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Residence times, exchange rates, migration patterns and behaviour of black marlin in the NW Coral Sea: Pilot study to evaluate interaction between recreational and commercial fishing sectors in Area E

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1. Non-technical summary

97/113 Residence times, exchange rates, migration patterns and behaviour of black marlin in the NW coral sea; pilot study to evaluate interaction between recreational and commercial fishing sectors in Area E

Poor catches of black marlin by the recreational sector off Cairns in 1994 triggered concerns that the local stocks were being depleted by domestic longline fishing within Area E. Assessing the level of interaction between the recreational and commercial fleets requires fishery data from both sectors, oceanographic models of circulation, and good information on the residence times, exchanges rates, migration and behaviour of the black marlin. These movement data cannot be collected using conventional tag and recapture approaches. This pilot project evaluates the application of two types of electronic tags in providing vital information on marlin movement dynamics. Pop-up radio tags (PRTs) float to the surface of the sea after they detach from the tagged fish. They then transmit a radio signal that can be detected and the position determined by an aircraft fitted with a suitable radio receiver that searches for the tag. We used PRTs to determine short-term movements and residence times of black marlin within the fringe reef region targeted by the recreational fishery. Pop-up satellite transmitting archival tags (PSTATs) also release from fish and float to the surface and transmit radio signals which are detected and, in this case, their location determined by satellite. We evaluated two PSTATs for obtaining information on large scale movements, exchange rates and residence times in Area E.

Pop-up radio experiments

Twenty nine PRTs were made using high power VHF radio transmitters fitted into a hydro-dynamically streamlined and slightly buoyant case. These tags were attached to marlin using tag heads developed for broadbill swordfish and successfully tested on southern bluefin tuna. Timed release was achieved by galvanic links placed between the tag and the tag head. The released tags were detected by a Cessna 172 fitted that overflew the area. A scanning receiver was used to detect signals transmitted on the frequencies used (150 MHz band). PRTs were deployed on 21 black marlin in three experiments.

The first experiment was near Lizard Island prior to the Lizard Island tournament. Sixteen black marlin were released with PRTs between 20 and 26 October 1997. Nine marlin charter boats were involved in the experiment. Galvanic releases of 3 to 9 days duration were used, so that all tags would release on 30-31 October. Flights of about 4 h duration were carried out twice a day on 30 and 31 October, returning each time to Lizard Island. A fifth flight was carried out on 1 November terminating at Cairns. Only one marlin was detected and this was detected twice; at 10:38 h and 14:40 h on 31 October. As the tag was beyond the flying range of the aircraft we could not pinpoint its position, but the most likely movement of the radio tag was 150 nm NNE of the point of release. Conditions during the experiment were characterised by a northbound current and a paucity of bait. These may have caused greater movement and throughput of the marlin than expected. Greater movement coupled with the longer than planned release intervals, may have caused the radio tags to pop up beyond the detection range of the aircraft transects. Alternatively, some aspect of the operation prevented the tags from transmitting as planned.

In order to determine whether failure to detect tags was due to migration out of the area a second experiment with very much shorter release intervals of 1 to 5 days was carried out nearer to Cairns on 23-28 November. Nine boats participated, fishing in the vicinity of Linden Bank. Two marlin were captured despite the large fishing effort. The area was searched three times, using Cairns as a base. One PRT was detected about 25 hours after tagging. During this time the marlin had moved 28.5 nm south at about 1.1 knots. The radio tag was relocated 19.5 hours later during which time it had drifted 21.3 nm SSE at about 1.09 knots. Both the marlin and subsequently the tag had drifted with the prevailing current. The similarity of the two speeds would suggest that while the marlin may have been actively swimming, its net movement had caused it to remain within the same body of water.

A third experiment was carried out on 7-12 December. Three marlin were released with PRTs with release intervals of 18 hours to 3 days. The area south of the releases was searched on the afternoon of 11 December, and the area to the north of the releases was searched on the morning of December 12. No PRTs were detected.

Only 2 out of 21 tags were detected successfully. The net movement was with the prevailing current. In the Lizard Island experiment it was thought that tagged marlin might have moved out of the surveyable area before they could be detected. The Linden Bank experiment was designed to determine whether this was the case. Unfortunately it was not possible to tag sufficient numbers of marlin in experiment 2 or 3 to answer this conclusively. However, it is likely that some aspect of the operation was failing. From these experiments it was clear that, even if successful, radio tag experiments were not ideal for determining short-term movements and residence times of black marlin within the fringe reef region because:

- Tags have to be put out over a very short space of time and this is unrealistic due to the nature of the fishery.
- Aircraft search range is limited.
- All tags need to pop-up within a short space of time because of the high cost associated with aerial searches.

Pop-up satellite transmitting archival tags experiments

The tags we used were programmed to release from a fish at a predetermined time, pop-up to the surface and transmit to satellite. A limited number of data points describing average water temperatures experienced by the fish during its time at liberty could be transmitted. The position of the tags would be determined by the ARGOS land station from satellites detecting the tag's transmissions. More advanced PSTATs designed to log, summarise and transmit data that would allow estimates of position over the entire time at liberty were still under development and not available at the time of the experiments.

The tags were attached to the fish by a 40 mm long stainless steel anchor as used for the PRT experiments. A electronically activated corrosive link allowed the tag to be released from a fish at a predetermined time. The tags were positively buoyant and could withstand pressures down to 690 m depth. Within the tag electronic circuits, a microprocessor controlled data logging, satellite transmission and release timing. The tags had a small data storage capacity and up to 61 average daily temperatures (temperature is recorded every hour) can be transmitted.

Two PSTATs were attached to marlin caught by longline and both were programmed to release 120 days after the activation date of 13 December 1997, and thus pop-up on 12 April 1998. No transmissions from the two tags were received until 19 November 1998, 341days after activation. Both tags transmitted only once and, due to poor data transmission, the position they popped-up could not be determined. These tags have been used successfully on bluefin tuna, but for some reason there has been low success rates on black, blue and striped marlin. Reasons why the tags have failed include:

- Capture and tagging stress in marlin is much higher than in bluefin tuna, resulting in higher short term mortalities.
- Marlin behaviour is different to that of bluefin tuna and there is a higher likelihood of tag damage, or shedding.
- Battery failure at high temperatures.

It is recommended that before we can justify further research we should address the questions of short term mortality of tagged marlin and/or tag failure due to fish behaviour. The new generations of PSTATs should be capable of doing this. If we can ascertain that tagging mortality and tag shedding were not a problem, then there seems every likelihood that this technology has the potential to answer many of the critical questions about black marlin population structure and movement dynamics.

2. Background

The potential for significant interactions and conflict over access to allocation of fish resources between the recreational and commercial fisheries has become a major management concern in recent years. Poor catches of black marlin by the recreational sector off Cairns in late 1994 triggered concerns that the local stocks were being depleted by domestic longline fishing within Area E. This concern led to calls for the cessation of all commercial longlining in this area and pressure to prohibit the taking of all marlin species by commercial operators.

However, a preliminary analysis of the current situation by the Eastern Tuna and Billfish MAC Billfish Assessment Group, highlighted the complex nature of the fishery interaction issue. They argued that an evaluation of the interaction required not only good fishery statistics but an understanding of the environmental and biological parameters that affect the movements and distribution of black marlin. For example, a plausible alternative explanation for the poor catches in late 1994 is that changes in strength and direction of critical currents associated with prevailing El Nino conditions meant that marlin were not present or available in the very limited area fished by the Cairns charter fishery.

In addition to understanding the dynamics of black marlin within Area E during the peak fishing season, it is also critical to obtain data on the dynamics of movement into, and residence times of black marlin in Area E from year to year. Once this information is available, it will then be possible to determine the oceanographic and environmental parameters that drive it, as well as the impact of fishing operations within the larger Western Pacific region on the overall stock. It is possible that black marlin recruiting to the Area E fishery may have a much broader geographical range than this, extending to the Indian Ocean via the Banda Sea, and to the Eastern Pacific. The extent of their geographical range can be determined by PSTATs and this should be demonstrated by the pilot study. Data from conventional tagging collected over the past three decades has not provided the spatial and temporal information needed to resolve these movements. Returns have been poor and the information obtained is point of release and point of capture (assuming accurate reporting). Recent development of archival tags suggest that they will provide the much needed input of data on the three dimensional movement of species - a critical input into spatial models integrating catch and oceanographic data. PSTATs provide at least, weekly positions and weekly average depths and temperatures for the entire period they are attached to the fish. This information is transmitted to satellite when they release and pop-up to the surface. If the tags are recovered by recapture, or when washed up on a beach, temperature and depth data recorded at two minute intervals can also be obtained.

It will also be important to determine whether the availability of black marlin in Area E is dependent on a high throughput with short residence times, or on a smaller throughput with longer residence times. The latter situation is likely to increase the possibility of a sizeable interaction, and the former reduce the possibility of an interaction since a constant replenishment of marlin into the area would keep availability high. Without understanding how the distribution, movements and residence time of black marlin in Area E interact with oceanographic variability and the impact of fisheries both within Area E and the Western Pacific, it is impossible to assess the level of interaction between the recreational/charter and commercial fleets within Area E.

The evaluation of interactions between recreational and commercial fisheries in Area E requires three core data inputs:

- Fishery data from both recreational and commercial sectors.
- Oceanographic models of circulation.
- Residence times, exchanges rates, migration and behaviour data on the black marlin.

AIMS is currently developing a model of the circulation in the Coral Sea that will form an integral part of any interaction modelling. The fishery data is available through the AFMA and SPC data bases and Japanese 5°x5° catch data logs. The historical recreational catch effort data is currently being compiled, and collection of recreational catch effort data is proposed for the east coast billfish charter fishery and a recreational fishing personal log book scheme has been initiated by QFMA. The missing link is the movement information on marlin, without which it will not be possible to examine in detail the extent and nature of interactions.

This pilot proposal is seen as the first step in collecting the vital information of marlin movement dynamics. The proposed project will collect fine-scale movement data and evaluate the utility of PSTATs (Pop-up Satellite Transmitting Archival Tags). PSTATs are seen as the only way in which to collect the data we require on marlin migration and behaviour. Because of very low recapture rates, conventional tagging provides little data on movement, and then only point to point information. Ultrasonic tracking is limited to short time scales. PSTATs are high tech, building on the success of archival tags used by CSIRO for studies of SBT migration. However, we believe it is important to test the PSTATs fully before moving into a large scale study. At the completion of this pilot project, and having demonstrated the utility of PSTATs, we will propose a more detailed study to determine marlin movement dynamics and behaviour, and integrate this information with the oceanography and the operational characteristics of the charter and longline fleets into a model to evaluate the availability of black marlin to the charter fleet under different levels of longline effort within Area E.

3. Need

A better understanding of the distribution and migration patterns of marlin and the environmental and biological parameters that determine it, together with an evaluation of the nature and extent of the interaction between the recreational and commercial fleets within Area E, is one of the Eastern Tuna MAC's top research priorities. This pilot study will provide fine-scale movement data in the recreational fishing areas, and evaluate PSTATs in providing the detailed information on movement dynamics of black marlin critical to any evaluation of the interaction between the two fisheries. Only when this information is available, will it be possible to incorporate movement dynamics, oceanographic models of circulation in the Coral Sea, and the operational characteristics of the charter and longline fleets into a model to evaluate the availability of black marlin to the charter fleet under different levels of longline effort within Area E.

4. Objectives

- Evaluate the local interaction between recreational and commercial fisheries in Area E by using pop-up radio tags to determine short-term movements and residence times of black marlin in the recreational fishery.

- Evaluate pop-up satellite transmitting archival tags as a cost effective method for obtaining information on large scale movements, exchange rates and residence times of black marlin for assessing fishery interactions on the scale of the NW Coral Sea.

5. Detailed results

5.1 Pop-up radio tags

5.1.1 Introduction

Pop-up radio tags were deployed in group releases, to determine residence times within the fringe reef region targeted by the recreational/charter fishery. The radio tags were fitted with electronic releases activated at staggered time intervals to determine point to point movements over nominated periods, i.e. 3-7 days. These tags were to be released in two experiments. In each experiment, the tags would release at nominated time intervals so as to pop up on the same day, rationalising fly-over time. A light aircraft would then overfly the region to determine where they popped up. These experiments would determine whether black marlin remained within the fringe reef area accessed by the recreational/charter fleet, or whether they moved further offshore.

5.1.2 Radio tag design

We used SIRTRACK high power two stageVHF radio transmitters with 250 mm long antennae operating on the 150 MHz band. Each transmitter operated on its own frequency for individual recognition, each spaced 20 KHz apart. Each transmitter was powered by three 10-25 lithium cells producing 10.8 v and transmitted a 25 ms pulse at 100 pulses per minute. The transmitters were activated at the time of release using an RSF reed switch, and had a transmission life of 30 days.

The transmitters were fitted into hydrodynamically streamlined and stable polycarbonate housings (Fig. 1). The design of the housing was developed and tested overseas with an intended application on broadbill swordfish. The housings were produced in-house at CSIRO and tested for suitable buoyancy and pressure resistance to 300 m. The tags were attached to marlin using tag heads also developed for broadbill swordfish and successfully tested on southern bluefin tuna (Appendix, Fig. 1). Timed release was achieved by galvanic links placed between the tag and the tag head (Appendix, Fig. 2). It was intended to use an electronic release but none were available within the time-frame and budget of the project. Thirty radios were purchased and 29 functional radio tags were produced.

5.1.3 Radio detection

There were two options available for antennae systems – directional or non-directional. We chose a directional system because it gave us the ability to both detect the direction from which a radio was transmitting, and enable us to locate the tag to within a few hundred metres. The disadvantage, however, was that the size of the antennae limited the air speed at which the tracking craft could operate. The alternative system could be used at higher speeds, but gave little indication of the direction and location of the radio transmitter.

A further restriction was that of choosing an appropriate antennae and mount design that had CASA approval for the designated aircraft. We chose twin 3-element Yagi antennae and an existing CASA approved mount certified for a Cessna 172. The choice of the Yagi antennae limited our flying speed to 125 knots. We used a Cessna 172 XP which flew at 124 knots, although air speed was reduced to 110 knots when the twin Yagi antennae were attached. We had investigated developing non-directional antennae and mount for use on a faster aircraft but became bogged down in CASA bureaucracy. We had no guarantee that a system would be approved in time or what the final cost would be, although indications were that it would cost $20,000-30,000. This had not been budgeted for.

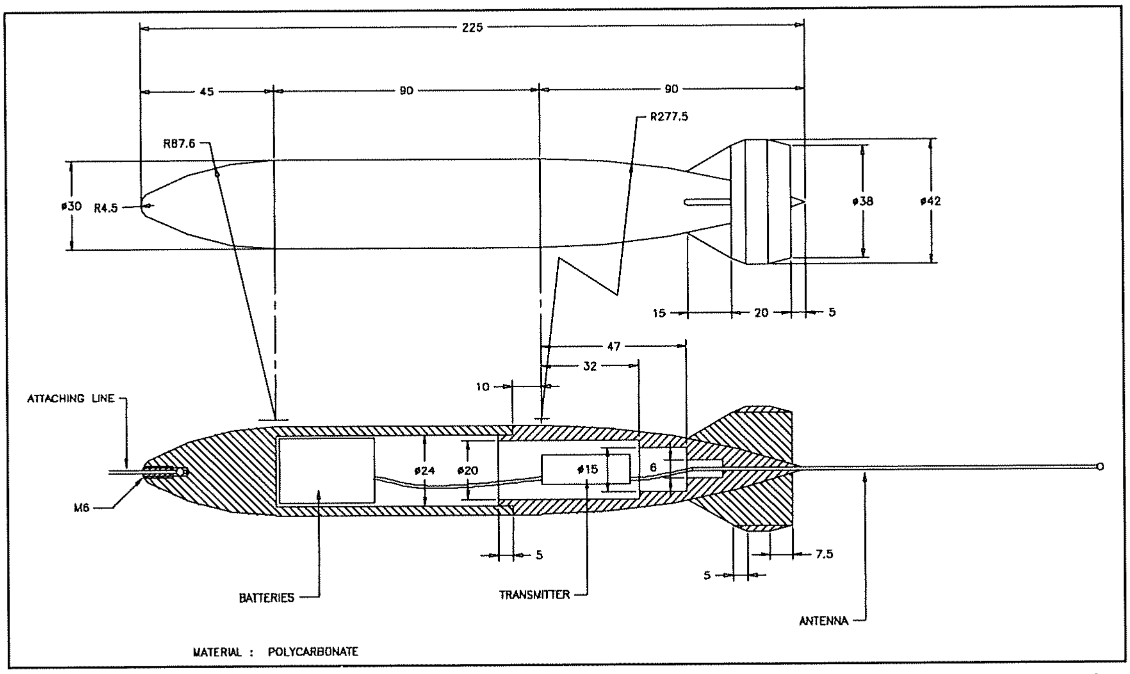

Figure 1. Design details of pop-up radio tag housing made of polycarbonate. Measurements in mm.

The Yagi antennas were attached to the left and right wing brackets of the aircraft (Appendix 1, Fig. 3) and were oriented to detect radio signals on either side of the aircraft. A left/right/both switch box enabled the operator to listen to either or both antennas and hence determine the direction from which radio signals were transmitted. A Uniden UHF scanning receiver was used to detect signals transmitted on the frequencies used (150 MHz band).

5.1.4 Experiment 1 – Lizard Island

The first experiment was carried out at Lizard Island. Originally we had intended to tag fish caught during the Lizard Island tournament. However, after discussion with fishers, it was decided that this would unduly interfere with the tag and release practiced during the tournament. As more than adequate numbers of boats were fishing near Lizard Island prior to the tournament, we had no difficulty distributing all available field tagging kits to participating skippers. Each tagging kit contained written instructions, two radio tags, a tagging pole, and a box of different timed galvanic releases. If a marlin was not tagged on the first day then the galvanic release was replaced with the appropriate one (labelled) for the following days fishing. Additional radio tags were provided to skippers that had succeeded in tagging a marlin at the end of each day's fishing.

Sixteen black marlin were released with radio tags between 20 and 26 October 1997 (Fig. 2 and Table 1). One of these tags was deployed with the wrong interval release and would not pop-up before the experiment had ended. Nine marlin charter boats were involved in the experiment – Lucky Strike, Balek III, Mauna Kea, Kiama, Assegai, Inkwazi, Kanahoe, Reel easy and Flamingo Bay. The

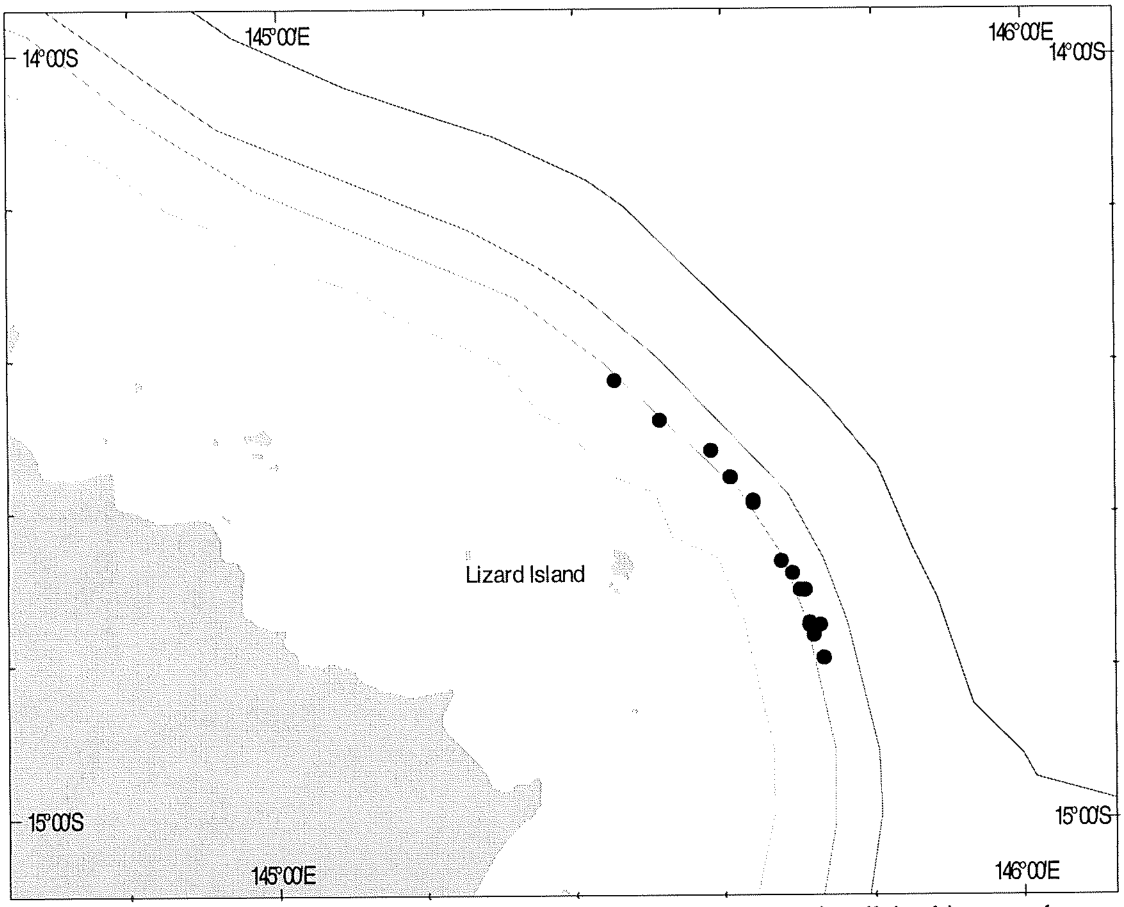

Figure 2. Positions of the16 radio tags released on black marlin caught off the fringe reefs (Boulder to Ribbon no. 10) east of Lizard Island between 20 and 26 October1997.

radio tags were fitted with galvanic releases of 3 to 9 days duration, so that all tags would release on 30-31 October. The area was then searched for radio tags using a Cessna 172.

Owing to the failure of the aircraft charter company to carry a life raft as requested, the aircraft was restricted to flying within 50 nm of land. A further restriction in search area was caused by the limited flying time (3.75 hours flight duration) of the aircraft and flights had to be carried out in daylight. Flights were carried out twice a day on 30 and 31 October, returning each time to Lizard Island (Fig. 3). A fifth flight was carried out on 1 November terminating at Cairns.

A spare radio tag was activated on Flamingo Bay which fished off Ribbon no. 10 during the aerial search. This was done so that we could check on the range of the signal while we were flying. The theoretical radio horizon was about 70 nm on either side of the aircraft at the search altitude used during flights (5000 ft). We regularly picked up the test tag at distances of 40-50 nm when the aircraft was side-on to the source of the signal. We noticed no difference in the strength of the signal on the test tag when it was sitting on Flamingo Bay or when it was floating on the surface of the water. Thus during each flight we should have detected any tags released to about 80 nm east of the fringe reefs and possibly further. In addition tags should have been detected if they had popped up within 90 nm north or 180 nm south of the point of tagging and within 80 nm of the fringe reefs.

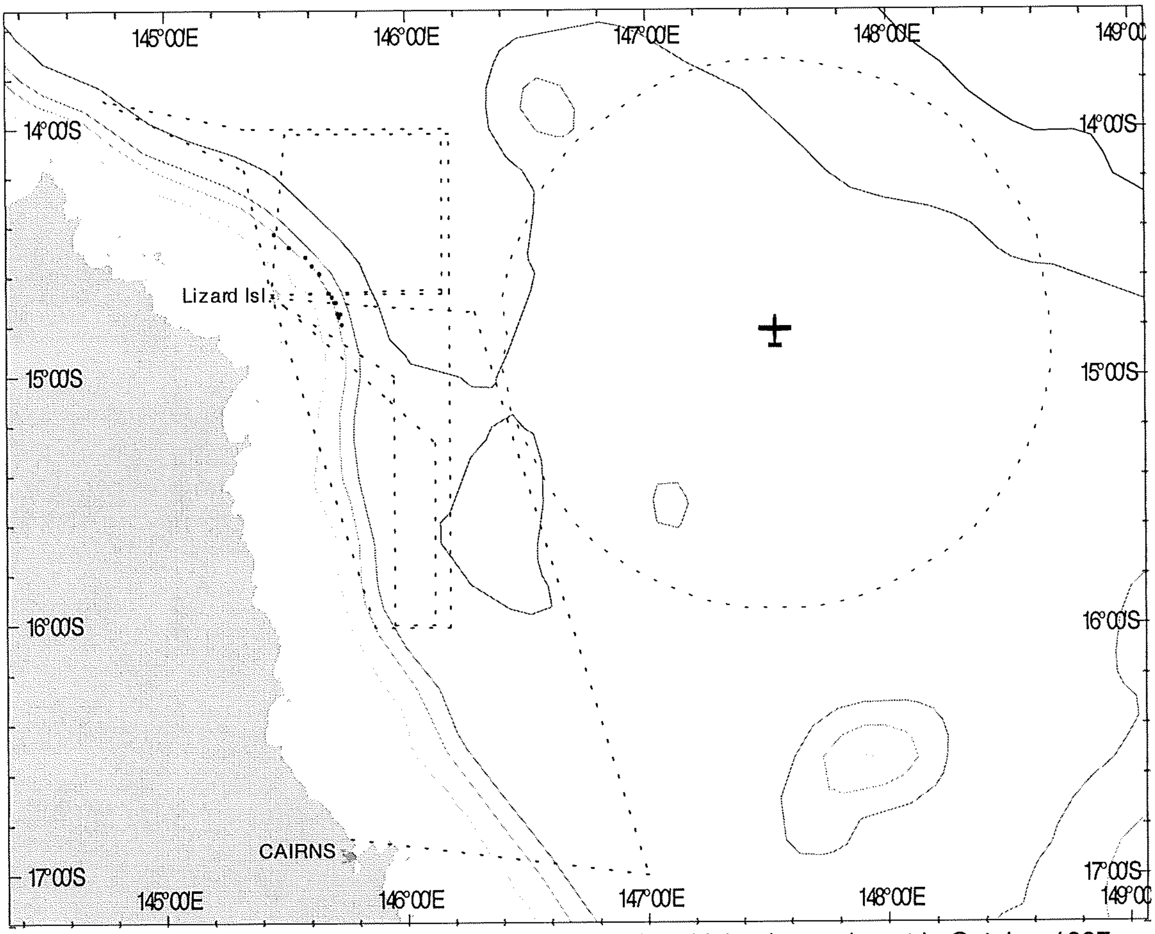

Figure 3. Search tracks of the five flights during the Lizard Island experiment in October 1997. The circle represents the theoretical radio horizon at the altitude flown (5000 ft).

Only one marlin was detected (tag 150.08) and this was detected twice; at 10:38 h and 14:40 h on 31 October (Fig. 4). As the tag was beyond the flying range of the aircraft we could not pinpoint its position. We obtained two estimates of the direction of the tag by circling and recording the sector in which the signal strength was greatest. The position at which the signal was detected while flying the southern section in the afternoon was 68 nm south of the position at which the tag was detected in the morning. This is the distance of the theoretical radio horizon. The poor resolution of direction at the first and second detection is a consequence of the extreme distance of the radio from the aircraft at that time. This is based on the good resolution of direction we were able to obtain on the test tag at a distance of 40 nm. This would suggest that the second detection was well beyond the radio horizon of 70 nm, and was probably more than 100 nm away. It would seem that special conditions enabled detection of the radio signal beyond the radio horizon at that time.

The most likely movement of radio tag 150.08 was 150 nm NNE of the point of release. This tag was placed on a 350 lb marlin at 15:01 h on 24 October with a D8 galvanic release. This tag should have released 100 hours later if the mean water temperature was >24° C. As it was not detected on 30 October it must have released at least 7 days after tagging. This would suggest that the mean water temperature inhabited by the marlin was much cooler than 24° C. Surface water temperatures in the tagging area were about 25° C which is cooler than about 28° C that we expected at that time of year. As significant time is spent below the surface by marlin tracked ultrasonically (Pepperell and Davis, In Prep), then mean temperatures encountered by the marlin would have been lower than 25° C, probably about 18° C.

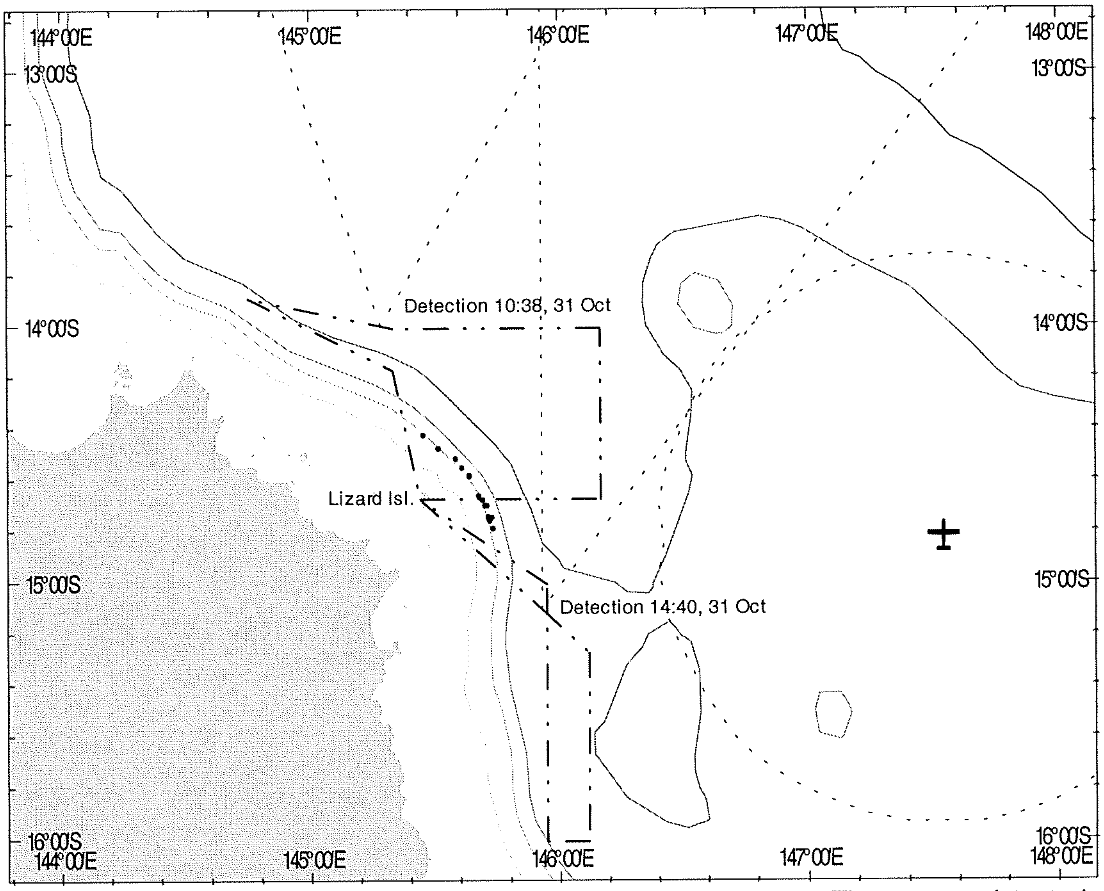

Figure 4. Detection of tag 8 on 31 October on two consecutive flights. The tag was detected towards the north in the morning when the northern sector was surveyed and in the afternoon when the southern sector was surveyed. The circle represents the theoretical radio horizon at the altitude flown (5000 ft). The afternoon detection and possibly the morning detection were beyond the theoretical radio horizon. — -- — flight tracks; - - - estimated bearing boundaries for each detection.

Conditions during the experiment were characterised by a northbound current and a paucity of bait. These may have caused greater movement and throughput of the marlin than expected from the ultrasonic tracking experiments carried out in 1992-1995 (Pepperell and Davis, In Prep). Greater movement coupled with the longer than planned release intervals, may have caused the radio tags to pop up beyond the detection range of the aircraft transects. Alternatively, some aspect of the operation prevented the tags from transmitting as planned. In order to determine whether failure to detect tags was due to migration out of the area a second experiment was planned for November with very much shorter release intervals of 1 to 5 days.

5.1.5 Experiment 2 – Linden Banks

The second experiment was carried out nearer to Cairns on 23-28 November. Nine boats participated, fishing in the vicinity of Linden Bank – Paketa, Tropic Seas, Bill Collector, Assagai, Kanahoe, Born Free, Sea Strike, The Judge, and Flamingo Bay. The release intervals were shortened to 1-5 days in light of the results of experiment 1. Only two marlin were captured despite the large fishing effort (Table 1, Fig. 5).

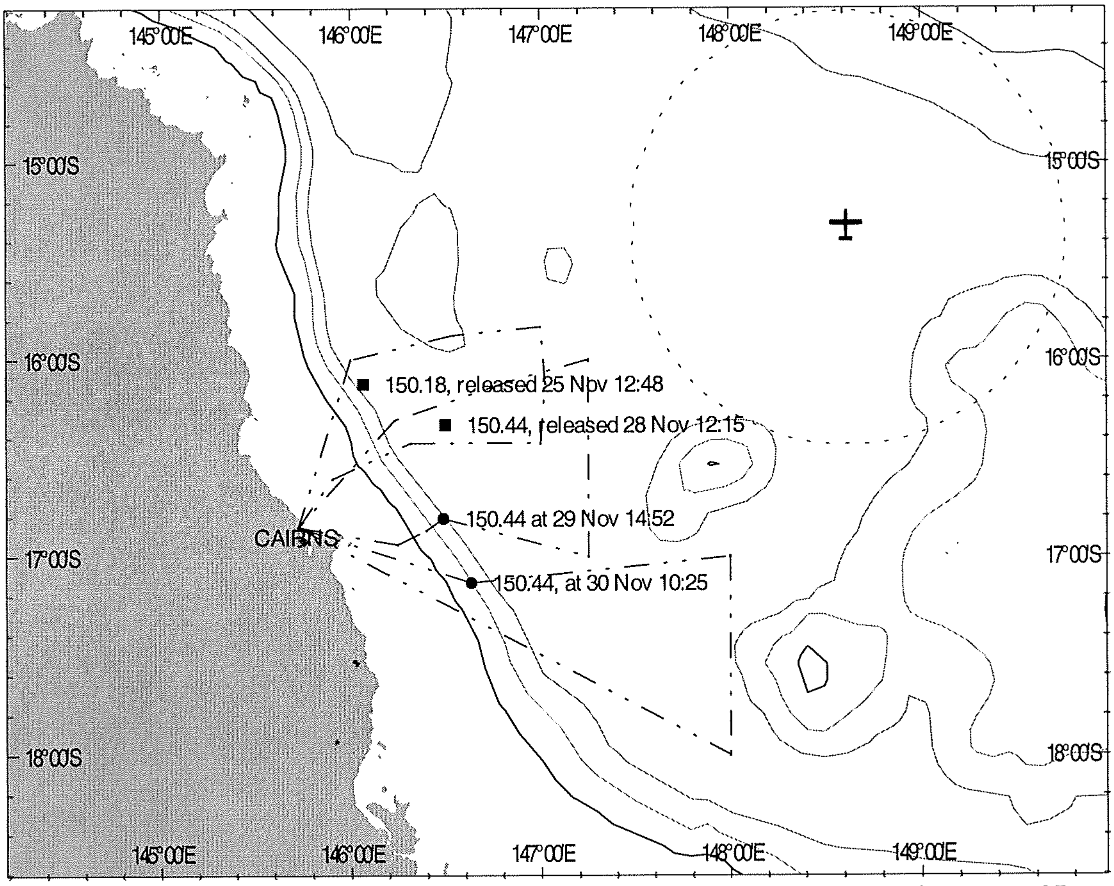

Figure 5. Positions of the two radio tags (squares) released in the Linden Bank area on 25 and 28 November 1997. Radio tag 150.44 was located on 29 and 30 November. – - - – represents the three search tracks flown.

The area was searched three times, using Cairns as a base. There were no restrictions on the distance we were able to fly from land as a life raft was carried. However, the 4 hour flying limit was still in effect because of the size of the Cessna's fuel tanks. No tags released from marlin were detected on the first flight on 29 November which took place from 09:50 to 12:20 h (the most northerly transect in Fig. 5). Radio tag 150.48 was detected on this flight but it had not been deployed. It must have been accidentally activated on board Assagai. Radio tag 150.44 placed on a 750 lb marlin was first located in the afternoon and then relocated the following morning. It would have been detected on the first flight had it popped up as it was well within radio detection range (Fig. 5). Thus it must have popped up between 12:00 and 14:30 h on 29 November; about 25 hours after tagging. During this time the marlin had moved 28.5 nm south at about 1.1 knots. The radio tag was relocated 19.5 hours later during which time it had drifted 21.3 nm SSE at about 1.09 knots. Both the marlin and subsequently the tag had drifted with the prevailing current. The similarity of the two speeds would suggest that while the marlin may have been actively swimming, its net movements had caused it to remain within the same body of water.

5.1.6 Experiment 3

Because of the poor fishing in November a third experiment was carried out on 7-12 December. Only one boat – Azura was involved. Three marlin were released with radio tags with release intervals of 18 hours to 3 days (Table 1, Fig. 6). Tag no. 150.58 was deployed after the planned completion of tagging and was not expected to release before the experiment had ended. Radio tag no. 150.50 was deployed 55 nm seaward of the fringe reefs. On 7 December, the current was moving southward, it slowed by 10 December and was moving slowly north on 11 December. The first flight was on 11 December from 13:30 h to 17:05 h, and covered the area south of the tag releases. No tags were detected. The second flight was on 12 December from 10:00 h to 12:50 h and covered the area to the north of the releases. Again no radio tags were detected.

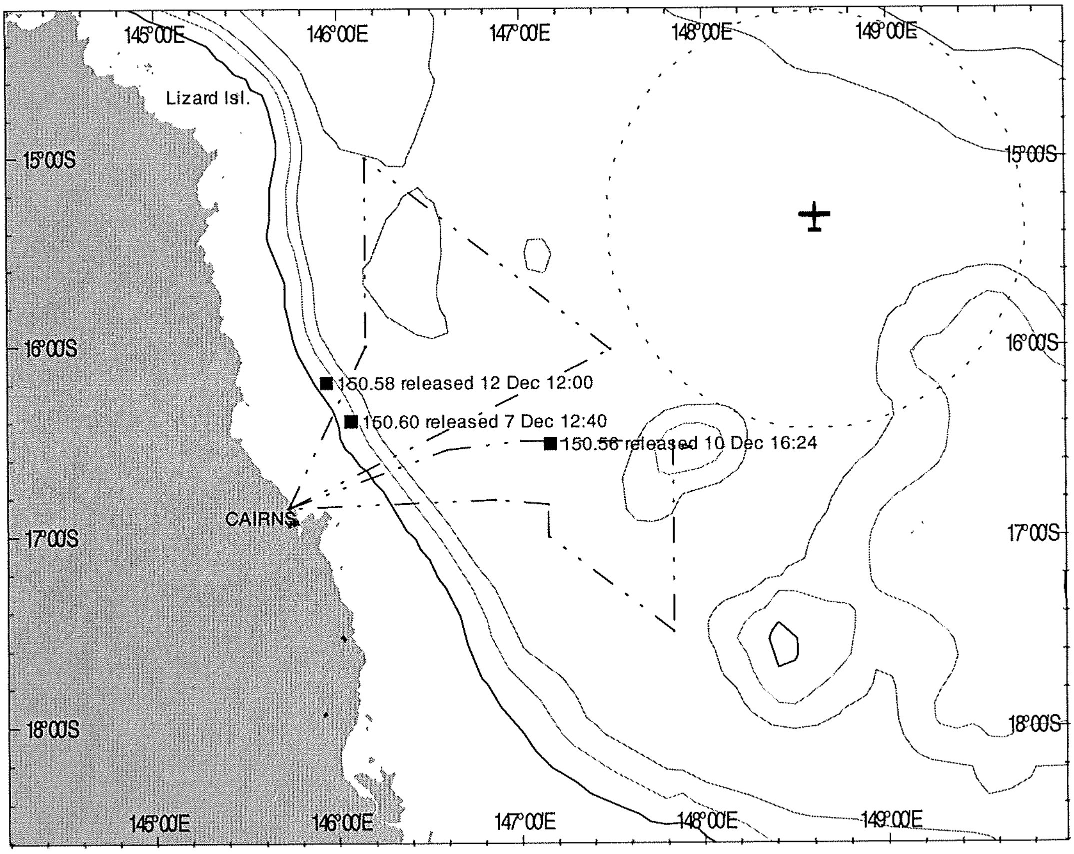

Figure 6. Position of the three marlin released with radio tags during experiment 3. – - - – represents the two search tracks flown on 11 and 12 December.

5.1.7 Discussion

Only 2 out of 19 properly deployed tags were detected successfully. The net movement was with the prevailing current. It has been suggested on the basis of ultrasonic tracking and simultaneous measurement of oceanic currents that the horizontal displacements of striped marlin can be strongly influenced by currents (Brill et al. 1993). In the Lizard Island experiment it was thought that this might have been due to the tagged marlin moving out of the surveyable area before they could be detected. The Linden Bank experiment was designed to determine whether this was the case. Unfortunately it was not possible to tag sufficient numbers of marlin in experiment 2 or 3 to answer this conclusively. However, it is likely that some aspect of the operation was failing.

Detection range

The radio signal emitted by the tags and the detection range of the aircraft was adequate to locate any tags that were released to at least 90 nm offshore of the reef edge. Anywhere further offshore of this would have be well outside the usual charter boat fishery. While it is possible that some of the marlin tagged with longer interval releases had moved beyond the surveyable area, many should have been detected within this area if some aspect of the operation had not failed.

Timed releases

The use of galvanic releases was the cheap but not the preferred option for releasing the tags. The main problem was the release interval was dependent on temperature. As we have no control on the depth and hence water temperature occupied by the tagged fish we have only crude control over the release interval. Some tags did not release until after the experiments, and it is possible that others also failed to release in time. Ideally, an electronic release should be used and this should be programmed to release at a particular time rather than after an interval of time. However, such a release was not available at the time.

Tag head

The tag head is an improvement of one used successfully on black marlin by Pepperell and Davis (In Prep.) and is not likely to have been the cause of failure in these experiments. If the tag heads had failed the radio tags would have sunk, as they did not have excess buoyancy to support the weight of the galvanic releases. If this had happened in water less than 400 m deep, the tags would have released and floated to the surface after considerable delay because of the lower water temperatures at depth. If the tags had sunk below 400 m they would have imploded. A similar fate would have happened if the marlin had died.

Radio tag housing

The hydrodynamic design of the radio tag housing was superior to any conventional design and was not seen to be a problem. In high winds the aerial should have remained above water as the tag had little windage, although the range of the radio transmission would have been restricted. During the Lizard Island experiment we had a moderate to strong sea breeze each day.

The tag housing was made of clear polycarbonate which might have reflected light and attracted predators such as wahoo and barracuda. Tags might have been attacked while on marlin, although this seems unlikely. It is more likely that tags would have been attacked after releasing, while on the surface. It is possible that wahoo and barracuda could break and sink a tag if they attacked it. This possibility was raised by a number of anglers during the tagging experiments. In retrospect, it may have been wiser to paint the tags a dull colour to reduce this possibility.

Conclusion

Determining the movements and residence times within the area fished by the recreational fishery requires methodology having a higher resolution than can be obtained from geopositioning using light data from archival tags available at the time. However radio tag experiments have the following limitations:

- Tags have to be put out over a very short space of time and this is unrealistic due to the nature of the fishery.
- Aircraft search range is limited.
- All tags need to pop-up within a short space of time because of the high cost associated with aerial searches.

The most effective system to resolve movements at the scale of the recreational fishery is to use pop-up tags which can be located by satellite. These do not need to be as sophisticated as the PSTATs that compute location from light data and then transmit summarised positional data to satellite when released. Thus marlin could be tagged throughout the season, taking advantage of periods of high catch rates and the tags would be located automatically by satellite when they released. Such a tag would have an electronic release with a programmable time interval or date. However, in the near future PSTATs should be capable of determining position from light data at a sufficiently high resolution to determine movements into and out of the fringe reef area and residence times within area E.

5.2 Pop-up Satellite Tag Experiments

5.2.1 Introduction

Pop-up satellite tag technology first became available in early 1997 when it was used in pilot studies on blue marlin by Block (pers. comm.) and Atlantic bluefin tuna by Block et al (1998) and Lutcavage et al. (1998). The concept of pop-up tags had been discussed over a decade before this in a review of the dynamics of movement in tunas (Hunter et al. 1986) and the potential use of a experiments using pop-up tags had been discussed by Gunn et al. 1994 and Restrepo (1995).

Hunter et al. (1986) discussed the concept of both archival and pop-up tags, recognising that the latter would be most useful in species where the probability of tag recovery from recaptured fish was low. Since the early 1990's, archival tags have been used on tunas (Gunn et al. 1994, Klimley et al. 1994) and have rapidly become an important tool in determining the movement of those tuna species for which recapture rates are relatively high (eg, SBT >20%, Atlantic Bluefin > 10% and bigeye >7.5% in the Pacific).

For species such as marlin and the large bluefin tunas, for which recovery rates of conventional tags are generally very low, pop-up tags are considered the only viable method of collecting data on medium to long term movement. In response to calls from researchers, Paul Howie and his associates at Microwave Telemetry P/L in Maryland USA developed the first pop-up tags in early 1997. Their first generation tags – the PTT 100 PU1 - could be programmed to release from a fish at a predetermined time, pop-up to the surface and transmit to satellite. A limited number of data points describing average water temperatures experienced by the fish during its time at liberty could be transmitted. The position of the tags would be determined by the ARGOS land station from satellite detection.

These tags allowed researchers to design an experiment to map out the movement of fish over a period of time, but only as a series of release and pop-up locations. Given the aggregated form of the temperature data on the Microwave telemetry PTT 100 PU1's it was difficult/impossible to infer position using temperature over the intervening period. Block et al. (1998) and Lutcavage et al. (1998) showed that pop-up tags could be successfully attached to large Atlantic bluefin tuna. In their experiments, over 90% of the tags released popped up at the predetermined times. All gave high quality locations and provided some data. Both teams had programmed the tags to pop-up after a range of times at liberty, allowing them to "map" migration of fish out of the very restricted tag release areas. Their data provided exciting new insights into the movement of the species.

Recognising the potential that pop-up tagging experiments offered for many species, CSIRO has been involved in the development of a more sophisticated pop-up tag for over three years. The tag is being designed to log, summarise and transmit data that will allow estimates of position over the entire time at liberty, allowing researchers to reconstruct a track of each fish's movement. While this tag was in development we considered the results achieved by Block et al. and Lutcavage using the simpler Microwave Telemetry pop-up tags to be promising enough to warrant a pilot study on black marlin.

As with many species of marlin, recapture rates for conventional tags attached to black marlin are very low (<1.0% from 20,000 releases). Many hypotheses have been proposed to account for the low recapture rate, ranging from huge populations and low exploitation rates, to high tagging mortality, high tag shedding rates, and low reporting rates from commercial longline vessels that are thought to be the main source of fishing mortality in the species. Whatever the explanation, the result is a very patchy understanding of the movement patterns of marlin after they leave their spawning ground in the Coral Sea in December/January.

The principal objectives of our experiment were to examine the feasibility of tagging black marlin with pop-up tags and to assess whether the tags would remain attached for the required period. With only two tags available to be deployed, the two pop-up points were going to be of limited value in determining migration routes. However, we programmed the pop-up times to be 120 days after tagging, to fall while black marlin are thought to be out of the Coral Sea.

5.2.2 Tag Specifications

The tags used were Microwave Telemetry P/L (also trading as Telemetry 2000, Inc) PTT 100 PU1 pop-up satellite tags. These comprise a polycarbonate cylinder housing the electronics, a tear-shaped float collar at one end of the cylinder, and a 160 mm steel antenna. This configuration allows the tag to float upright, with the antenna above water level once the tag has released from the fish. The cylindrical/collar set up is designed to minimise drag when the tag is attached to the fish. At the opposite end to the antenna is a corrosive link that allows the tag to be released from a fish at a predetermined time. At that time, a current is passed along this link facilitating a rapid corrosion. The tag is attached to the fish by a 40 mm long stainless steel anchor. The anchor is an upsized version of the conventional steel game fish anchor used throughout the work for conventional tag programs (Appendix, Fig. 1).

The tags are positively buoyant and weight 65-68 g in air. They are pressure tested by the manufacturer and can withstand at least 1000 psi (690 m depth). Within the tag electronic circuits, a microprocessor controls data logging, satellite transmission and release timing. The tags have a small data storage capacity and up to 61 average daily temperatures (temperature is recorded every hour) can be transmitted.

The PTT 100 PU1's transmit to an ARGOS receiver on board a NOAA satellite. According to the manufacturer's specifications, the tags transmit data for at least 30 days following pop-up. Data from the tags are transmitted to the user's laboratory by email from ARGOS CLS offices. In Australia, the CLS office in Melbourne and for this project an account used by John Stevens of CSIRO was used. ARGOS provides users with unique tag identity codes for each transmitter. All transmitters require this identity code before ARGOS will enable a receiver to receive messages.

5.2.3 Tag deployment

The design of our experiment using satellite pop-up tags called for one of the two tags to be released from a fish caught by rod and reel on a game fishing vessel, the other from a longliner. Poor fishing prevented a release from a game fishing vessel. Thus, both tags were released from commercial longliners.

According to our instructions, both tags were programmed by Microwave Telemetry to pop-up 120 days after activation. Activation is initiated prior to deploying the tag by removing a small magnet from the side of the poly-carbonate cylinder.

Tags 9316 and 9317 were activated on 13 December 1997. Tag 9317 was released by John Gunn (CSIRO) on a 350 lb (estimated weight) black marlin, on 13 December 1997. The fish was caught by FV Total, on a longline. It appeared in good condition (based on its colour, eyes and fin movement) and was very lively when tagged. The tag anchor was inserted in the upper shoulder region, approximately 10 cm anterior to the origin of the dorsal fin. The fish was then cut free, with the longline hook still attached. The release position was 16°49'S, 146°55'E.

Tag 9316 was released by Peter Hibbert, captain of FV Total, on a very large (estimated weight >800lb) black marlin, on 4 January 1998. The tag anchor was inserted in the upper shoulder as per the other tag. The fish was lively and appeared to be in good condition. The release position was 16°33'S, 147°47'E.

5.2.4 Results

Pop-up time was expected 120 days after activation, on 12 April 1998. We received no transmissions from the two tags on this date, nor for the next 200 days.

On 19 November 1998, 341days after activation, we received the following ARGOS transmission message from the first tag we released:

"09317 16.933S 147.076E 0 323/1440Z-???/????
(1) 255 255 255 243
3F EE 4F C8
8F F1 D8 47
0F D9 87 FD

EF C7 8F FF
FC E6 ED 72
27 42 25 CF
BF 67 BA D6"

The message provides, the tag number, an estimate of position for the last occasion the tag transmitted enough data for CLS ARGOS to calculate the position (latitude and longitude), the class of message received (0= poorest quality transmission, from which a position estimate is impossible), the day (323) and time (1440) of the last transmission, and the position estimate made from that transmission (???/????). In this case the transmission class (0), meant that no position estimate was possible, hence the question marks. On the second line of the transmission, the number in brackets is the number of transmissions received from the tag. In this case, only one transmission was received. Depending on weather conditions and tag condition, we would have expected to get at least eight transmissions per day from the tags, each day, for two weeks. The remaining data on line 2 tell us that the ARGOS message had data from four channels, each with eight bit data. The following lines are a data stream in hexi-decimal format.

On 18 January 1999, 401 days after activation, we received the following ARGOS transmission from the second tag we released:

09316 0.000N 0.000E 0 018/2002Z-???/????

>(1) 138 166 223 185

Once again, the tag transmission was a low class from which it was not possible to estimate a position for the pop-up. As with the other tag, only one transmission was ever recorded by ARGOS from tag 09316. If the tag had worked correctly we would have expected many more transmissions and from these an accurate pop-up position.

5.2.5 Discussion

There are a number of questions regarding the data we received for the two tags from ARGOS:

- Why was the data of such poor quality?
- Did we only hear from each tag on one occasion, instead of over a two week period as per the tag specifications?
- Why didn't the tags pop-up after 120 days, as programmed?
- Why was the data within the message forwarded from ARGOS not in the format used by the tag manufacturer?

Before we can discuss the data in any scientific context it is important to consider these questions and ascertain whether in fact the tags popped up and transmitted as indicated in the ARGOS messages.

In our attempts to objectively answer the questions, we have had extensive discussions and correspondence with the tag manufacturer (Microwave Telemetry), another PTT/tag manufacturer, CLS ARGOS Melbourne office and head office in France, and other scientists who have used Microwave Telemetry pop-up tags. Below we attempt to synthesize what are widely varying views of what happened to the two tags.

Why did the tag transmit only once and why was the data of poor quality?

Other users of Microwave Telemetry tags have experienced similar single transmissions to those we describe above. In experiments on marlin, more than half the tags deployed have not popped up and of these a small proportion have registered single transmissions. Microwave Telemetry and these users have concluded that when a tag transmits only once, on a date after it was programmed to pop-up, that it was a "phantom" transmission. Microwave Telemetry believes that these are the result from poor data quality control from CLS ARGOS. If this is the correct, then we would conclude that our two tags never popped up and the data we received is false.

On the other hand however, CLS ARGOS have investigated the issue of data quality control and suggest that while phantom transmissions are possible they are very, very rare (<1% of cases). Thus, the relatively high level of "phantom" transmissions for Microwave Telemetry tags is seen as anomalous. Our query regarding the marlin tags is the first instance known to the CLS ARGOS Melbourne office where a manufacturer had claimed faults in ARGOS data, rather than the transmission performance of the PTT. CLS ARGOS believe that the fact that a number of users of Microwave Telemetry are having phantom pop-ups is an indication of manufacturing problems rather than errors in ARGOS messages. Thus, from CLS ARGOS point of view, the two marlin tags did pop-up, but for technical or mechanical reasons could not transmit reliably.

Why didn't the tags pop-up after 120 days as programmed, and if the tags did transmit to ARGOS after 341 and 401 days, how could this happen?

Microwave Telemetry assure us that it is not possible for their tags to pop-up at a date other than that programmed, and believe there is very little chance that the tags we had were incorrectly programmed. Also, the tags we used came from a batch that have worked as per specifications on experiments with Atlantic bluefin tuna on the east coast of the USA. Each batch of tags is built and tested together and there is no reason from a manufacturing point of view for two tags from a batch to fail while the others perform well. Thus, Microwave Telemetry believe that because the two tags did not pop-up after 120 days, they have either failed, or were damaged by fish behaviour (such as jumping, or diving below the 1000 psi level), or were attached to fish that have died and sunk to the bottom. Other possibilities are that the attachments have failed prematurely and that the tags have been attacked before they were due to transmit. Attacking by predators immediately after surfacing could also account for limited transmissions.

Other electronic tag manufacturers have suggested that the batteries used by Microwave Telemetry may suffer from passivisation when exposed to the high water temperatures of tropical regions. Passivisation is the process whereby batteries under low current load go to "sleep". If this was the case, and the Microwave Telemetry tag's circuitry does not provide for regular conditioning of the batteries while the tag was attached to the fish, then it might explain why a tag would power down between sampling and never "wake up".

Whether the battery/tag would wake up at a later date, either in response to changed temperature conditions, or some kind of mechanical stress (bumping/knocking due to fish jumping) is speculation. The passivisation could certainly explain why tags wouldn't pop-up , but it seems unlikely that a sleeping tag would wake up at a future time/date without a significant reconditioning.

Why was the data format in the ARGOS message unlike that from other "successful" Microwave Telemetry pop-up tags?

There is no doubt that the data transmitted are not in the format used by Microwave Telemetry. This supports the manufacturer's contention that the transmissions are "phantoms". CLS ARGOS can not explain why the data format is different. However, they point to the fact that the data are in a four sensor/8 bit format as specified in the ARGOS program profiles. That is, they would expect the data to be in the format we received given the profiles they had for our tags.

In conclusion, there remains significant doubt whether the two tags we deployed popped up and transmitted to an ARGOS receiver. If they did, they did so only once and thus, we are unable to determine with any certainty the location at which they popped up. As we know the time of the transmission, it is possible to determine the footprints of the two NOAA satellites that carry ARGOS receivers and from these examine the general areas in which the tags may have transmitted. (Figures showing NOAA footprints).

None of the footprints (ie. potential pop-up sites) is close to the Coral Sea, where we would expect black marlin to aggregate during the summer spawning season. However, black marlin are known to undertake extensive migrations and it is conceivable that they may not return to the Coral Sea each summer. Thus, although it is plausible that the fish may have been in the areas covered by the NOAA footprints, this seems unlikely.

If our tags did fail, what caused the failure, and why have the tags worked so well in bluefin tuna but not on marlin species?

As noted above, Microwave Telemetry PU1 tags have worked very successfully in studies of Atlantic bluefin tuna. Lutcavage et al. (1998) and Block et al. (1998) report that over 90% of the tags they released popped up successfully and that data transmitted was of high quality. Thus, at least for this species the technology has been well proven.

The success rate for marlin is much lower. Block and associates have tagged blue marlin off Madeira in the Atlantic (4 of seven releases have popped up) and off Hawaii in the central Pacific (60% of these tags popped up successfully). Block has also used the technology with striped marlin off Baja California, with similar success rates. From all of these pilot studies it is clear that the success rates with pop-ups on marlin are much lower than with Atlantic bluefin tuna. If we assume that the two tags we attached to black marlin in this study did not pop-up successfully, the overall success rates for Microwave Telemetry PU1's on marlins is approximately 50%.

Why the pop-up tags should perform so differently on tuna and marlin is extremely difficult to determine at this stage. There are a number of plausible explanations:

1. *Capture and tagging stress in marlin is much higher than in bluefin tuna, resulting in higher short term mortalities.*

This is something that can be examined through long term tracking, or perhaps through short-term pop-up experiments. Previous tracking studies on black marlin (Pepperell and Davis In Prep) indicate that a small proportion of marlin caught by rod and reel die as a result of capture, either through shark attack while the fish is still attached to the line, or shortly thereafter. Out of eight marlin tracked, one marlin was killed by sharks within 15 minutes of tagging. However, Pepperell et al. (In Prep) did not track for longer than 27 hours, leaving the question of whether the stress of capture and tagging may result in death after this time. The post-capture stress levels in blue marlin have been studied (Dobson et al. 1985; Daxboeck and Davie 1986) through examination of lactate levels in the blood. These studies found a very high level of lactate, which reduces the oxygen carrying capacity of blood as it travels across the gills. This means that fish caught by rod and reel (and perhaps also longline), are potentially subject to severe hypoxia (Block pers. comm.). In blue marlin there is characteristically a long "recovery" swim after capture by rod and reel, which is believed to be a period of rebuilding oxygen levels in the muscle, brain etc. Block and others suggest that this is a period during which the marlin is particularly vulnerable to predators.

Tuna undergo similar lactate build up after capture on rod and reel and could be expected to undergo a recovery period. However, the areas in which Block and Lutcavage tagged bluefin tuna do not carry the same density of large predators as the tropical waters frequented by marlin. It may be that they simply survive this period of recovery better.

We know very little of the physiology of black marlin, although it is likely to be similar to that of its close relative the blue marlin. As we note above, the fish we tagged were apparently in good condition when released and showed no obvious signs of capture stress. Fish caught on longlines are generally thought to go through an initial fight/frenzy period (similar to but of shorter duration than those caught by rod and reel) and then to calm down. The marlin we tagged were not frenzied. However, there are very large populations of sharks in the Coral Sea, and at times they are responsible for damaging large numbers of fish on longlines.

2. *Marlin behaviour is different to that of bluefin tuna and there is a higher likelihood of tag damage, or shedding.*

We know that blue and black marlin free jump, whereas this behaviour is uncommon in bluefin tuna. Why marlin do so is not clear. However, it is possible that free jumping could damage the tag (eg. bend the aerial, rendering it unserviceable) or result in the tag anchor dislodging. In the latter case, the tag would float to the surface where it would be very likely to attract the attention of predatory fish and sharks. Any damage caused by these animals would render the tag unserviceable.

Another behavioural pattern that could account for different success rates would be in diving behaviour – if marlin dive to a significantly greater depth than bluefin tuna, there is the possibility that they could exceed the maximum depth rating of the tags, thereby rendering them unserviceable. The PU1 tags are rated to 1000 psi (depth of approximately 690m). We know from archival tagging of Atlantic and southern bluefin tuna that they are capable of diving to depths in excess of 500 m (Block pers. comm., CSIRO unpublished data). Ultrasonic tracks of black marlin in the Coral Sea suggest that they dwell predominantly in the upper 100 m of the water column with the deepest recorded dive being 178 m (Pepperell and Davis In Prep). It seems from the data available on black marlin that they are unlikely to dive deeper than the maximum depth rating of the PU1 tags.

3. *Battery failure at high temperatures.*

Block and others have raised the possibility that the batteries used in the Microwave Telemetry PU1 tags may suffer from passivisation at high temperatures. Passivisation is caused by a chemical build up in the lithium power cell. It can result in lower power output in the battery, or in the tag falling asleep if it is not conditioned regularly. If passivisation at higher temperatures was a problem with the PU1 tags, it could explain why the tags on bluefin, which were tagged and remained in temperatures of predominantly less than 20°C, worked successfully, while the tags on black marlin, which were exposed to temperatures in excess of 28°C throughout their operational life, failed.

We contacted Paul Howie of Microwave Telemetry P/L regarding the possibility of passivisation. He assured us that this was unlikely to be a problem as his tags underwent regular cycling as they sensed water temperature.

5.3 The potential for future work using pop-up technology to determine marlin movement

The success of the first generation of pop-up technology in studies of bluefin tuna (Block et al. 1998, Lutcavage et al. 1998) provides us with a clear indication of what could be achieved with marlin. Within the next 12 months new generations of pop-up tags will be available that provide much more data on movement and behaviour of the study animals. However, the low success rates with the first generation pop-up technology on black, blue and striped marlin suggest that before we can justify further research we should address the questions of short term mortality of tagged marlin and/or tag failure due to fish behaviour.

To study whether short-term mortality following capture is a significant issue for black marlin we need to do more than track fish for 27 hours (as Pepperell and Davis (In Prep) have already done). It is quite possible that damage to fish resulting from capture may result in mortality more than 24-48 hours after capture – internal organ damage, high stress levels, hypoxia etc. may all result in protracted illness resulting in death. To examine whether fish are dying within the first week or so after capture, we need information on the behaviour of fish during this period, and a tag that is able to indicate when death occurs.

The next generation of pop-up tags will be smart enough to detect when a tag/fish has dived below its normal diving range, and to pop-off immediately this point is reached. This feature would allow researchers to program in a depth at which they believe the tag was on a sinking/dead fish. If the tag were not able to release at this depth it would quickly descend below its pressure limits, resulting in tag failure. Based on the tracking data on black marlin, and similar research on its very close relative the blue marlin, we could assume they do not swim below 350m. Thus, if the tag went below we would assume that it was attached to a dead (or dying) marlin that was sinking.

The new generations of pop-up tags, developed since we deployed the PU1s, will also be capable of collecting, summarising and transmitting data on the diving behaviour of the fish. If we were to program these tags to provide a short (1-2 week) time-at-liberty, the data produced would allow researchers to determine:

- whether the tag was on a fish that had behaved "normally"
- if the tag had detached from the fish prematurely (say following free jumping)
- if the fish had died in shallow water and sank to the bottom.

Thus, using the new generations of pop-up tags it would be possible to address two key uncertainties surrounding application of pop-up technology for studying marlin migration patterns and behaviour. If we could ascertain that tagging mortality and tag shedding were not a problem, then there seems every likelihood that this technology has the potential to answer many of the critical questions about black marlin population structure and movement dynamics.

If pop-up experiments to determine short term mortality indicate that this is a significant problem in either longline or rod and reel-captured fish, then these results will need to be carefully considered in developing management strategies for black marlin in the Coral Sea as this is considered to be the only spawning ground for this species in the Pacific Ocean.

6. Acknowledgments

The release of the radio tags depended upon the cooperation of the skippers and crew of the marlin fishing vessels involved: Mauna Kea (Dean Beech), Reel Easy (Darren Hayden), Assagai (Greg Edwards), Coocoran (Martyn Tischler), Lucky Strike (Ross McCubbin), Balek III (Laurie Wright), Kiama (Terry Parker), Inkwazi (Geoff Ferguson), Paketa (Peter Wright), Sea Strike (Bob Jones), Kanahoe (Brian Felton), Bill Collector (Chris Jones), Born Free (Dennis Wallace), Flamingo Bay (David Tomlinson), Azura (Barry Cross), The Judge (Craig Denham), Tropic Seas (Neil Yates), and Viking (Bill Bilson). David Tomlinson assisted as field coordinator, and Flamingo Baywas used as the base for field operations. The satellite tags were put out on longline vessels operated by Great Barrier Reef Tuna.

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8. Benefits

This pilot study determined that there are considerable logistical problems in using radio tag radio tag experiments to determine short-term movements and residence times of black marlin within the fringe reef region. Simple pop-up satellite tags are now available to adequately address this issue. It also identified problems with pop-up satellite tags and indicated that further research should address the questions of short-term mortality of tagged marlin and/or tag failure due to fish behaviour, before a full-scale PSTAT study was undertaken.

9. Further development

New generations of pop-up tags should be able to address two key uncertainties surrounding application of pop-up technology for studying marlin migration patterns and behaviour. They should be able to determine whether tagging mortality and tag shedding were the cause of failures seen in the pilot study. Once this has been resolved, this technology has the potential to answer many of the critical questions about black marlin population structure and movement dynamics.

10. Intellectual property

No commercial intellectual property arose from this work.

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Table 1. Release details of black marlin tagged with pop-up radio tags.

Date	Time	Frequency	Latitude	Longitude	Wt. (lbs)	Fight time	Condition on release
20-Oct-97	14:29	150.06	14°45.027'	145°43.303'	250	5	very good
21-Oct-97	12:47	150.02	14°25.624'	145°27.243'	350	22	hooked deep, bleeding initially, briefly tail-wrapped
22-Oct-97	14:30	150.10	14°35.105'	145°38.35'	350	5	gill hook, bleeding
23-Oct-97	09:42	150.16	14°33.270'	145°36.56'	300	5	very good
23-Oct-97	15:51	150.20	14°42.106'	145°42.504'	300	8	good
24-Oct-97	12:13	150.28	14°40.786'	145°41.479'	600	7	good
24-Oct-97	14:17	150.22	14°45.631'	145°43.183'	300	7	very good
24-Oct-97	15:01	150.08	14°44.685'	145°42.861'	350	6	very good
25-Oct-97	10:45	150.04	14°35.283'	145°38.353'	400	20	good
25-Oct-97	13:40	150.12	14°31.166'	145°35.026'	225	5	good
25-Oct-97	18:00	150.40	14°44.851'	145°30.91'	700	17	plate size shark bite near tail, good
25-Oct-97	15:13	150.38	14°44.851'	145°42.83'	300	5	bleeding a lot
26-Oct-97	12:53	150.36	14°47.440'	145°43.96'	300	7	good
26-Oct-97	15:00	150.26	14°42.097'	145°42.096'	250	5	tail wrapped briefly but good
26-Oct-97	15:35	150.14	14°39.842'	145°40.582'	275	7	good
27-Oct-97	18:00	150.42	14°28.778'	145°30.91'	800	20	tired
25-Nov-97	12:48	150.18	16°07.500'	146°04.8'	550	10	good
28-Nov-97	12:15	150.44	16°19.896'	146°29.778'	750	15	good
7-Dec-97	12:40	150.60	16°23.580'	146°04.189'	200	10	good
10-Dec-97	16:24	150.56	16°30.830'	147°09.743'	250	10	good
12-Dec-97	12:00	150.58	16°11.460'	145°56.19'	150	10	good

Table 2. Release details of black marlin tagged with pop-up satellite tags.

Date	Tag no.	Latitude	Longitude	Wt. (lbs)
13-Dec-97	Q9316	16°49'	146°55'	300
4-Jan-98	Q9317	16°33'	146°47'	>800

12. Appendix figures

Figure 1. Photograph of tag stainless steel tag head.

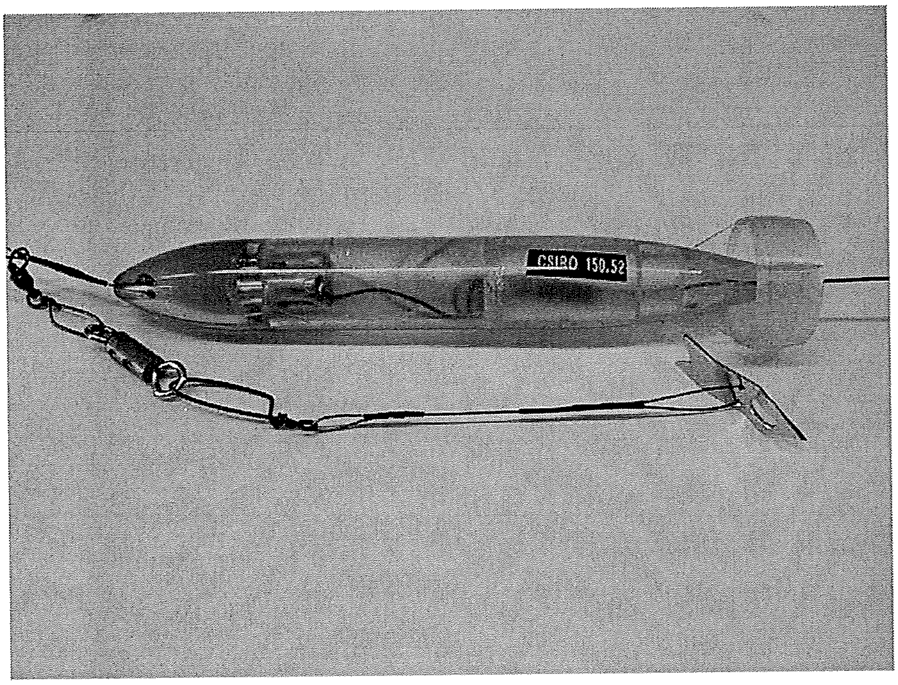

Figure 2. Photograph of radio tag with galvanic release and tag head attached.

Figure 3. Photograph of starboard 3-element Yagi antennae mounted on wing strut of the Cessna 172. The antennae is directed downward at 45° and starboard of the aircraft.