A proposal for using GPS-logger equipped flying-foxes as monitors of change in tropical rainforest resource distribution

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ABSTRACT

Anthropogenic global warming is expected to cause major changes in the phenology of tropical rainforests in the short term and cause significant structural changes in the long term that will result in local species losses and possibly extinctions. Monitoring these changes is labour intensive and with steadily reducing funding for field environmental research, it is unlikely that such monitoring will take place, thus opportunities for some corrective actions will most certainly be lost. We propose to utilise flying foxes, *Pteropus spp*., which are large and highly mobile herbivorous megabats, as "flying monitors" of the changes to forest resources, by fitting them with GPS-logger collars. To allow us to economically track multiple animals with high spatial and temporal resolution, we have developed a solar-powered GPS-based logger, that following further size reduction small enough can be carried by an adult Spectacled Flying-fox *Pteropus conspicillatus* and costing less than one fifth of an Argos GPS-based system. This logger (capable of storing over 60,000 locations) will permit us to monitor detailed shifts in flying-fox feeding behaviour and energetics to monitor forest phenology with changing climate. Data are remotely downloaded without having to capture the animal or wait for the collar to fall off. Each collar has a radio-beacon to permit location of the animal for data download. Data from the loggers can be plotted on a GIS topographical and vegetation map data base.

Key words GPS, logger, climate change, *Pteropus*, phenology, logger-collars, solar-powered, energetics, flying-monitors, forest

Introduction

Flying foxes are considered critical seed dispersers and long-distance pollinators for a large assemblage of rainforest and sclereophyll tree species, and might be considered 'keystone species' for long-term forest survival (Shilton *et al.* 2008). Being herbivores, they also visit commercial fruit orchards when available wild food is scarce. The amount of damage caused by their activities is difficult to verify, but many of the reports are believed to be exaggerated (C.Booth, *pers comm*.). Nevertheless in some years the damage to exotic fruit crops, such as lychees and rambutans, can be considerable (M Gray, *pers comm*.). In Eastern Australia, there are major actions being mounted by some of the farming and urban community against the flying-fox (all species), driven in part by a social unwillingness to share living space with native animals coupled with a fear of bat-borne diseases. We can expect that shifts in flowering and fruiting patterns caused by global warming may have a further major negative impact on these animals and on unprotected orchards..

The present population of spectacled flying-foxes ,*Pteropus conspicillatus*, has been variously estimated to range from 80,000 (Whybird quoted in Martin and MacIllwee 01) to 250,000 animals(Westcott *et al.* 2001, Shilton *et al.* 2008), but in the absence of reliable census methods, estimating the the population size is highly problematic (Forsyth *et al.* 2005). Unfortunately, there are no reliable figures for the population before 1990, but a number of observations suggests that there would have been significantly higher numbers in the 1950's – as there have been a substantial loss of habitat, destruction of colony sites, in and around urban areas since then, coupled with a reported major kill of about 12,000 animals associated with a large lychee farm in Kennedy (FNQ) in Dec 2000, continuing use of lethal grids for crop protection (until 2008), mortality due to tick paralysis (Eggert 1994) and the demolition of flying-fox camps in the region between Cairns and Townsville as a result of Cyclone Larry (March '06) (Shilton *et al.* 2008). This has raised repeated calls for the spectacled flying-fox to be listed as "Vulnerable" by the Queensland State Government, although both it and the Grey-headed flying-fox, *Pteropus. poliocephalus*, are already listed as vulnerable by the Federal Government. Flying-foxes are slow recruiters, having one baby per year after 3 years of age and as such are easily impacted by "control" activities such as shooting, poisoning and electrocution, as well as destructive loss of colony sites and habitat (Martin and MacIlwee 2001, Fox *et al.*, 2008). Recent aging studies indicate that, with a life expectancy of less than seven years in the wild for *P conspicillatus*, (Fox *et al.* 2008) (compared to up to 20 years in captivity – H.S. pers observations), the population was observed to decline by 16% over the 2 years of the study and as the *P conspicillatus* population appears to be genetically homogenous, this observation probably applies to the entire Wet Tropics population (Fox *et al.* 2008).

Given this 'vulnerable' conservation status, any method that can supply the much needed data on their movements, their choice of food trees, their time and energy budgets, to say nothing of the possibility of discovering new colony sites, must be fully exploited. Research carried out so far

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(Spencer 1991, Eby 1991, Westcott *et al.* 2006, Roberts *et al.* 2008) indicates that flying- foxes do not in fact restrict themselves to specific locales, but move over the entire distribution range of the animal, so that it is highly probable that spectacled flying-foxes tagged in Kuranda or Atherton could well visit a large proportion of their total range over their lifetimes.

For their long-term conservation, it is imperative that a significant body of detailed information on their movements and feeding patterns become available. In this regard, availability of good habitat use data may help promote development of non-lethal control methods and improve community sympathy for these animals. This paper outlines progress on the development of a GPS tracking device intended to be fitted to flying foxes for the purpose of collecting such detailed habitat data

Monitoring vegetation resource changes in response to Global Warming.

As flying-foxes are highly mobile foragers, capable of covering thousands of square kilometres each year, their movements can be expected to provide a sensitive indication of shifts in forest resource availability – flowering, fruiting and leaf flush – all of which can provide flying-foxes with feeding resources (Westcott *et al.* 2001). Flying-foxes have the capability to range well in excess of 600km during a year (Spencer *et al.* 1991, Eby 1991, Roberts 2008) and can have daily feeding ranges of over 50km each way. In the year following Cyclone Larry in 2006, the pattern of activity of spectacled flying-foxes in the Wet Tropics was seriously disturbed, with animals remaining in widely scattered 'feeding camps' of a few thousand individuals at the most, throughout most of the year and congregating at 'maternity camps' very late in the season (Shilton *et al.* 2008). In the absence of the ability to gather 'fine-grained' data we cannot determine the details of such movements, nor can we determine the underlying resource changes involved. Increasing temperatures due to global warming will (and are) most certainly resulting in shifts of flowering and fruiting patterns of many critical food trees. Unfortunately there are just not nearly enough field biologists 'out-there' to assess and record these changes. Flying-foxes fitted with GPS loggers have the potential to function as highly mobile 'field observers', for the suite of plant species that are of concern to them. Data from the loggers will provide very considerable amounts of positional data – accurate to 20meters or better – which will permit researchers to identify (and if necessary, visit) the actual trees visited. There is no other way of obtaining data of this quality. Conventional radio tracking gives only a glimpse of their activities as it is limited by the ability of the researchers to be close to the tagged animals when they are feeding or roosting, which tends to be largely a matter of luck (or access to aircraft).

A brief history of "backpack' GPS Monitoring

Developments in the technology of Global Positioning Systems (GPS) receivers have advanced markedly since 2000, when self-contained GPS receivers had become small enough to be placed on birds such as pigeons (300–500 g). The removal in 2000 of 'Selective Availability' constraints on GPS signals (http://www.argos-system.org/manual/) has greatly increased positional resolution, allowing GPS users to achieve positional accuracies of better than 1 m, in conjunction with techniques such as differential GPS. von Hünerbein and Wiltschko (2000, 2001) described a system based on a then commercially available miniature GPS receiver chipset (Ublox-TIM), that was used to trace the detailed movements of homing pigeons from their point of release to their re-capture point at the home loft. Central to the success of their work was the fact that these GPS receivers had an integral flash memory, capable of storing some 90,000 positions, at a sample rate of 1 per sec. On recapture, the GPS units were removed from the birds and the contents downloaded to an appropriate GIS program on a computer Since it used non-volatile flash memory, there would be no loss of data should the battery have failed.

From the information gathered, the pigeon's path, as well as its flight velocities and rests, could be examined in great detail. As it was not considered prudent to load birds with loads greater than 10% of their body weight, the units weighed 33 g. This weight restriction severely tested the developers of the project, as the then current GPS technology was barely able to fulfil their needs.

Recent developments in GPS 'engines' have allowed relatively lightweight backpack loggers to be developed in the USA for birds, but these have no capability for remote downloads – thereby necessitating the recapture of the animal, or, relying instead for the collar to drop-off after a pre-determined period (finding the jettisoned collar in dense forests could be a major task).

At the Cape Tribulation Tropical Research Station, we have developed a prototype backpack GPS collar design which addresses most of the design issues that have restricted the use of this technology on animals smaller than large dogs. This system has been designed for the express purpose of being able to track the fine details of flying-fox movements over their habitat, permit remote data collection, and to cost $A1000 or less per unit to deploy (compared to AUS$5,600 each for Argos GPS units at current exchange rates (http://www.wikipedia.org/wiki/Global_Positioning_System).

Benefits of the GPS logger approach over GPS–ARGOS

ARGOS PTT satellite systems (used extensively to track migratory birds and cetaceans) have the virtue of operating over the whole globe (as does GPS), but the basic PTT transmitters are expensive (nominally $US 2,500 each for standard PTT's, and $US 4,000 for the GPS versions), making it difficult for large-scale projects to receive funding in the future. Each positional "fix" is charged for – the cost reflecting the resolution desired as well as the number of fixes (approximately $US 100 per month per transmitter). Usually the most common resolution called for is 1 km (Class 1) – quite adequate for following long distance migrations, but quite useless for detailed examination of time and energy budgets of flying-foxes (or birds), let alone determining specific camp locations or feeding sites. Presently the best accuracy that can be delivered is 250 m (class 3), and the fact that ARGOS utilises a simple triangulation procedure based on measuring the differential Doppler shift of the received transmitter signals, prevents higher levels of distance resolution being achieved. GPS-based ARGOS platforms have far better resolution than this, but the number of data points sampled per day is severely limited by battery size.

Table 1. Distribution of Argos fix quality for 4075 fixes 16/10/07 to 22/02/09 for 16 Argos collared grey headed flying foxes in northern New South Wales (data from Roberts-unpublished). 62.5% were considered useable (categories 3-1). GPS-based ARGOS collars would have greatly improved accuracy – but at the cost of only a few fixes per day and substantially higher package energy requirements and cost.

Argos category	Range (Argos User's Manual 2007–8)	Number
3	>250	600
2	250 – 500	920
1	500 – 1.5 km	1030
0	>1.5km	700
A	No accuracy det	415
B	No accuracy det	395
Z	Invalid	15

Argos's main advantage is the immediacy of the results, so they can be displayed on a web-based bulletin board, on a day-by-day basis, whereas GPS loggers only deliver their data in a large block whenever they can be accessed and downloaded by field workers. Argos PTTs have been used in Australia to track flying-foxes . Roberts *et al.* (2008) has recently employed 16 Argos systems in the field, but the number of points per day is severely limited by the energy constraints to only 5 or 6.

The Project

We intend to use the GPS logger-collar technology that we have developed (subject to further refinement) to monitor changes, in both space and time, in rainforest resource distribution (as utilised by Spectacled Flying-foxes – a highly mobile and opportunistic forager) in response to global warming. We expect that this project will generate a wealth of detailed data which will give significant insights into the biology of the Far North Queensland Wet Tropics rainforest, as well as insights into the flying-fox and its considered role as a 'keystone' species. Most importantly, it will provide us detailed information on the shifts in plant phenology and resource availability resulting from climate change and, hopefully, allow us the opportunity for undertaking corrective actions. We expect that it should provide the basis for a substantial body of post-graduate research.

The characteristics of the GPS system we have developed are:

- No limit to the area or distances covered by the tracking system.
- Cost (estimated) about $A1000 per animal package (maximum) in large enough numbers.
- GPS package weight 50 grams or less.
- available data memory – up to 60,000 positions.
- system spatial accuracy – better than 20 m
- life time on an animal – at least 2 years
- data aquisition rate can be programmed, and can be re-programmed remotely as conditions change.
- solar assisted battery (as animals generally roost in bright sunlight, but are active at night)
- use of 'shut-down' capability of unit to save battery power between readings.
- integral 'finder beacon' – nominally a low power 150 MHz signal (nominal) to permit location of animal (during day) .
- use of existing Wireless Local Area Network (WLAN) technology (Bluetooth or Xbee) for managing downloads.
- data recovery – by duplex radio link (Bluetooth or Xbee) – whenever animal can be located in a camp-hand-held Bluetooth or Xbee link antenna, (integrated with locator antenna), permits remote downloading of data and resetting of GPS memory.
- Download range 200m for Bluetooth, (Xbee has the potential for far greater range)
- unlimited downloads of data during life of transmitter
- no charges involved in downloads.
- Animal does not have to be captured, handled (or even visible) for data to be downloaded.
- Technology applicable to a wide range of other animal and bird species. Basic GPS Collar design

System operation

In its current configuration, the logger can be configured for different sampling rates to accommodate subjects' nocturnal or diurnal activity patterns. In the case of flying-foxes, (as the animals are resting during the day), only a very few location points are required – so 5 location points are logged. At dusk, when fly-out commences (nominally 6 pm), the logging rate increases to one every 5 minutes. However, to save battery (and memory space), if the animal rests during the evening, the logger will only record a significantly changed location. This sample rate continues until nominally 6 am (these times can be re-programmed remotely), when it returns to the day rate.

As it is unlikely that a researcher or volunteer will be available to locate the animal and download the data until mid-morning – in the current configuration, the finder beacon is switched on for 5 minutes at 10 am and every half hour thereafter (unless the animal has been located and the data downloaded that day). Immediately after the beacon has ceased transmission, the Bluetooth link turns on and if the observer is in place with the download antenna, he or she can download the data.

Prior to the beacon being turned on the GPS attempts to make a fix, and at the same time updates the collar's realtime clock from the GPS signal. In this way, the observer and the logger are completely time-synchronised. Each location logged is accompanied with a time stamp. (Fig 4 – RH column)

We are currently using Bluetooth (presently version 1.1) as the data transceiver technology, as it has a well established communications protocol, thus obviating the need to write a proprietary code for data transfer. Bluetooth is also an industry standard, and is compatible with a very wide range of products - from antennas to operating systems and PDA's. It is also available as a completely integrated sub-board together with an integral chip antenna (middle module, Fig 2). Because of the intense pressure for continual miniaturisation of consumer electronics we can expect to see these modules, like the GPS 'Engines', become progressively smaller and less energy demanding. In fact a new ultra low-power Blue Tooth (WIBREE) is now available. Xbee, a new industry-standard protocol, which we are investigating, operates at 900 MHz, and avoids some of the serious vegetation absorption issues that limit the range of Bluetooth, which operates in the 2.4 GHz band, although download rates are slower.

The GPS 'engine' uses NMEA-0183/SiRF (1575 MHz) technology – sensitivity nominally –155dBm – a technology supported by a number of manufacturers. Under open sky conditions, acquisition from start-up ('Cold') can take 42 sec and 1 sec ('Hot') and the use of appropriate additional memory support can speed this up. We have found that with the passive 'slab' antenna illustrated (Fig 1), we have been able to get reliable fixes under the densest rainforest. In fact we have made use of this feature to construct a hand-held GPS logger that can be used to map tree positions under dense rainforest conditions without the necessity for an external high gain antenna. This logger has served as the 'test-bed' for developing this GPS system.

Data format

Figure 4 illustrates a typical data dump in NMEA format (the actual data from the GPS has to be converted to create this comma-delineated file – a fairly simple process). This can be readily imported into mapping programs such as MapInfo.

Downloading system

The 'downloader' is simply a suitable Bluetooth (or Xbee) compatible antenna (Figs 5 and 6) physically linked to a standard 150 MHz radio-tracking Yagi antenna, so that their radiation patterns are in line. The radio-tracking antenna is connected to a suitable receiver (Spencer 1988), and the 2.4 GHz Bluetooth antenna is connected to a Bluetooth-enabled PDA, or a purpose-built receiver. While the location of the animal requires active searching for the animal using traditional radio-tracking approaches (simplified, as the animal is either in the colony or it is elsewhere), the download operation itself can be completely automatic, the data being transferred to non-volatile memory for later download to a computer. Once the download is completed then the animal collar memory can be erased. However, should anything happen to the downloaded data – it would be lost – so leaving the data on the animal logger would provide some form of backup – and it would simply be written over when the memory is full. Download ranges depend on the technology used – Bluetooth is limited to about 200 m – even with a high gain antenna, due to the high absorbance of 2.4 GHz radio signals by vegetation. Newer technologies such as Xbee offer far longer ranges (reportedly up to 1 km), because of the lower radio frequency used (900 MHz).

Weight and collar issues

The large flying foxes can carry loads up to half their body weight (this is manifested in cities during mango season

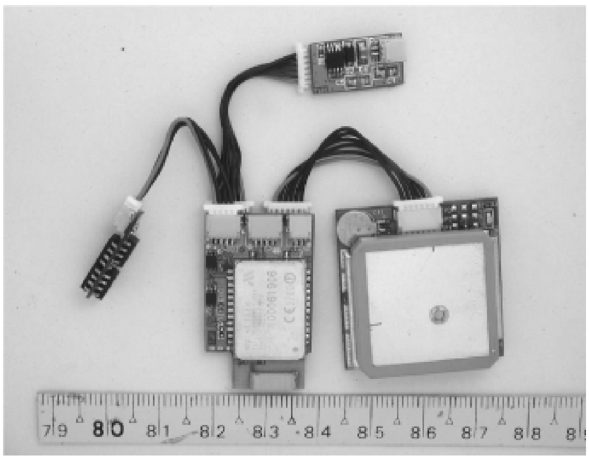

Figure 1: The complete prototype GPS logger (exploded view) – due to the size of the antenna (orange-bordered square on the right), this unit is still too large and heavy . (The beacon transmitter, battery and solar cells have to be included as well as the encapsulation and collar). The components to the left are the memory chips, at the top is the battery/power controller, to the lower left, is the microprocessor and the Blue-tooth transceivers and to the lower right the GPS antenna (orange block) and GPS 'engine' under it.. Scale is in cm.

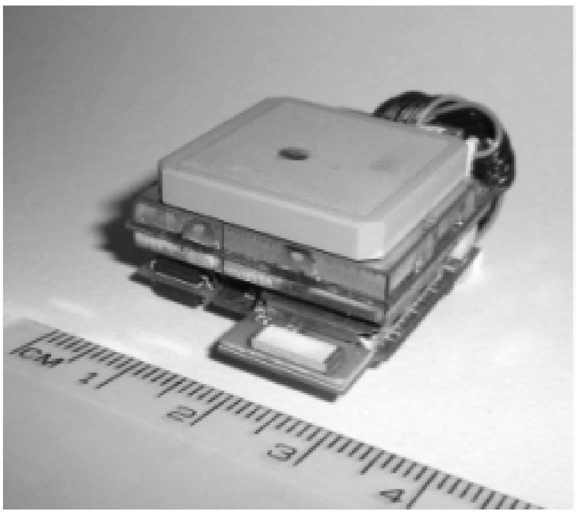

Figure 2: Assembled GPS unit – the small projection is the Bluetooth antenna.

as the animals tire of carrying mangoes from a raided tree – and drop them on roofs). Female flying foxes carry 75 g new born young – and continue carrying them until they weigh about 150 g (currently accepted weight ranges for adult Spectacled Flying foxes are 350–950 g; J. Maclean *pers. comm.*). A 50 g package would not appear to be an imposition on an 800 g+ animal (6.3 %). Additionally, flying foxes do not depend on very high levels of aerial manoueverability to catch food, unlike insectivorous micro-bats (where the accepted transmitter load is 5% of body weight). The leather collar design used in the 1991 radio-tracking study (Spencer *et al*. 1991) has proved to be excellent and has been adopted by other workers, and will be used for attaching the logger to the flying-foxes. Collar release is a vexed question, as observations indicate that the neck secretions, while somewhat thickening leather, also tend to preserve it. Use of cotton thread to provide a weak link will probably be appropriate.

Camp Monitoring

Central to the utility of this project is the use of a network of observers who are able to visit likely camps at suitable intervals, check for collared animals, and, if present, download the data, and send it to the investigators as e-mailed files. This approach worked well for an extensive radio-tracking study carried out in the past (Spencer *et al.* 1991), and it was the only way we were then able to monitor colonies which ranged from Ulladulla to Brisbane. The cost of providing monitoring technology to the volunteers was far lower (and the monitoring rates were far higher) than the costs of attempting to service all the known colony sites using a dedicated observer. Besides, even encountering a collared animal once a year, can still yield a wealth of detailed data. For the present project, we will attempt to continue with this model. It also encourages community engagement in the research.

Where to from here??

The next development stage is to integrate the electronics into a smaller package, fit the Li-ion cell and the solar cells. We have samples of high output solar cells courtesy of the UNSW Centre for Photovoltaic Research which appear suitable for this application. Encapsulation will require some fairly new techniques, as the encapsulant will have to be not only clear, but very hard to withstand abrasions and the attentions of the flying-foxes. For animals such as cassowaries, for which suitable transmitter packages have already been devised (D. Westcott *pers. comm.*) and for which solar recharging is not an option, immediate deployment of this technology would be a fairly simple matter. We are seeing a number of consumer-led improvements to GPS technology, such as smaller helical (or turnstile) antennas, which we are still in a position to integrate into the design.

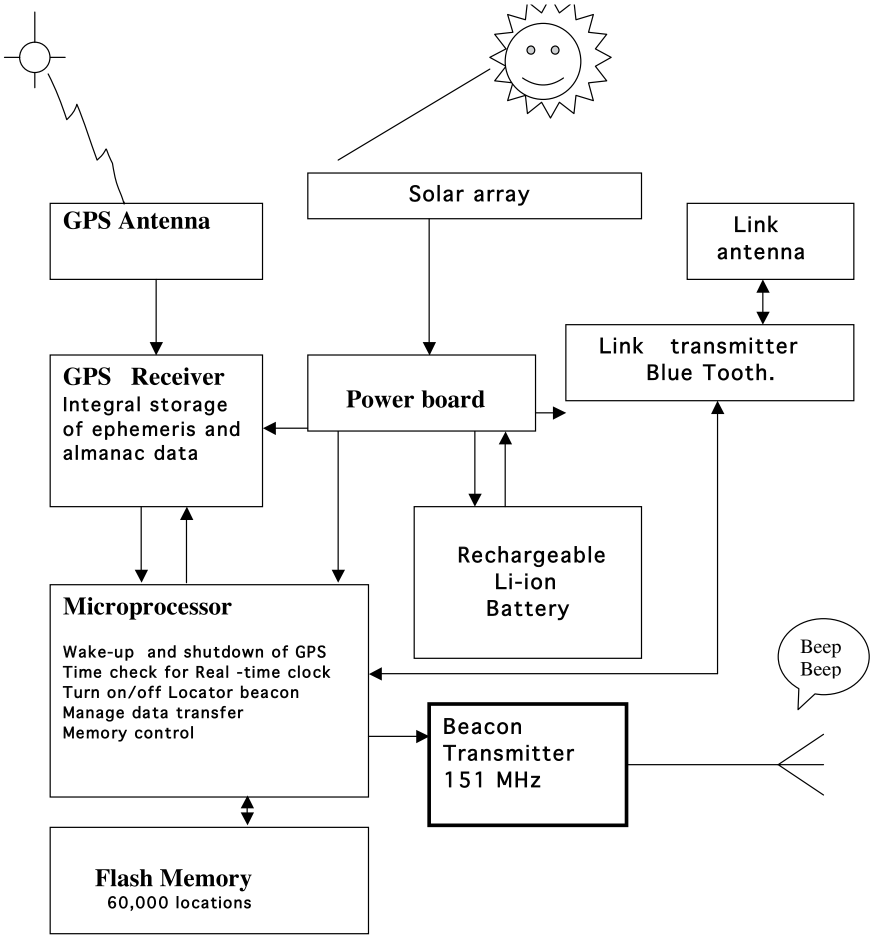

Figure 3: Block schematic of the GPS logger.

Conclusion

We have developed a low cost GPS logger collar technology that (following further size reduction) can be used on flying foxes with the intent of both obtaining behavioural information as well as 'fine-grain' information on resource use. It will also enable us to use the collared flying foxes as 'mobile monitors' of the changes in forest phenology resulting from anthropogenic global warming. Once fully implemented, this system will also have application to studies of other animals.

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ID . Lat. hemisphere. Long. hemisphere. UTC time. Status
16, 1606.3904, S, 14527.7480, E, 043248.000, A
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1:  1606.6498,S,14527.5281,E,040428.000,A
2:  1606.5628,S,14527.5950,E,040950.000,A
3:  1606.5492,S,14527.6049,E,041044.000,A
4:  1606.5360,S,14527.6153,E,041242.000,A
5:  1606.5261,S,14527.6265,E,041629.000,A
6:  1606.5132,S,14527.6387,E,041743.000,A
7:  1606.5019,S,14527.6509,E,041954.000,A
8:  1606.4915,S,14527.6629,E,042122.000,A
9:  1606.4799,S,14527.6744,E,042312.000,A
10: 1606.4678,S,14527.6872,E,042530.000,A
11: 1606.4581,S,14527.6986,E,042620.000,A
12: 1606.4449,S,14527.7101,E,042716.000,A
13: 1606.4321,S,14527.7212,E,042801.000,A
14: 1606.4171,S,14527.7310,E,042941.000,A
15: 1606.4039,S,14527.7401,E,043120.000,A
16: 1606.3904,S,14527.7480,E,043248.000,A
17: 1606.3694,S,14527.7469,E,043500.000,A
18: 1606.3533,S,14527.7530,E,043630.000,A
19: 1606.3373,S,14527.7593,E,043726.000,A
20: 1606.2368,S,14527.8549,E,044151.000,A
21: 1606.2226,S,14527.8642,E,044424.000,A
22: 1606.2087,S,14527.8735,E,044615.000,A
23: 1606.1962,S,14527.8833,E,044841.000,A
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Figure 4: An NMEA data dump. There are a variety of data formats generated by the GPS "engine" – we have chosen the simplest NMEA (or National Marine) as this allows far more data storage in limited memory. This does not give information such as height - which is fairly inaccurate with GPS systems. Status (A) - indicates a 'good' fix. Elevations are not part of this data set.

Fig. 6: This 2.4 GHz, 26dB gain antenna is capable of ranges of about 250 m in open forest (assuming you can detect the beacon transmission of course!!).

Fig 5: A handheld 2.4 GHz antenna like this (8db gain) is adequate for downloading data over a distance of one hundred metres. It would be 'piggy-backed' on a conventional 151 MHz radio-tracking array (used to find the beacon transmission).

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