Tracking wildlife radio-tag signals by light fixed-wing aircraft

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ABSTRACT

New Zealand wildlife biologists have considerable experience tracking radio-tagged animals using conventional, ground-based techniques. However, despite having to work in rugged and relatively inaccessible terrain, they have not used aerial telemetry techniques to the same extent. This report considers aerial tracking by light fixed-wing aircraft, and reviews the equipment and transmitter location techniques required for efficient aerial telemetry. Best practice configuration of light fixed-wing aircraft for aerial telemetry is described, and four techniques for transmitter location are detailed. In addition to ground-based and aerial telemetry, biologists embarking on a radio-tracking study can now also use satellite-based methods. We review the pros and cons of each. We conclude with a listing of New Zealand biologists with experience in aerial telemetry using light fixed-wing aircraft. Details of suppliers of hardware for aerial telemetry, and a selection of other relevant websites are provided.

Keywords: Aerial telemetry, radio-tracking, New Zealand.

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1. Introduction

New Zealand biologists have used conventional ground-based radio-telemetry in research and management programmes since the first transmitters became available for use on wildlife in the 1960s; and a wealth of experience has been gained and shared. Possibly due to the comparatively greater costs involved, aerial telemetry techniques have been less frequently applied in New Zealand, despite the rugged terrain over which many projects operate. Increasingly, however, New Zealand biologists are using both helicopters and light fixed-wing aircraft to facilitate animal location over large areas and in remote or inaccessible locations.

To date, the application of aerial telemetry has proceeded piecemeal, with appropriate equipment and techniques being discovered, tested and applied on a project-by-project basis, and experiences disseminated informally between colleagues. This review provides guidelines for New Zealand field biologists who wish to use aerial telemetry techniques (particularly using light fixed-wing aircraft), to assist them in selecting the most appropriate equipment, and in applying the most efficient techniques.

2. Aim and scope of the report

This review sought to address three questions:

- What equipment is needed to undertake cost-effective aerial radio-tracking?
- What is the best-practice method for aerial radio-tracking of wild animals using a light fixed-wing aircraft?
- What is the range of aerial radio-tracking projects using aeroplanes currently being undertaken within New Zealand?

Helicopters are used extensively for radio-telemetry throughout the world, particularly in rugged terrain. Because of their ability to hover, helicopters can function as mobile, high-altitude platforms for receiving signals and locating radio-transmitters. Although much of the receiving equipment is the same as that used in helicopters, searching for and locating the position of transmitters from light fixed-wing aircraft requires very different techniques to those used in helicopters. This review considers radio tracking from fixed-wing aircraft only; locating transmitters from helicopters is not further considered.

Section 3 assesses the pros and cons of aerial telemetry and ground tracking, and considers some recent developments that have the potential to change the way telemetry is carried out.

Section 4 considers the equipment needed to set up a light fixed-wing aircraft for efficient radio-telemetry, and suggests some alternative configurations to facilitate observer-pilot communication.

Section 5 sets out the standard techniques used to search for and to locate radio-transmitters from a light fixed-wing aircraft, including estimation of location errors, and sources of signal bias.

Section 6 reviews some of the current use of aerial telemetry for wildlife research in New Zealand, based on a survey of projects in the Department of Conservation (DOC) and Landcare Research.

Appendices 1 and 2 provide details of suppliers of hardware suitable for aerial telemetry projects, and a selection of other relevant websites.

3. What is the most suitable type of telemetry for a particular study?

A feature of conventional ground-based radio tracking is the need to find higher ground from which to search for faint or missing signals. At ground level, the line-of-sight range of reception from a radio-transmitter on an animal in open terrain (not in a burrow or up a tree) is usually in the order of 1–5 km; from even a moderately-sized hill this can be extended up to 8–15 km. One way of viewing the facility of aerial radio tracking is to think of the aircraft as a very high platform, from which even basic radio transmitters can be detected from as far away as 20 or 30+ km. Add to this the speed and mobility of a plane, and you have a high, mobile tracking platform able to move over inaccessible areas, and to cover large areas of ground rapidly. Match this speed and mobility to a scanning receiver and you are then able to quickly search for and locate a large number of radio transmitters on animals that may have moved long distances over rugged terrain.

There are some disadvantages to aerial telemetry, however. Cost is the most significant of these. Most conservation projects using radio telemetry will not have a dedicated tracking aircraft and will need to book and pay for a pilot and air-time. Flights may be postponed or cancelled due to weather conditions that might not hamper ground operations, and extra care needs to be taken to ensure that locations recorded from the air accurately reflect the true locations of animals on the ground.

Beyond tracking on the ground or in the air is the use of satellites—satellite transmitters or Platform Transmitter Terminals (PTTs) and, more recently, Geographic Positioning Devices (GPDs)—which log transmitter locations without the need for tracking by a human observer (these two satellite techniques are reviewed in Mech & Barber 2002). Cost, however, is a significant factor for both of the satellite-based systems.

Three main questions must be addressed (Sections 3.1 to 3.3) before commitments are made to one or other type of tracking system.

3.1 WHAT IS THE FOCUS OF THE STUDY?

A study of migration patterns, or dispersal, for example, will have different spatial-scale requirements than one on fine-scale habitat selection, or den or roost-site use. The ability to cope with long-distance movements may make PTTs most suitable for the first two examples, whereas ground-based triangulation methods may be best for the latter two. With relatively few tagged animals moving over shorter distances, conventional VHF transmitters and ground-based tracking will be appropriate and cost effective.

3.2 WHAT ARE THE BIOLOGICAL CHARACTERISTICS OF THE TARGET SPECIES?

A number of parameters need to be addressed, such as:

Size: this sets limits to transmitter weight. For example, very small animals (rodents, lizards, invertebrates) and those requiring implantable transmitters (fish, eels, snakes) can carry only small transmitters; thus, currently, PTT and GPD options would not be suitable.

Habitat: rugged or inaccessible terrain may necessitate aerial telemetry. Animals in thick vegetation may not be suitable for satellite-based methods.

Activity: aerial tracking may be less suitable for nocturnal animals because of possible flight restrictions on some small fixed-wing aircraft.

Movements: longer-range movements, migration and dispersal may require aerial telemetry, but very long distance movements, especially those across national boundaries, will be best monitored by satellite telemetry.

3.3 WHAT IS THE AVAILABLE BUDGET?

The project budget must be appropriate to the aims of the study, and care must be taken that the expense of acquiring locations—by aerial tracking, for example—does not compromise the number of transmitters that can be used and, hence, the sample sizes that can be obtained. Similarly, there is little point having a large sample of tagged animals if the resources to track them all are not available. There is a tendency, however, for researchers to over-emphasise the costs of equipment, and under-emphasise those relating to staff time spent tracking using conventional methods. The efficiency of aircraft-based telemetry, or the unit costs of PTTs and GPDs, must be balanced against the time, effort and expense of having people tracking on the ground.

Table 1 gives a summary of the pros and cons of the three principal telemetry alternatives: ground telemetry, aerial telemetry, and satellite telemetry.

TABLE 1. SUMMARY OF THE PROS AND CONS OF CONVENTIONAL GROUND-BASED TELEMETRY, AERIAL TELEMETRY AND SATELLITE TELEMETRY.

	GROUND TELEMETRY	AERIAL TELEMETRY	SATELLITE TELEMETRY
USES	Animals that are slow-moving, sedentary, unwary, and / or that undertake only short-range movements or have a predictable distribution	Animals that range over large areas, and / or move over large distances, or undertake unpredictable, long-range movements Animals that range over rugged terrain in remote or inaccessible areas	Animals that are large enough to carry the appropriate transmitter unit (minimum unit wt. c. 20 g). Otherwise as for aerial telemetry
EXAMPLE	Any studies of shorter-range animal movements, including habitat use, resource selection To facilitate collection of data from individuals on behaviour, reproductive performance, and rates and causes of mortality	Studies of migration and dispersal Studies in rugged, inaccessible terrain Studies of released animals that may have unpredictable movements	As for aerial telemetry, but also for: • Very wary, or fast-moving animals • Studies for which triangulation errors would be too great (GPD only) • Studies of marine mammals
TYPES	Mobile: foot or vehicle (or ship-based) tracking, using triangulation, sightings, or mortality signals Fixed station: triangulation from fixed, known location, often using null-peak array of parallel Yagi antennae to improve precision of fixes Automatic: Logging the proximity of particular transmitters, sometimes with an estimate of location and distance from receiver	Variety of platforms possible: • Light fixed-wing aircraft • Micro-light aircraft • Helicopter • Helium balloon	Platform Transmitter Terminal (PTT): location registered by satellite (ARGOS system) and remotely down-loaded to user Geographic Positioning Device (GPD): calculates location from NAVSTAR satellites and stores for down-load when tag recovered by user. Remote and satellite down-load possible
PROS	Relatively inexpensive Useful to precisely locate key features of an animal's home range, e.g. den or nest sites, site of kill or scavenge Useful to recover dead animals, or to monitor activity, or proximity of conspecifics With Geographical Positioning System (GPS) technology there is improved accuracy when plotting locations on maps	Efficient means to scan for numerous tagged animals over a large area Able to locate large numbers of tags quickly Able to locate tags in rugged and inaccessible terrain Can facilitate the visual location of larger, and wary, animals Especially efficient for searches for large numbers of transmitters where only mortality information is required	PTT: global coverage; desktop real-time tracking possible; labour costs limited to tag attachment GPD: highly accurate locations possible (with 3+ satellites); labour costs limited to tag attachment and recovery; able to adjust the frequency and timing of location recording
CONS	Direct sighting of, or close approaches to tagged animals may cause changes in behaviour, such as avoidance Triangulation of location often necessary, and subject to errors Labour- and time-intensive Insensitive to rapid changes in animal location Difficult in remote or rugged environments	Expensive: mostly flight time, but also some equipment Without actual visual confirmation, location errors are possible Can be weather-dependent Observer may be affected by airsickness	Expensive: Both PTTs and GPDs are relatively expensive to purchase; PTTs also require satellite acquisition costs Needs line-of-sight to satellites; less efficient in, for example, dense vegetation, or down burrows PTT satellite coverage less than GPS Large transmitter unit size limits applicability for many species

4. Equipment required for efficient aerial telemetry

For any conventional radio tracking system, the core elements are a receiver tuned to the appropriate frequencies, connected by coaxial cable to an antenna in order to improve signal detection. Aerial telemetry requires an expansion of this basic scheme, by the use of two externally-mounted (on the aircraft) antennae, attached to a receiver via a control box that determines whether signals are received from the left, the right, or both antennae. An observer inside the aircraft monitors transmitter signals via headphones which, ideally, plug into both the receiver and the aircraft intercom system to allow communication with the pilot.

4.1 ANTENNAE AND ANTENNA MOUNTS

Antenna size depends on the frequency of the signal being detected. Virtually all radio telemetry in New Zealand uses VHF (very high frequency) equipment, requiring relatively smaller antennae. Antennae do two things: they increase the gain (the signal gathering capacity) of a receiver, and they aid in determining the direction from which a signal is coming (Mech & Barber 2002). To reduce drag and stress on both antenna and aircraft, most aerial tracking is done with lightweight 3- or 4-element Yagi antennae (Kenward 1987). A lightweight alternative provided for aerial tracking by some commercial suppliers is a variation on the Adcock or 'H' antenna; one element is shorter than the other and the two elements are phased to give maximum signal reinforcement when the shorter element is nearest the transmitter—in effect, making a two-element Yagi (Kenward 2001). Antennae mounted on aircraft are most commonly two Yagis or 'H' types. 'H' antennae are recommended for aerial tracking by Telonics, a company specialising in aerial telemetry applications (Appendix 1), which supplies the RA-2A directional antenna (Jones 1997). These are designed to also be used by hand and come equipped with a wooden handle for this purpose.

To obtain the greatest lateral range, and thus maximise reception range and minimise search times, a vertically-polarised Yagi antenna should be mounted under each wing, at right-angles to the plane's fuselage and pointing 15°–30° downwards from horizontal (Gilmer et al. 1981). Because wing struts provide the best antenna mounts, the ideal aircraft for radio-tracking are high-winged monoplanes, such as the Cessna 150 or 172, the Piper Cub, and the Maule.

For optimal reception, the upper element of the Yagi should be at least 15 cm below the wing surface and 30 cm forward of the leading edge (Gilmer et al. 1981). One way to achieve this is to mount the antenna on a forward-projecting boom. A more secure and simpler attachment involves clamping the antenna boom itself next to the strut, where the de-tuning influence of the wing and fuselage reduces range only slightly (Kenward 1987).

Well-padded clamps are necessary to avoid damaging the strut. Commercially produced antennae-mounting brackets designed to attach to the wing struts of 12 common light aircraft are available from Telonics (Appendix 1), especially for use with the RA-2A H antennae. Coaxial cables should be taped to the strut to reduce vibration, and then fed through either an air-vent, or around the edge of the door, providing these are sufficiently padded to avoid crimping the cable. Alternatively, cables can be fed internally up the wing strut, into the wing, then along the inner wing surface and directly into the plane's control panel. The cable length from each antenna must be the same.

Other aerial attachment options are possible, and include a floor-mounted swivel 'H' antenna that can be controlled from inside the plane, and forward-facing vertically-mounted aerials on wing struts. In general, however, side-facing aerials give the greatest coverage and allow for greater distances between transects.

4.2 CONTROL BOX

Antennae leads meet at a control box, or switch box. This commonly has two simple toggle switches: one to switch between receiving from both or only one antenna, and one to switch between right and left antennae. Some control boxes have, in addition to switching between right and left antennae, added capacity to switch to a third, typically omni-directional, antenna.

Telonics (Appendix 1) produces three types of control unit, with the basic standard unit, the TAC-2, warranted for 100 000 operations. The control box is attached to the receiver by a short coaxial cable.

4.3 RECEIVER

Any type of appropriately-tuned receiver can be used within an aerial tracking configuration. Most aircraft-based tracking is used to locate a number of transmitters over large areas. With more than two or three transmitters, and / or with widely-spaced frequencies, it becomes very inefficient (and eventually painful) to cycle through search frequencies manually. In this case, a programmable receiver with scanner capability is required.

Scanner receivers can be programmed to scan through a number of transmitter frequencies. The user is able to enter the desired number of specific frequencies (common capacity is between 40 and 400), and set a scan dwell time of anywhere between 1 s and several minutes (usually 3–10 s). The entered frequencies are then scanned in a repeating sequence; when a signal is heard, the sequence can be stopped by the observer and the specific transmitter tracked.

Some commonly used programmable receivers include:

- Telonics TR-5 (255 channels)
- Advanced Telemetry Systems R2000, R2100 (200 channels) and R4000 (400 channels)
- Televilt RX-900 (83 channels)

(see Appendix 1 for supplier contact details)

Noise reduction during tracking is important. Engine ignition noise reduction can be achieved by installing shielded ignition cables. Additional shielding of magnetos is also beneficial, and involves connecting a noise filter between each magneto and ignition switch using shielded cable, and grounding it to the magneto case on the ignition side of the filter (Carrel 1999).

4.4 HEADPHONE AND INTERCOM

The observer monitors scanning and frequency acquisition via headphones, preferably high-quality, noise-cancelling, low-impedance aircraft-type headphones, e.g. series H-10 *David Clark*© headphones (David Clark Company Inc., Massachusetts, USA. http://www.davidclark.com). Headphones used in conjunction with a headset microphone within the aircraft's intercom system allow the observer to communicate directly with the pilot. Configuration options can allow the pilot, observer and up to four other passengers to have voice-activated communications, and to monitor transmitter signals.

The two most important components of effective aerial radio-telemetry are obtaining a high quality signal and communicating where that signal is to the pilot to minimise search time. Our view is that specialisation of tasks is the best approach to achieving these efficiently. The simplest and safest system is to have the observer search for transmitters and then tell the pilot what plane movements are required. The pilot monitors other radio traffic and flies the plane. Clear, well-thought-out hand signals are all that are required to do this. By adding a headphone adapter with a single Y-splitter, one-way communication from the observer to the pilot can be achieved (and the observer does not have to deal with radio interference). By using a double headset adapter, everybody will hear everything.

We do not consider pilot-only systems to be effective or safe, especially when a large number of signals need to be scanned and tracked. Intensive radio-tracking from the air is a full-time job. Skilled observers can be scanning for several transmitters, reprogramming the scanner, recording location information—all while tracking a single transmitter, making the task very efficient. For example, by flicking between adjacent frequencies while flying towards a single distant frequency, observers can determine whether other transmitters are located nearby, and thus reduce the number of repeated movements across the search area. However, listening in on this will be, from the pilot's perspective, very confusing, since signal strengths apparently change abruptly, as the observer switches frequencies.

4.5 AIRWORTHINESS APPROVALS

The Civil Aviation Authority (CAA) has oversight responsibility for all commercial and private aviation standards and certification within New Zealand. While no specific regulations exist to cover biotelemetry applications, the use of telemetry equipment, particularly the mounting of antennae on wing struts, will be subject to airworthiness inspection. Biologists wishing to undertake radio tracking from a fixed-wing aircraft need to work closely with the pilot to select the appropriate equipment and methods of attachment. It may be possible for the maintenance engineering firm responsible for the avionics of a particular aircraft to check and approve any attachments, or to advise on procedures to obtain CAA approval (M. Falconer, CAA, pers. comm.). Wherever possible, it would be best to use equipment that has been subject to a prior approval process and for which detailed specifications are available; for example, the Telonics TAB-series antennae mounting brackets have been designed to conform to US Federal Aviation Regulations (Jones 1997).

4.6 GUIDELINES FOR CARRIAGE OF DOC STAFF IN AIRCRAFT

The Department of Conservation has developed its own internal guidelines for the use of aircraft. Staff can find full details on the Intranet under DOC Resources/Health and Safety/Standard operating procedures and guidelines (not under the standard SOP links); or by contacting Mike Massaar at DOC Southern Regional Office, Christchurch.

Briefly, these guidelines require aircraft used (hired or otherwise) by the Department for the carriage of staff or other DOC-related associates (volunteers, conservation board members, interpretation programme participants, etc.) to be appropriately maintained and operated and flown by people with the appropriate CAA documentation.

For safety reasons, the Department has decided to require a higher standard of certification than the law requires in some cases. This includes the requirement that when DOC passengers are carried in an aircraft for any reason, the flight company must have an operations specification that specifies the carriage of passengers on that aircraft.

A list of CAA-certified operators that is updated daily can be found at http://www.caa.govt.nz

5. Locating radio-transmitters by fixed-wing aircraft

5.1 SIGNAL CHARACTERISTICS

Radio-waves act in much the same way as light waves, and may be subject to reflection, refraction (transmitters under water), diffraction and interference. Signal intensity decreases with distance from the transmitter according to the inverse-square law, whereby strength of signal is reduced by 75% if the distance from the source is doubled (Kenward 2001).

Signals may be reflected by any object, such as a building, hills or trees, resulting in false bearings. Radio-wave diffraction results in the detection of a signal slightly off-line from the source, because of signals bending around the edge of an impenetrable object, such as a tree trunk (Kenward 2001). Reflection and diffraction thus make tracking of transmitters within heavily vegetated areas particularly challenging.

Reception interference occurs when signals reach the receiver by different path lengths and are, therefore, sometimes out of phase (Kenward 2001). Interference of direct radio-waves by reflected waves may result in signals that are in phase and reinforce each other to produce a signal peak in the direction of the tag at one distance; but at another distance from the tag, direct and reflected waves may be out of phase and produce a signal null (no signal can be heard).

The expected range for signal acquisition depends on transmission strength, obstacles and altitude above ground level. The authors' experience is that a good standard transmitter mounted on the collar of a cat, for example, could be detected by a state-of-the-art receiver on level ground anywhere from 2 to 8 km away. By standing on a modest-sized hill, this range could be extended to 8–16 km; from an aircraft, however, ranges typically extend to 16–40+ km (PJS and RFM, pers. obs.).

5.2 ASSESSING LOCATION ERRORS

Although aerial telemetry does not rely on triangulation methods to obtain an estimate of the location of a transmitter (see below), tag locations are subject to error. The degree of error may vary between different observers, with observer experience, and depending on the terrain in which the tagged animal is located. It is important to estimate the degree of error in tag locations. This is especially the case for habitat selection and resource-use studies, where animal location accuracy must be matched to that of habitat discrimination accuracy, to avoid incorrect assignment of an animal to a habitat.

There is some confusion in the literature over the difference between precision and accuracy when interpreting and reporting telemetry error (Withey et al. 2001). In the more familiar sense of general sampling (for example, estimating the abundance of an animal population), precision is a measure of the variability of the sampling units used to derive the estimate, whereas accuracy of the estimate relates to how close the estimate is to the actual population size. In telemetry, precision is a measure of the consistency of a tracking system. For ground-based tracking using triangulation methods to estimate an animal's position, precision would be reported as the standard deviation of bearing errors, or as the error polygon associated with a location estimate (Withey et al. 2001). For aerial telemetry, where bearings are not usually taken but the presumed position of the tag is overflown and a location recorded, the precision of location estimates relates to the consistency of repeat estimates of a given tag at a given location. Precision can be influenced by such things as plane speed, reaction times and the experience of the observer and can, therefore, be improved by observer training and the use of standardised techniques and equipment.

Because the focus of aerial tracking is to pinpoint the location of a study animal in space, of greater importance is accuracy, a measure of how close the estimated position was to the actual location of a given tag. This may be influenced by signal characteristics, such as reflection and transmitter intensity, and needs to be assessed and taken into account when analysing animal location data.

Assessment of accuracy involves the tracking of beacon transmitters placed at fixed locations. Estimated locations of a number of transmitters are obtained by trained observers using standard equipment, and are compared with actual locations to derive the mean distance between actual and estimated locations, expressed as a linear error. A comparison can then be made between different observers, and for errors associated with different terrain, or a single mean error can be calculated. From this it is possible to calculate the radius of a 95% Confidence Circle around the actual location, within which the actual location of an animal can be assumed to lie, using the equation below (Withey et al. 2001).

Radius = mean linear error + (1.96) (SE of mean linear error)

SE = standard error

In habitat selection studies, this error circle can be used as a buffer to define the habitat(s) within which the animal is located at that time. In ground-tracking, used to follow-up on aerial fixes, the error circle can help define the search area required to locate a transmitter, and this is particularly useful in rugged terrain where observer movement on the ground is difficult.

5.3 GPS RECEIVERS

In 1993 the US Department of Defence (USDD) Geographical Positioning System (GPS) network became fully operational, allowing users 24h/d access to a network consisting of 24 satellites continuously broadcasting radio-signals which, in turn, utilise a network of ground stations that maintain the system time standard and calculate exact orbital information. With the advent of affordable hand-held units, determining the position of the tracking station and of the animal being tracked became easier. However, until May 2000, the USDD, for reasons of national security, maintained a system of 'Selective Availability' (SA), whereby civilian GPS receivers were subject to degraded accuracy of horizontal position estimates to within 100 m of their true location 95% of the time (Rodgers 2001). Selective Availability was overcome by using reference GPS receivers placed at a surveyed location and recording deviations from the known co-ordinates of the site. This differential correction could then be applied to reduce location errors for GPS units within about 300 km of the base station. Differentially corrected location errors were < 10 m from the true location. After May 2000, the USDD discontinued SA and, consequently, most civilian GPS receivers are now able to obtain position estimates to within 20 m of their true location 95% of the time. Differential correction without SA can provide an accuracy of less than 10 m 95% of the time, with median errors of 1–3 m possible (Rodgers 2001). The level of accuracy required will depend on the scale and the objectives of each specific project.

By mounting a GPS unit in the aircraft, observers can track plane movements to determine the search effort or area covered. They can also plot latitude and longitude co-ordinates of each transmitter either manually or by marking and storing records within the GPS memory for later downloading.

5.4 SEARCH PATTERNS

Before an aerial radio-tracking survey starts, the researcher should discuss the aims of the session with the pilot. The aim may be either to fly to the last location of a tag and attempt to pick up a signal and pinpoint a location, or to conduct a systematic search of a given area. If searching for large numbers of transmitters (> 30) over a large area, it will be necessary to plan ahead by anticipating the likely location of transmitters, and to consider only scanning for those expected within a smaller sub-set of the total search area.

If, at the last recorded location of a tagged animal(s), it is not possible locate a signal, there are three options: check other likely sites; search while radiating outwards from the last known location; or systematically search over potentially suitable terrain. For the last option, the tagged animal could be situated anywhere over a large expanse, thus a search will be the same as that for missing transmitters over a given area.

The most efficient way to systematically search for transmitters over a large area is to use a regular search grid with parallel transects separated by just less than twice the lateral distance at which you expect to be able to detect your transmitters. A flight altitude of 300–1000 m AGL (above ground level) is adequate for tracking weak transmitters in lowland areas (Kenward 1987), but there is a trade-off between height and accuracy. Accuracy improves with lower flight paths, while search range increases with higher flight paths. A researcher should consider gaining altitude to 2000–2500 m AGL to increase range during searches for missing transmitters. The system should be tested at a range of altitudes using test transmitters placed in a range of 'normal' positions on the ground (e.g. down burrows, in forest etc.).

A search should start with the control box set to receive input from 'both' antennae, and the receiver's gain at maximum. The scan dwell time should be set to not less than 3–5 s, even with tag pulse rates of much greater than 60 pulses/s. Longer scan times are better for detection if there are few transmitters and if signals are weak, or the animal is moving erratically. The aim is to cover all the frequencies being searched for at least once while the aircraft's forward track is approximately two-thirds the sideways detection limit (Kenward 1987). For example, with search transects 9 km apart (and a lateral detection limit of 4.5 km), scan all frequencies every 3 km. With a maximum ground speed of 180 km/h, all frequencies would be scanned every minute (Kenward 2001). With 12 frequencies to scan, scan dwell time would need to be 5 s.

5.5 LOCATING AND PINPOINTING TRANSMITTERS

If only mortality signals are required, the best procedure is to listen to the signal for 3–10 pulses to confirm its state, delete it, then continue with scan. To pinpoint a signal, stop scanning at the frequency of the incoming signal, switch the control box from 'both' and start to flick between right and left antenna to determine on which side of the plane the signal is the strongest.

If the signal cannot be detected again, ask the pilot to do a 360° turn while you listen to the antenna on the outer (upper during the turn) wing. The plane needs to be turned so that the outer antenna points at the horizon. If there is still no signal, resume the search pattern after noting the possible location of the frequency on a map.

If a clear signal can be detected with one antenna connected, four techniques for locating the transmitter are then possible. These are described in the following text.

To obtain a general location, perhaps for later follow-up on the ground or to make best use of available search time, have the pilot circle away from the direction of the tag and note the location of the plane and the bearing at which the signal is strongest while monitoring the antenna on the outer wing. Resume the transect and continue monitoring signal strength; when this is greatest, the tag will be at some distance at 90° to the flight path. Note this location using landmarks or GPS, and maintain the transect. If, at some point further on, you wish to confirm the general location of the tag, you could circle away from the tag, note the location of the plane and take a second bearing. These bearings can be triangulated to estimate the tag position, or tag location could be estimated along a parallel transect.

To obtain a much more accurate estimate of tag position, there are three possible options. Once learned, these offer the most efficient use of search time.

The first, described in Beaty & Tomkiewicz (1997), involves the pilot circling away from the direction of the tag while you (the observer) monitor the signal from antenna on the outer (upper) wing. Note the bearing at which the signal is the strongest, come out of the circle and head along the noted bearing (Fig. 1). The trans-mitter will, theoretically, lie directly ahead of the plane and the signal will be null (i.e. you may not initially hear the signal after the turn). Switch between right and left antenna and adjust the course to maintain the null.

If the signal is a long way off, it is sometimes reassuring to check its bearing by making another slow circle, because the signal can be null for several kilometres of flight distance. As you approach, the null phase will be passed, and the signal should be equalised between the two antennae. Signal intensity will maximise as the plane passes directly overhead; as soon as the signal starts to fade, direct the pilot to make a 360° turn. This time monitor the antenna on

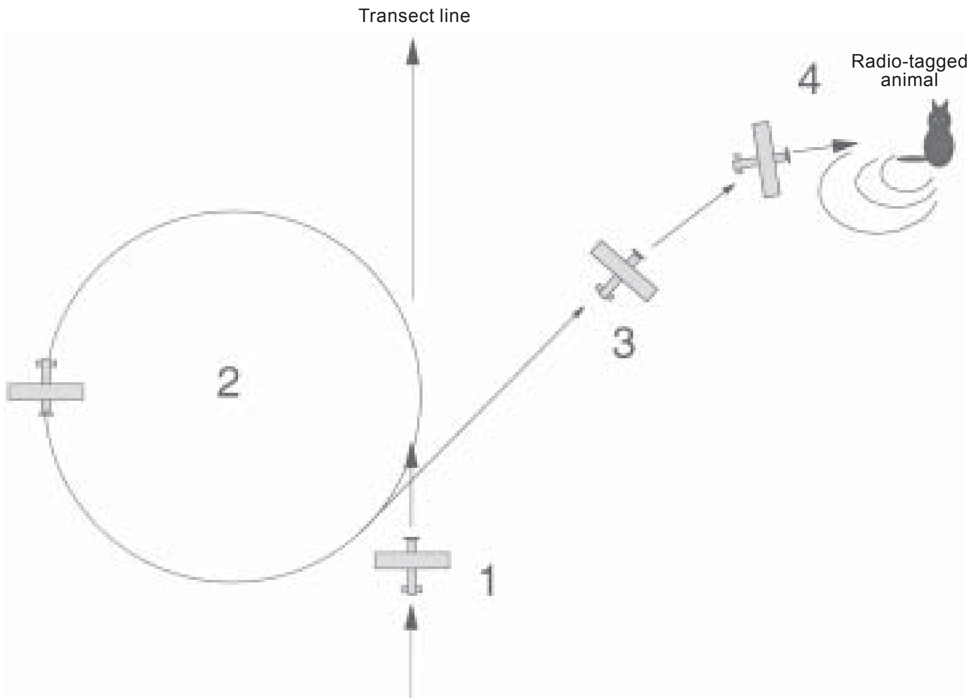

Figure 1. Circling technique for transmitter location. 1 = signal first detected and confirmed strongest to the right; 2 = circle away from the direction of the signal, take a bearing where the signal is strongest, and head along that bearing; 3 = adjust direction to maintain null; 4 = re-acquire signal and adjust so signal intensity is maximised from both sides.

the inner (lower) wing; its downward tilt will give maximum gain as it will be pointed directly at the centre of the area being circled. If the transmitter indeed lies within this circle, the receiver will be receiving an extremely strong signal (a supersaturated signal). Record the position with GPS.

An alternative method involves making a series of right-angled turns to the side from which the signal is the loudest (Fig. 2). For example, if the signal is strongest from the right, continue along the transect checking that it remains loudest on the right and monitoring signal intensity. At peak intensity, or as soon as the signal strength starts the decrease, make a sharp 90° turn to the right, and maintain a straight line while monitoring signal direction and strength.

It is unlikely that the first turn will have been at exactly the correct point, so be prepared to turn 90° again when signal strength peaks on one or other side. Continue this 'moth-to-a-flame' procedure until you are flying directly over the tag and the signal is received at high intensity from both antennae. Enter a 360° turn to confirm the inner antenna is pointed directly at the transmitter (as above).

The third pinpointing method does away with circling or 90° turns; using, instead, a series of smaller turns and corrections towards the side receiving the strongest signal until a null is achieved, or until the signal strength is equalised between the two antennae (Fig. 3). This 'short-cut' technique requires observer familiarity with individual transmitter signal characteristics to avoid excessive turns and too much zig-zagging.

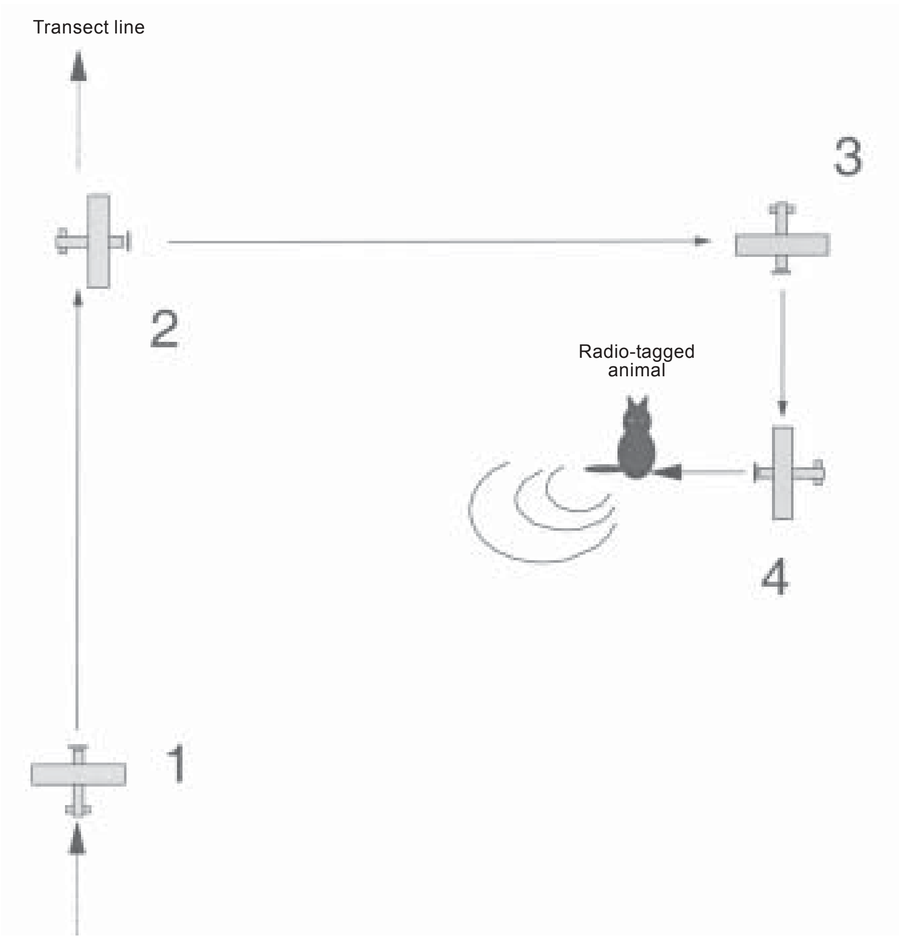

Figure 2. Right-angle turn technique for transmitter location. 1 = signal first detected and confirmed strongest to the right; 2 = continue along the transect line until the signal is at maximum intensity or starts to fade on the right, then make a 90° turn to the right and fly straight while monitoring both sides; 3 = signal grows stronger on the right (indicating you made the first turn a little too late), fly straight until maximised on right then make another 90° turn; 4 = repeat until signal at maximum intensity on both sides.

An altitude of 300–500 m AGL is usually sufficient to obtain a position of reasonable accuracy. To reduce position errors, it may be possible—at least in lightly-vegetated flat areas and with larger animals—to obtain a visual confirmation by flying low and slow over the site of maximum signal strength.

5.6 COMMON TRACKING ERRORS

The two most common errors an inexperienced observer makes when first acquiring a signal are:

- Turning the plane towards a transmitter, thus entering a null, but misreading the null as a loss of signal and asking for another turn or circle when no adjustment to the heading was actually required.
- Being slightly off-course when very close to the transmitter position and, therefore, getting a super-saturated signal on one side of the plane, but a not-quite-saturated signal from the other. The best recovery technique in this instance is to continue on a straight and level flight on the current heading until the signal fades off significantly, then do a rapid 180° course change to return on the previous path, and finally re-adjust the flight path to fly over the transmitter. An alternative recovery technique is to immediately enter the final 360° turn towards the transmitter. However, it is unlikely that the inner antenna will point directly at the transmitter, and it will require several abrupt wing movements while in the turn to find the true transmitter location, and further time-consuming adjustments to fly there.

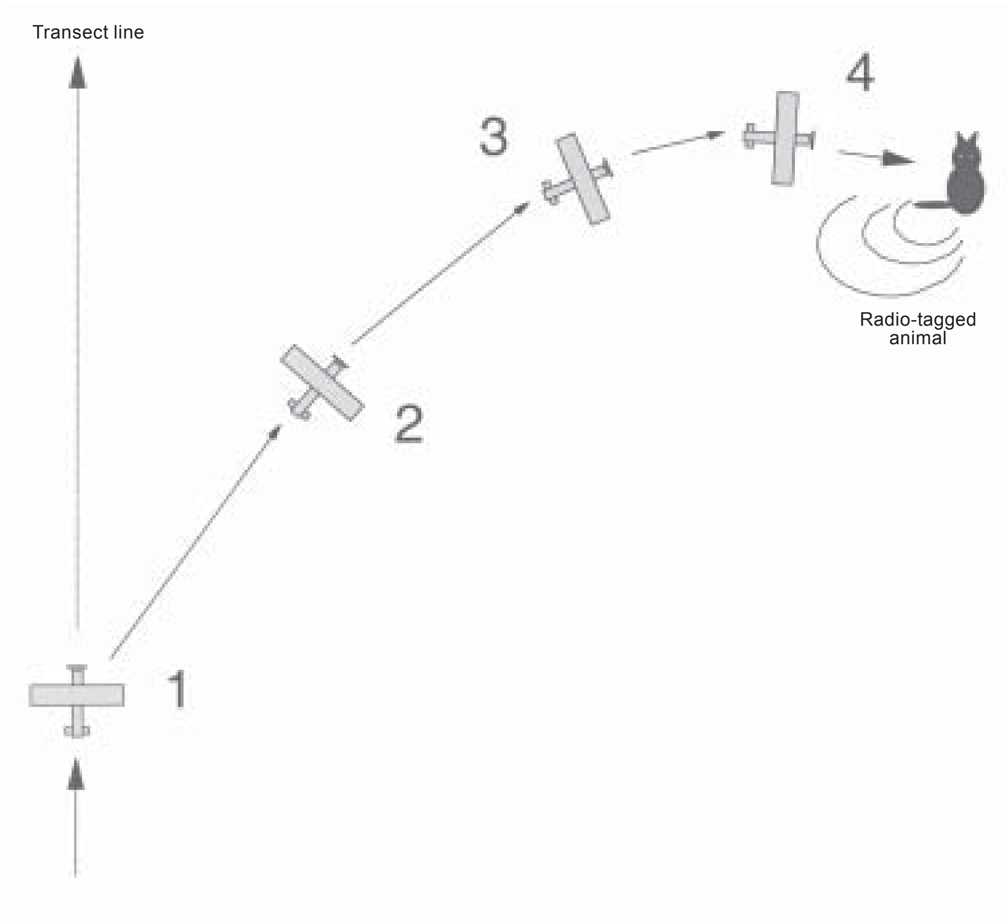

Figure 3. Short-cut technique for transmitter location. 1 = signal acquired and confirmed strongest on the right, head towards that side making a 45° turn to the right; 2 and 3 = monitor both sides and adjust heading to either obtain and maintain a null, or until signal is re-acquired at the same intensity on both sides; 4 = signal at maximum intensity on both sides.

6. Current fixed-wing aerial telemetry in New Zealand

This section of the report reviews some of the current uses of aerial telemetry by light fixed-wing aircraft for wildlife tracking in New Zealand. The intention is to provide a picture of the current extent of these types of projects and to identify some key contact personnel who have sufficient experience to be able to advise those considering or starting out on aerial telemetry projects in New Zealand.

One of the authors (RFM) placed an initial query on the DOC Intranet, seeking a response from those wildlife biologists who were, or had been, involved in aerial telemetry work. Twenty-four responses were forthcoming, some indicating their own direct experience, and some providing referrals to others. A list of 36 names was compiled, and a follow-up query sent out to determine the following: whether the project involved helicopters or fixed-wing aircraft in the main; the region in which tracking took place; the species tracked; and details of the type of aircraft used.

Fourteen people on the contact list were confirmed to have had recent or current experience with radio-tracking by light fixed-wing aircraft (Table 2). Note that this is not intended to be an exhaustive list of researchers in New Zealand with aerial telemetry experience.

Apart from a few individuals who have been involved in tracking a number of species in a variety of areas over several years, the aerial telemetry experience of the New Zealand wildlife biologists surveyed is usually limited to a relatively small number of flight hours during the course of one or two specific projects. Biologists have tended to use existing project equipment in fixed-wing aircraft

TABLE 2. SUMMARY OF NEW ZEALAND WILDLIFE BIOLOGISTS WITH EXPERIENCE IN AERIAL TELEMETRY USING LIGHT FIXED-WING AIRCRAFT, AS REVEALED BY OUR DOC-BASED SURVEY.

NAME	ORGANISATION	EMAIL	REGION	SPECIES
Dean Caskey	DOC	dcaskey@doc.govt.nz	Stratford	Blue duck
James Fraser	DOC	jfraser@doc.govt.nz	Whangarei	Pateke (brown teal), kiwi
Emma Neill	DOC	eneill@doc.govt.nz	Whangarei	?
Paul Gasson	DOC	pgasson@doc.govt.nz	St Arnaud	Kea
John Innes*	Landcare Research	InnesJ@landcareresearch.co.nz	Hamilton	Tui
Josh Kemp	DOC	jkemp@doc.govt.nz	Nelson Lakes	Kea
Brian Lloyd	DOC	bclloyd@doc.govt.nz	Various	Various
Sid Marsh	DOC	smarsh@doc.govt.nz	Pureora Forest, Okarito	Kiwi
Rob McLay	DOC	rmclay@doc.govt.nz	Tongariro	?
Shirley McQueen	DOC	smcqueen@doc.govt.nz	Various	Bats
Patrick Miller	DOC	pmiller@doc.govt.nz	Whangarei	Pateke, kiwi
Milton Staples	Malborough Electric	miltonstaples@linesmarl.co.nz	Wairau catchment	Trout
Philip Seddon	Otago University	philip.seddon@stonebow.otago.ac.nz	(Saudi Arabia)	Various
Richard Maloney	DOC	rmaloney@doc.govt.nz	(Saudi Arabia)	Various

* Has equipment but hasn't yet started flight work.

Note: Further information about the techniques used by people on the list is available on the DOC DME at TWIAO-13149, or by contacting the authors.

to facilitate searches for missing or dispersed tagged animals. During the course of this review we received a number of inquiries from biologists who were interested in setting up aerial telemetry operations, and who were seeking advice on how best to go about this.

7. Acknowledgments

We would like to thank Andy Grant and Dave Murray for initiating this review, and DOC's Science Advice Fund for support. Thanks to all those who responded to our requests for information. Merv Falconer, Manager of the Fixed Wing Unit, General Aviation Group, Civil Aviation Authority, kindly provided guidance on airworthiness approvals procedures. Yolanda van Heezik read and commented on earlier versions of the report.

8. References

Beaty, D.; Tomkiewicz, S. 1997: Aircraft tracking: recommended aircraft general search pattern. *Telonics Quarterly 10(1)*: 5–6.

Carrel, W. 1999: Forward-phased twin-yagi antenna array. Internal Association of Natural Resource Pilots Handbook. Nashville, USA.

Gilmer, D.S.; Cowardin, L.M.; Duval, R.L.; Mechlin, L.M.; Shaiffer, C.W.; Kuechie, V.B. 1981: Procedures for the use of aircraft in wildlife biotelemetry studies. *Fish and Wildlife Service Resource Publication 140*. United States Department of the Interior, Washington, DC, USA.

Jones, G. 1997: Antennae mounting brackets: step-by-step, here's how to do it. *Telonics Quarterly 10(1)*: 1–2.

Kenward, R.E. 1987: Wildlife radio-tagging: equipment, field techniques and data analysis. Biological Techniques Series. Academic Press, London, UK.

Kenward, R.E. 2001: A manual for wildlife radio-tagging. Academic Press, London, UK.

Mech, L.D.; Barber, S.M. 2002: A critique of wildlife radio-tracking and its use in national parks: a report to the US National Park Service. US Geological Survey, Northern Prairie Wildlife Research Center, Jamestown, ND.; and Jamestown, ND: Northern Prairie Wildlife Research Center Home Page. http://www.npwrc.usgs.gov/resource/2002/radiotrk/radiotrk.htm (version viewed 30 Dec 2002).

Rodgers, A.R. 2001: Recent telemetry technology. Pp. 70–121 in Millspaugh, J.; Marzluff, J. (Eds): Radio tracking and animal populations. Academic Press, San Diego, USA.

Withey, J.C.; Bloxton, T.D.; Marzluff, J.M. 2001: Effects of tagging and location error in wildlife radiotelemetry studies. Pp. 43–75 in Millspaugh, J.; Marzluff, J. (Eds): Radio tracking and animal populations. Academic Press, San Diego, USA.

Appendix 1

SUPPLIERS OF HARDWARE USED IN AERIAL BIOTELEMETRY

(See also directory at www.biotelem.org)

Advanced Telemetry Systems (ATS) Inc.

470 1st Avenue No., Box 398, Isanti, Minnesota 55040, USA
Tel: +1 763 444 9267
Fax: +1 763 444 9384
Email: sales@atstrack.com
Web: www.atstrack.com

Avm Instrument Company, Ltd

PO Box 1898, 1213 South Auburn Street, Colfax, California 95713, USA
Tel: +1 530 346 6300
Fax: +1 530 346 6306
Email: bckermeen@avminstrument.com
Web: www.avminstrument.com

Biotrack Ltd

52 Furzebrook Road, Wareham, Dorset BH20 5AX, United Kingdom
Tel: +44 1929 552 992
Fax: +44 1929 554 948
Email: info@biotrack.co.uk; sean@biotrack.co.uk (Sean Walls); brian@biotrack.co.uk (Brian Cresswell)
Web: www.biotrack.co.uk

Sirtrack Ltd

Private Bag 1403, Goddard Lane, Havelock North 4201, New Zealand
Tel.: +64 6 877 7736
Fax: +64 6 877 5422
Email: sirtrack@landcareresearch.co.nz
Web: www.sirtrack.com

Televilt International AB

TVP Positioning AB, Box 53, Bandygatan 2, S-7113, Lindesberg, Sweden
Tel: +46 581 17195
Fax: +46 581 17196
Email: vhf@televilt.se
per-arne.lemnell@televilt.se (Per Arne Lemnell)
Web: www.televilt.se

Telonics Inc.

932 East Impala Avenue, Mesa, Arizona 25204, USA
Tel: +1 602 892 4444
Fax: +1 602 892 9139
Email: info@telonics.com
Web: www.telonics.com

Wildlife Materials Inc.

1031 Autumn Ridge Road, Carbondale, IL 62901, USA
Tel: +1 618 549 6330
Fax: +1 618 457 3340
Email: wmi@midwest.net
Web: www.wildlifematerials.com

Appendix 2

OTHER USEFUL WEBSITES AND ADDRESSES

http://www.aircraft-spruce.com
Aircraft components

http://www.radioshack.com
Cables, connectors etc.

http://www.biotelem.org
Directory of biotelemetry equipment manufacturers

http://www.caa.govt.nz
The Civil Aviation Authority of New Zealand
Aviation House, 1 Marker Grove, PO Box 31441, Lower Hutt, New Zealand
Tel: +64 4 560 9400
Fax: +64 4 569 2024

For pilots

Pilots could consider joining:
International Association of Natural Resource Pilots (IANRP).
http://ianrp.org/index.htm

The IANRP website is published to provide the members of the International Association of Natural Resource Pilots and resource aviation managers, who depend on their skills, with a forum for the presentation of information, the promotion of understanding, and the improvement of communications between fellow professionals. The IANRP is a group of pilots who utilise aircraft in the field of renewable resources. Their aviation specialties are varied and include aircraft use for forestry, wildlife, and fisheries applications, plus enforcement of natural resource regulations. Each individual has a wealth of knowledge in their particular field, and through the Association they can share their experience and knowledge with others.

Subscription costs $US25, and once a member, pilots can subscribe to a email user list (Con-aero), and ask questions regarding any aspect of wildlife flying (see the website for details).