INVESTIGATIONS OF THE BEHAVIOUR OF DEEP-SEA FISH USING AN INGESTIBLE CODE ACTIVATED TRANSPONDER (CAT) FISH TAG OPERATING AT ABYSSAL DEPTHS

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1. INTRODUCTION

Baited camera systems have been used for many years to observe deep-sea demersal fish in-situ (e.g. ISAACS[1]; ISAACS and SCHWARTZLOSE[2]; SMITH et al.[3]; WILSON and SMITH[4]). PRIEDE and SMITH[5] showed that abyssal grenadier fishes, *Coryphaenoides armatus* and *Coryphaenoides yaquinae*, would ingest acoustic pingers embedded in the bait deployed within view of the camera. The pingers are retained in the stomach for at least 26h (ARMSTRONG and BALDWIN[6]) and experiments on shallow water species indicate much longer retention times without disturbing normal feeding behaviour (ARMSTRONG et al.[7]). Using these acoustic stomach tags, the movements of *C.(N.) armatus* and *C.(N.) yaquinae* have been studied at different localities in the North Atlantic and Pacific oceans (PRIEDE et al.[8]; PRIEDE et al.[9]; ARMSTRONG et al.[10]; ARMSTRONG et al.[7]). The rate of fish dispersal from the bait source was estimated using signal attenuation as a measure of distance from a calibrated hydrophone attached to the camera vehicle. This method is not very precise (BAGLEY et al.[11]) but by averaging over a large number of readings mean radial velocity was estimated as 0.11 ms^{-1}. This is of the same order of magnitude as the bottom tidal current and the question arises as to whether grenadiers, drift with the current to save energy as do some shallow-water fishes (METCALFE et al.[12]), or do they move across or against the current in an optimal search pattern (DUSENBERRY[13]). Some useful information has been gained by use of a scanning directional hydrophone (PRIEDE et al.[9], ARMSTRONG et al.[7]) to measure bearing but a method is required that can unambiguously provide instantaneous locations of individual fish within a two dimensional coordinate system. Fish equipped with pingers can be tracked by measurement of time of arrival of signals at locations within a multiple hydrophone array (HAWKINS et al.[14], URQUHART and SMITH[15]). Precision deployment of such an array at abyssal depths would be difficult. We have adopted an alternative approach using a instruments on board the camera platform to measure location in a polar coordinate system referenced to either compass direction or current flow direction.

A new code activated transponder (CAT) is described that is comparable in size to the original pingers used by PRIEDE et al

[8] and is readily ingested by deep-sea grenadiers. The transponder principle has been used previously by MITSON and STORETON-WEST[16], to track plaice (Pleuronectes platessa L.) in the North sea. Their transponder, attached to the fish externally, was triggered by acoustic pulses from a ship-borne sonar. The transponder response appeared as a bright spot on the sonar display indicating the fish position against the background echoes from the bottom and other features in the water. The new CAT only responds if interrogated by a predetermined code specific to an individual transponder. This system therefore can track several individually distinguishable fish simultaneously and can also select a single fish ignoring other transponders within range of the system.

The distance between the surface and abyssal ocean floor exceeds the range of any practical ship-borne high frequency sonar (MITSON[17]) so the CAT system is used with a sea-bed autonomous interrogation and data-logging system. The system was developed as part of a study of the abyssal and Continential rise/slope fauna at two locations; Station M (abyssal plain) in the North Pacific at 32°50'N, 122°50'W, depth 4100m, and at the Porcupine Seabight (Continential rise/slope) in the North Atlantic at 49° 50'N, 50°W, depth 4050m - 500m . These are relatively eutrophic areas with a rich benthic community. At depths greater than 2500m there are mobile grenadier fish which may play a significant role in transport of organic carbon.

2. THE CODE ACTIVATED TRANSPONDER

2.1 Operation principle

The transponder is activated by a dual pulse code transmitted by the interrogating sonar. The activation code consists of two 10mS acoustic pulses, separated by a programmable time period (Figure 1). The arrival of the first acoustic interrogation pulse 'wakes up' all CAT tags within acoustic range. Each CAT then waits for a unique pre-programmed period of time before expecting a second 10mS acoustic pulse. If this second acoustic pulse falls within the expected time window the transmitter is activated, returning an acoustic pulse to the interrogating sonar. Should a second acoustic pulse not appear

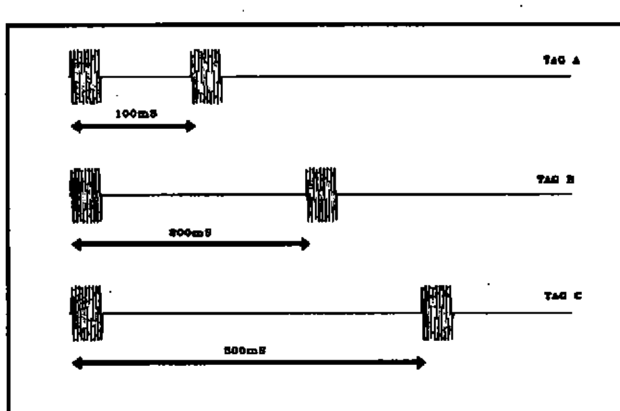

Figure 1 Typical activation codes for 3 CATs deployed simultaneously (100ms, 200ms and 300ms) BAGLEY[18].

CODE ACTIVATED TRANSPONDER

during the expected window, the CAT will return to a 'sleep' state without activating the transmitter. The time (t, secs) between the transmission of an interrogation pulse and the detection of an acoustic return from a CAT defines the range (r):

$$r = \frac{t}{2} \times c \quad \text{(metres)}$$

where
c = speed of sound in water.

2.2 Circuit Description

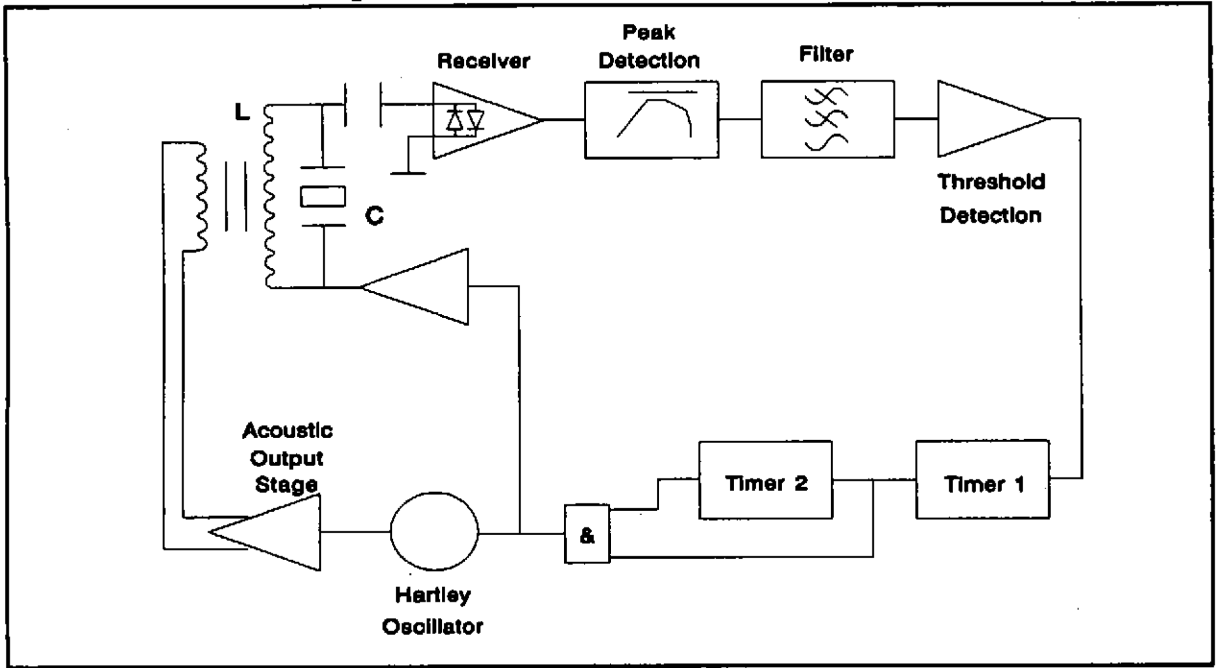

Figure 2 Block diagram of a Code Activated Transponder ingestible fish tag.

Figure 2 shows the basic operational diagram of the CAT. A common transducer is used for both the receiver and transmitter. The parallel combination of the transducer (C) and the output transformer (L) forms a 77 kHz tuned circuit that helps to reject spurious signals. The transducer is capacitively coupled into the receiver and the signal is amplified by a three stage transistor amplifier with a gain of 87 dB. The receiver output is wave shaped by a peak detector and filtered to produce a suitable input to the digital detection stage. A threshold detection circuit maintains a level below which any receiver output will be ignored, thereby preventing background noise falsely triggering the following digital stage. Due to the limited space available, the CAT receiver is very basic and therefore distortion occurs due to high gain and the use of limited DC biasing. For our application this effect does not present a real problem as only the envelope of the input acoustic pulse is required by the digital detection stage.

Timers 1 and 2 are digital non-retriggerable monostables. When triggered by a receiver output voltage that is above the detection threshold level, these timers will ignore any further inputs until the end of their timing sequence. Due to the serial connection of these timers, timer 1 triggers on the first pulse of an acoustic interrogation code, and timer 2 triggers on the completion of the timing sequence of timer 1. The second acoustic pulse, therefore, must occur after the timing sequence of timer 1, but before the end of the timing sequence of timer 2 to enable the next stage. When this occurs, the Hartley oscillator generates a 77 Khz waveform that drives the high power (167 dB re 1 μPascal @ 1m) output stage, otherwise the oscillator is not enabled and the CAT returns to a 'sleep' state. The return pulse length is determined by the duration from the reception of the second interrogation pulse to the end of the activation period of timer 2. Varying the value of the timing elements of timer 2 therefore can be used to adjust the return pulse length. This can further aid the recognition of individual transponders within a batch triggered by the same code interval. The activation code of each CAT is pre-programmed by selection of timing components during assembly.

2.3 Mechanical design considerations.
The CAT is designed to withstand hydrostatic pressures of up to 600 atmospheres. Solid state surface mount electronic components are used which, due to their small volume, are able to withstand such pressures. The circuit is constructed on four 13mm diameter circular printed circuit boards. After testing, the circuits are built into a stack configuration and inserted into a polypropylene test tube 13mm internal diameter and 65mm long. The transducer is a lead zirconate titanate ceramic cylinder (12.5mm in diameter) which is resonant in the hoop mode at a frequency of 77 KHz (HUETER and BOLT[19]). The resonant frequency depends on transducer diameter and this is an important factor determining the physical dimensions of the CAT.

The circuit and battery are inserted into a silicon oil filled tube and sealed with a rubber bung. The oil acts as a pressure compensation fluid and provides acoustic coupling between the transducer and the sea water. A 6-volt Lithium Manganese battery is used (Duracell type PX28L), comprising two DL1/3N 3V cells. These have an air space inside and when subjected to pressure the casing distorts creating a short circuit between the central cathode and external casing. A hole drilled into the top (negative end) of each cell, permits infusion of inert silicon oil to compensate for compression and thus prevents collapse (This operation is not recommended by the battery manufacturer, and the user must be aware of the explosive nature of lithium batteries).

3.0 THE AUDOS FREE-FALL LANDER

3.1 AUDOS.

The Aberdeen University Deep Ocean Submersible (AUDOS) is a conventional free-fall camera vehicle similar to those described by WILSON & SMITH[4]; LAVER et al.[20] and PRIEDE et al.[8], with the addition of the CAT interrogation system. AUDOS consists of a light weight tubular framework which supports and protects a number of instrument housings. Instruments aboard the vehicle include a camera and flash unit, compass, current meter, interrogating sonar, and a microprocessor control and data logging unit (BAGLEY[21]). Data from these instruments are off-loaded on recovery of the vehicle and used to generate two dimensional tracks of tagged fish (figure 3.)

3.2 Experimental protocol

Fish are attracted to AUDOS by a mackerel (Scomber spp.) bait standardised at c. 0.5 Kg to allow comparison of data between studies (PRIEDE et al.[8]). Flesh from the mackerel was ground up and used to fill a nylon mesh bait bag into which the CAT was inserted. The rest of the fish, was tied to the middle of the cruciform scale. The CAT bait bags were attached to the scale by cotton threads about 2-10 cm long so that the baits were no more than 30 cm above the sea-floor. Three CAT tags were deployed at a time, each with a different activation codes i.e. 100ms, 200ms and 300ms nominal pulse intervals (figure 1).

The AUDOS software enables the system sampling rates to be altered depending on the expected response time of the deep-sea fauna of interest. A typical operational sampling rate for a eutrophic area, where scavenging fish respond more rapidly to bait fall, would be to take a photograph every minute and to initiate a scanning sequence every 10 minutes. In more oligotrophic areas, when fish respond more slowly, longer time intervals between samples can be used possibly tapering with increasing durations between samples as the experiment progresses. The samples can be distributed optimally throughout the planned time course of the experiment making full use of the available film and memory capacity.

4.0 RESULTS

To date the Code Activated Transponder system has tracked 22 fish, 6 at Station M in the Pacific Ocean and 16 at the Porcupine Seabight station in the North Atlantic Ocean. An example of one of these fish tracks is shown in figure 3.

CODE ACTIVATED TRANSPONDER

5.0 DISCUSSION.

The CAT is a relatively complex device compared with pingers usually used in animal tracking studies. This study shows that such devices can now be built small enough to be ingested by fish and an experiment can be carried out on several fish simultaneously using a autonomous vehicle. The surface ship is only required for initial deployment and recovery of the tracking system. Immediate advantages over the previous pinger system are apparent. Using pingers it was not possible to distinguish between individual fish so all data was pooled to give population mean dispersal rates (PRIEDE et al.[9]). Using CATs it is evident that fish do not move in straight lines. It is also possible to estimate individual fish swimming speeds.

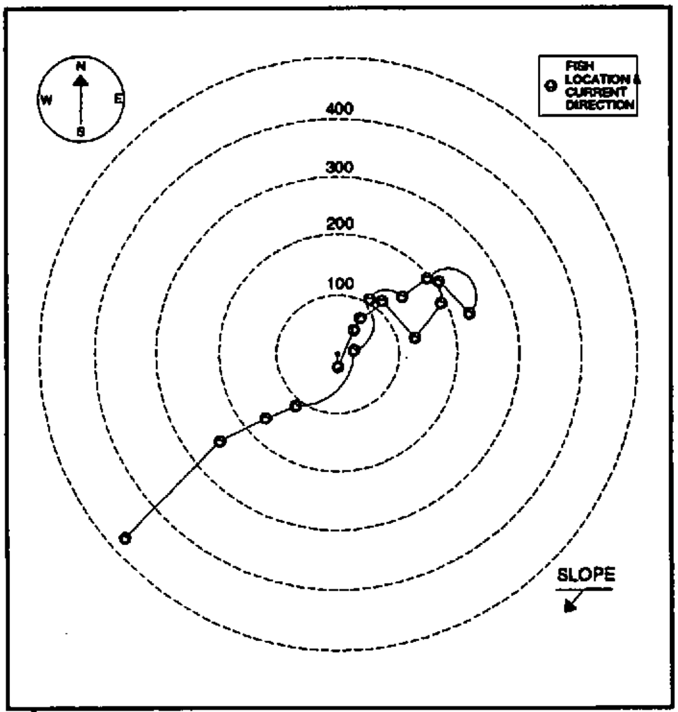

Figure 3 Track of fish in the Porcupine Seabight, North Atlantic Ocean, 1650m depth.

Using pingers the estimated ranges were ascribed to 200m range bins (PRIEDE et al.[8], ARMSTRONG et al[10]). The range precision of the CAT system is 0.5m. The range error using the pingers increased with range so that at maximum range (c 900m-1100) the true uncertainty might be as much as 500m. It was only by averaging large numbers of data points that estimates of speeds were obtained. The velocities observed in the present study are somewhat lower than the mean radial velocity of $0.11m.s^{-1}$ estimated by PRIEDE et al.[9]. The previous velocity measurements depended on assumptions regarding signal source levels and attenuation in the abyss which could not be independently verified. The CAT range measurements however are robust with little scope for error other than perturbations in the velocity of sound which varies by less than 1%. The code serves to prevent spurious triggering from reverberations or noise which can be problem with some transponder systems. The present sample size is small but it appears that velocity estimates in the previous studies may have been too high. The overall mean fish swimming speed was $0.0248\ m.s^{-1}$. There are however likely to be differences in swimming speeds of fish in different areas. The CAT system is clearly capable of measuring differences in swimming speed and will be useful tool for future research. The operational range of a fully optimised system is around 500m.

The movements of the fish are across or against the current this would help optimise chances of encountering odour plumes from new food falls. The fish despite their low speeds are clearly not drifting with the current and move independently. Organic carbon emanating from the surface layer provides the major energy input for life on the ocean floor. PRIEDE et al.[22] using data from the CAT system has shown that horizontal movement of organic carbon by the grenadier can be very important. Any shift in grenadier distribution, such as seasonal migration could result in a major redistribution of organic carbon on the sea floor.

5.0 ACKNOWLEDGEMENTS

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