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Landscape-Scale Wireless Technology for Vertebrate Pest Control

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ABSTRACT: A unique wireless communications and sensor network has been developed by Encounter Solutions Ltd, New Zealand, with a specific aim of fundamentally changing the way pest control operations can be carried out. This wireless technology has the potential to open up new, safer, and more efficient and cost-effective ways of monitoring and servicing control devices. The network is designed for deployment over large areas and can operate where there is no cell phone coverage by making efficient use of satellite technology. It requires very little power to run, and complex high-power radio equipment is not needed. This makes it readily portable, with each sensor node able to operate on small inexpensive batteries for several years. With the help of Hawke's Bay Regional Council and Auckland Council, the system is presently undergoing trials at a number of New Zealand sites with promising results. Landcare Research New Zealand Ltd has been engaged to evaluate the performance, the effect on contractor behaviour, and to undertake economic analyses of the potential benefits of large-scale roll out of such wireless technology. The first large-scale installation of wireless technology is planned for the 26,000-hectare multi-agency Cape-to-City project. This multi-species predator control project is considered a world-leading programme that will focus on ultra-low-cost, large-scale predator control across productive landscapes. The project aims to restore native biodiversity, whilst at the same time delivering economic benefits to farmers through reduced risk to livestock diseases. If successful, it is anticipated that the Cape-to-City model will be expanded across hundreds of thousands of hectares of the Hawke's Bay region of New Zealand, with the wireless network being integral to this expansion.

KEY WORDS: biodiversity decline, conservation, economic analysis, New Zealand, predator control, trapping, trap network optimisation, wireless sensor networks

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THE PROBLEM Biodiversity Decline

New Zealand is recognised for its biodiversity and high proportion of endemic species. However, since human colonisation, New Zealand has suffered high rates of biodiversity decline, largely due to the effects of invasive species and habitat loss. The effects of introduced mammalian predators and browsers have been particularly severe, as New Zealand indigenous species have not evolved in the presence of these types of predators and therefore did not develop defences against predation and browsing. Indeed, many of New Zealand's plants and animals are now threatened or extinct as a result of introduced mammals and other key threats.

The Global Invasive Species Database (see: www.iucngisd.org/gist/) identifies the 100 "World's Worst Invasive Alien Species" (Lowe et al. 2000). Of the 19 vertebrates on this list, New Zealand has 13. Introduced mammalian pests threatening New Zealand indigenous species are widespread and abundant. They include brushtail possums (*Trichosurus vulpecula*), feral cats (*Felis catus*), mustelids (*Mustela spp.*), rats (*Rattus spp.*), and European hedgehogs (*Erinaceus europaeus*). Protecting biodiversity footholds against these pest species typically requires long-term and labour-intensive trapping programs, often carried out over large areas of government-managed and other conservation land tenures (Jones et al. 2015).

There are numerous biodiversity enhancement endeavours underway in New Zealand (e.g., Kavermann et al. 2012). These are carried out all over the country on Department of Conservation land, on covenanted land under the Queen Elizabeth II National Trust, and many other initiatives. However, these biodiversity footholds are often only relatively small areas or fragments.

Most of New Zealand's land mass is privately owned and used for primary production. Furthermore, these landscapes can support significant populations of introduced mammalian pests. If the pests in these landscapes are not able to be adequately managed, then the footholds of biodiversity within them are unlikely to be able to provide New Zealand with significant long-term biodiversity restoration success.

Human Health

In addition to be instrumental to the cause of New Zealand's biodiversity decline, these invasive mammalian pests also carry diseases that are a risk to human health, particularly toxoplasmosis and bovine TB.

Toxoplasmosis is a common parasitic disease caused by exposure to the *Toxoplasma gondii* parasite, which completes its life cycle in cats. Studies indicate that about 40% of New Zealanders are infected with toxoplasmosis at some time in their lives, and they also suggest an increased incidence of chronic toxoplasmosis in rural New Zealand areas (Zarkovic et al. 2007). Unfortunately,

it is not widely appreciated that for many, acute toxoplasmosis is a moderately disabling illness with relatively severe and sometimes prolonged neuropsychiatric effects (Wong et al. 2013). Although the clinical signs can be mild, risk groups, such as pregnant women and patients with compromised immune systems, can suffer very serious side-effects. Research indicates that toxoplasma infection may influence human personality, leading to risk-taking or the initiation of more severe forms of schizophrenia. Studies also link toxoplasma infection to delayed reaction times and an increased probability of traffic accidents in infected subjects (Webster et al. 2013). Latent toxoplasmosis is also associated with immunosuppression (Flegr 2013).

Bovine Tb is much less common in humans than toxoplasmosis but is still considered a risk. *Mycobacterium bovis*, the bacterium that causes bovine Tb, is usually transmitted to humans via infected milk. Although New Zealand has a significant dairy industry, human cases are rare, thanks to pasteurisation and testing programmes.

Economic Well-Being

Both toxoplasmosis and bovine Tb impose significant economic costs on New Zealand. A considerable amount is spent controlling bovine Tb in New Zealand each year. Sheep serve as an intermediate host of toxoplasma, and toxoplasmosis is the second-most-common cause of abortion in sheep and a significant cost to that industry. It may also be a very significant cost to the health of rural communities, but that is less well understood.

The economic costs of a continuing decline in New Zealand's native biodiversity are difficult to quantify. In 2009 the Ministry of Agriculture and Forestry estimated the total economic cost of pests to New Zealand's primary sector to be potentially as high as NZ\$3.3 billion (MAF 2009). This cost estimate is likely to be understated, because it does not allow for losses to indigenous biodiversity, and would likely rise significantly as the pest threat to New Zealand increased.

Social and Cultural Impacts

There are clear social and cultural losses from the continuing decline of biodiversity. For iwi, the very essence of the Māori world view is relationships – not only between people, but also between the spiritual world and the natural world. Relationships extend from the deities to whānau, to hapū, to iwi, to fauna and to flora. There is a strong belief in the inter-relationship of all living things to each other. As a result, Maori well-being is directly linked to the health of the environment. This world view is compromised in an environment of impoverished biodiversity. However, bringing Maori back into connection with a healthy environment will have significant social and economic benefits.

Many New Zealanders have little regular contact or experience with our native natural heritage. This is true for those living in an urban (or peri-urban) environments, as well as for those in rural areas where many native species are uncommon. This can be viewed as a loss in and of itself. However, it also is a huge practical impediment to biodiversity restoration. People protect

what they care about, and it is difficult to care for something you know little or nothing about. The success of conservation in New Zealand is dependent on community engagement, active participation, and buy-in. It must therefore be a priority to build bridges across this void, providing opportunities for communities and the general public to interact with and care for the natural environment.

WHAT IS REQUIRED

As stated above, managing small islands of biodiversity in an increasingly crowded sea of weed and animal pests is unlikely to provide New Zealand with significant long-term biodiversity restoration success. What is required is that we integrate large-scale biodiversity restoration projects into business as usual primary production landscapes in ways that deliver economic and environmental outcomes to landowners. This, combined with appropriately targeted intensive high-biodiversity-value site protection, gives us the greatest likelihood of significant long-term integrated biodiversity recovery and primary production benefits across New Zealand.

CAPE TO CITY PROJECT

The Cape to City is a five-year project designed to provide a transferable model that is potentially part of a credible pathway to the vision of a predator-free New Zealand. It aims to show how pest management and community engagement can deliver more integrated economic and environmental outcomes across both private and Crown-managed land.

The vision of Cape to City is to see native species thrive where we live, work, and play, at large scales on our agricultural primary productive landscape. It plans to achieve this vision through transformational change in pest management, research, and community engagement in ecological restoration initiatives within the Hawke's Bay.

A Project Template That Can Be Applied Very Large-scale

Cape to City is a collaborative landscape scale project, covering 26,000 hectare (100 square miles) of land with a variety of land uses. It builds on the success and learnings of a complementary project called Poutiri Ao ō Tāne, an 8,000-hectare (31 square mile) ecological restoration project located 50 kilometres (31 miles) north of Napier City.

Cape to City has three principle objectives:

- 1) Trial large-scale, low cost predator (possums, stoats, ferrets, and feral cats) control techniques for biodiversity and economic enhancement within an agricultural landscape in Hawke's Bay. The intention is to deliver a template for wide-scale predator control that can be incrementally rolled out across the region and New Zealand.
- 2) Act as a regional project that, in conjunction with the Regional Biodiversity Strategy, will drive a long-term positive step change in regional biodiversity profile, funding, community engagement, and conservation outcomes.

- 3) To leverage the native species and research success of privately-owned Cape Sanctuary to deliver significant conservation outcomes within the project area through rare and threatened species outflow into the backyards of major urban areas.

Cape to City plans to achieve these objectives through research, habitat protection, pest control, species reintroductions, community engagement and education, and strong governance and project management.

Partnership

Cape to City is a partnership between the Hawke's Bay Regional Council, Department of Conservation, Cape Sanctuary, Landcare Research, and various land-owners and businesses. Local farmers are critical to the success of the project, as are Maori. Maori engagement is anticipated across a range of levels throughout the project duration. The partnership with Landcare Research provides the project with scientific credibility, measured outcomes, and access to other academic organisations. The project is also very fortunate to have secured funding from the Aotearoa Foundation, a philanthropic trust of Julian Robertson.

A key project deliverable is transformational change in predator pest management to allow very low cost integrated predator pest control across primary production landscapes. The intention is to build on the success within Hawke's Bay of the large-scale suppression of possums across 900,000 hectares (3,475 square miles) of rateable land by integrating control of additional predator pests into this existing successful possum control programme.

Transformational Change

Delivering the project objectives will require much more than business as usual. A number of innovative levers are being tested to drive the transformational change including:

- Wireless trapping technology for predator pest control in farmland;
- Motion-sensitive cameras for monitoring predator pest populations;
- Toxoplasmosis disease research to see if the large-scale reduction of feral cats can potentially reduce the incidence of this disease for the sheep farming community; and
- Linking the innovative predator control template to the Hawke's Bay Regional Pest Management Plan to ensure it is sustainable long term for the farming community.

REMOTE WIRELESS MONITORING OF TRAPS

Background

Over recent years, there has been an increasing number of vertebrate pest control programmes using permanent networks of traps to maintain pest numbers at low levels, and in parallel, a growing interest in the potential of wireless systems for remote monitoring of these networks to minimise the time and cost associated with checking traps.

The Hawke's Bay Regional Council contracted Landcare Research to review the potential and economics

of using such wireless technology for monitoring a kill-trap network.

Methodology

Landcare Research's wireless technology review covered a number of issues. These include historical and currently available wireless sensor networks (WSN), transmission frequency used, network configurations, node capability, and the method of transmission of data from the network to the "office." The study also investigated the use of WSNs for monitoring both live- and kill-trap scenarios.

The work of Jones et al. (2015) was used to assess the potential operational cost savings from using a WSN for monitoring live-capture traps. This work used a simple deterministic spreadsheet model, informed by mean monthly trap-rates from a predator trapping programme in the South Island of New Zealand.

Similarly, a simple spreadsheet deterministic economic model was developed to assess the economics of using a WSN for monitoring kill-trap scenarios. The input parameters for the model were based on the kill-trap network established for the *Poutiri Ao O Tane* predator control programme.

Findings

The key findings from Landcare Research's review and economic analysis of using WSNs for monitoring trapping programs are summarised in bullet point form below:

- A range of commercially available wireless sensor network (WSN) systems is available, with most running on 2.4 GHz frequency.
- A high frequency, such as 2.4 GHz, has limited range in undulating topography and through dense vegetation.
- The lower frequency of 160 MHz, like 2.4 GHz, is freely available if used below a specified power output, but because of its greater range across undulating topography and through dense vegetation, it is more suitable for use in hub-and-spoke network configurations.
- There are two main types of network configurations: 1) mesh-networks (including lines or chain configurations), and 2) hub-and-spoke networks.
- When selecting a WSN, node capability, transmission frequency, method for uploading data from the network, and network configuration need to be taken into account.
- There are three main reasons for checking traps: 1) legal requirements, 2) trap saturation, and 3) bait replacement. Each of these factors will impact on the benefit-to-cost ratio of using a WSN.
- For both live- and kill-trap networks, significant benefit-to-cost ratios can be obtained, but these depend particularly on the price of the technology but also on other parameter values used.
- If it is too expensive to monitor every trap in a network, a subset of traps could be monitored to assess when the proportion of traps sprung has met a pre-determined trigger level. The number of traps monitored depends on the precision required, but is

likely to be 200-250 traps for a network of 500 or more traps.

Conclusions

- The integration of WSN into large-scale permanent trap networks has the potential to deliver significant savings through the reduction in trap checking time.
- Economic models of both live-trap and kill-trap systems show that WSN monitoring can result in positive and significant benefit-to-cost ratios, with the correct mix of factors.
- The extent of the savings when using WSNs will depend on the scale of the networks (the larger the network, the larger the benefits), the availability of long-life bait (the longer the bait life the greater the benefits), and the capture rate (the lower the capture rate and time for traps to fill, the greater the benefit).
- Additional benefits will accrue if volunteers (farmers/community groups) are used for checking sprung traps.
- If long-life baits become available, ideally every trap would be monitored, so a responder (trap checker) would have to check only those traps that have sprung.
- If, because of cost, only a subset of traps can be monitored to determine when to check the whole trap network, about 250 traps need to be monitored (number will depend on precision required). However, as the trap network increases in size, the benefit-to-cost ratio will increase when using this number of monitored traps.

WIRELESS TRAP MONITORING TRIALS

Requirements

A key objective of the Cape-to-City project is to deliver transformational change in predator pest management. One of the innovative levers being tested to achieve this is the use of wireless trapping technology across large areas of farmland. As part of the Cape-to-City project, Hawke's Bay Regional Council intends to use WSN technology to monitor a network of approximately 2,500 traps across the 26,000-hectare (100-square mile) project footprint.

The Cape-to-City project landscape predominantly comprises undulating to steep farmland topography dissected by numerous streams and incised gullies, but also includes sandy beaches and numerous coastal cliff features. The elevation over the project ranges from sea level to around 400 meters (1,300 feet) elevation at Te Mata Peak.

Selecting the correct WSN technology solution to deploy over this size area of challenging topography necessitates careful consideration. To be practical, the communication system should be able to deliver not only long-range, but also non-line-of-sight performance and under a variety of climatic conditions. The sensor nodes need to be robust enough to withstand typical business as usual farming practices as well as regular disturbance by inquisitive cattle, sheep, and other animals. The network must be easy and simple to deploy, as well as simple to operate, in order to enable a range of different user and

age groups to use it effectively. Additionally, it needs to be cost effective so that it can be used at scale.

Celium

After evaluating potential WSN options, Hawke's Bay Regional Council elected to trial wireless technology (Celium®) developed by Encounter Solutions Ltd, an Auckland-based New Zealand company.

Celium is optimised to operate at 160-MHz in New Zealand and in the Multi-Use Radio Service channels (151-154-MHz) in the United States. Alternative low-power coded wideband or spread spectrum-based networks typically operate in higher spectrum ranges above 800-MHz or the 2.4-GHz band. Celium uses narrowband technology that provides very efficient low data rate communications. The combination of narrowband technology and a relatively low operating frequency means the network can provide effective long-range low data rate communications in undulating topography, through dense vegetation and in a range of climatic conditions.

Other factors influencing Hawke's Bay Regional Council's decision to use this particular WSN technology were its low power requirements, portability, simple installation, and the ability of the sensor nodes to perform a variety of functions.

Trials

A key objective of the wireless trials is to assess the capability of the selected WSN to deliver acceptable communications performance across a range of topographic conditions and environments. A second objective is to explore ways that a range of different users, including farmers, landowners, and restoration groups might use the technology, as well as establishing effective ways of notifying them that the traps had been activated.

Initial small-scale trials in the Hawke's Bay region began in March 2015 at the Poutiri Ao ō Tāne project and involved both live-capture and kill-trap scenarios serviced by Council personnel. Hawke's Bay Regional Council considered these trials a success and moved on to commence more extensive second-stage trials of the system in September 2015.

The second-stage trials comprised setting up eight networks of relatively small numbers (around 20 each) of instrumented kill-traps within the Hawke's Bay region. These networks encompassed steep productive farmland topography, forested areas, lakes, and wetland areas, and in many instances the traps were placed in locations accessible by inquisitive cattle. Although deployed using Hawke's Bay Regional Council personnel, generally the servicing of the trap of the networks has been undertaken by the participating farmers, landowners, and restoration groups.

All installations were deployed in star (hub-and-spoke) network configurations. Each hub was set up to on-forward all messages via the Iridium satellite network.

Instrumented traps were placed on the ground at distances of up to 6 km (3.7 miles) away from hub sites, with a median distance from their respective hubs of approximately 1.6 km (1 mile).

A number of the trap deployments were positioned

successfully with non-line-of-sight conditions between the nodes and hubs. Detailed analysis of the number, range, and path profiles for these deployments has yet to be carried out. One successful non-line-of-sight communication test was carried out at a location some of 17.5 km (11 miles) away from a hub site near the Mohaka River.

Systematic evaluation of maximum ranges was not able to be undertaken for each site. This was largely due to resource constraints and in part due to topographical and access challenges. However, successful line-of-sight communication tests were carried out at ground level on the coast at over 50 km (31 miles) from the hub site positioned on the Mahia Peninsula. In addition, a line-of-sight communication test was carried out with the same hub across a range of around 108 km (67 miles) from the top of Te Mata Peak in the footprint of the Cape to City project. This test was carried out in fine weather using the same Celium sensor node used on the traps, without any modification or performance enhancements. Although the node used for this test indicated the measured signal strength was marginal, and thus not suitable for a working trap deployment, the ability to communicate over this range at such low power is worth noting.

For the purpose of the trials, all Celium nodes were set up to provide scheduled supervision messages typically every 12 hours. Trap trigger and trap reset event messages, as well as node power-up messages were sent as soon as possible after the relevant event. A feature of the trap-node setup adopted for the trials was that a number of messages were sent as a result of stock disturbing the traps. An interesting aside about this point is that it was possible to determine when stock were 'harassing' the traps and send out alerts if desired.

Since the start of the trials and up to the time of writing, the Celium installations operating within the Hawke's Bay region transmitted over 36,000 messages associated with the trapping networks. In the process of doing so, communications between the hubs and nodes traversed nearly 110,000 km (68,351 miles) across relatively remote and rural landscapes.

At the time of writing, the wireless trials with Hawke's Bay Regional Council are still in progress. Much of the equipment is being brought in from the field to be redeployed in live-capture trapping operations over the Cape to City footprint commencing in April 2016.

Broad Findings

The performance results to date from the Celium wireless trap monitoring field trials demonstrates that it is technically feasible to use wireless sensor networks to monitor trapping programs over large areas and in challenging topography. This can be achieved without the need for specialist radio communications input, and the networks can generally be installed and made operational in a relatively short period of time, with minimal training.

As mentioned earlier in this paper, the success of conservation in New Zealand is dependent on community engagement, active participation, and buy-in. Thus, a very encouraging outcome of the wireless field trials to date is the generally high level of enthusiasm and engagement observed from a wide cross-section of stakeholders. This has also been observed with stakeholders

associated with Celium installations in other regions of New Zealand.

CONCLUSIONS

New Zealand's current predator pest management models are not able to deliver significant long-term biodiversity restoration success. New Zealand requires an integrated solution involving large-scale biodiversity restoration projects incorporated into business as usual primary production landscapes. However, this needs to be done with community engagement and in ways that deliver economic and environmental outcomes to land-owners. The Cape to City project is designed to provide the template necessary to enable this transformational change. Wireless trap monitoring technology, along with other innovations, will most likely play a critical role in this new model. Field trials and economic modelling indicate that it is both technically and economically feasible to use wireless sensor networks to monitor trapping programs over large areas.

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