

Final Report: USFS 20-DG-11052021-227

Improving Coconut Rhinoceros Beetle Breeding Site Detection Using Harmonic Radar

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<https://github.com/aubreymoore/Harmonic-Radar/raw/master/final-report-202212/final-report-202212.pdf>

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1. Using Harmonic Radar to Detect CRB Breeding Sites

Effective control of CRB requires location and destruction of larval breeding sites which may occur anywhere where there is an accumulation of decaying plant material. Previously, we successfully tracked radio-tagged CRB adults to find cryptic breeding sites [1]. But high cost of radio transmitters (about \$200 each) and limited battery capacity make this method too expensive for regular use.

We suggest that harmonic radar tags may be a cost-effective replacement for miniaturized radio transmitters. Harmonic radar tags do not require a battery, are very inexpensive (about \$4 per tag) and have unlimited shelf and field life.

US Forest Service funded a field test of this idea based on a small grant proposal attached as Appendix A. We also published the idea as a journal article [2] attached as Appendix B.

2. Field Test

In July 2022, Dr. Matt Siderhurst, from Eastern Mennonite University, Virginia and two of his students, Skylar List and Theodore Yoder, travelled to Guam to collaborate with us on Guam to field test the idea of tracking beetles with miniature harmonic radar tags attached to them. We were also assisted by Michael Jordan, US Forest Service and my technician, Christian Cayanan.

We used an Open Science Framework (OSF) project [3] to document this field trial. The following subsections summarize what we did and what we learned. Further details are available in the OSF project at <https://osf.io/esnc7/>.

2.1. Materials and Methods

Harmonic radar tags We fabricated dipole harmonic radar tags by attaching antennae to Schottky diodes (RECCO AB, Lidingö, Sweden). Two 8 cm lengths of super-elastic nitinol wire (0.076 mm diameter, McMaster-Carr, Aurora, OH, USA) were attached to each diode with UV-activated adhesive (Bondic, Niagara Falls, NY, USA), so that each wire touched one of the diode contacts while avoiding the opposite diode contact and the other wire. Electrical connections between the wires and diode contacts were secured using conductive silver paint (GC Electronics, Rockford, IL, USA). Radar tags were glued to the top of the pronotum of each test beetle using UV-activated adhesive.

Insects CRB adults were collected from pheromone traps at the Leo Palace Resort on July 5 2023. These insects were held in moist coir (Burpee Seed Starting Mix) and were fed banana slices.

Tagged insect releases About an hour before sunset at release sites, tagged beetles were placed in a 10 cm deep layer of damp coir at the bottom of a large plastic garbage container. Most beetles readily flew out of the container within an hour after sunset. Early the next morning, beetles remaining in the coir were counted.

A total of 27 tagged beetles were released at the University of Guam Yigo Experiment Station on July 7 and 11 and 39 beetles were released in Yona on July 12.

Search for tagged insects During days following tagged beetle releases, we performed surveys using three hand-held harmonic radar devices (RECCO AB, Lidingö, Sweden) designed for finding avalanche victims. Searchers monitored audio output from the radar devices using headphones and recorded their search paths using a smart phone app (SW Maps).

Surveys were conducted at Yigo on July 8, 12 and 15 and at Yona on July 13 and 15.

2.2. Results and Discussion

About two-thirds of the tagged beetles flew out of the large plastic garbage containers at release sites (Table 1). However, no tagged beetles were detected during 5 harmonic radar surveys conducted following release.

Table 1: Numbers of beetles which flew out of and remained in large garbage containers at release sites.

site	date	total	flew	did not fly
Yigo	July 7	32	12	20
Yigo	July 11	30	19	11
Yona	July 12	39	33	5
		101	64	36

Failure analysis Examination of beetles which failed to fly out of the large garbage containers at release sites showed a problem with attachment of antennae to the diodes. Sixty-one percent (22 of the 36) beetles which did not fly had damaged tags: 22 had one or more detached antenna wires and one had a detached diode (Table 2).

We suspect that we failed to detect any tagged beetles because the silver conductive paint and UV-cured glue did not create a physical bond strong enough for this application. Electrical connectivity may also be a problem.

We are attempting to solve this technical problem by attaching antennae wires by soldering them to diodes under a microscope. We purchased precision soldering equipment for this. However, our first attempt failed. Getting solder to "wet" nitinol wire, made from an alloy of nickel and tin, is difficult because of oxides on the surface of the wire need to be removed. We have ordered a special soldering kit specifically designed for nitinol and will give this a try when it arrives.

Table 2: Status of harmonic radar tags attached to beetles remaining in release containers.

site	date	total	wire(s) detached	diode detached
Yigo	July 7	20	6	0
Yigo	July 11	11	11	1
Yona	July 12	5	5	0
		36	22	1

3. Ancillary experiments

3.1. Expt. 1: Maximum detection distances for each of the 3 RECCO transceivers we used

Please see Jupyter notebook in Appendix [D](#).

3.2. Expt. 2: Maximum detection distances for single and double tagged CRB

Please see Jupyter notebook in Appendix [E](#).

3.3. Expt. 3: Attenuation of maximum detection distances when targets are buried in coir

Please see Jupyter notebook in Appendix F.

4. References

- [1] Aubrey Moore et al. “Judas Beetles: Discovering Cryptic Breeding Sites by Radio-Tracking Coconut Rhinoceros Beetles, *Oryctes* *Rhinoceros* (Coleoptera: Scarabaeidae)”. In: *Journal of Environmental Entomology* 46.1 (2017), pp. 92–99. DOI: [10.1093/ee/nvw152](https://doi.org/10.1093/ee/nvw152).
- [2] Aubrey Moore and Matthew Siderhurst. “Proposal for Detecting Coconut Rhinoceros Beetle Breeding Sites Using Harmonic Radar”. In: *Research Ideas and Outcomes* 8 (Oct. 27, 2022), e86422. ISSN: 2367-7163. DOI: [10.3897/rio.8.e86422](https://doi.org/10.3897/rio.8.e86422). URL: <https://riojournal.com/article/86422/> (visited on 01/03/2023).
- [3] Aubrey Moore et al. *CRB Harmonic Radar*. Mar. 2023. URL: <https://osf.io/esnc7>.

Appendices

Appendix A Grant Proposal

Please see next page.

Improving Coconut Rhinoceros Beetle Breeding Site Detection Using Harmonic Radar

Funding proposal to US Forest Service, Pacific Southwest Region

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May 6, 2020

Overview

The coconut rhinoceros beetle, *Oryctes rhinoceros* L., is a serious pest of coconut and other palms throughout Southeast Asia and on several Pacific Islands including Hawaii, Guam, Rota and the Palau Islands. One of the major hurdles for eradication and control of CRB is the location of cryptic breeding sites. Location and destruction of all CRB breeding sites is essential for eradication, but this has been achieved only once, on the very small (36 km^2) Niuatoputapu Island (Catley 1969). While searching for cryptic breeding sites can be conducted by both humans and dogs, these search methods have drawbacks. Supported by a previous US Forest Service grant, we successfully developed a third detection method for cryptic CRB breeding sites using radio-tagged CRB (a so-called "Judas beetle" technique). However, there are both financial and operational issues with radio-tracking: radio tags are expensive and have both limited field- and shelf-life. Harmonic radar (HR) is a cheaper and longer lasting alternative to radio-tracking. HR uses cheaper tags that have a near infinite operational lifetime but have a shorter range and more limited available tracking frequencies. We have recently been successful in using harmonic radar to track the spotted lanternfly, *Lycorma delicatula*, and are eager to employ this technology to locate cryptic CRB breeding sites. We propose to develop a HR radar tag based CRB tracking system to provide a more cost-effective method for finding cryptic breeding sites, therefore providing a needed tool for CRB eradication and control. Our idea is to tag and release adult CRB. We will then attempt to locate the end points for these tags, rather than to track CRB movement. Our hypothesis is that the tags will accumulate at breeding sites. We expect that tags will be locatable even months after beetle releases.

We request funding support to do a feasibility study of HR on Guam, similar to the CRB radio tracking study we did a few years ago (Moore et al. 2017). If HR successfully locates CRB breeding sites, this technology could become important to development of effective early detection and rapid response (EDRR) for CRB: HR equipment and tags could be quickly deployed to newly invaded islands to help detect active and potential breeding sites.

Background

Oryctes rhinoceros (Linnaeus 1758) (Coleoptera: Scarabaeidae: Dynastinae), commonly known as the coconut rhinoceros beetle (CRB), is endemic to the tropical Asia region (including South East Asia). CRB adults damage both coconut and oil palm, and can sometimes kill palms when they bore into crowns to feed on sap (Bedford 2013). In contrast to adults, CRB grubs cause no economic damage, as they feed on decaying vegetation at breeding sites, which include dead standing coconut palms, fallen coconut logs, rotting coconut stumps, and decaying wood of many tree species (Bedford 1976, 2013). Breeding sites are also found in piles of compost, sawdust, and manure where these materials are available.

CRB was inadvertently introduced into the Pacific in 1909 when infested rubber tree plants were transported to Samoa from Sri Lanka (previously known as Ceylon) (Catley 1969). The pest rapidly multiplied in Samoa and subsequently spread to several nearby Polynesian islands. Separate invasions further distributed CRB through Palau, parts of Papua New Guinea, and other Pacific nations through disruptions and uncontrolled movements during World War II

(Gressitt 1953, Catley 1969). The invasive phase of the beetle was brought under control by the discovery and distribution of a viral biocontrol agent, *Oryctes rhinoceros* nudivirus (OrNV). OrNV is currently present and causes persistent population suppression on many of the CRB infested Pacific Islands (Huger 2005, Bedford 2013).

Detection of CRB on Guam in 2007 (Smith and Moore 2008) heralded a second wave of Pacific island invasions by this pest. Following a failed eradication attempt, it was discovered that the Guam beetles are an OrNV resistant form which is being referred to as the CRB-G biotype (Marshall et al. 2017).

Eradication of coconut rhinoceros beetles from an island is difficult once this pest has become established. On two islands in Fiji, mass trapping using the now superseded synthetic attractant ethyl chrysanthemate coupled with sanitation from 1971 through 1974 failed to eradicate coconut rhinoceros beetles (Bedford 1980). The only proven tactic for eradication is a vigorous sanitation program that discovers and destroys all active and potential breeding sites. The single successful coconut rhinoceros beetle eradication to date was accomplished during the 1920s on the tiny (36 km^2) Niuatopapu Island (also known as Keppel Island), which lies between Samoa and Tonga, using sanitation alone (Catley 1969, Bedford 1976). Given the importance of finding and destroying breeding sites for the success of coconut rhinoceros beetle eradication and control programs and the inherent difficulty of locating breeding sites, which are often cryptic and are found in a wide range of locations (Hinckley 1973, Bedford 1976), there is a pressing need to develop detection methods to reliably find these sites.

To date, three techniques have been used to locate active and potential CRB breeding sites: visual search by humans, search by humans with the assistance of detector dogs, and search by humans radio-tracking CRB carrying miniature transmitters. Unaided human searches can identify both active and potential breeding sites but are inefficient compared to other techniques. Detector dogs trained to smell CRB breeding sites can be more efficient but are more expensive and are limited to ground searches potentially missing arboreal breeding sites (Moore et al. 2015). Radio-tracking has the potential to discover cryptic breeding sites on both the ground and in trees using the so-called Judas technique. Our previous work with CRB radio-tracking (Moore et al. 2017) was performed at two locations on Guam (Fig. 1). We released radio-tagged adults to discover cryptic breeding sites, for potential coconut rhinoceros beetle control. Of 33 radio-tagged beetles that were released, 19 were successfully tracked to landing sites, 11 of which were considered to be active or potential breeding sites, in five different microhabitats. The remaining 14 beetles were lost when they flew beyond the range of receivers. Only one of the radio-tagged beetles was caught in the numerous pheromone traps present at the release sites. Radio-tracking coconut rhinoceros beetles in this way showed promise as a method to identify cryptic breeding sites, which could then be treated, removed, or destroyed.

While radio-tracking allowed the detection of cryptic breeding sites there remain both financial and operational issues with broader implementation of this detection technique: radio tags are expensive (\$120-\$300/tag) and radio tags have limited field- and shelf-life (several weeks and several months respectively). A cheaper and longer lasting alternative to radio-tracking is harmonic radar, which uses cheaper tags (\$3 diode + \$1 in wire and adhesive). These tags have a near infinite operational lifetime but have a shorter range and more limited available tracking frequencies.

Vertical-looking radar has been used to track flying insects since the 1970s. Unfortunately, reflections from the ground and vegetation (clutter) prevent use of conventional radar for observing low-flying, crawling or burrowing insects. However, HR can be used for this

application (Riley et al. 1996). Use of HR requires target insects to be “tagged” with a device (a ‘chip’) designed to re-radiate a harmonic of the radar signal which can be detected against even strong radar clutter. The re-radiated energy is detected by a circuit in the transceiver tuned to a harmonic of the outgoing radar frequency. The energy to operate the tag is delivered by the illuminating radar, so no on-board battery is required and extreme miniaturization is therefore possible.

Harmonic radar has been applied for tracking insects for several decades using custom built equipment (Mascanzoni and Wallin 1986, Riley et al. 1996, O’Neal et al. 2004, Kissling et al. 2014). In recent years, harmonic radar has been developed commercially for finding avalanche victims, resulting in availability of prebuilt equipment (<https://recco.com/>) which can be repurposed for tracking insects (O’Neal et al. 2004, Milanesio et al. 2016, Maggiora et al. 2019).

Dr. Siderhurst and his students along with colleagues from USDA APHIS have recently been successful in using harmonic radar to track the spotted lanternfly (SLF), *Lycorma delicatula*, in eastern Pennsylvania (Fig. 2). SLF is a much smaller insect than CRB and was able to carry diode tags quite easily. Released tagged SLF were tracked to both locations on the ground and in trees near the release site.

We are eager to employ our previous experiences with both CRB tracking and harmonic radar to locate cryptic CRB breeding sites. We propose to develop a harmonic radar tag based CRB tracking system to provide a more cost-effective method for finding cryptic breeding sites, therefore providing a needed tool for CRB eradication and control.

Methodology

TAG FABRICATION: HR diodes will be purchased from RECCO Technology (Lidingö, Sweden). Tag fabrication will be carried out at Eastern Mennonite University (EMU). In brief, several different types of wire and adhesives/contacts will be tested to maximize tag robustness and range. Previously produced SLF HR tags needed to be lighter weight than for CRB so we are cautiously optimistic about improving the performance of the HR tags.

INSECTS: CRB to be used for tracking will be wild-caught from barrel traps containing oryctalure and collected within one week of capture. These beetles will be placed in tubs containing moist peat moss, fed fresh banana slices, and allowed to rest for at least three days.

Only flight-capable CRB will be selected for tagging and release (Moore et al. 2017). Flight-capable beetles will be marked with a unique four-digit identification number engraved on one elytrum using a laser engraver. The ID number, sex, mass, and elytral dimensions of each beetle will be recorded before release. HR tags will be affixed to the pronotum of each beetle using an adhesive.

RELEASE SITES: HR tagged CRB will be released at two locations on Guam: the War in the Pacific National Historical Park in Asan (13.465972° N, 144.710944° E, Figure 1A) and the University of Guam Agricultural Research Station in Yigo (13.532444° N, 144.873333° E, Figure 1B). Asan Beach National Park is roughly triangular with the ocean bordering one side, coastal wetlands on another, and forested hillside on the third. The park itself is a large, open, grassy field and includes coconut palms on the edges, many of which displayed routine CRB damage. The anticipated release site (144.708537° E, 13.473904° N) is at the middle of a large, grassy

field. The Yigo site is an inland agricultural experiment station farm bordered by residential areas and uncultivated forest areas that include coconut palms along with many other trees. Again, many of the coconut palms on the station show routine signs of CRB damage. The anticipated release site (144.872750° E, 13.531333° N) is in the middle of an uncultivated field. Thus, both sites feature relatively accessible terrain that provides a variety of potential breeding sites as well as adult food sources.

TRACKING: We will not be tracking beetles in real time. Instead, we will be releasing CRB with attached HR diode tags and after a period of time (initially several days) we will determine where tagged CRB are aggregating. Presumably, CRB will be aggregate at two types of locations, feeding and breeding sites. All HR tags will be on the same frequency, which means that multiple tagged CRB at a location will act to amplify the signal. We will generally follow tracking techniques previously described in Moore et al. (2017).

DATA RECORDING: All release sites and discovery sites (where CRB are found) will be marked with GPS. Where possible, CRB will be recovered to determine the release number engraved on the beetle. Mapping of release and discovery points will be carried out using ArcGIS.

Schedule of Activities (2020)

March-April: Tag fabrication and testing at EMU.

April-early May: Capture, flight test, and mark CRB at UoG.

May: Conduct field releases and tracking on tagged CRB (two week intensive fieldwork period).

June-August: Data analysis.

August-December: Manuscript(s) and final report preparation. Discuss findings with state agencies. Make presentations at scientific meetings. Plan further research with cooperators to implement findings in monitoring and control efforts.

Description of Deliverable Products

We expect to demonstrate the feasibility of detecting cryptic CRB breeding sites using harmonic radar tagged beetles. Results will be disseminated to action agencies and the scientific community through journal articles, conference presentations and personal contacts to ensure further development of the technology for detection and control applications.

We intend to write a detailed protocol for CRB tracking using harmonic radar to describe preparation of beetles, tags, equipment operation, and data recording.

Two harmonic radar transceivers and assembled tags will be kept at the University of Guam for use in subsequent research and/or rapid response projects within Micronesia and the greater Pacific.

Personnel and Partners

Dr. Aubrey Moore: Professor of Entomology at University of Guam. Dr. Moore has over 30 year's experience in working on invasive species in the Pacific. His current research is focussed on finding solutions to problems caused by coconut rhinoceros beetle, biotype G.

Dr. Matthew Siderhurst: Professor of Chemistry at Eastern Mennonite University. Dr. Siderhurst has over 15 years' experience working on invasive insects in the Pacific and Australia. His research focuses on insect chemical ecology, natural products structural determination and synthesis. Dr. Siderhurst is involved in several ongoing insect tracking projects using both radiotelemetry and harmonic radar. Tracking projects have included work with Coleoptera, Lepidoptera, Diptera, and Hemiptera.

Drs. Moore and Siderhurst have collaborated on CRB projects for almost 10 years. Their previous radio-tracking work successfully demonstrated the feasibility of using the Judas beetle technique to find cryptic CRB breeding sites (Moore et al., 2017).

If this proposal is funded, others working on CRB on Guam and elsewhere in the Pacific will be invited to participate in the project.

Budget

UoG and EMU will be providing (in-kind) nearly half of the cost for this proposed project, including salaries, partial supplies, equipment and local travel. UoG will provide the lab space and logistical support for the tracking work in Guam. EMU will provide the lab space and equipment for tag fabrication and one of the HR transceivers needed for the research. The requested \$20,000 will be used for some supplies, two additional HR transceivers, and travel. Travel costs include flights from VA to Guam (~\$2,500 x 3), hotel accommodations (~\$100/day x 14 days x 2), and meals (~\$50/day x 14 days x 3).

		Requested	UoG (matching)	EMU (matching)
Personnel	Scientists, students	-	\$5,000	\$5,000
Supplies	Diodes and wire for tags, field supplies	\$2,000	\$1,000	\$1,000
Equipment	RECCO receivers/transmitters (two transmitters will be purchased and EMU currently has one)	\$6,000	-	\$3,000
Travel	Flights for 3 from VA to Guam, hotel accommodations, and meals (UoG will provide local transport)	\$12,000	\$1,000	-
Admin. fee	15% of above direct costs charged by RCUOG as administrative fee	\$3,000	_____	_____
		\$23,000	\$7,000	\$9,000

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Figures



Figure 1. A radio-tagged CRB (left) before release. A successfully located CRB in soil (right). A tracking crew from USDA ARS and Eastern Mennonite University (inset).



Figure 2. Spotted lanternfly with attached harmonic radar diode tag (top left) and radio-frequency tag (bottom left). USDA APHIS tracker holding RECCO harmonic radar emitter/receiver and a tagged spotted lanternfly (right).

Appendix B Journal Article

Please see next page.

Research Idea

Proposal for detecting coconut rhinoceros beetle breeding sites using harmonic radar

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Abstract

Coconut rhinoceros beetle (CRB), a major pest of coconut and oil palms, is causing severe economic and environmental damage following recent invasions of several Pacific islands. Population suppression and eradication of this pest requires location and destruction of active and potential breeding sites where all life stages aggregate. Three search tactics for discovering breeding sites have been used with limited success: visual search by humans, search with assistance from detector dogs and search by tracking CRB adults fitted with radio transmitters.

Here, we suggest a fourth search tactic: releasing CRB adults fitted with harmonic radar tags to locate breeding sites. Our idea is to find static end points for tags which accumulate at breeding sites, rather than active tracking of individual beetles. We plan to use commercially available hand-held harmonic radar devices. If we are successful, this technique may be useful for locating other insects which aggregate, such as hornets and other social insects.

Keywords

harmonic radar, coconut rhinoceros beetle, *Oryctes rhinoceros*

Coconut rhinoceros beetle biology

Life cycle and feeding behaviour

Oryctes rhinoceros (Linnaeus 1758) (Coleoptera, Scarabaeidae, Dynastinae), commonly known as the coconut rhinoceros beetle (CRB) is a major pest of coconut and oil palm. CRB undergo complete metamorphosis with four distinct life stages: egg, larva, pupa and adult. Larvae feed exclusively on dead and decaying vegetation and cause no economic damage. Damage is done only by adults. Both sexes bore into palm crownshafts to feed on sap to fuel their flight muscles. They typically bore through several fronds developing within the crownshaft. When these fronds emerge and expand several weeks later, large v-shaped cuts become visible, a distinctive sign of CRB damage. Palms are killed only when the apical meristem (growing tip), located at the base of the crownshaft, is damaged by boring activity. However, mortality caused by CRB is rare unless CRB population densities are high and individual palms are attacked simultaneously by multiple adults. Adults reside in crowns of live palms only briefly, exiting bore holes within a few days to aggregate at breeding sites where they mate and lay eggs. Each CRB may feed up to six times during its adult lifetime (Vander Meer and Mclean 1975), boring a new hole each time.

Gressitt (1953) estimated that 88% of a CRB population occurs in breeding site aggregations. The remaining 12% accounts for adults temporarily visiting live palm crowns to feed on sap. Breeding site aggregations occur in a wide variety of decaying plant material including dead standing coconut palms, fallen coconut logs, rotting coconut stumps, decaying wood of many tree species, piles of compost, sawdust and manure. Small breeding sites are sometimes located in live coconut palm crowns where grubs feed on accumulated detritus (Moore et al. 2015).

Severe damage by CRB is often triggered by an abundant larval food supply in the form of massive amounts of decaying vegetation generated by typhoons, large-scale land clearing and wars. CRB damage can be totally avoided if all breeding sites are located and destroyed prior to first emergence of adults at about six months after sites are established.

Location and destruction of breeding sites, usually referred to as *sanitation*, is essential for CRB population suppression leading to eradication. Sanitation is likely to suppress CRB populations much more effectively than control programmes aimed primarily at killing only adults, such as mass trapping and insecticides applied to live palms.

Eradication programmes

The recipe for eradicating coconut rhinoceros beetle from an island is simple:

- find and destroy all active and potential breeding sites
- prevent re-infestation by closing invasion pathways

However, eradication of CRB from an island has proven extremely difficult once this pest has become established. There have been many CRB eradication attempts and some are

currently in progress. However, there has been only one success. This was accomplished on the tiny (36 km^2) Niuatoputapu Island (also known as Keppel Island), which lies between Samoa and Tonga (Catley 1969). During a period spanning 1922 to 1930, all CRB breeding sites were located and destroyed.

We suggest that harmonic radar may be useful for efficient detection of CRB breeding sites, thus facilitating efficient sanitation and improved probability of successful eradication. Sanitation methods for CRB breeding site material include burning, fumigation, insecticide application, composting, burial and steam sterilisation (U.S. Department of Agriculture, Animal Plant Health Inspection Service, Plant Protection and Quarantine 2014). U.S. Department of Agriculture, Animal Plant Health Inspection Service, Plant Protection and Quarantine (2014)

Invasion history

CRB is endemic to the tropical Asia region (including South East Asia). The beetle was inadvertently introduced into the Pacific in 1909 when infested rubber tree plants were transported to Samoa from Sri Lanka (previously known as Ceylon). The pest rapidly multiplied in Samoa and subsequently spread to several nearby Polynesian islands. Separate invasions further distributed CRB through Palau, parts of Papua New Guinea and other Pacific nations through disruptions and uncontrolled movements during World War II (Catley 1969). The invasive phase of the beetle was brought under control by the discovery and distribution of a viral biocontrol agent, *Oryctes rhinoceros* nudivirus (OrNV) (Huger 2005). OrNV causes persistent population suppression on many of the CRB-infested Pacific Islands where it was introduced (Bedford 1986, Bedford 2013).

Detection of CRB on Guam in 2007 heralded a second wave of Pacific island invasions by this pest. Following a failed eradication attempt, it was discovered that the Guam beetles are apparently resistant to OrNV infection and they are being referred to as the CRB-G biotype (Marshall et al. 2017). This problematic biotype has been detected on several previously uninfested Pacific islands including Guam (2007), Papua New Guinea (2009), Hawaiian Islands (2013) and Solomon Islands (2015). CRB-G is damaging and killing coconut and oil palms on these islands and it is expected to spread further if high populations are not suppressed (Jackson 2015).

Methods for Detecting Coconut Rhinoceros Beetle Breeding Sites

Three methods have previously been used for detecting CRB breeding sites: unassisted search by humans, search with assistance from detector dogs and search with assistance from CRB adults equipped with radio transmitters. Pros and cons of these methods plus a fourth method, search with assistance from CRB adults equipped with harmonic radar tags, are presented in Table 1.

Table 1.

Pros and cons for methods used to search for *Oryctes rhinoceros* breeding sites.

Method	Pros	Cons
Humans	<ul style="list-style-type: none"> Minimal training required Both active and potential breeding sites are detected 	<ul style="list-style-type: none"> May be expensive (depends on labour costs)
Dogs (Fig. 1)	<ul style="list-style-type: none"> Dogs can detect cryptic breeding sites which may not be obvious to human searchers. 	<ul style="list-style-type: none"> Arboreal breeding sites will be missed Training, handling and upkeep is expensive Each dog must be attended by a human handler
Beetles with radio tags (Fig. 2)	<ul style="list-style-type: none"> No training required Both ground-based and arboreal breeding sites are detected Tags can have different frequencies 	<ul style="list-style-type: none"> Tags are expensive (about \$200 each) Tags have limited battery life (limited shelf life, limited field endurance) The ATS A2414 radio transmitter we used had a relatively heavy mass of 400 mg Releasing live beetles may be undesirable
Beetles with harmonic radar tags (Fig. 3 and Fig. 4)	<ul style="list-style-type: none"> No training required Both ground-based and arboreal breeding sites are detected Tags are cheap, costing approximately \$4 each including materials (~ \$2.50) and labour for antenna attachment (\$1.50 at \$15 per h) Unlimited shelf life Unlimited field life The diode plus antenna we plan to use as a harmonic radar tag has a mass of only 20.4 mg 	<ul style="list-style-type: none"> Tags do not have different frequencies (but CRB can be marked uniquely) Releasing live beetles may be undesirable Detection range is short: 50 to 70 m under ideal conditions (line of sight and correction orientation). Detection range under field conditions is approximately 10 m.

Search by humans

Unassisted visual search by humans is limited because many CRB breeding sites are cryptic with a high probability of being undetected.

Search assisted by detector dogs

Use of dogs trained to detect odours associated with CRB grubs was pioneered by the Guam Coconut Rhinoceros Eradication Program. Four teams of CRB detector dogs and handlers were deployed on Guam from July 2009 until November 2011. The idea was that

visual search by handlers, coupled with olfactory search by dogs, would be most valuable towards the end of the eradication programme in the last few cryptic breeding sites. The Guam detector dogs were effective in finding breeding sites. However, maintaining detector dogs was expensive and could not be sustained with the limited funding available. CRB detector dog teams are currently deployed by the Hawaii CRB Eradication Program on the Island of Oahu.

Search assisted by beetles, equipped with radio transmitters

After discontinuation of the Guam CRB detector dog programme, we began investigating the prospect of replacing dogs with CRB adults for olfactory detection of breeding sites.

Location of mammals and birds is commonly done by attaching radio transmitters to individuals. These individuals can then be tracked using a directional antenna attached to a radio receiver. Miniaturised transmitters are now small enough to be carried by large insects and these can be tracked using receivers and antennae identical to what is used for locating mammals and birds. Our idea was to track CRB adults, equipped with miniature radio transmitters, to see if they would lead us to breeding sites.

A feasibility trial performed on Guam showed that the method worked (Moore et al. 2017). However, this method has not been used operationally because of financial and logistic limitations:

- transmitters are expensive, about \$200 each
- transmitters require batteries which are not replaceable or rechargeable. These batteries are relatively heavy, have a shelf life of a few months and an operational field life of a few weeks.

Search by beetles, equipped with harmonic radar tags

To continue investigating the prospect of replacing dogs with CRB adults for olfactory detection of breeding sites, we are now considering use of harmonic radar tags which are much cheaper, lighter and longer lasting than radio transmitters. Harmonic radar (HR) has been used for locating and tracking insects for more than a quarter of a century. Mascanzoni and Wallin (1986) used HR to track carabid beetles and Riley et al. (1996) used HR to track bees.

HR can be used to locate and track tagged insects. The key to HR is a tiny tag consisting of a wire antenna and diode attached to the insect being tracked. When the tag is illuminated by a beam of fixed-frequency radio waves from an HR transceiver, the tag radiates at integer multiples of that frequency (harmonic frequencies). The HR transceiver is designed to detect harmonic frequencies and to reject the original frequency. In this way, the HR transceiver detects the harmonic frequencies radiated by the tag and rejects backscatter (reflections of the original frequency from foliage, the ground and other objects). More comprehensive descriptions of insect location and tracking using HR are presented by Mascanzoni and Wallin (1986) and O'Neal et al. (2004).

Objectives

Given the importance of finding and destroying breeding sites in order to suppress and eradicate coconut rhinoceros beetle populations and the inherent difficulty of locating cryptic breeding sites which are found in a wide range of habitats, there is a pressing need to develop cheap yet efficient detection methods to find these sites. We hope that harmonic radar will allow efficient detection of cryptic aggregation sites where tags have accumulated. We are planning a field trial on Guam to assess the feasibility of this approach. We will essentially repeat the previous trial in which we tagged CRB adults with radio transmitters (Moore et al. 2017), but this time, we will use HR tags.

Materials and Methods

HR tagged CRB will be released at two sites, War in the Pacific National Historical Park in Asan (13.4659 N, 144.7109 E) and the University of Guam Agricultural Research Station in Yigo (13.5324 N, 144.8733 E). After a period of several days, location of the tags will be determined.

We will use a hand-held harmonic radar device (RECCO AB, Lidingö, Sweden) designed for finding avalanche victims.

We will fabricate dipole harmonic radar tags by attaching antennae to Schottky diodes (RECCO AB, Lidingö, Sweden). Two 8 cm lengths of super-elastic nitinol wire (0.076 mm diameter, McMaster-Carr, Aurora, OH, USA) will be attached to the diode with UV-activated adhesive (Bondic, Niagara Falls, NY, USA), so that each wire touches one of the diode contacts while avoiding the opposite diode contact and the other wire. Electrical connections between the wires and the diode contacts will be secured using conductive silver paint (GC Electronics, Rockford, IL, USA).

As with our previous work with radio transmitters, CRB adults caught in pheromone traps will be fed banana slices in the laboratory and their flight ability will be tested prior to selection for the feasibility study. Tagged beetles will be released in the evening about one hour after sunset.

A thorough ground search of the release site neighbourhood using RECCO harmonic radar devices will start several days after release. Search paths and location of detected tags will be recorded using GPS devices.

Discussion

Development of a relatively cheap and efficient method for locating CRB breeding sites using harmonic radar will facilitate population suppression and increase the probability of eradication. This method may also be applied to other invasive species, especially those that aggregate, such as hornets and other social insects.

Searches may be highly automated by mounting an HR transceiver, equipped with a data logger on an aerial drone. The drone will fly programmed search paths close to the ground with the HR beam pointing downwards, thus compensating for the relative short detection range of the HR transceiver. At the completion of a search, a map will be compiled by merging the HR data log with search path coordinates recorded by the drone.



Figure 1. [doi](#)

CRB detector dogs and handlers deployed on Guam from July 2009 until November 2011.

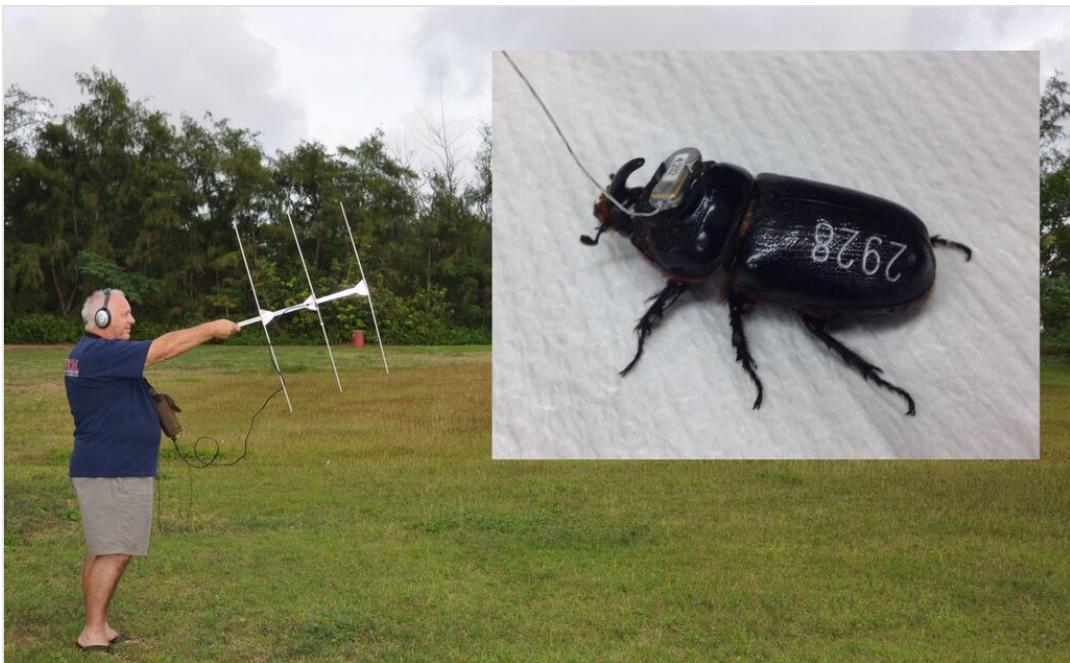


Figure 2. [doi](#)

Miniaturised radio transmitter tag attached to the thorax of a coconut rhinoceros beetle. A radio receiver and yagi antenna are used for locating the tag.

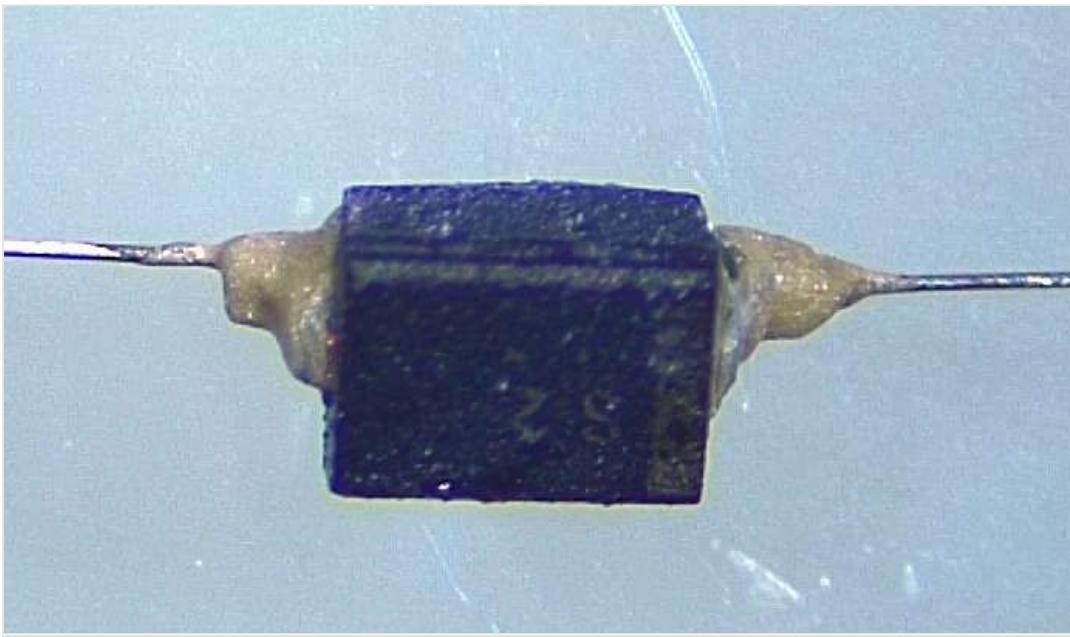


Figure 3. [doi](#)

Harmonic radar tag consisting of a diode with a dipole antenna. The diode is about 2 mm long.



Figure 4. [doi](#)

RECCO hand-held harmonic radar transceiver.

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Appendix C Progress Report 4

Please see next page.

Improving Coconut Rhinoceros Beetle Breeding Site Detection Using Harmonic Radar

Aubrey Moore, University of Guam

October 29, 2022

GRANTEE: Aubrey Moore, University of Guam

GRANT YEAR: 2020

GRANT NUMBER: 20-DG-11052021-227

GRANT PROGRAM: Forest Health Protection

GRANT EXPIRATION DATE: 2022-12-31 (extended)

DATES COVERED BY THIS REPORT: 2022-01-01 through 2022-06-30

GRANT STATUS: Active

Note to Reader: Significant changes from the previous report are indicated by **bold-faced text**.

<https://github.com/aubreymoore/Harmonic-Radar/raw/master/FS-CRB-HR-report4.pdf>

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3	MONITORING & EVALUATION	7
4	BUDGET EXPENDITURES	7
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6	CHANGES PLANNED	7
7	CIVIL RIGHTS	8
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Figure 1: RECCO harmonic radar device suspended from an agricultural drone piloted by Dr. Glenn Dulla, Guam Department of Agriculture.

1 OBJECTIVES AND SPECIFIC ACTIVITIES

The objective of this grant project is to evaluate harmonic radar as an alternative to radio tracking for CRB breeding site detection. Detection of CRB breeding sites is essential for CRB control and eradication.

Previously, we successfully tracked CRB to cryptic breeding sites using miniature radio transmitters. However, the high cost of radio tags (>\$100 each) and short shelf life and field life of nonreplacable batteries (about 1 month and one week, respectively) make this technique too expensive for routine surveys to detect CRB breeding sites.

A promising alternative technology is harmonic radar. Harmonic radar tags do not require a battery. They are inexpensive (about \$1 each) and they have unlimited shelf-life and field life. We are evaluating hand-held harmonic radar equipment and tags manufactured by RECCO in Sweden. Rescuers use the hand-held units to rapidly locate victims wearing tags sown into their clothing. RECCO technology has been used to track other insects but has not yet been tried with CRB.

Our objective is not to track CRB tagged beetles in real-time, but to discover the end points of tags several days or even weeks after release of tagged beetles. We anticipate that tags will accumulate at breeding sites.

Here is the plan from the approved grant proposal:

Schedule of Activities (2020)

March-April: Tag fabrication and testing at EMU.

April-early May: Capture, flight test, and mark CRB at UoG.

May: Conduct field releases and tracking of tagged CRB (two week intensive fieldwork period).

June-August: Data analysis.

August-December: Manuscript(s) and final report preparation. Discuss findings with state agencies. Make presentations at scientific meetings. Plan further research with cooperators to implement findings in monitoring and control efforts.

Progress to date includes:

- Procurement of harmonic radar equipment and tags
- Tag fabrication (soldering antennae to diodes) in Matt Siderhurst's lab.
- Preliminary field testing of equipment on Guam.

- Published our research idea as a preprint in the Research Ideas and Outcomes Journal ([Moore and Siderhurst 2022](#)). This article will be peer reviewed.
- Continued to investigate the idea of mounting our harmonic radar transceiver on an aerial drone to facilitate automated surveys over large areas (See Methods Development section below).

The most important activity in our work plan is to conduct field releases and tracking of tagged CRB over a two week intensive fieldwork period. This intensive fieldwork will be performed on Guam in collaboration with Matt Siderhurst's team of students who have experience in tracking insects with harmonic radar. (We are following an approach similar to what we did in the radio-tracking feasibility study [Moore et al. 2017](#)). This fieldwork activity has not yet been scheduled because of COVID-19 travel restrictions (See section 5 for details.). Otherwise we are prepared to proceed. **Our field trial is now planned for July 2022.**

1.1 Methods Development

The RECCO hand-held harmonic radar device we are using is designed for ground-based location of tags. We are collaborating with Dr. Glenn Dulla, Guam Department of Agriculture, to test the idea of mounting the device on a drone to allow efficient downward-looking scans over large areas. The idea is to mount the RECCO device on a drone which is programmed to fly a defined search path. A digital recorder cabled to the RECCO's headphone jack records the audio signal from the device and the drone's GPS records location. Georeferencing is done by matching timestamps in the audio recording with timestamps in the GPS data. Postprocessing generates a map of signal strength with peaks indicating probable tag locations requiring confirmation by ground searches.

Preliminary tests are promising:

- Used digital recordings of the RECCO's audio output to locate tags (See Technical Report: [Using a Cell Phone as a Datalogger for Handheld Harmonic Radar](#))
- Flown the RECCO harmonic radar device attached to a drone (Fig. 1)
- Based on initial flight tests we determined that the audio data recorder we were using was too heavy for use on the drone. We purchased a much smaller and light audio data recorder. Walk tests with this recorder show that we can locate harmonic radar tags by correlating audio recordings with GPS data (Fig. 2).

- On June 9, 2022 we flew a drone with our harmonic radar transceiver suspended beneath it. Audio output from the transceiver was recorded on a small audio data recorder. By correlating audio data with the drone’s GPS log, we were able to locate harmonic detector tags on the ground (See [technical report](#)).

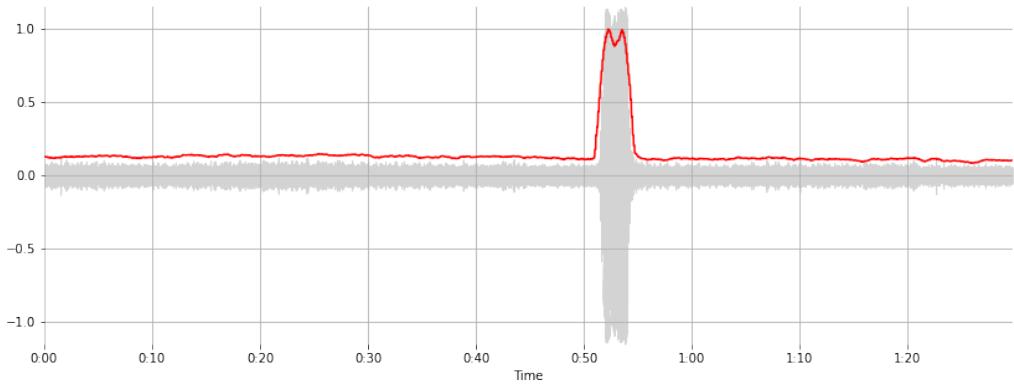


Figure 2: Audio output from a RECCO harmonic radar device recorded using a Zoom F2 field recorder. This was a walk test along a linear transect in which a harmonic radar tag had been placed. Location of the tag in the recording is clear.

2 OUTPUTS

On December 18, Aubrey Moore made a presentation on the technology used in this project at a meeting of the Guam Beekeepers Association (GBA). Members of the GBA and the Guam Department of Agriculture are interested in using harmonic radar to track greater banded hornets (GBH), *Vespa tropica*, to their nests so that they can be destroyed. GBH, a recently arrived invasive species which raids honeybee hives, is a serious threat to Guam's nascent beekeeping industry.

3 MONITORING & EVALUATION

Nothing to report.

4 BUDGET EXPENDITURES

Category	Budget	Spent	Note
Equipment and supplies	\$8,000	\$316.93	Miniturized audio field recorder and hardware
Travel	\$12,000	\$0	
Admin. fee	\$3,000	\$0	

5 PROBLEMS ENCOUNTERED DURING THIS REPORTING PERIOD

Progress on this project was impeded by COVID-19 travel restrictions which prevented collaborators from visiting Guam to participate in field work. Further delayed by delay was caused by Government of Guam *stay at home* orders.

The University of Guam was officially closed from March 20 to May 10 2020 and again from August 16 2020 to January 15 2021.

COVID travel restrictions during the current reporting period did not allow Dr. Siderhurst and students to visit Guam to perform the planned field work on schedule. Guam still has extremely high local transmission of COVID due to delayed arrival of the OMICRON variant. However, quarantine for fully vaccinated visitors from the mainland is no longer required. Travel arrangements have been made for Dr. Siderhurst and students experienced with using harmonic radar to track insects to visit Guam during July 2022 to complete planned field trial.

6 CHANGES PLANNED

Nothing to report.

7 CIVIL RIGHTS

Nothing to report.

8 ATTACHMENTS

None.

9 PLANS

Nothing to report.

Appendix D Jupyter Notebook for Experiment 1: Maximum detection distances for each of the 3 RECCO transceivers we used

Please see next page.

RECCOTag

March 19, 2023

1 RECCOTag.ipynb

1.1 Objective

In this experiment we measured line-of-sight detection distance for tagged CRB using a standard RECCO test tag (labelled UOG2) using 3 transceivers marked EMU1, UOG1 and UOG2. The test tag was placed on a piece of wood about 6 inches above the ground at one end of a measured linear transect. Using the most sensitive setting, the distance between the transceiver and the target was increased until no signal could be heard in the headphones. For each transceiver, detection distance was measured three times with the test tag in two orientations: with the long axis perpendicular and parallel to the transect.

1.2 Results

- There was no significant difference in maximum detection range among the 3 devices tested (Kruskall-Wallace test; $p = 0.051$ for tag in perpendicular orientation, $p = 0.065$ for tag in parallel orientation).
- In perpendicular orientation, detection range was 183 to 225 feet.
- In parallel orientation, detection range was 38 to 78 feet.

```
[1]: import pandas as pd
import plotly.express as px
from scipy import stats
import scikit_posthocs as sp
```

```
[2]: df = pd.read_csv('RECCOTag.csv')
df
```

```
[2]:   detector    orientation  feet
 0      EMU1  perpendicular  135
 1      EMU1  perpendicular  133
 2      EMU1  perpendicular  170
 3      EMU1      parallel  68
 4      EMU1      parallel  72
 5      EMU1      parallel  70
 6      UOG1  perpendicular  143
 7      UOG1  perpendicular  122
 8      UOG1  perpendicular  104
 9      UOG1      parallel  47
```

```

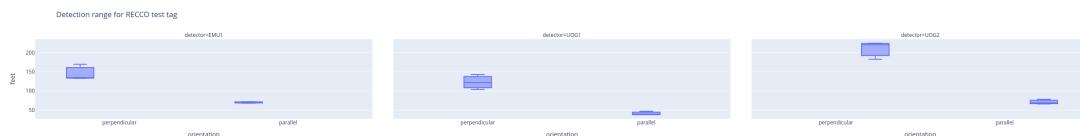
10    UOG1      parallel   38
11    UOG1      parallel   38
12    UOG2  perpendicular 183
13    UOG2  perpendicular 225
14    UOG2  perpendicular 221
15    UOG2      parallel   66
16    UOG2      parallel   78
17    UOG2      parallel   69

```

[3]: `g = df.groupby('orientation')
g['feet'].describe()`

orientation	count	mean	std	min	25%	50%	75%	max
parallel	9.0	60.666667	15.337862	38.0	47.0	68.0	70.0	78.0
perpendicular	9.0	159.555556	43.006137	104.0	133.0	143.0	183.0	225.0

[4]: `px.box(data_frame=df,x='orientation',y='feet', facet_col='detector',
 title='Detection range for RECCO test tag')`



[25]: `df1 = df.query("orientation=='perpendicular'")
EMU1 = df1.query("detector=='EMU1'")['feet']
UOG1 = df1.query("detector=='UOG1'")['feet']
UOG2= df1.query("detector=='UOG2'")['feet']
stats.kruskal(EMU1, UOG1, UOG2)`

[25]: `KruskalResult(statistic=5.955555555555556, pvalue=0.05090583233639852)`

[28]: `# Dunn's multiple comparison test to find significant differences
Unnecessary in this case because the p-value from the Kruskal-Wallis test is
greater than 0.05
sp.posthoc_dunn([EMU1, UOG1, UOG2], p_adjust = 'bonferroni')`

[28]:

	1	2	3
1	1.000000	1.000000	0.303151
2	1.000000	1.000000	0.051218
3	0.303151	0.051218	1.000000

```
[29]: df1 = df.query("orientation=='parallel'")  
EMU1 = df1.query("detector=='EMU1'")['feet']  
UOG1 = df1.query("detector=='UOG1'")['feet']  
UOG2= df1.query("detector=='UOG2'")['feet']  
stats.kruskal(EMU1, UOG1, UOG2)
```

```
[29]: KruskalResult(statistic=5.46778711484594, pvalue=0.06496584833309137)
```

```
[30]: # Dunn's multiple comparison test to find significant differences  
# Unnecessary in this case because the p-value from the Kruskal-Wallis test is  
# greater than 0.05  
sp.posthoc_dunn([EMU1, UOG1, UOG2], p_adjust = 'bonferroni')
```

```
[30]:
```

	1	2	3
1	1.000000	0.108314	1.000000
2	0.108314	1.000000	0.154946
3	1.000000	0.154946	1.000000

```
[ ]:
```

Appendix E Jupyter Notebook for Experiment 2: Maximum detection distances for single and double tagged CRB

Please see next page.

beetles

March 19, 2023

1 tagged_beetles.ipynb

1.1 Objective

In this experiment we measured line-of-sight detection distance for tagged CRB using the UOG2 RECCO harmonic radar transceiver. Targets were 5 single-tagged and 5 double-tagged dead CRB. Each target was pinned to a piece of wood about 6 inches above the ground at one end of a measured linear transect. Using the most sensitive setting, the distance between the transceiver and the target was increased until no signal could be heard in the headphones. Each beetle was pinned in two orientations: perpendicular and parallel to the transect (see diagram below).

1.2 Results

- Double-tagged beetles had a detection range of between 82 and 102 feet. Orientation of the beetle did not affect detection range.
- Single-tagged beetles had a detection range of only 18 to 38 feet when the tag antenna was parallel to the line-of-sight. But this increased to 74 to 93 feet when the tag antenna was perpendicular to the line of sight.
- Detection range for the tagged beetles (82 to 102 feet) was only about half of what we measured for the standard RECCO tag (183 to 225 feet).

```
[6]: import pandas as pd
      import plotly.express as px
```

```
[9]: df = pd.read_csv('beetles.csv')
      df
```

```
[9]:   beetle  tags    orientation  feet
      0       1     1  perpendicular  22
      1       1     1      parallel  74
      2       2     1  perpendicular  18
      3       2     1      parallel  83
      4       3     1  perpendicular  26
      5       3     1      parallel  79
      6       4     1  perpendicular  38
      7       4     1      parallel  87
      8       5     1  perpendicular  29
      9       5     1      parallel  93
     10      6     2  perpendicular  82
```

```

11      6    2      parallel   84
12      7    2 perpendicular  97
13      7    2      parallel   86
14      8    2 perpendicular  88
15      8    2      parallel   95
16      9    2 perpendicular 102
17      9    2      parallel   95
18     10    2 perpendicular  85
19     10    2      parallel   92

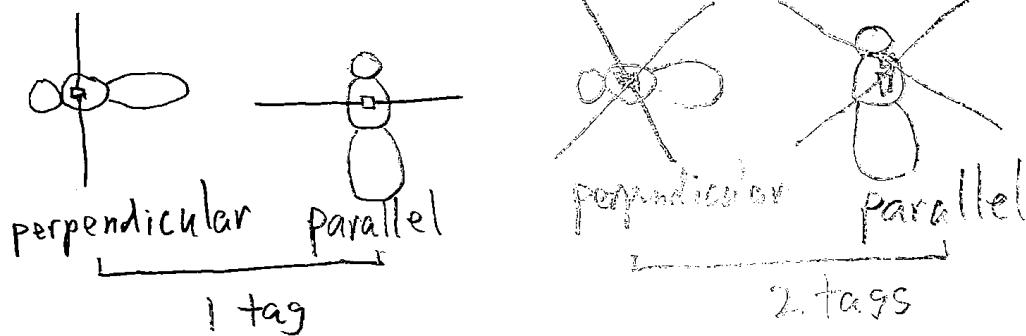
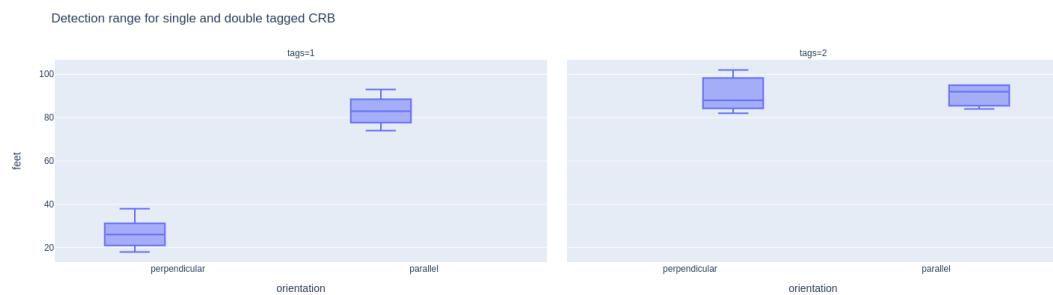
```

```
[7]: g = df.groupby(['tags','orientation'])
g['feet'].describe()
```

```
[7]:
```

tags orientation	count	mean	std	min	25%	50%	75%	max
1 parallel	5.0	83.2	7.293833	74.0	79.0	83.0	87.0	93.0
1 perpendicular	5.0	26.6	7.602631	18.0	22.0	26.0	29.0	38.0
2 parallel	5.0	90.4	5.128353	84.0	86.0	92.0	95.0	95.0
2 perpendicular	5.0	90.8	8.408329	82.0	85.0	88.0	97.0	102.0

```
[10]: px.box(data_frame=df,x='orientation',y='feet',facet_col='tags',  
           title='Detection range for single and double tagged CRB')
```



[]:

Appendix F Jupyter Notebook for Experiment 3: Attenuation of maximum detection distances when targets are buried in coir

Please see next page.

attenuation

March 19, 2023

1 attenuation.ipynb

1.1 Objective

1.2 Results

```
[2]: import pandas as pd  
import plotly.express as px
```

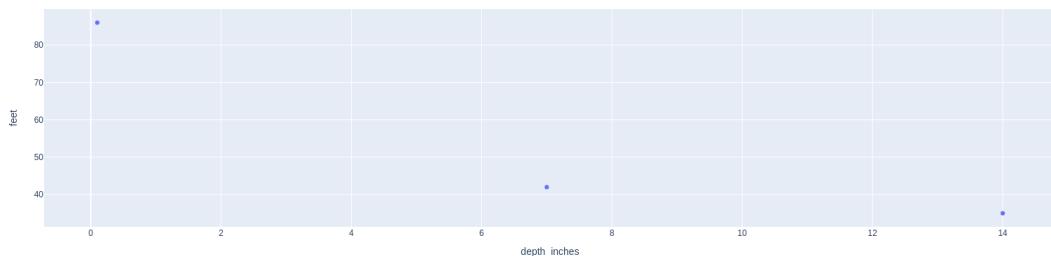
```
[4]: df = pd.read_csv('attenuation.csv')  
df
```

```
[4]:      tag  depth_inches  feet  
0      RECCO        0.0    176  
1      RECCO        0.1     86  
2      RECCO        7.0     42  
3      RECCO       14.0     35  
4  beetle1_1tag      7.0     38  
5  beetle2-2tags      7.0     45
```

```
[7]: temp = df[df.tag=='RECCO']
```

```
[10]: temp = temp[temp.depth_inches>0]
```

```
[11]: px.scatter(temp, x='depth_inches', y='feet')
```



[]: