Satellite tracking of large seabirds
- a practical guide

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ABSTRACT

Radio telemetry using satellite tracking services of ARGOS allows large seabirds to be followed daily on their migration and foraging journeys. Studies using this technology are briefly reviewed. The capability of this system and the forthcoming system SAFIR are discussed for seabird studies. The methods of attaching the telemetry equipment are compared. The factors controling the length of life of the transmitter are discussed with results from successful field studies. The cost of the satellite equipment and services, and the methods to gain access to results of the tracking are provided.

1. Scope

Satellite telemetry has tracked the flights of large birds, including the wandering albatross *Diomedea exulans* which has been the most spectacular (Jouventain &Weimerskirch 1990). This paper discusses issues of tracking large seabirds at sea in New Zealand.

This paper reviews the information required to decide the feasibility of, and the quality of results that might flow from, a satellite telemetry study. The scientific opportunities for satellite tracking seabirds, in particular albatrosses, are discussed briefly. The practical considerations (from a biologist's perspective) for planning such a project are described. The forthcoming and complementary technologies for studying these birds at sea are listed.

2. Review of progress

In 1989 French scientists at Possession Island, Crozet Archipelago tracked six separate flights of up to one month in duration. The birds occasionally travelled of more than 1000 km per day, but averaged about 500 km per day. They ranged south to the Antarctic Continent and north to 30°S. They travelled with the wind or tacked across the wind by day or on moonlit nights (Jouventain &Weimerskirch 1990). The British Antarctic Survey team at Bird Island, South Georgia, reported similar extensive flights north to the longline tuna fishing area off Brazil in latitude of 35°S, northwest to the fin fisheries of the Falkland Islands, and southwest to the Antarctic Peninsula (Prince et al 1992).

In the winters of 1992 and 1993, an Australian group tracked five Wandering Albatrosses *Diomedea exulans chionoptera* on their return migration from Australian waters at Bellambi, New South Wales. These birds flew into the Tasman Sea, around the Australian coast and into the Indian Ocean. Two birds were tracked right across the Indian Ocean. One bird was examined at the French study colony at Possession Island after flying with the transmitter for 103 days. The bird had mated and laid an egg (Nicholls et al 1992). The PTT, which had fallen off the bird, was also recovered.

Meanwhile, French and British scientists have extended their tracking studies to smaller albatrosses - Grey-headed, *Diomedea chrysostoma,* and Black-browed *Diomedea melanophris* and Sooty Albatrosses *Phoebetria spp.* The technique of marking the bird, recovering nearly all the transmitters each deployment and renewing the batteries is now a routine procedure at these isolated subantarctic scientific stations. Light-mantled Sooty Albatrosses were tracked at Macquarie Island in a joint venture between the French CNRS and the Australian Antarctic Division in the summer of 1992/93. In the spring of 1993 over thirty separate developments were made on Shy Albatrosses *Diomedea cauta* at Albatross Island, Bass Strait (G Robertson *pers. comm*)

All the above tracking described depended on long-term banding studies, some of which started in the 1950s and have been maintained with great dedication and consistency over the decades. These studies have given an understanding of the timing of the birds' seasonal behaviour and a detailed picture of the breeding and migration histories of individual birds. The bird tracked by satellite from Australia to Crozet was already in the scientific literature after banding had established that the birds migrate in the year they are not breeding at Crozet.

3. Science, Conservation and Management

Satellite tracking gives detailed scientific information on flight patterns, indicating where the birds are travelling and feeding day-by-day. Such information adds to science and it may have implications for management of the conservation of these seabirds as they interact with fishermen.

The technique may be relevant to New Zealand with its large number of albatrosses. The conservation of these species is of concern (Brothers 1989, Murray et al. 1993). Satellite technology offers the opportunity to provide a marvellous way to explain the fascinating flights of these birds to the public. Computer simulations to display the flights with satellite images are being developed.

4. Satellite Services

4.1 ARGOS services

The satellite system ARGOS can locate the transmitter anywhere in the world, typically 1-20 times per day with an accuracy of 1 km standard deviation. This capability has allowed over 5000 locations of albatrosses during three months of field work. The birds were tracked over 10 million square kilometres of ocean.

The CLS-ARGOS PTT consists of a sophisticated UHV transmitter and an antenna; a digital logic circuit with a clock; a set of sensors and their processing circuits and interface to the transmitter. There is a power supply and robust packaging to provide support for the entire unit when it is operating.

The ARGOS system was designed for the location of, and data collection from, oceanic buoys, weather balloons and other environmental monitors. For almost 20 years weather and oceanographic measurements have been received by satellite and transmitted to scientists. A minimum of four messages are transmitted with every ARGOS location. This transfer of information uses precious battery power and is transmitted by the PTT whether the data are used or not. Wildlife telemetry biologists have appreciated the value of the location information.

There is however a data collection component of the system that also has very great value. For example biologists studying seals and penguins have been remarkably ingenious in collecting sea temperatures, light intensity, heart rate, stomach temperature, salinity and depth. Some of these sensing and recording techniques have been adapted to albatross studies. It is emphasised here that there is the opportunity to transmit such data in real time via satellite and bypass the necessity for recovering the data logging system otherwise used.

The group of scientists studying albatrosses from Albatross Research La Trobe University (ART) and Microwave Telemetry Inc. have combined the ARGOS capability and sensing technologies. They have monitored the movement of the PTT-bird using a mercury switch and the temperature. Battery voltage is also transmitted, indicating whether the battery or the attachment fails first. Other sensors are being developed.

A suggested list of sensors that might be used include the improved activity meters for detecting the animal's posture or activity (Douglas M. & R. Pichard 1992); piezoelectric ceramics and stress gauges to determine acceleration; thermistors to measure the temperature of the air, the sea, or the animal's body; air pressure; sensors for aerodynamic parameters; a magnetometer to detect ships; light meter; depth gauge; and a variety of physiological sensors to measure heart rate, stomach temperature or ECG. Improved location measurements using Geographical Positioning System have been transmitted via the data pathway of ARGOS.

4.2 New Satellite services SAFIR

A new satellite has recently been launched - SAFIR - Satellite for Information Relay. This is a bidirectional communication satellite system. It can locate, track and collect data from fixed or mobile objects and it can control the miniature communication unit on a mobile object.

The microstation, which is the unit on the object to be tracked, is both a transmitter and a receiver. It weighs 167 g and this is just small enough to fit on an albatross. The new SAFIR service allows an experimenter to locate and collect environmental data, a service similar to ARGOS, but the experimenter can control the microstation on the bird.

Two major improvements could result from this technology. First the microstation is a receiver, which uses little power until the satellite is overhead. Only then is a message sent to the microstation and the transmitter turned on. The microstation responds with its location signal and accumulated messages before reverting to a low power receiver. This results in lighter power supply or longer life for the tracking unit. The second improvement is to turn on appropriate sensors or other equipment as required. In this way the properties of the equipment on the bird can be changed after it has has been released, or when circumstances change.

4.3 Collection and distribution of ARGOS data

The ARGOS data from the PTTs can be made available in a variety of ways. These include computer files on a variety of media (distributed monthly); telexed or fax messages, maps on A3 paper of the plots; or on-line via a modem telephone link. In Australia there is a free modem link in almost real time. In New Zealand there is similar access via PACNET of New Zealand at a cost to the user.

Most, if not all, albatross studies have used the on-line service. In the case of some studies, such as the subantarctic island studies, there has been the additional task of relaying the information via other communication methods to the field workers, e.g. telephone, fax or INMARSAT messages.

A communication session via modem is provided in the appendix. Scientists familiar with computers will have no difficulty using this system. The ARGOS manual describes the commands used to request the information from ARGOS on the location and the data messages. A variety of different formats is available. A user's selection of commands is discussed later.

4.4 Access to ARGOS from New Zealand

The CLS-ARGOS computer can be accessed from New Zealand via PACNET. One needs to register with PACNET, obtaining a network user identification number (NUI) and then use PACNET to place a data link to Australia. Charges to rent access to PACNET (about $15/month per region at January 1994. There are three regions covering New Zealand). There is also a charge for the cost of the international call to Australia. The process can be automated and set to occur at off-peak times to minimise costs. Most communication software allows this setup.

5. Equipment Available

5.1 Satellite Transmitters ARGOS-PTTs

Animal-tracking PTTs are available from a number of manufacturers. ARGOS certifies manufacturer's models as being suitable for use with the ARGOS system. This approval can be taken as sufficient quality control. Some manufacturers have a reputation for quality and up-to-date advice needs to be sought from agents like Sirtrack and from scientists using PTTs.

Table 1 compares the different PTTs available, as at January 1994. Their prices depend on exchange rates. Shopping around between agents and manufacturers may produce significant price differences. Telonics are reliable and conservative with a long reputation for excellence in wildlife telemetry equipment. Toyocom produced the first small PTTs and their equipment was used in most of the French work. The recent version of model 2038 has been revised with the addition of a transformer to isolate the antenna. Their newest model 2050 is available in a very small package and 60 units have performed faultlessly (ARGOS staff *pers. comm*., Higuchi *et al*, 1992). Microwave Telemetry is a small innovative company which tailors equipment to user's needs. They supplied units to the British Antarctic Survey and the Australian programs.

5.2 Packaging of PTTs for wildlife studies

The PTTs are sold by the manufacturer in either a splash-proof or waterproof container. These are rectangular and uncomfortable. The procedure for attaching the package to the bird needs to consider both the skills of the telemetry engineering and the animal's requirements.

Some manufacturers supply the PTT and the batteries completely sealed. Others only seal the electronic components; either way the PTT may need additional packaging. A value-adding manufacturer may improve the power supply; provide appropriate sealing and strengthening for the antenna; and add a suitably-shaped package and straps for easy attachment to animals. Today the facility to interchange batteries under field conditions is a minimal requirement. Different batteries may be fitted without returning the sealed unit to the overseas manufacturer. The shape of the package can be perfected locally with experience from the field.

If the PTT electronics are separated from the batteries, additional weight can be minimised. The casing for the PTT may be an integral part of the radio transmitter as well as a protective cover for the electronics. Normally only air (or nitrogen) is in the electronics compartment but with the seal and penguin transmitters this space needs to be filled with resin to prevent the units collapsing under the water pressure. This is not necessary for albatross transmitters, but for the petrels, which are deeper divers, this protection may warrant the increase in weight.

As biologists learn to use the data transmission capabilities of ARGOS they will require flexibility to attach different sensor assemblies.

Sirtrack Ltd New Zealand and Faunatech Pty Ltd Australia can be consulted for services.

5.3 Receivers

A ground-based receiver is used by some workers to confirm that the PTTs are turned on and working, especially in field conditions when there is no contact with ARGOS. An inexpensive receiver or general purpose scanner will detect the pulse of a transmitter confirming it has been turned on, but it does not identify the PTT. It requires a more elaborate receiver to detect and decode the PTT signal. This might be required for testing in the laboratory or calibrating the sensors in the field conditions.

The Telonics Uplink Satellite Receiver and Decoder allows the full reception from a PTT. It costs $US 10 000. The scanner AOR Japan Model AR1500 is a simple monitor costing $NZ800.

Ground based tracking of PTTs is not practical (see later section on ground based tracking and monitoring).

6. Considerations on the PTT design affecting the tracking technique

The PTT transmits (by animal radio-telemetry standards) a very stable and sophisticated radio transmission. This signal is received by the polar-orbiting NOAA satellite.

The transmitter transmits a 0.3 to 1 second signal every 40-90 seconds. This pulse rate is called the repetition rate. For most animal tracking experiments it needs to be 60-90 seconds and shorter for some applications (e.g. penguins that are under the water). Longer repetition rates, while saving batteries, result in lower accuracy and fewer successful locations.

If the transmitter is on permanently, it can be located by the satellite about 8-12 times per day in the latitudes 30-50°S. To save batteries and extend the working life of the transmitter, it may be programmed to be off for part of the day. Duty cycles of 8 hours on, 16 hours off, or 12 hours on, 12 hours off, are typical. The combination is a compromise between length of transmitter battery life, the number of positions per day and the times which the satellite can receive the transmitter. Experience with PTT on continuously, albatross tracking in the Southern Ocean reports 11.7 locations per day at 40-60°S, 6.8 locations per day from the South Island of New Zealand (44°S), and approximately 10 locations per day from the New Zealand Subantarctic (50°S). Using about 50% duty cycle (3 hrs on - 3 hrs off, and 5 hrs on - 4 hrs off) at 30-45°S there were 3 to 4 locations per day.

After the satellite receives the signal from the transmitter on the bird, the messages are passed to a ground station and processed by computer to determine the location. Soon after this information is made available using a computer and modem link to an ARGOS computer. In Australasia the most accessible ARGOS computer is in Melbourne. The information is available within a few minutes to a few hours from the time the satellite receives it.

In Australia, these positions are concentrated during two seven-hour periods: between approximately 2:00 am and 9:00 am, and between 3:00 pm and 10 pm. As a consequence, the start time of the on-period needs to be adjusted to give the most frequent receptions. However for a PTT-albatross that moves across the meridians of longitude, a start time that is optimal for one area will not be suitable for other longitudes.

A solution is to use duty cycles that differ from the 24 hour cycle; e.g. not 8 hours on -16 hours off but 9 on - 16 off or 5 on - 4 off rather than 3 on - 3 off. These combinations give an on-period that 'creeps' over time and ensures that the transmitter does not remain in phase with the satellite. Finally long duty-cycles with off-periods greater than three days make the gap between successful locations too long. The ARGOS location procedures require several fixes close together to give unique locations. Thus there may be delays before the satellite tracking program can calculate a new position of the PTT. Interpreting such data for Wandering Albatrosses that may fly more than 1000 km/day may be difficult.

6.1 Accuracy of ARGOS positions

ARGOS provides three grades of accuracy for the locations of the PTTs. These are Class One to Three which have an accuracy of 1000 m, 350 m and 100 m at 1 Standard Deviation respectively i.e. 66% of the locations are within that error. In addition, CLS-ARGOS (upon request and at a cost) provide Class Zero positions where the interpretation of the position is the responsibility of the user.

Joining the points which are accurate to within one kilometre or better gives a minimum representation of the track. The real track is considerably further and is a more complex journey. The difference is greatest when the bird is flying.

Inspection of the tracks comparing the Class Zero and the accurate positions (Classes One to Three) suggests that the error may be tens, occasionally even hundreds, of kilometres (see Appendix). This was important in cases when the birds were inshore and/or if the birds were flying over a small area (<25 km between successive positions). It was also important in determining whether the bird was over the shelf edge. In the open ocean many of the Class Zero points are plausible; the error represented only a few hours of flying by an albatross.

It is difficult for the user to determine the error. Measurements of a stationary PTT (e.g. on an albatross incubating) indicates an error of 1 km SD (Weimerskirch et al 1992). The error increases markedly as the bird flies at sea, and as the number of messages per location and the number of locations per day is reduced (Nicholls - unpublished).

For a bird on its nest site about 40% of the locations were Class 1 or better. For a bird at sea, the proportion of reported positions that were Class Zero ranged from a third (when the birds were relatively immobile inshore at the Illawarra coast) to the more usual proportion of nine tenths or higher (when the birds were on the long distance flights into the Tasman or around the south coast of Australia). Joining these widely spaced accurate points gave a position every two to five days, with many Class Zero points in between.

ARGOS grades the Class Zero positions further using a ten-point scale (0 to -10), called the Location Index. Our experience indicates that CLS-ARGOS Class 0

Location Index 0 to - 3 gave results of comparable accuracy to the Class One locations for the inshore bird. But once a bird started flying long distances (>100 km) in the open ocean nearly all of the locations were Class Zero: most had Location Indexes of -8. Class Zero Location Index -5 was associated with much larger errors. When the PTT was almost directly underneath the satellite path, the error appeared larger than for the majority of Class Zero positions.

The bird's high speed is a further factor which can cause ARGOS to allocate the position to Class Zero. ARGOS was designed for oceanic buoys, which are slow-moving objects, but albatrosses fly in excess of 60 km/hr. Therefore, in the ten-minute pass used by ARGOS to determine its position, the bird will fly 10 km. Thus the movement is greater than the error class. The calculation procedures of ARGOS must be changed if we are to improve the accuracy. The loss of accuracy is exacerbated when the number of locations per day is decreased (to lengthen the life of the PTT).

These considerations become increasingly important when calculating distance travelled and the direction of travel. Techniques are being developed to identify outliers and to smooth the estimated flight path.

6.2 Ground tracking of PTTs

Ground tracking of PTTs is impractical because the on times are short and too widely spaced for the simple procedures used by animal-trackers using VHF equipment. The detection of the local proximity of a PTT is practical. Such a technique may be helpful for nesting albatrosses to determine if the marked bird is in the colony area.

A solution adopted by several workers is to use a light-weight VHF transmitter. Such transmitters can have a one-year life and weigh only a few more grams than the PTT packages. Also, a second antenna is fitted. Such a combination can greatly increase the chance of recovering the PTT in some circumstances.

6.3 On-line verses off-line - Real time Access verses archiving/monthly reports

It is every telemetry-user's nightmare to carefully fit a transmitter, release the animal and then discover the transmitter is not working. The infallible test for a working PTT is to turn the PTT on and then check with ARGOS to determine that the satellite has received the signals. This requires on-line service.

Following the transmitters in real time offers a new kind of long distance tracking where the animal is followed hour by hour. Those studying the albatrosses at the breeding island use the service to get warning of the likely time of arrival back at the nest and successfully recover the transmitter. It may be possible to recover the birds at sea; make new kinds of measurements after an animal has flown a known route; or renew the batteries and track the bird for another few months.

The alternative is to use a ground receiver to ensure the transmitter is functioning correctly and then accept a long wait before getting the month's results in a single dispatch via a floppy or magnetic tape. The receivers are very expensive, but the once-a-month service is a fraction of the cost of on-line service.

7. Data analysis

French and British albatross studies have resulted in 10 000 locations per year. If the PTTs also collect data at each location then this increases the amount of data tenfold. Computer assistance becomes essential in these circumstances.

A variety of computer software solutions are available for helping the analysis. Standard spreadsheets, word processors and editors, statistical and graphing or database software are powerful but inexpensive introductions. As users become familiar with the requirements for the analysis, they may consider specialist telemetry software.

Some agencies have developed their own software (BAS use an ORACLE database, the Australian Antarctic Division have a custom database on their VAX). Typically these automatically collect the data from CLS-ARGOS, report distances and directions travelled, rates of travel, distance from a specified location (e.g. a nest) and map the journeys. CLS-ARGOS provides the software specifically designed for ARGOS data, ELSA, which is a user-friendly graphical interface to the proprietary database. It provides a map display for any part of the world.

7.1 Location Class Zero Surcharge

CLS-ARGOS charges for the Class Zero locations. Since these will form 60-90% of the data collected on albatrosses they are recommended for animal trackers.

7.2 Backup Copy of the ARGOS data

Although the on-line service only holds data from the last four days, it is generally possible to obtain a complete record of the data over time. However, loss from the experimenter's computer system or loss through the telephone link may interrupt the full data set. CLS-ARGOS provides, at an additional cost, a complete monthly copy of the data in the following month. It is a complete data set free of communication glitches and only has unique records. It thus provides a complete and accurate record for systematic analysis.

7.3 Other ARGOS charges

Changing the status of the program, the PTT technical file, and changing services like Class Zero incur modest additional charges. The ARGOS manual and the Catalogue of Services and Products explain this French system.

7.4 JTA or Commercial rates

Users can buy the CLS-ARGOS services and products direct from ARGOS on a pay-as-you-go basis. You only pay for what you use (generally on a monthly basis with some discounts for specified calendar month periods). It is expensive, but there is an alternative.

The major users, the world's meteorology services, buy in bulk the basic ARGOS service. This is called the JTA, the joint tariff agreement. For the Australasian area, the scientific community is able to join this agreement and benefit from a reduced cost that is agreed annually; it is about a quarter of the commercial rate. This service is provided free by the Bureau of Meteorology. To join, one specifies one's requirements late in the year, about November, for the forthcoming year. One pays three-quarters of the cost of one's estimated requirement early in the year of the service. The remaining quarter is paid the year after. There are no refunds; one pays for all the service requested for the year. If one exceeds one's request, one pays at the JTA rate plus a penalty of an additional 25%. For animal tracking with very small programs it is often difficult to judge one's needs accurately; a solution is to combine with fellow animal-trackers.

This JTA service only provides a minimal standard service. The Class Zero data and the floppy disc archival service and all other services are invoiced from CLS-ARGOS France and are paid in French francs direct to France. The JTA service is invoiced from the Australian Bureau of Meteorology and is paid in Australian dollars.

Generally, the cost of the JTA service for location and data, Class Zero data, the archive service and other incidentals is under $A 10 000 for each PTT for 365 days. CLS-ARGOS Australasia and the Satellite Services Section at the Bureau of Meteorology will advise on a suitable solution for each tracker's individual needs.

8. Attachment design

8.1 Care of the bird

A variety of techniques have been developed to handle seabirds both at sea and breeding at the nest. It takes 5-30 minutes to attach the satellite telemetry equipment to the bird using routine bird-handling techniques, so there is additional stress to the animal. Assistants who are experienced with handling birds are essential. In addition, familiarity with telemetry procedures on wild animals is highly desirable.

Practising the attachment procedures on dead specimens or 'dry' runs on live birds, and the use of light-weight dummy packs, are exercises that can help ensure the bird's safety. Developing good team-work where each member has the opportunity to rehearse their contribution is a necessary preparation. Telemetry takes time and effort. Where they are a part of wider program, they must be properly integrated into that program. Discussing the priorities, and a willingness to accept more modest objectives if there are setbacks and delays, are part of these preparations. The high cost of the PTTs adds to the need to ensure everything is done correctly the first time and this adds significantly to the stress on those responsible for this work.
At least initially, the telemetry procedures need to be used as an alternative to other procedures (banding, census or physiological studies, ...) and not as an additional procedure. This may create some tension in studies where the cost of the telemetry procedure makes it highly desirable to obtain other measurements which will enhance the telemetry. Caution and incremental progress with the bird's well-being as the primary consideration must be the guideline to those contemplating such things. Such integrated studies are possible however and they can be very rewarding; the outstanding studies of Peter Prince serve as an example. In this case the bird had its bird-bands, a VHF transmitter and an activity logger on its leg, a subcutaneous heart monitor in its chest, and an external PTT on its back. Its nest was modified to regularly weigh the bird (Prince pers. comm.). It must be strongly emphasised that these procedures were exhaustively tested both separately and in combination before this achievement was attempted.

8.2 Design of the PTT pack

The design of the transmitter pack should ensure that the insulation properties of the feathers are maintained. It should enable preening of the feathers so that they remain waterproof and so that ectoparasites do not increase. The shape of the bird, especially its aerodynamic profile, must be unaltered and the package should be small enough so as not to disturb its behaviour. The effect of attachments to birds is review in Calvo, B & Furness, R.W. 1992.

The mass of the PTT must be minimal. There are 'rules of thumb' on the maximum advised mass of payloads. There are also cautionary tales where experimenters have underestimated the effects or have not measured the effect of the payload. Work on pigeons, penguins and waders has emphasised the need for care.

Nesting seabirds with their relative ease of recapture provide opportunities for the recovery of the equipment and more importantly the opportunity to measure the effect on the animal.

Success has been reported for wandering albatrosses carrying payloads of 180 grams for 33 days or 150 grams for 103 days (Weimerskirch et al 1992, Prince et al 1992, Nicholls et al 1992). Smaller species of *Diomedea* and *Phoebetria* have carried payloads from 150 - 75 grams for flights of 10-20 days' duration. In some of these studies there have been measurements from control animals without payloads.

Adequate quantitative data on the effect of the payload are not available. This is especially true for experiments which last for more than one month. A conservative interpretation of the effect of the payload is that it may reduce the mass of fat and other reserves. In the short term, this may not endanger the bird, but when the bird calls on these reserves in colder climates, or during a long non-feeding incubation shift, the bird may be in danger. A mechanism that releases the payload is required.

8.3 PTT position on the bird

The PTTs are placed on the back between the wings, nominally over the centre of gravity. The hydrodynamics studies of Culik, Bannasch and Wilson (1992) show the need to keep the payload from increasing the frontal profile of the bird, as the drag will be increased. Aerodynamic studies show that the energy required to overcome the increase in drag is much more important than the effort required to carry the mass.

The antenna, about 150-170 mm long, usually trails out the back of the PTT (Weimerskirch et al 1992, Prince et al 1992) but it can be orientated with the antenna at the anterior. In this orientation, it can lie neatly back over the PTT thereby minimising the bird's leverage on the PTT (Prince pers. comm and my own experiences). For the best radiation to the satellite, the antenna needs to be vertical. A horizontal antenna near the back radiates the poorest signal. An angle of more than 45° off the back is satisfactory.

8.4 Attachment methods - short term

The following methods have worked for periods up to one month. First, harnesses have been used successfully on albatrosses (Weimerskirch et al 1992). Second, the British Antarctic Survey team used a quick-setting epoxy glue to hold a base plate to the feathers. The PTT was lashed to the plate with plastic cable ties so that at the end of the deployment the three ties could be cut quickly to release the PTT (Prince et al 1992).

Thirdly, since 1992, the French have used TESSA tape. The very sticky plastic tape is approximately 15 mm wide with cotton reinforcing threads woven through it. The PTTs are long rectangular boxes or tubes, typically 150 mm by 45 mm by 20 mm. Three or four tapes are wrapped around bundles of feathers to the PTT. Two turns of each tape are sufficient for two- to four-week attachments. When the deployment has finished, the tape is unwound and the PTT removed. The feathers remain almost unharmed.

Fourth, the smallest PTTs have been implanted subcutaneously in eider ducks *Somateria mollissima*. The difficulties of bringing the antenna through the skin were solved, but the removal of the transmitter on completion of the tracking requires recatching the animal. (Paul Howey *pers. comm.*)

There have been no reports of adverse effects of the PTT on the behaviour of birds that have been satellite-tracked. The methods were designed to minimise the handling and stress to the bird. They were deployed on breeding birds at their nest. Almost invariably the PTT was recovered. After the deployment, the birds were left undisturbed, hence there was little information on how the attachment might have performed over a longer period. The first three methods have worked satisfactorily for up to one month on albatrosses.

8.5 Attachment methods - more than one month

8.5.1 Gluing and Taping

In Australian experiments there was little likelihood of recovering the PTT, therefore they were seen as expendable. It was very important to secure the PTT for more than two months. The approach taken was to increase the surface area of the glue to the feathers. This was achieved by adding tapes as 'out riggers' to the PTT. For the large PTTs used in 1992-1993 there were four tapes, one extending from each corner. The feathers on the bird's back were lifted and the glued underside of the PTT was applied to the down. The lower and upper surfaces of the tapes were covered in glue and pressed onto the down under the feathers and a layer of smaller feathers covered the upper surface of the tape. Using this procedure the PTTs stayed attached for 70-103 days. One of the PTTs fell off the bird after its flight from Australia to Crozet Archipelago, Indian Ocean; both the bird and its PTT were recovered. The female bird had laid her egg and was incubating. There was no visible damage to the feathers on the back and the PTT was functioning correctly.

In 1993, to achieve a longer attachment period, pairs of tapes were used from each corner of the PTT. A pliable glue was used to stick the contour feathers between the pairs of tapes. This disrupted a larger number of feathers. The contour feathers were considered to be stronger than the down feathers, and it was hoped that this procedure would enable a longer attachment period (this method was used on only one bird). Contact was lost with the bird after 40 days, presumably because the attachment failed.

Tests with Loctite 401 (one of the cyanoacrylate instant glues, recommended after thorough testing on penguins G Robertson *pers. comm.*) did not perform as well on swans as did the 5-minute Araldite epoxy resin. The Araldite 256 adhesive (also available as a kit of 1 kg as K256) which was successful for attaching data loggers to seal fur took longer to set and has not been used on birds. Silastic adhesives peel off the feathers. Sikaflex 241 and 255 (which are the same) were used in 1993. A pliable, fast-setting and non-toxic glue is required to replace the Araldite.

8.5.2 Harnesses

Harnesses remain an option for a long-term attachment given the success of the first French experiments. However further tests on albatrosses must proceed with the utmost caution. A failsafe release mechanism is an essential part of such a harness. Harnesses are successfully used on raptors. A finely woven tape of Teflon is commonly used for these harnesses (Telonics Inc. publications, Microwave Telemetry Inc. catalogues).

Harness experiments of the author (with field help by the British Antarctic Survey in the 1970s) and work by N Brothers in the 1980s were not successful. The reasons for failure are unknown to this author. The failure occurs at sea. Using smooth tubing and a tubular pack, CJR Robertson was successful over a five month period. After breeding, the bird was not seen again (CJR Robertson *pers. comm*.).

Conclusions

There are many examples of successfull satellite tracking of albatrosses. The technology provides both the location of the bird and the opportunity to measure its environment during flight. New Zealand scientists have local telemetry skills and access to many of the world's albatrosses. Therefore they are well placed to extend the world's knowledge of seabird biology.

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APPENDICES

Comparison of ARGOS-PTTs - available as at January 1994

Useful Contacts

Attachment Procedures

Comparison harness verses gluing

APPENDIX

Useful Contacts

Bureau of Meteorology, Satellite Services Secion, Mr Brian Tideman, 150 Lonsdale Street, Melbourne, Vic Australia. PO Box 1289K Melbourne 3001 Australia. Fax 61 3 669 4168 Coordinates the JTA ARGOS requirements for Australasia.

CLS-ARGOS France 18, avenue Edouard Belin 31055 Toulouse CEDEX FRANCE Telephone +33 61 39 47 00 Fax +33 61 75 10 14. The company responsible off the ARGOS service.

CLS-ARGOS Australia, Manager Mrs Shlomit Shachori, CLS-ARGOS Australasia, 150 Lonsdale Street, MELBOURNE, PO Box 1289K, MELBOURNE. Telephone +613 669 4650 Fax 669 4675

Sirtrack, Mr David Ward, Manager, Sirtrack Ltd., PO Box 1403, Goddards Lane, HAVELOCK NORTH, NEW ZEALAND. Telephone +64 6 877 7736 Fax 877 5422 Provide sales, and engineering and biological support for satellite and other advanced telemetry.

Satellite Telemetry Mr Michael Hildebrandt, Pleasant Grove HAWTHORN EAST Vic 3123 AUSTRALIA. Provides sales of satellite tracking and other satellite services. Agent for several PTTs (including Telonics, Toyocom) and SAFIR. Telephone +613 882 1177

Faunatech, Wildlife Technical Consultants, Mr Ross Meggs, 11 Wattle Grove ELTHAM VIC Phone 61 3 439 2165. Manufactures high quality hydrodynamics telemetry packages.

Wildlife Computers 20630 NE 150th Street Woodinville, WA USA 98072-7641 Design and manufacture data logging telemetry equipment for wildlife studies.

Attachment Procedures

D G Nicholls Description and Figure.
Comparison of Harness and Gluing techniques.

Comparison of ARGOS-PTTs available as at January 1994

PTT , Model	**Albatross Package 6 mth. life** Mass g.	**Electronics Size- mm Mass**	**Power mW**	**Comment**	**Price $A**
Telonics, ST6	150	107x38x12 60	125 @ 6v	Workhorse of wildlife PTTs Activity, Temp. Bat., Serial port	
Telonics ST10	70	45x40x11 28	335 @ 6v	Reliable, digital sensor interface available	3250
Toyocom 2038IT	125	46x3lxl2 40 76x31x12 45	500	Must have transformer mod. 1993.	4600
Toyocom 2050	55	41x33xl9 25	125		<4600
Microwave 100 Telemetry loos	75	75x25x l8	125 125	4 data channels 5 data channels multiplexed	3500
Microwave Telemetry Micro93	28	40x20x 10 3.5	125		
Southwest Research	n. a.	~ 40x5Ox12 tx ~ 40x25x l2 sensor unit		Modular transmitter and sensor units	n. a.

Glueing procedures for attaching long-life PTTs.

Preamble

Methods of fitting Platform Transmitter Terminals, PTTs, to birds used include: harnesses around the body, glueing and taping to the feathers. Harnesses are not advised. Taping has replaced glueing for short-term attachments up to one month. Long-life attachments have been pioneered by Nicholls using the glueing procedures of Prince, but increasing the surface area glued.

The total glueing procedure will take 15-30 minutes from first approach to finish after withdrawal and observation. The actual attachment of the PTT will take 3 minutes with half a minute to select the attachment site. After the attachment the unit will need to be held for a minute to let the glue set. It is important to prewarm the glue to ensure a quick and effective setting. A warm fluid glue helps ensure the glue thoroughly 'wets' the tape and the feathers. However the warmed glue requires a rapid application of the PTT if the glue is not to set prematurely.

The holding of the bird must be quiet and with minimal contact of the bird's body. It should be in a sheltered site to minimise the wind rustling the feathers. The bill must be held very securely. It may be desirable to cover the head with a black cloth. The wings can be gently held open. Talking quietly may quieten the bird.

For incubating birds it may be appropriate to use a dummy egg to substitute for the real one, temporarily removed to a safe warm site.

Seek additional advice from Christopher JR Robertson and his team at Taiaroa Head on holding the bird. Some groups, e.g. French CNRS Crozet Henri Weimerskirch, and the Australian Antarctic Division G Roberston are catching the bird at change-over thereby minimising interference.

The site for attaching the PTT is on the back mid-way between the wings with leading edge of the PTT mid-way between the lines of leading and the tailing edges of the wings. Attaching the package further forward raises the frontal profile and therefore the drag. It may result in the tapes interfering with the action of the main bone (humerus) of the wing. The feathers in this forward area may be shorter and therefore inadequately cover the PTT. Further back may result in better coverage of the PTT by the feathers; the feathers in this area may be twice the length of the feathers on the line of the leading edge. Too far back moves the unit increasingly further from the centre of gravity of the bird. It may place the tapes too close to the legs. Too far back brings the unit too close to the preen gland. The bird may interfere with the unit more the further back it is placed. The antenna does not radiate optimally if the unit is too far back. The best orientation of the antenna is still to be determined - either at the front bending back over the PTT, or at the rear of the PTT hanging out the back.

It is important to secure the PTT well under the body contour feathers. The tapes are secured to the down feathers. It requires great care to keep the glue just on the tapes and the area of attachment. The procedure suggested minimises spills. It is clearly important that the glue does not spill on the wing or the body feathers. It can be cleaned off with acetone but this is a time-consuming process. The tapes should not be glued to the body contour feathers, save for a feather or so above and below the tapes. It is important that the tapes are secure on the down and that they do not flap around attached to the body contour feathers.

D G Nicholls 28 December 1993

Procedure

1. Place the tubes of glue and the PTT under the operator's clothing next to the underwear; over the stomach is a good place. Warm to 25-30°C.

2. Have a helper select the bird. While the helper catches the bird, remove the warmed glue. Mix 3/4 of the tubes. Have the bird held with the wings outstretched and the bird lying with its undersurface on the ground. This should take one minute.

3. Hold the cotton tapes neatly over the top of the PTT Apply the glue generously to the underside of the PTT.

4. Have a helper lift the feathers of the back over the site.

5. Feel for the backbone to indicate the centre of the back, and locate the fore-aft position on the back and within the wings.

6. Turn the PPT so that the aerial (antenna) is correct. See underside for arrow showing orientation. Apply the PTT in the mid-line to the down. Have the helper hold the PTT in place and on the down of the back (under the feathers).

7. Quickly apply the glue to the exposed underside of the tape except for a 5-8mm gap near the PTT The gap is left to provide a hinge and to allow for a faster removal of PTT Roll the tape down over the feather-down and over a few small feathers.

8. Apply glue except for a gap along side the PTT to the now-exposed upper side and attach small feathers.

9. Repeat above step for the other tape.

10. Hold the bird for a further minute. Lay the loose back feathers over the PTT.

11. Release the bird's wings and most of the hold on the bird, holding just the bill. Watch the remaining glue and when set in the container, release the bird. This may take a further minute.

12. Move back and watch the bird for 5-10 minutes to ensure all is correct.

Comments on procedure in the field
Location: ....
Bird ID: .... PTT#: ....
Date: / / . Time:

Time Complete:
Observer: ....

Comparison of attachment techniques
August 1991
Prepared by D G Nicholls

HARNESS

allows the bird to adjust the position for seasonal changes in body size, physiological condition and minimising drag

bird can preen under the package thereby controlling feather condition with its insulation/aerodynamic properties and reduction of parasitic infestations

in practice, it is difficult to have a design that is firm enough without causing feather and skin wear

can develop pressure sores from harness straps especially over wing/shoulders

extra weight 20-40+ % of total pack
may cause harm as the partially released or broken harness dangles from or tangles the bird

A successful design can remain for a many months; 12 month? Unproven although a swan carried for four months unharmed.

Fail-safe release mechanism requires extra weight and complication

Some individuals will not tolerate a harness - pers com Nigel Brothers (a summary of 3 years experience). This is consistent with my own observations.

In practice
problems hinted at by French, only 1-2 months proven

GLUE

inflexible and perhaps 'floppy' when stuck on the ends of the body feathers

may develop pressure sores at the shaft/skin junctions as a result of localised tension

ectoparasites may build up with inadequate preening {solution: add an insecticide? }

minimal opportunities for bird to optimise position and allow partial restoration of a new favourable aerodynamic contour and thermo-dymanic conditions

low weight, 5 to 25% of total pack
PTT or plastic "scab" sloughed off as bird moults

Life of mount depends on moulting; requires accurate knowledge of moult cycle to control and predict life of mount. Literature suggests 30 days life is common.

Biological release certain without further weight cost

Platform allows for rapid interchange of dummy packs and transmitters.

Successes reported from the British, only 1-2 months proven

Conclusion

1. Glueing is prefered for short term attachment.
2. Harness are only acceptable if a reliably-timed release is perfected and is used for the known safe period, i.e. <2 months for albatrosses.

Warnings
It is not clear how long the glue patch lasts and its effect on the bird. The transmitter falls off, but how long does the glue last and with what effect?

Appendix Example of an interrogation of ARGOS.

Telephone modem data link contact has been established with ARGOS, a user name and password entered at the prompts. The commands produce

COM/ C - the latest position. This will be subsequently confirmed. The details may change.

DIAG/C - a succinct form of all the locations together with a summary of the quality of the observation, and the data measured at that location and time

PRV/C - all the data measurements, one line for each message received during a pass. In this particular case an index for each of the following was transmitted, PTT temperature/battery voltage alternate, barometric pressure, angle of the roll and the angle of the pitch.

The "/C" compresses the reports and reduces telephone charges. This file is stripped of the unnecessary text and converted to a tab delimited file with a text editor ready for a spreadsheet.

```
        LOGIN AT 334/1916 LAST ACCESS AT 334/0139 LTC

ARGOS READY

/COM/C,,,A

 Prog 1137
 00580 175.756E 1 322/0244Z-321/1425
 (1) 93 138 85 156
 00581 45.777S 170.714E 1 333/1927Z-333/1659
 ( 1) 141 101 220 227

ARGOS READY

/DIAG/C,,3310,581
 Prog 1137
 00581 Date: 26.11.93 04:25:10 LC: 1
 Lat1 : 45.404S Lon1 :171.510E Lat2 : 39.340S Lon2: 159.514W
 Nb mes : 008 Nb mes>-120dB : 000 Best level: -128 dB
 Pass duration : 408s Dist track: 11
 Calcul freq : 401 648890.7 Hz Altitude: 0 m
 200 133 47 226

 00581 Date: 26.11.93 06:08:35 LC : 1
 Lat1 : 45.439S Lon1 : 171.550E Lat2 : 4.199S Lon2: 9.158W
 Nb mes : 006 Nb mes>-120clB : 000 Best level : -128 dB
 Pass duration : 697s Dist track: 7
 Calcul freq : 401 648907.6 Hz Altitude: 0 m
 143 164 62 228

ARGOS READY

/PRV/C,,DS,330,581

01137 00581 6 8 H 1 1993-11-26 04:25:10 -45.404171.510 0.000 401648904
 1993-11-26 04:21:46 1 200 133 49 227
 1993-11-26 04:22:44 1 141 133 110 227
 1993-11-26 04:23:43 1 200 133 47 227
 1993-11-26 04:24:41 1 141 133 47 227
 1993-11-26 04:25:39 1 200 133 47 226

ARGOS READY
/LO

    LOGOUT AT 334/1919

CLR PAD 180
```