. Weights, lengths and sexes of each individual should be recorded.

Electrofishing is unique in that it may sufficiently immobilize a specimen (electronarcosis) to act as an anesthesia. For instance, HOCUTT *et al.* (1990) used electrofishing to capture striped bass, and then immediately performed surgery on-board the boat after spraying the fish's gills with a 10 $mg.l^{-1}$ solution of quinaldine.

Protocol for tagging procedure

Transmitters may be attached to fish in three general ways : (1) inserted into the stomach (e.g., STASKO and ROMMEL, 1974; GRAY and HAYNES, 1979), (2) externally affixed to the dorsal musculature (e.g., HAYNES *et al.*, 1978; ROSS and MCCORMICK, 1981), or (3) surgically implanted into the peritoneal cavity (e.g., ZIEBELL, 1973; HART and SUMMERFELT, 1975; WINTER, 1983). If practical, all fishes equipped with transmitters should be tagged with a conventional numbered tag labelled with the address of the research team; this increases the probability of specimen identification in the event the tag is lost or expires, but the fish is recaptured. Most suppliers provide transmitters with embedded labels listing the investigator, address, and telephone number.

The biases arising from transmitter attachment are both species and procedural dependent, affecting the two basic assumptions of a successful telemetry investigation : (a) fish health and behaviour remain normal, and (b) the tag will be retained sufficiently long to provide valuable data (BARAS, 1991). MELLAS and HAYNES (1985) maintained that stomach insertion is the least traumatic means of attaching a transmitter. This procedure should be considered for sensitive species; however, regurgitation or stomach atrophy can occur, or the tag can interfere with eating and stomach fullness. BARAS (1991) also lists rupture of the oesophagus, hyperactivity, and alternation of swimming speed/behaviour as documented side effects. In the case of stomach-inserted transmitters, they are sterilized with ethanol prior to being force fed through the mouth and the alimentary canal. A thin coat of glycerin will facilitate their ease of insertion. If a trailing omni-directional antenna is present on a radio-transmitter, it will dangle out the mouth.

Procedures for the external attachment of tags to largemouth bass were discussed by SEIBOLD (1992). Transmitters to be externally attached have two wires perpendicular to the axis of the transmitter which are passed through the dorsal musculature of the fish using a 12-gauge sterilized surgical needle, and crimped together on the opposing side. The skin surface of the fish is treated with a 10 % Povidone-Iodine solution before transmitter attachment. Neoprene pads can be used to protect the surface of the fish from excessive abrasion (GRAY and HAYNES, 1979). During transmitter attachment all wounds should be treated with a triple-antibiotic paste consisting of Polymyxin B Sulfate, Bacitracin, and Neomycin Sulfate. The individual should be provided with a tetracycline injection prior to being reintroduced into the water, or alternately put into a terramycin bath so that the antibiotic is absorbed through the gills. Externally-attached transmitters offer a degree of certainty that they will not be lost from the fish, as opposed to orally-inserted transmitters. However, several investigators have noted abrasion, lack of healing of the dorsal wounds (e.g., SEIBOLD, 1992), and aberrant feeding and swimming behaviour (BARAS, 1991).

Most authorities agree that surgically-implanted transmitters are preferable to externally-attached transmitters in terms of minimizing stress to the animal (e.g., STASKO and PINCOCK, 1977), particularly in long-term investigations (HOCUTT *et al.*, 1990). Specific methodologies for anesthesia and surgically implanting telemetry tags are provided in a number of publications (e.g., WINTER, 1983; HOCUTT, 1989a, b; HOCUTT *et al.*, 1990; SUMMERFELT and SMITH, 1990), and summarized below.

To prepare an anesthetized specimen for surgery, its abdomen is washed with a 10 % Povidone-Iodine or Iso-Betadine solution. Sufficient scales are removed to permit a 2-4 cm mid-ventral incision for insertion of a sterilized transmitter in the abdomen; if a trailing antenna is present, we have found it practical to use a 12-gauge surgical needle to create an exit for it posterior to the incision. If required to quieten the animal down during the operation procedure, a 2-10 $mg.l^{-1}$ solution of quinaldine can be sprayed directly on the gills (PEDERSEN and ANDERSEN, 1985).

SUMMERFELT and SMITH (1990) provide details on suturing materials and procedures; however, we recommend the use of a surgical skin stapler to close the incision (MULFORD, 1984). This procedure enables much faster closing of the incision than is possible with conventional suturing, significantly decreasing time and stress during surgery; the entire surgical procedure with the use of a stapler will require 3-4 minutes per individual as compared to 15-20 minutes if conventional suturing is employed (FILIPEK, 1989). The use of a stapler permits one to simply lay out a fish on an " operation table ", covering the specimen with a wet towel to prevent its drying out; the longer, traditional suturing method will require that the gills be continuously flushed with water during the procedure.

We also employ a cyanoacrylate glue in combination with the surgical stapler to close the incision (SEIBOLD, 1992). NEMETZ and MACMILLAN (1988) reported the glue as effective in closing incisions in channel catfish *(Ictalurus punctatus)*, but PETERING and JOHNSON (1991) considered it ineffective for black crappie *(Pomoxis nigromaculatus)*. These studies used the adhesive only as an alternative to sutures or staples, while SEIBOLD (1992) and our subsequent studies successfully used it in addition to staples. We did, however, take the precaution of removing sufficient scales around the suture area which might inhibit efficient use of the stapler. None-the-less, there is concern that permanent suture material or staples may cause infection or harm in long-term studies, especially in warmer water (e.g., BARAS and PHILIPPART, 1989; KALPERS *et al.*, 1989).

After surgery the incision is treated with a triple-antibiotic paste. We inject each fish with tetracycline prior to release; however, LUCAS (1989) found no real benefit of using antibiotics and fungicidal agents. Given the rapidity of the operation procedure, it is currently in vogue to release tagged animals immediately after surgery at the capture site to minimize trauma (e.g. HART and SUMMERFELT, 1975; SEIBOLD, 1992).

As compared to the mid-ventral procedure discussed above, there are alternate sites for implantation or forms of incisions (e.g., Ross and KLEINER, 1982; SCHRAMM and BLACK, 1984). For instance, the J-shaped lateral incision (SCHRAMM and BLACK, 1984) might be useful for characids with hard thick medioventral body walls, or in clariid catfish with high vascularization on the ventral surface.

Despite the advantages of surgically-implanted transmitters for long-term investigations, there are also certain limitations. First, and clearly understood, is the need to maintain as sterile conditions as possible. Secondly, there is evidence (PETERSON, 1975; WARDEN and LORIO, 1975) that aberrant behaviour might occur in the first few days after tagging; in retrospect, however, atypical responses might well be minimized by the significant shortening of the surgery procedure by using staplers to close incisions. Thirdly, if the sutures rupture there might be tag loss. Additionally, it has been identified for some North American species that the transmitter might become encapsulated in the intestine lumen and passed outside the body by peristalsis (MARTY and SUMMERFELT, 1986); this needs investigating for African species. BARAS (1991) noted other physical and physiological side effects of the surgical implantation procedure.

Transmitters

It is a fundamental requirement in all marking or tagging studies that the mark or tag does not significantly affect the individual. Transmitters normally weigh no more than 1.5-2.5 % of fish weight in water to reduce their influence on buoyancy, swimming performance, feeding, energetics and behaviour (STASKO and PINCOCK, 1977; SUMMERFELT and MOSIER, 1976; BARAS, 1991). Specimen size governs transmitter package weight, which limits the size of the battery and its life. Long-term transmitters are powered by lithium batteries. Units come in a variety of sizes, e.g., ca. 1.0 to >135 grams with operational lives from 8 to 1,200 days, depending upon pulse configuration.

The presence of a whip antenna on transmitters enhances reception over distance and depth, as compared to a coiled antenna sealed within the transmitter package; the former is more omni-directional, while reception with the latter can be dependent upon the animal's orientation to the receiver. One must make a judgement call on which antenna suits a particular study. For instance, if investigating longitudinal movements of fishes that are not apt to enter highly vegetated areas, a trailing antenna might be preferred. Conversely, in a study concerning horizontal movement of fish onto a floodplain where macrophytes are dominant structure, an internally-coiled antenna is preferred to eliminate entanglement. The use of an internally-coiled antenna might be advisable in African waters where predation from tigerfish and crocodiles is a concern.

Many manufacturers offer options for custom-designed transmitters which can incorporate mortality/activity sensors that alter the transmitters pulse rate depending upon the level of activity. Electromyogram (Kaseloo *et al.* 1992) and heart rate (Armstrong *et al.*, 1989; Lucas *et al.*, 1991; Sureau and Lagardere, 1991) transmitters facilitate physiological studies. Environmental variables such as temperature (Berman and Quinn, 1991), dissolved oxygen (Priede *et al.*, 1988), salinity (Priede, 1982), depth (Stasko and Rommel, 1974), and location (Wilson *et al.*, 1992; Gunn *et al.*, 1994), can also be explored. Any of these features may be desirable; however, they invariably result in a more costly, higher weight and shorter life transmitter. Some small vendors sell only transmitters, which are entirely compatible with any receiver operating at the same frequency.

Transmitters can continually relay information, or optionally be configured to increase longetivity by transmitting at pre-set time intervals. Data loggers can also be included with a sensor to store information (Priede, 1992); data is retrieved when data loggers are recovered and down-loaded, or when information is periodically radio-transmitted to a receiver (Woakes, 1992).

Transmitters need not be considered expendable items. Their cost in the USA averages about $165-200 (without options), which encourages one to recover them for refurbishing. Vendors normally provide these services at less than half the original cost.

Receivers

Radio receivers come with a variety of functions depending upon need; costs range from about $700 to over $6,000 (USA) for a fully programmable/data logging unit. We recommend the following features at a minimum, however they are often included with receiver packages : (a) as wide a frequency range as possible to permit the tagging and tracking of a large number of individuals, (b) a signal strength indicator, with gain control, (c) both an audio speaker and headset receptacle, with variable volume control, (d) battery pack-operated, with a 12-v DC adaptor, (e) an automatic scan feature, imperative for aerial surveys, rated from 2 sec to 1 minute or longer, (f) a lighted display for night time use, and (g) high sensitivity and noise rejection. The receiver housing should be as miniature as possible, and well constructed to stand up to the rigours of field research. The receiver should be accompanied by an antennae designed for the specific frequencies being employed.

A basic ultrasonic receiver can be purchased for about $500; more sophisticated units incorporating many of the recommended features above will cost about $2,500. A hydrophone will be required ($200), and can be either directional or omni-directional depending upon need.

Tracking

For gross movements, fishes can be tracked by boat (or a vehicle if conditions permit) using a single receiver and a hand-held antenna (Hocutt *et al.*, 1990), or receiver/hydrophone. The more subtle movements sometimes associated with diel behaviour and habitat preferences can be performed from a boat, but care must be taken to minimize behavioural side-effects by keeping a reasonable distance from the tagged fish (Shepherd, 1973; Hocutt, 1989a, b).

Aerial tracking procedures require the attachment of an antenna to either side of the undercarriage of the airplane, one pointed in the gain position and the other pointed in the null position (White and Garrott, 1990). Thus, the two antennae are set to receive signals originating parallel and perpendicular to the direction of flight. A switch box between the antennae and a head set enables the observer to listen to either antennae or both to ascertain signal direction.

Today's technology permits one to establish a series of remote shoreline-based or moored receivers/data loggers to record signal reception of migrating fishes (Solomon and Potter, 1988; O'Dor *et al.*, 1989). Typical data stored are date, time and frequency of the transmitter, and other information if the transmitter has optional features.

Recording position

Topographic maps (7.5 minute series; 1:24,000 scale) if available should be used to create a series of field sheets/base maps of the study area. Physical features such as shoreline characteristics or structures can be used to refine the base map. Positions of an experimental fish can be plotted chronologically on a map to create an "instant reference" data base on seasonal activity centers and home range. If conducting an aerial survey, a single base map might be used to record the positions of all fish tracked on that date. This does not, however, preclude the need to maintain duplicate records, base maps or files in the laboratory. As the situation dictates, other data to be tabulated might include : species, frequency, pulse rate, date, time, latitude, longitude, description of activity or inactivity, and name of recorder.

For all tracking surveys, locations can be determined using a hand-held Global Positioning System (GPS) receiver. These units perform admirably, with our verification trials conducted 3-months apart in Namibia indicating excellent repeatability of longitude and latitude coordinates. Most GPS receivers have programmable navigation/way-point functions which permit calculation of distances between fixes. The prices of portable units has decreased sharply in recent years to the point that a GPS unit should be a standard instrument used in every telemetry study. Some data logger-receivers now have scratchpads where it is possible to add GPS coordinates.

Despite the overall utility of GPS, the technology was originally developed for the U.S. Department of Defense rather than for commercial purposes. Portable units have a margin of error built into them, thus there should be a sense of caution when calculating home ranges relying on small scale (< 1 km) changes in location. Excellent accuracy (< 10 m) can be achieved using "differential GPS" technology, however at substantially higher cost (ALSIP *et al.*, 1992).

Safety

No amount of words can express the need to practice safety during telemetry studies. The co-author, and a fellow colleague, succumbed to a boating accident during a tracking exercise three weeks after the submission of his Master of Science thesis.

Telemetry is an intriguing technology, and persons conducting tracking exercises can be distracted from the elements around them, even to the point of momentarily loosing orientation. Night-time surveys can be particularly hazardous. Submerged logs, rocks and sand bars are all sufficient to upset a boat; strong currents, cataracts and dams can place boaters in jeopardy. On the sub-continent, such physical features are augmented by crocodiles, hippopotamuses, elephants and buffalo. Mis-understanding villagers and errant soldiers might cause concern, especially if you can not communicate with them.

All personnel should be trained in the proper handling of a boat, and at least two persons should be aboard during tracking exercises with one being dedicated to piloting the vessel. Safety equipment should be aboard, and life jackets used. Aerial tracking requires a pilot plus an observer; it has been said that most aerial tracking deaths in the USA have been a consequence of the tracker being the pilot.

FISHERIES APPLICATIONS

Telemetry can be employed to research a number of life history and behavioural phenomena in fishes. Several studies have revolved around the topics presented below; however, the list is by no means exhaustive, nor the literature coverage complete. A good starting point to review the various applications of fish telemetry are the bibliographies of EMERY and WYDOSKI (1987) and BARAS (1991).

Migrations/Seasonal movements

Migration in fishes is well documented (e.g., HASLER, 1971), however for the most part it has been poorly researched for African species. WHITE and GARROTT (1990) define migration as "...a regular, round-trip movement of individuals between two or more areas or seasonal ranges", which results in a net movement of zero. Dispersal is a one-way movement in which an individual leaves its living space (perhaps natal site) for another, and is distinguished from dispersion which refers to the spacial arrangement of individuals within a population (LIDICKER and CALDWELL, 1982).

Migrations can be stimulated by any combination of environmental variables and internal rhythms, and occur on a diel, lunar, seasonal or annual cycle (LOWE-MCCONNELL, 1987). With approximately 3,000 species it is to be expected that Africa has abundant examples of potamodromous and diadromous fishes, although information on most is anecdotal.

There is disagreement in the literature as to which physico-chemical factors are the most important stimuli to fishes living in seasonally-varying environments such as floodplain rivers (JUNK *et al.*, 1983), which account for nearly one-half of the total fishery catch in African fresh waters (WELCOMME, 1979). For instance, temperature is generally considered as a controlling factor of activity in poikilotherms (FRY, 1947). Winter temperatures can lead to sustained periods of decreased activity or dormancy (e.g., CRAWSHAW, 1984) followed by a phase of wide-ranging activity in spring and summer as observed in the sharptooth catfish *(C. gariepinus)* in Zimbabwe (HOCUTT, 1989a). However, temperature in tropical streams is relatively consistent, thus is considered to be less a governing factor of fish behaviour than in temperate catchments (LOWE-MCCONNELL, 1987).

The ecology and behaviour of African riverine fishes may well be correlated primarily to changes in water level (LOWE-MCCONNELL, 1988; WELCOMME and DE MERONA, 1988). Longitudinal and lateral migrations of fishes often are timed in relation to flooding cycles (BRUTON and JACKSON, 1983). Variable flows impact the fishery directly (e.g., stimulating spawning migrations, or concentrating fish during droughts) and indirectly by controlling productivity (JUNK *et al.*, 1989) and effort of the artisanal fishery (WELCOMME, 1979; BAYLEY, 1981; MALVESTUTO and MEREDITH, 1989). MERRON and BRUTON (1989) noted pre-flooding migrations of *C. gariepinus* and tigerfish *(Hydrocynus vittatus)* in the Okavango Delta, and an annual "catfish run" that included the blunttooth catfish *(Clarias ngamensis)*. JACKSON and COETZEE (1982) reported post-flooding spawning runs of the mud mullet *(Labeo umbratus)*. Some mormyrids such as the Zambezi parrotfish *(Hippopotamyrus discorhynchus)* and the bulldog *(Marcusenius macrolepidotus)* are known to migrate up streams in shoals during the flood season, but the nature of the migrations are unknown (BELL-CROSS, 1960; BOWMAKER, 1973). The greenhead tilapia *(Oreochromis macrochir)* is considered to primarily breed before the rainy season, but lateral migration and secondary breeding can be stimulated by a rise in water level (MARSHALL, 1979). In floodplain environments, the lateral migration of fishes (e.g., "tilapia" and cyprinids) will accompany inundation of newly flooded areas, which will act as sites of feeding, reproduction, nurseries, shelter or refugia (LOWE-MCCONNELL, 1987).

WHITEHEAD (1959) conducted an extensive survey of the anadromous habits of Lake Victoria's fish fauna. He recognized three distinct migration patterns : (1) long duration, with some fishes entering tributaries over an extended time frame and migrating 80 $\pm$ km to spawn upstream ; (2) moderate duration, where species maintained schooling integrity and migrated 8-25 km upstream to spawn; and (3) short duration, with species ascending rivers *en masse* during temporary stream flooding. LOWE-MCCONNELL (1987) provided other examples of lacustrine migrations and anadromy.

Telemetry is an ideal way to explore a number of these environmentally-related hypotheses pertaining to migration and dispersal.

Home range

"Home range" is generally defined to be the cumulative area required by an animal for feeding, breeding, and shelter requirements, as well as social interactions (e.g., JEWELL, 1966; TESTER and SINIFF, 1973; NOVICK and STEWART, 1982). Most vertebrates often restrict their movements and actions to particular localities, especially during some period of the annual cycle (BURT, 1943; ODUM and KUENZLER, 1955), which results in the formation of "activity centers" within the home range (ABLES, 1969) that can change daily or seasonally with the overriding stimulus. Home range is distinct from a "territory", which is an actively defended area (BURT, 1943).

An animal's home range can change in size and location as a result of seasonal shifts, forage and habitat availability, size, age, life history requirements of the individual, or other variables not yet completely understood (e.g., GERKING, 1950, 1953; MCNAB, 1963; SAVITZ *et al.*, 1983). Consequently, methods have been developed which attempt to describe accurately the utilized range of the animal for a specific period of time or activity. The only objective basis for selecting "normal" movements is the use of a probability level, usually a home range that includes 95 % of the animal's locations (WHITE and GARROTT, 1990). ODUM and KUENZLER (1955) introduced the concepts of maximum and utilized home range, where maximum range includes all locations of the animal and utilized range is an attempted measure of the proportion of the maximum range that is exploited by the animal. HAYNE (1949) presented the calculation of an arithmetic mean center of activity, which is the center point of a home range; DIXON and CHAPMAN (1980) expanded upon this concept, and their harmonic mean measure of the activity center is now commonly used in telemetry studies.

The need to determine seasonal home range patterns and activity centers represents a principal requirement to address many hypotheses tested by telemetry technology. The definition of "season" is required, and in Africa might be based on parameters such as flow characteristics, temperature or calendar months. WHITE and GARROTT (1990) outlined several parametric and non-parametric procedures to calculate home range, and listed a number of software packages which can be employed. The earliest and most common technique used in the determination of home range area of is the minimum convex polygon (MOHR, 1947), which connects the outlying positions of a detected animal. The technique must be modified for use near land-water interfaces, however, as it is impossible to draw a convex polygon without including land in the estimate (or in the case of terrestrial animals, water), which results in areal overestimation. Therefore, it is often necessary to construct a minimum area polygon which is concave in shape. Although there is no objective procedure based on biological theory for use in determining a concave polygon (WHITE and

GARROTT, 1990), shoreline features such as trees and coves provide rather obvious sites for placement of points of the polygon, thereby decreasing subjectivity. This method of using the shoreline as a boundary of the home range is accepted and commonly used in fish telemetry experiments, e.g., WINTER (1977), DOERZBACHER (1980), NIEMAN and CLADY (1981), MESING and WICKER (1986) and SEIBOLD (1992).

Other normal bivariate elliptical or circular models (e.g., MACDONALD *et al.*, 1980; VALERIAN and SINGH, 1992), or simple distribution grids (WINTER and Ross, 1982; HOCUTT, 1989a), may be used for calculating home ranges; however, the use of minimum area polygons as described above are currently favored for aquatic studies. Regardless of procedure for data analysis, they are all limited by treating three-dimensional data in two dimensions (e.g., see SMITH *et al.*, 1989). MABAYE (1994) attempted to overcome this in Lake Kariba, Zimbabwe by using telemetry in combination with netting and sonar to locate preferred depths.

Homing

The term "homing" implies the ability of an individual to return to an area during a migratory cycle; a classical example is the homing behaviour of Pacific salmon (HASLER, 1971) to return to spawn in their natal stream. PAPI (1990) defined homing as "... a movement undertaken to reach a spatially restricted area which is already known to an animal".

Fishes may also exhibit homing behaviour if they have been displaced. In this sense, HASLER and WISBY (1958) defined "homing" as "... the ability of a displaced fish to orient itself in the new location, with the aid of perhaps a variety of mechanisms and stimuli, in order to return to familiar territory, which then might be recognized as 'landmarks', whether detected by olfaction, vision, or other senses as learned from previous experience".

One of the greatest difficulties in determining whether homing occurs is in recognizing what constitutes the original home range (SEIBOLD, 1992). SEIBOLD (1992) studied the effects of displacement on tournament-caught largemouth bass in the tidal Potomac River, Maryland (USA). He found that the home range of the tidal population was generally larger than other literature accounts for the species. Thus, a fish might not appear to home if it is displaced only to the fringe of its natural range.

HOCUTT *et al.* (1990) applied radiotelemetry to study annual homing in anadromous striped bass, a species common to the mid-Atlantic seaboard of North America with annual spawning runs into the freshwaters of Pamlico Sound, NC north to the Hudson River, NY. Despite the limitations of radiotelemetry in marine waters, they were able to (1) estimate residence times for males (up to 45 d) and females (maximum ca. 10 d) on the freshwater spawning grounds, (2) demonstrate homing to a specific river, (3) show that some females return annually to spawn, i.e., iteroparity, (4) document that males cruise 15-30 $km.d^{-1}$ between the brackish estuary and the prime freshwater spawning arena, and (5) provide conservative estimates of migration rates of 15 $km.d^{-1}$ between the Chesapeake Bay-tributary spawning grounds and the Long Island Sound summer feeding grounds. This data base was gathered over a 1-year cycle, and provided strong evidence supporting the hypothesis of a natal homing response of striped bass to the Chesapeake Bay tributaries.

Straying

Straying is a natural phenomenon opposite to homing behaviour that adds to the genetic plasticity of a stock. For instance, some individuals (strays) of a migrating anadromous species might not exhibit a natal homing response, or do not return to spawn in a system in which they were tagged. Straying has been little studied, but QUINN *et al.* (1991) presented evidence that (a) high rates of straying (ca. 20 %) can occasionally occur in chinook salmon *(Oncorhynchus tshawytscha)*, and (b) straying is more likely to occur in older individuals or in hatchery-reared fish. While straying does occur amongst individuals, mass homing maintains stock integrity.

Diel movement

Diel movement, or 24-hr studies, can produce interesting results on the daily activities, behaviour and habitat preferences of telemetered fish. HOCUTT's (1989a) study of the sharptooth catfish, for instance, provided information contrasting with the popular conception that the species has nocturnal habits (BRUTON, 1978). HOCUTT (1989a) found that major movements were not restricted to dusk or night-time, nor were inshore/offshore movements related to time of day. SOLOMON (1982) reported similar results studying sea trout migration, i.e., they appeared to travel only short distances at night even though water levels were low.

Researchers should be cautioned, however, that diel movement might well be finite, and due to the lack of precision in distance positioning of telemetered fish, care must be taken to approach tagged individuals without disturbing them.

Site fidelity/residence times

The term "fidelity" has been applied mainly to wildlife investigations, but has utility for fishery scientists. Fidelity has been defined either as the tendency of an animal to remain in an area for an extended time period, or for it to return to a previously occupied area (WHITE and GARROTT, 1990). The former definition infers the "residence time" at a location, while the latter definition is analogous to "homing".

Fidelity can be expected to vary by species, season or life history requirements; however, the phenomenon of fidelity adds credence to the establishment of biologically-based environmental assessment protocols, e.g., indices of biotic integrity (HOCUTT *et al.*, *in press*). In its simplest form, fidelity can be measured as a percentage of telemetered animals returning to a specific seasonal range, or the percentage of time an animal remains in a given area on a seasonal or annual basis. A more quantitative approach is the non-parametric test of MIELKE and BERRY (1982) which analyzes whether two sets of location data are similar.

Swimming rates/activity

It is expected that seasonal differences in swimming rates and activity patterns of tropical fishes will occur, stimulated by either exogenous or endogenous factors. The rate of swimming can simply be measured physically or electronically as the distance covered between two points per unit of time. For instance, HOCUTT (1989a, b) using telemetry reported that the rate of swimming of the sharptooth catfish and the redbreast bream *(Tilapia rendalli)* seasonally exceeded 470 and 150 m.hr^{-1}, respectively, in Lake Ngezi, Zimbabwe. The rate of movement for the catfish was considerably faster than 1.0 km.d^{-1} reported by WILLOUGHBY and TWEDDLE (1978) for the same species using conventional tags.

HOCUTT (1989a) also determined that the number of long-distance movements (>200 m) of the catfish peaked in July/August and again in January. These alternating periods of activity were indicative of seasonal activity centers which should be taken into account when calculating home ranges.

HOCUTT *et al.* (1990) noted that anadromous male striped bass exhibited a "cruising behaviour", i.e., they appeared to wander up and down the river, covering 20-30 km per day. It was hypothesized that males may exhibit this behaviour searching for females newly arrived on the spawning grounds. It was also observed in 1990 that some females wandered about the river at rates exceeding 1.0 km.hr^{-1} prior to spawning, but departed immediately thereafter. BRUTON (1978) observed social aggregations in the sharptooth catfish which he termed as either social hunting or pack hunting, both of which exhibited "cruising" behaviour.

Stock assessment

JOHNSEN (1980) proposed the "Judas fish" concept to locate populations of fish for harvesting. This procedure holds much promise for stock assessments for targeted or endangered species by facilitating the location of population centers, discerning migratory behaviour, identifying preferred habitats, or assessing the integration of cultured fish into wild stocks. This application in concert with sonar would maximize the benefits of each technology.

Data on residence times can be used to calibrate maturation rate models for a particular species. Such models are premised on catch per unit effort of females and males, and can produce severely skewed results if residence times differ significantly between sexes, e.g., as noted for striped bass in Chesapeake Bay tributaries (HOCUTT *et al.*, 1990).

Other applications

This manuscript stresses the employment of telemetry to study fish, however the technology has been employed for a variety of other aquatic and amphibious vertebrates, e.g., otter (POLECHLA, 1989), sea turtles (BYLES, 1987), manatees (MATE *et al.*, 1987), diving birds (BUTLER and WOAKES, 1982), crabs (WOLCOTT and HINES, 1989), salamanders (STOUFFER *et al.*, 1973), and Nile crocodile (HOCUTT *et al.*, 1992b), to name a few. In many instances, the applicability and limitations of the technology to these and other aquatic vertebrates are the same as for fish.

TECHNOLOGY DEVELOPMENT

We agree completely with the views of KUECHLE (1982) that a difficulty we are facing now in biotelemetry is the lack of research and development of the technology, particularly as related to fishes. Much equipment is purchased through commercial vendors who run relatively small businesses. This keeps price down on equipment, the quality may be excellent and custom designed systems are possible; however this does not necessarily promote technology development. Fortunately, there are some companies and research laboratories that are at the cutting edge of the science.

Although currently being considered primarily for wildlife, the employment of the U.S. Department of Defense's Global Positioning System (GPS) into a telemetry package offers the prospect of pin-point accuracy, but development costs of the technique and overcoming data retrieval difficulties represent significant obstacles (LOTEK, 1990). The Fisheries Laboratory at Lowestoft, UK has a mission of research and development, and given that it is a government-funded facility, it is not unexpected that many significant applications of biotelemetry have been born there. Their employment of acoustic tags has facilitated research on trawler efficiency as well as fish behaviour, and the development of compass-bearing transponding tags (HARDEN JONES and ARNOLD, 1982) and data storage tags (METCALFE *et al.*, 1992) offers much potential for use in marine, brackish and fresh water fisheries.

One California firm has developed crystal coded, dual frequency ultrasonic transmitters/receiver packages to minimize noise and reception errors; transmitters are reported to have a high signal strength, a life exceeding 4 months and a reported range of 1-2 km dependent upon conditions. Accessory to this system are microprocessor based submersible data logging receivers which can collect data in the form of transmitter ID-code, time of arrival to the nearest minute, date, time of departure, and mooring location, all of which is stored on IBM compatible diskettes. We should for clarity sake point out that several firms have developed data logging receivers to facilitate remote sensing programs, both ultrasonic and radiotelemetry.

A Canadian firm has introduced digitally-encoded radio-transmitters/receivers that permit the tracking of 200 individuals on the same frequency. This significantly (1) reduces scanning time for a series of frequencies if a large number of animals have been tagged, and (2) decreases the energy requirements of the transmitters, while (3) increasing their power and life span.

SUMMARY

Biotelemetry is a powerful tool available to fishery researchers for sub-Saharan African and other tropical waters. It has the distinct advantage of being able to provide a significant information base on target species within a reasonably short period of time. In many instances, telemetry can be used to verify results of conventional tagging programs, and can provide information that conventional tagging cannot. For instance, telemetry can be used to test hypotheses of movement resulting from large scale tagging programmes, or provide detailed information on short term movements of fish, habitat preference and environmental variables that regulate movement, i.e, tide, temperature and rainfall events.

The application of the technology is reasonably straight forward, and requires minimal manpower for data collecting. The cost of incorporating telemetry into management-oriented research agenda might be construed to be a limitation, however the richness of the data base which can be gathered in a short period of time should out-weigh this consideration.

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Annex 1

A comparison of advantages and disadvantages of radio and acoustic telemetry

Radiotelemetry

Advantages

1. The receiver and antennae can be located completely in air. This (a) facilitates tracking by boat and airplane, (b) reduces tracking time, and (c) enhances the linking of remote data loggers to a "home base" receiver station should one be considered.
2. Radio-signals are virtually unaffected by turbulence, algae or macrophytes in the water column.
3. Radio frequencies are higher. The wider bandwidths (a) allow for more animals to be tagged, (b) facilitate identification of individual animals, and (c) permit digital encoding of transmitters for greater information retrieval.
4. Radio-tags have relatively lower power consumption, permitting miniaturization of transmitter packages with longer lives.

Disadvantages

1. Radio signal strength attenuates rapidly at salinities higher than 800-1,000 µmhos.
2. There is a decay of signal strength with depth.
3. There is the potential for radio-reception interference in urban areas, or in hilly areas where signals can be reflected.
4. Dense algae mats, floating islands, forest canopies, and meandering water courses, might be concerns in tropical countries on a case-by-case basis.

Ultrasonic telemetry

Advantages

1. Acoustic transmitters have superior utility in brackish and marine waters (> 1 ppt salinity), and at greater depths (> 35 m).

Disadvantages

1. Lower frequencies result in far less animals which can be tracked simultaneously, influencing robustness of study and its objectives.
2. Water turbulence, boat traffic, physical obstacles, thermoclines, algae patches, and other factors influence signal strength.
3. Tracking is performed exclusively with a hydrophone, which limits speed and means of tracking.
4. Transmitter packages are relatively larger with reduced life times, influencing both the size and species which can be effectively tagged.
5. If remote monitoring to a "home base" station is desired, ultrasonic signals would have to be converted to radiofrequencies for transmission link.

Annex 2

Advantages of using biotelemetry in developing countries as opposed to conventional mark-and-recapture programmes

1. Biotelemetry eliminates the need to recapture tagged specimens to gather valuable observational information on targeted species.
2. The above advantage permits the testing of many hypotheses on life history, behaviour and environmental relationships, that can not be performed easily by conventional tagging programmes.
3. Manpower requirements are significantly reduced.
4. The time element for completion of a study is greatly reduced, facilitating the rapid development of a data base on targeted species. This is vitally important in a world of deteriorating environmental conditions and declining fish stocks.
5. Fewer numbers of specimens need to be tagged to acquire a robust data base.
6. Biotelemetry can be linked readily to other technologies and/or methodologies (e.g., physicochemical monitoring programmes, hydroacoustic surveys or quantitative netting programmes) to more effectively ascertain the role of targeted fishes in their environment.
7. The technology can be easily adapted to protected species and their environmental requirements, or to evaluate the successful integration of cultured individuals into wild stocks or aquatic systems.