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SHORT COMMUNICATION

HARMONIC RADAR - A METHOD USING INEXPENSIVE TAGS TO STUDY INVERTEBRATE MOVEMENT ON LAND

Summary: We describe the use of harmonic radar in the field with simple, inexpensive tags with extended lifespan. The effects of aerial size and shape, and the detection range of several types of diodes under different conditions are described. Examples are provided of tracking short-term movement of a ground beetle, *Plocamosthetus planiusculus*, and long-term movement of a snail, *Paryphanta busbyi watti*. The potential and limitations of the method are discussed.

Keywords: Harmonic radar; Carabidae; Pulmonata; land snails; movement; tracking.

Introduction

Spatial behaviour of individuals is a key component to understanding the population dynamics of organisms (Turchin, 1991). Many animals do not easily lend themselves to such studies and observing them without disturbing their natural behaviour and habitat is sometimes almost impossible. Moreover, many organisms are cryptic, sensitive, or too rare to study directly. Capture-recapture methods are suitable for using with a wide range of organisms (Southwood, 1978) but their resolution levels in space and time are often not fine enough. To overcome this, many types of tracking and remote sensing methods have been applied to studies of migration and behaviour (Riley, 1989; Pride and Swift, 1992).

The application of these methods to the study of small organisms has been problematic. Following individuals usually requires some form of radiotracking, i.e. locating an individual carrying a small radio transmitter. Two important technical limitations to overcome are the size of the transmitter and its battery, and the limited lifetime of the energy source. Thanks to recent technological developments, miniature, lightweight transmitters are now available, and have been used for tracking invertebrates (Riecken and Raths, 1996). Their cost, however, puts them beyond many research budgets. Moreover, even a miniature transmitter needs an energy source, and this limits its useful life. Technical failures can be frequent (Riecken and Raths, 1996) and this contributes to the cost of using these devices.

An alternative is to use a passive reflector that does not depend on an attached energy source. If a conductor with nonlinear characteristics, a diode, is illuminated by radar waves, it can re-radiate an harmonic of the original radar signal. This harmonic signal can be detected and used to locate the reflector together with anything attached to it. The energy to operate the reflector is delivered by the illuminating radar. The harmonic radar is such a device. It is a hand-held emitter which generates a continuous, unmodulated wave. Diodes are available that reflect the signal at double the original wavelength. The harmonic radar unit also detects the reflected signal and transforms it into an audible signal. The harmonic radar was originally developed to locate avalanche victims and it was first used for tracking invertebrate movements around 1985 (Mascanzoni and Wallin, 1986; Hockmann *et al.*, 1989; Wallin, 1991). The reflected signal is not specific, so individual markings have to be applied to the animals if they are to be identified once they are found.

In this communication we call attention to the potential usefulness of this equipment for tracking invertebrates in New Zealand. We present detection distance data for several types of diodes which can be used as transponders, and provide examples of its use for tracking the short term movements of a ground beetle and long term movements of an endangered snail.

Methods

We used a portable transmitter-receiver designed by Recco (Recco Rescue Systems, Lidingö, Sweden), which weighs about 8 kg. It consists of a battery, a hand-held Yagi aerial which is both the transmitter

Table 1: *Maximum detectable distance for different diodes, orientations and aerial shapes tested. The aerial length was 12 cm in all cases.*

Aerial shape/ orientation	Maximum detectable distance (m) Recco S2	HI 48	HP 280C 3C1	Z 3040	Z 3232	1N 34 1N 60	HP 2835	BAT 85[1]
Elongated parallel	9.82	4.00	4.90	12.00	10.12	10.36	8.00	not tested
Elongated perpendicular	2.40	0.65	1.81	4.00	3.85	3.61	1.90	not tested
Circular	2.20	0.60	1.40	2.60	1.90	2.80	2.10	not tested
Recco parallel	13.20	7.70	3.80	8.00	8.00	7.00	10.30	1.20
Recco perpendicular	3.60	3.00	1.40	3.40	3.40	2.90	6.00	0.00

[1] The BAT 85 diode responded poorly in initial tests so was not tested in all combinations.

and the receiver, and earphones. The transmitter emits a 1.7 W continuous microwave frequency of 917 MHz.

The tag on the target organism reflects this energy at double the frequency (1,834 MHz). The detection range depends on the type of diode used to construct the tag, and the shape and size of the aerial connected to the diode.

We tested the following Schottkey type diodes: Recco®, S2 (provided by Recco, Lidingö, Sweden), HI 48, Hewlett-Packard HP 280C 3C1 (5082-2800), HP 2835, Z 3040 (Dick Smith Electronics, equivalent to 1N 60 specifications), Z 3232 (Dick Smith Electronics), 1N 34 and 1N 60 (which are equivalents), and BAT 85.

Transponders were made by soldering an aerial of copper wire (0.5 mm diameter) to a diode to form a closed loop. Each transponder was tested ten times with the wire loop in two configurations, a circle and an elongated oval. The maximum detection distance was measured with the harmonic radar. Two orientations of the oval aerial were tested, with the long axis either parallel or perpendicular to the microwave beam.

Following testing with closed-loops, each diode was connected to the rectangular Recco®, aerial and the maximum detection range measured with the aerial parallel and perpendicular to the microwave beam.

The three diodes which performed best were tested again with a single length of wire attached to the cathode end of each diode. This was the same design as used by Mascanzoni and Wallin (1986). The length of the copper wire varied between 0 - 20 cm. Parallel and perpendicular readings were made.

Tests were conducted in an open field. Each transponder was placed on a plastic plate to isolate it from the ground to control for environmental factors such as damp grass that alter detectable range. Readings were taken with the radar held 1.2 m above the ground. Care was taken to keep the polarity of the diodes the same in relation to the direction of the beam. The diode that proved most effective in the first part of the experiment was then used to test different aerial shapes on the maximum detection range.

Transponders were attached to five ground beetles (*Plocamosthetus planiusculus* White, Coleoptera: Carabidae), and 37 snails (*Paryphanta busbyi watti* (Powell), Pulmonata: Rhytididae), to study their spatial behaviour and habitat preference. Tagged organisms were relocated at periodic intervals by systematic searching. The period between relocations was short (15-30 min) for ground beetles, but was up to several months for *Paryphanta* snails.

Table 2: *Maximum detectable distance (m) for transponders manufactured from Z 3040 diode - copper sheet combinations.*

Orientation / location	Aerial shape Narrow rectangular	Wide rectangular	Continuous circular/ diode across	Large circular	Small circular
Parallel	5.50	10.70	1.50	7.60	6.10
Perpendicular	5.50	10.60	1.50	7.40	6.20
Behind tree	1.70	3.80	0.00	3.10	1.90
Under dry litter	5.50	10.90	1.50	7.50	4.60

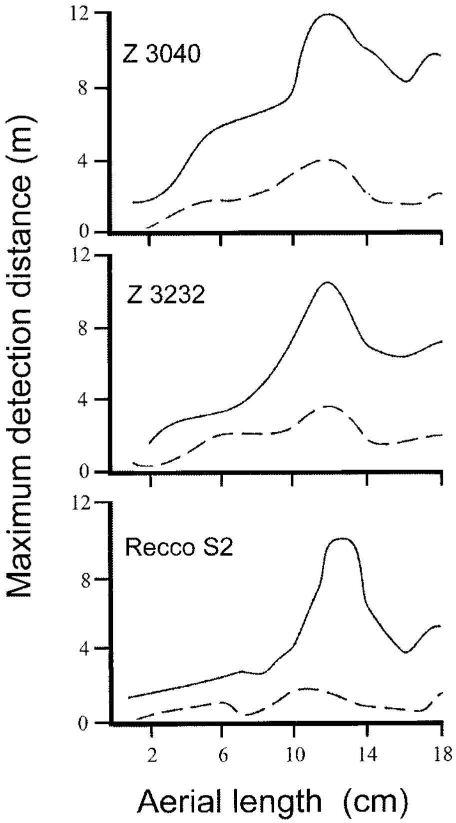

Figure 1: *Maximum detection range of the diodes Z 3040, Z 3232, and Recco S2 with different aerial lengths in parallel (solid line) and perpendicular (broken line) orientation to the radar beam. The aerial was always attached to the cathode end of the diode.*

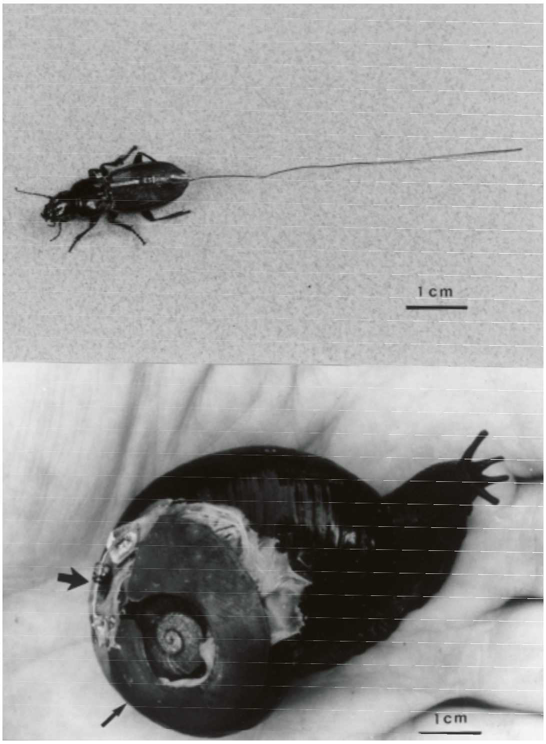

Figure 2: *Two invertebrates fitted with a Schottkey-type diode and appropriate aerial for harmonic radar studies. Top: a female carabid beetle,* Plocamosthetus planiusculus. *Bottom: the snail* Paryphanta busbyi watti. *Note the different aerial shapes. The thick arrow points to the diode, the narrow one to the aerial.*

Results

The effects of diode type and aerial design on detection distances

The maximum detection distances varied from less than 2 m to 13 m, depending upon diode type, position, aerial length and shape (Tables 1, 2). Transponders were always detected from further away when parallel to the radar beam rather than perpendicular to it. The aerial length allowing maximum detection distance was 12 cm for both linear or oval aerials, orientations and all types of diodes tested (Fig. 1; data for oval aerials not shown).

The Recco aerial was superior to the simple wire loop aerials (Table 1), possibly because of its larger surface area. Diodes with copper sheet aerials were always superior to the wire loop aerials of similar size and were sometimes better than wire loop aerials regardless of loop size (Devine, 1997). The 'open circuit' design (with the aerial attached to only one end of the diode) used by Mascanzoni and Wallin (1986) was detected from greater distances than the Recco design, especially when the aerials were parallel to the microwave beam (data not shown).

Diode attachment and movements of tagged animals

Each tag, consisting of a diode with an appropriately shaped aerial, was glued to the elytra of the ground beetle or to the shell of the snail (Fig. 2). We found that quick-drying adhesive (Ados1 or Uhu brand) was suitable for ground beetles whereas either

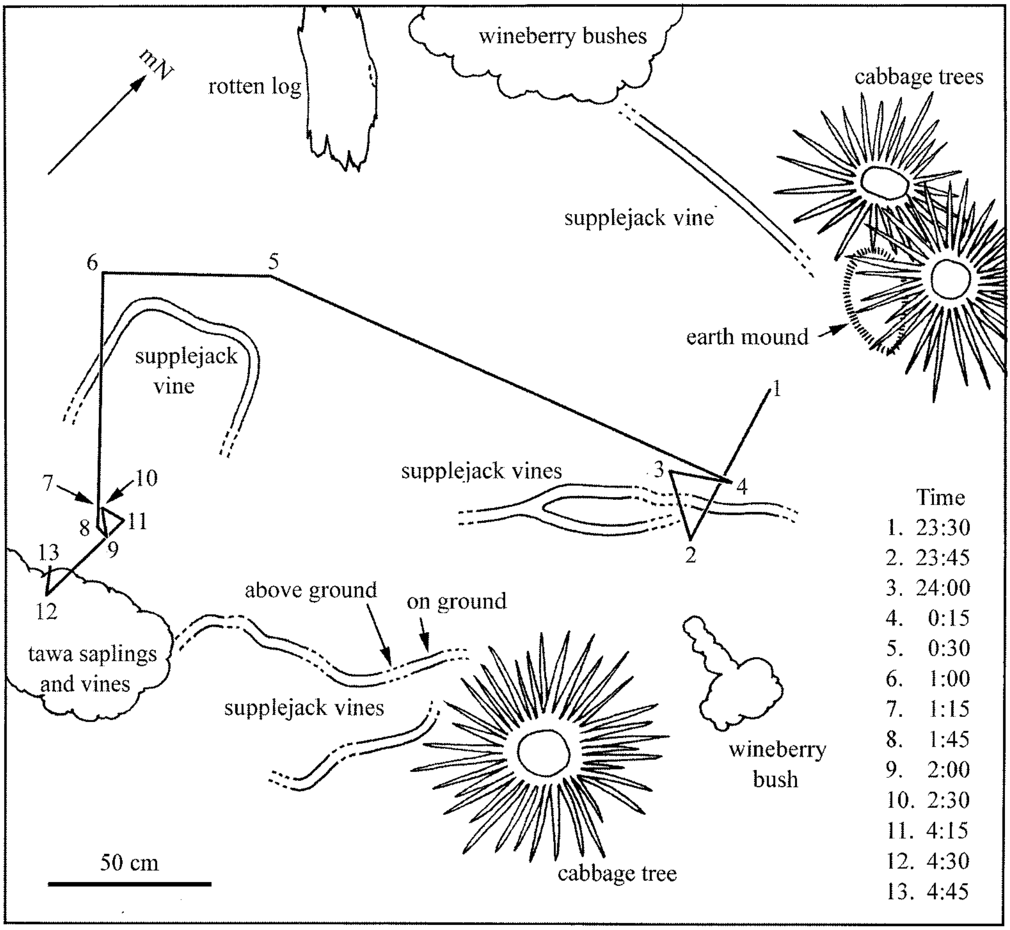

Figure 3: *Movements of a male carabid beetle,* Plocamostethus planiusculus, *in Keeble's Bush, Manawatu, North Island, New Zealand, during the night of 23-24 February 1997. The beetle was relocated every 15 min.*

5-minute Araldite or 'Liquid nails' (Selleys) were the most suitable for snails. The periostracum of the latter was lightly buffed first with fine carborundum paper to effect good attachment. Note the different shape of the aerial for the two organisms. The long aerial simply trails behind the beetle. The flat, circular copper aerial was moulded to the shape of the snail shell so that it did not impede its movement through litter.

We were able to relocate ground beetles over several one-night sessions. Typically, movement was only a few metres per night. We relocated the beetles every 15 or 30 min. No long term directional movement was detected (Fig. 3) but the beetles showed signs of 'typical' invertebrate searching behaviour. This included movement within a small area with frequent turns, followed by longer walks in straight lines.

One snail was relocated at intervals of 6-16 weeks over 30 months. It showed a tendency to occupy a localised area of ecotone between kanuka scrub (*Kunzia ericoides* (A.Rich)) and a grass clearing although it often showed periodic displacements of up to 25 m from this (Fig. 4). On one occasion another snail was relocated under a rock 25 cm thick and other snails were frequently detected under concrete slabs up to 10 cm in thickness.

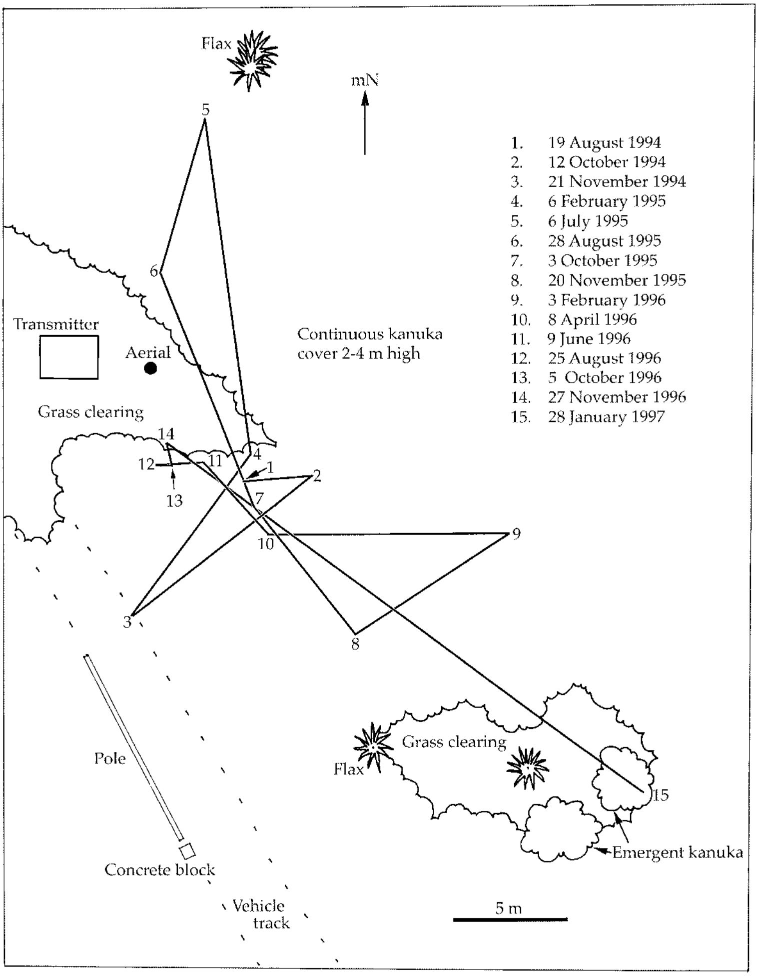

Figure 4: *Movement pattern of an individual snail,* Paryphanta busbyi watti, *over a 30 month period from August 1994 to January 1997 at Te Paki Farm Park, Northland, New Zealand.*

Discussion

We have shown that harmonic radar is suitable for conducting detailed studies of spatial behaviour over both short and long intervals providing the animals have localised ranges. It also has the advantage of allowing cryptic invertebrates to be relocated with minimal disturbance to the habitat. This was especially applicable to working with the snail *P. busby watti.* Earlier research on this depended on hand-searching through leaf-litter which caused considerable habitat disturbance, was very time-consuming and was relatively inefficient. The use of an harmonic radar unit allowed the snails to be quickly and easily relocated and habitat disturbance was minimised to less than 0.25 m^2 of forest floor around each snail.

The normal movement speed of the study organism should be considered when deciding on the time intervals between relocations. Ground beetles can move fast and far enough (up to 30 m within an hour, Wallin, 1991) to make relocation very difficult in dense forest habitats so common in New Zealand. For such organisms, relocation every 10-15 min is recommended, at least during the initial phase of the study.

Mascanzoni and Wallin (1986) found that virtually no spurious signals were generated by the harmonic radar. In contrast, we experienced a variable amount of background noise, caused by incidental metal objects such as refuse, metal fences or rubbish tins. Operator experience helped with distinguishing background noise from the transponder signal at extreme range.

Water (also humidity) attenuated the signal, and other, unexplained interference sometimes reduced the detection range to a few metres. In our experience, the clarity of the signal improved but the maximum detection distance did not change when the target was above the ground on vegetation.

The orientation of a transponder with respect to the microwave beam had a marked effect on the maximum detectable distance: when the long axis of the transponder was perpendicular to the beam, the detectable distance was much smaller. Mascanzoni and Wallin (1986) did not discuss orientation, but probably made their measurements with the transponder in the parallel position. The only diode common to both studies (the HP 2835) gave similar readings to theirs in this position only. It should be noted that Mascanzoni and Wallin (1986) used an older version of the harmonic radar unit with a different type of antenna.

It is also worth noting that some organisms may spontaneously generate false signals. When tracking ground beetles, we were misled several times by a false signal, whose origin was always a tree weta (*Hemideina crassidens* (Blanchard), Orthoptera: Stenopelmatidae).

A circular transponder was chosen for attachment to *P. busbyi watti* to avoid the low perpendicular detection distance. This circular design was not as good as long rectangular transponders measured parallel but it was consistently good from all directions. This design weighed more than the thin wire aerial. Terrestrial snails can carry up to 50 times their body weight (Croizer and Federighi, 1925, cited by Jones, 1975) but in this case the transponder weight (0.7 - 1.25 g) was approximately 10 % of body weight of the snails.

While the weight of the aerial was not significant for the carabid, the necessary length of the aerial could hamper normal movement. To minimize this, a very fine and flexible wire is preferred that can freely trail behind the beetle.

We believe that the harmonic radar can be used for tracking a wide range of invertebrates and vertebrates that are expected to undertake small-scale movements. Many such animals are in need of protection and management, but our lack of knowledge of their spatial behaviour and habitat preferences often limits the effectiveness of our actions. We suggest that harmonic radar can be fruitfully used to describe habitat use of such animals as geckoes, tuatara, weta, as well as large flightless beetles. The inability to identify the target individual is not necessarily an obstacle because we are often interested in microhabitat use, and/or direct measurements (size, body mass), so the organism has to be handled anyway. Even lighter tag designs now exist for smaller organisms that are active above ground level, so bees (Riley *et al.*, 1996), caterpillars, butterflies and parasitic flies (Roland *et al.*, 1996) can now be tagged and relocated. This extends the applicability of the method to an even wider range of organisms.

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