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Investigating the potential of RFID in identifying individual white-tailed deer for PZP immunocontraceptive programs

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Introduction: Identifying individual white-tailed deer (*Odocoileus virginianus*) for treatment with porcine zona pellucida (PZP) immunocontraceptive vaccines is critical to the success of fertility management programs, but adult female deer are very difficult to distinguish in the field. Past research has relied on chemical immobilization and ear-tagging to assure individual identification, but this approach is more technically challenging, time-consuming, costly, and stressful to animals and field personnel than is remote darting with PZP.

Methods: To explore the use of radio frequency identification (RFID) as an alternative to permanently identify deer, we captured, ear-tagged, and implanted 52 wild deer with passive integrated transponder (PIT) tags and deployed 3 fixed tag-reader stations in a nature reserve in Head of the Harbor, NY. Motion-sensor cameras were used to confirm the presence, location, and identity of PIT-tagged deer.

Results: Results showed that tag reader stations consistently read the PIT tags in tagged deer within 0.6 to 1.2 meters of the apparatus, and that tags remained readable multiple years after implantation.

Discussion: RFID's may be a viable strategy for remote identification of individual deer. Developing a single dart that delivers both a PIT tag and the fertility control agent would significantly improve the animal's experience as well as the feasibility and cost effectiveness of immunocontraception programs.

KEYWORDS

identification, immunocontraception, individual recognition, population monitoring, PZP, remote detection, white-tailed deer

1 Introduction

Human-wildlife conflicts related to deer in urban and suburban areas throughout North America are well-documented. Root causes of conflicts are often traced to potential risks to human health and safety such as tick-borne illness, deer-vehicle collisions, residential property damage, and environmental impacts related to browse (McShea, 2012; Urbanek et al., 2011; Westerfield et al., 2019). Furthermore, female deer in urban environments typically have high site fidelity and small home ranges, and often utilize landscapes close to residential areas, which contribute to localized deer conflicts (Rodén-Reynolds et al., 2022; Walter et al., 2011). The increase in frequency and intensity of such conflicts often fuels a

call for managing deer populations in areas where natural predators are absent and traditional methods focused on public hunting are insufficient or difficult to implement.

Remotely-delivered porcine zona pellucida (PZP) immunocontraceptive vaccines are a potentially important and minimally invasive method to stabilize and reduce free-roaming deer populations. PZP vaccines, which are federally registered with the Environmental Protection Agency (EPA) for use in horses and burros as Zonastat-H and for deer as Zonastat-D, have been used for over thirty-five years to limit fertility of individual animals in confined settings such as zoos and sanctuaries, and reduce reproduction rates of populations of free-roaming animals. These formulations, often referred to as “Native PZP”, and preparations under development to extend their effects, such as PZP-22, have demonstrated effective birth control in several species, including horses (Kirkpatrick and Turner, 2008; Carey et al., 2019; Grams et al., 2017, 2022), white-tailed deer (McShea et al., 1997; Naugle et al., 2002; Rutberg et al., 2004, 2013, 2024; Rutberg and Naugle, 2008) African elephants (Fayrer-Hosken et al., 1999; Delsink et al., 2007), and many species of animals held in zoos, including bears (Frank et al., 2005).

The efficacy of PZP immunocontraceptive vaccines to reduce fertility in female white-tailed deer (*Odocoileus virginianus*) in suburban environments where deer are acclimated to living closely alongside humans is well established (Naugle et al., 2002; Rutberg et al., 2004, 2013, 2024; Rutberg and Naugle, 2008). Such studies also indicate that effective treatments can be achieved when delivered by dart, confirming a fully remote application to animals in their natural habitats. But because contraceptive effectiveness of Zonastat-D requires a priming dose followed by a booster approximately 2–4 weeks after plus subsequent annual boosters (Rutberg and Naugle, 2008), identifying individual animals for treatment and remote re-treatment is a critical component of PZP programs and remains a primary practical challenge to wider application. Even with the development of PZP-22, which shows two to three years of effectiveness with a single treatment and multiple years of additional effectiveness with a booster delivered two to three years later, identifying individuals will be crucial for cost-effective delivery of the vaccine (Rutberg et al., 2013, 2024).

Many species exhibit distinctive indicators that can be readily assessed for individual identification purposes by simple observation and comparison to catalogued images. Animals commonly known for distinctive patterns in their haircoat, such as giraffes, zebras, and leopards, may be more easily differentiated from each other through simple observation. Individual identification of other species requires a deeper assessment of finer details in their physical appearance. For example, elephants have been identified through description of ear patterns or facial wrinkles (Bedetti et al., 2020; Chan et al., 2022), Asiatic black bears by unique chest marks (Higashide et al., 2012), armadillos by distinctive head shield patterns (Gallo et al., 2022), and bottlenose dolphins by pigment patterns (Bichell et al., 2018).

Unlike these species, however, visual identification of individual adult female white-tailed deer is extremely challenging (Bengsen et al., 2022). While individual male white-tailed deer can be identified by their unique antler arrangement before shedding

them annually (Lockwood et al., 2007; Hewitt et al., 2014) and fawns by a unique spot pattern that disappears as they age (Jacobs et al., 2021), adult female deer show little obvious variation in physical appearance that can be used for confirming individual identity. This limitation can be exacerbated by seasonal coat changes and environmental conditions such as snow or rain that change hair coat appearance. Habitat elements such as tall grasses and vegetation can also hide subtle individual markings.

Prototype marker-darts (Pneu-dart[®], Williamsburg, Pennsylvania, USA) that release a dye or stain upon injection were tested in one deer PZP field project (Naugle et al., 2002), but because of fastidious deer grooming habits, social grooming, weather, hair type, and seasonal moulting markings did not persist and the technique showed only limited success. Even when successful, marker dart media are short lived and not suited for long term immunocontraception programs where individual identification of animals may be required over several years.

Because of the challenges of visually identifying individual deer, most field studies of PZP in deer have incorporated capturing and tagging deer for identification purposes prior to administering PZP treatments. However, capturing wild deer for ear-tagging or collaring is time-consuming and costly, and poses increased safety risks to deer and field personnel. This technique also requires a higher level of training, expertise, and regulatory oversight, which would constitute significant burdens to communities, agencies, or service providers that are considering implementing a deer PZP program. Therefore, exploring alternative, less invasive ways to remotely identify individual deer will improve capabilities in immunocontraception programs. In a study using captive elk Walter et al. (2012) introduces the potential for remotely delivering passive integrated transponder (PIT) tags in cervids, which lays the foundation for using radio frequency identification (RFID) technologies to permanently and remotely identify animals to provide an avenue for capture-free methods in marking and monitoring wildlife.

Radio frequency identification (RFID) uses a signal transmitted between an electronic device (tag or transponder) and a reading device (scanner, reader) to confirm individual identity. Studies using RFID to remotely identify wildlife have demonstrated success in a variety of species including but not limited to fish (Zydlowski et al., 2006), birds (Bonter and Bridge, 2011), insects (Streit et al., 2003; Silcox et al., 2011; Blight et al., 2023), amphibians (Charney et al., 2009), and mammals (Briggs et al., 2021; Schooley et al., 1993; Fagerstone and Johns, 1987). RFID devices most widely used in animal studies include PIT tags. Unlike satellite or global positioning (GPS) tags, PIT tags require no battery and the uniquely coded microchip inside the PIT tag remains inactive until read with a scanner. To read the PIT tag, a scanner apparatus sends a low frequency signal (inductive charge) to the microchip providing the power needed to communicate its unique identification code back to the scanner. PIT tags are designed to remain operational for decades, potentiating a reliable long-term method for individual identification. Further, PIT tags can be injected into an animal rather than only being attached to an animal's exterior.

The challenge for the use of PIT tags on free-ranging wildlife is designing and placing a scanner in position to consistently read them. Scanner apparatuses using fixed antennas for capturing

transponder tags in fish have been successfully deployed in rivers, streams, or other narrow bodies of water as these landscapes create a natural chute for animals to move through freely but close enough to readers to have their tag detected (Fetherman et al., 2014; Zydlewski et al., 2006). Charney et al. (2009) adapted rectangular antenna styles used in fish studies laid across the ground to detect the presence and movement of salamanders in terrestrial environments, and Briggs et al. (2021) monitored Eurasian beavers by placing fixed readers at the opening of lodges to capture PIT tag information while animals entered or exited their family dwellings. These techniques all rely on the placement of reader devices in close proximity to animal transit points. For larger terrestrial species, the animal's size, behavior, and habitat may impact the success of fixed antennas to detect animals and require further exploration.

The ability of RFID to identify deer in the field is not yet well-documented. Injectable transponder tag migration (Stein et al., 2003) and effects of injection position and transponder size (Conill et al., 2000) have been assessed in livestock. Belser et al. (2017) assessed PIT tag retention at the base of the ear and lower hindlimb in free-range and captive white-tailed deer, while Walter et al. (2012) demonstrated successful remote delivery of PIT tags by dart in post mortem white tailed deer and live captive elk (*Cervus elaphus*). However, no papers describe methodologies for remotely reading PIT tags in live deer in their natural habitats.

This study explored the utility of RFID to remotely identify individual white-tailed deer long-term. Further, we investigated the impact of tag size on its detection reliability and developed a methodology for remotely capturing PIT tag information to improve real-time identification of deer during field operations in an immunocontraceptive program. More specifically we asked,

1. Can stationary RFID readers remotely detect indwelling PIT tags in free-roaming white-tailed deer in real time?
2. Do deer retain PIT tags long enough to serve as individual identification for multi-year immunocontraception treatment plans?
3. Does PIT tag size impact the reliability and efficiency of remote identification?

2 Methods

2.1 Study site

The Village of Head of the Harbor is located in Suffolk County, New York, on the north shore of Long Island, (coordinates: 40° 53' 54" N, 73° 9' 44" W) (Figure 1). The village sits at an elevation of roughly 37 meters and has a total area of approximately 7.8 km², including 0.5 square kilometers of water. The 2020 United States Census Bureau indicates a residential human population of 1,520 (~208/km²). The village is primarily residential and is host to a 0.87 km² (~87-hectare) nature preserve, Avalon Nature Preserve, at its northern border. The preserve comprises fields, forests, and wetland habitats. Approximately 0.56 km² (56-hectares) are

accessible to the public, where walking and biking along several trails is permitted. Both the village and the preserve are home to many native wildlife species, including an abundant and visible population of white-tailed deer. Browsing habits of this local population of deer are reported to have significant impact on private and public landscaping and managed green spaces.

Head of the Harbor, NY, is in the temperate climate zone and experiences all four distinct seasons. Summers are generally warm and humid with average temperatures ranging from 21 to 26 C while winters are moderate, snowy, and windy, with average temperatures between 1 to 9 C. Over the course of the year, the temperature typically varies from -3.8 °C to 27.8 °C and is rarely below -11 °C or above 31.6 °C. Precipitation (rain, snow, sleet, or hail greater than 0.25 mm) occurs approximately 110 days per year. Approximate average annual rainfall is 1194 mm; snowfall is 711 mm.

2.2 Field methods

2.2.1 Animal capture & handling

A total of 75 adult female white-tailed deer were captured using chemical immobilization between February and April, 2019-2021. Capture efforts were conducted opportunistically from a vehicle at the roadside, or from blinds located at temporary bait stations. Automatic bait stations (200-lb. Deer Feeder Standard Game Feeder, Model MFG-15103, Moultrie®, Birmingham, Alabama, USA) were programmed to release whole corn several times per day to draw target animals into safe darting scenarios compliant with New York State Department of Environmental Conservation (NYSDEC) permitting guidelines. Chemical immobilization drugs were delivered by remote intramuscular injection using self-injecting 2 cc Pneu-Dart® (Williamsport, PA, USA) transmitter darts with 1" wire-barbed needles deployed from a Dan-Inject® (DanInject USA, Austin, TX, USA) Model JM Standard CO2 rifle or a Pneu-Dart® Excalibur CO2 rifle. Deer were immobilized with 2.0 mL of a pre-mixed formulation of BAM™ (butorphanol/azaperone/medetomidine) from Wildlife Pharmaceuticals, Inc. (Windsor, CO, USA) per manufacturer dosing guide for adult white-tailed deer. This formula provides approximate dosages of 0.6-1.2 mg/kg butorphanol, 0.2-0.4 mg/kg azaperone, and 0.2-0.5 mg/kg medetomidine. Supplemental intramuscular injections of BAM™ in volume increments of 1 to 2 mL were administered as needed if animals were not fully sedated at time of approach for handling. Supplemental oxygen via mask was provided to each deer during work-up and until release. Vital signs including rectal temperature, pulse rate and quality, respiration rate and quality, and mucous membrane color were monitored every 3 to 5 minutes. If the dart was still retained in hip musculature, it was carefully removed with a #15 surgical blade and the injection site was cleaned with 0.9% sterile saline irrigation solution and a topical antibiotic ointment was applied. To reduce risk of infection related to chemical capture darting, 3 mL (600mg) of Liqueamycin® Antibiotic (Zoetis Inc. Kalamazoo, MI) was administered subcutaneously. During this period deer also received ear tags, PIT tags, and an immunocontraceptive agent further described below. Measurements of body length, girth, and hindlimb length were collected. When possible, 10 mL of venous whole blood

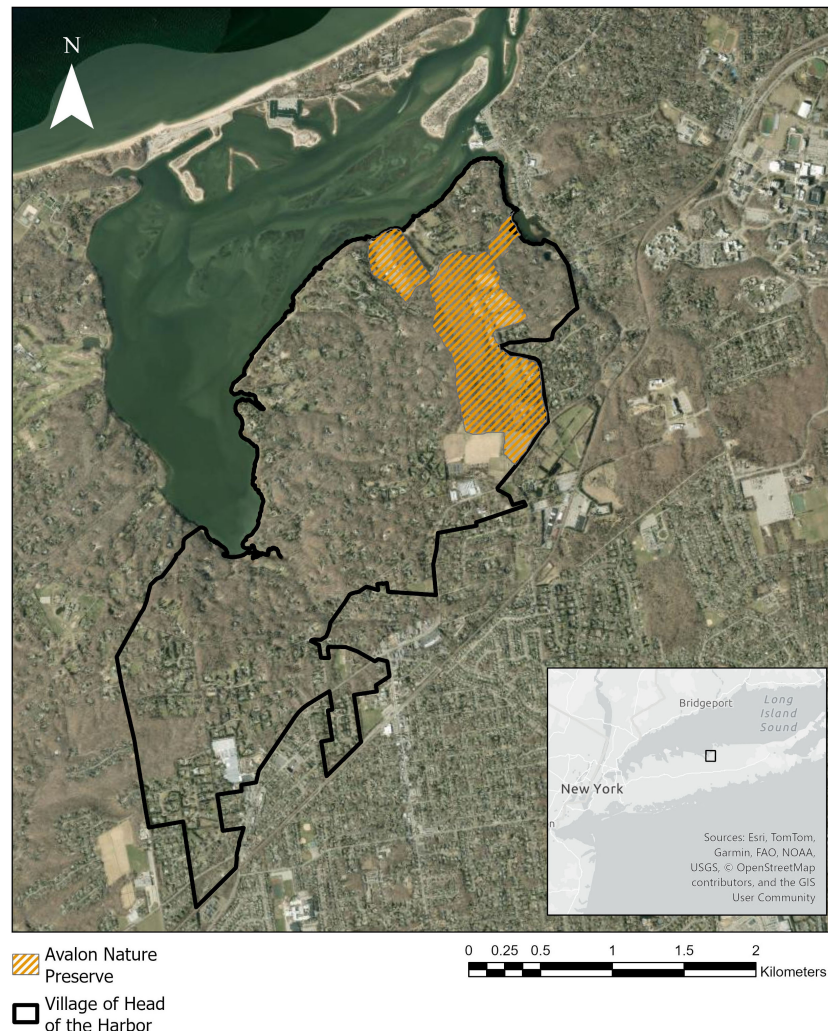


FIGURE 1
Map of study location at Avalon Nature Preserve in the Village of Head of the Harbor, New York, USA.

was collected from the jugular vein, or cephalic or saphenous veins of the lower leg and sent for pregnancy testing using BioPRYN's Pregnancy-Specific Protein B assay at Biotracking, Inc. (Moscow, ID). Upon completion of work-up procedures, deer received reversal agents of 0.5 ml naltrexone at 50mg/ml I.M. plus atipamezole at twice the total volume of BAM delivery (4.0-8.0 cc, equivalent to 100 to 200mg, I.M.), and were monitored from a distance until they were fully ambulatory. During the time of immobilization, PZP-22 injections were administered intramuscularly by hand in the hip/gluteal musculature of the leg opposite the dart site to approximately half of all deer captured. The remaining half of the study cohort received a dose of PZP-22 remotely via opportunistic darting. Vaccine delivery methods and effectiveness of related to PZP-22 treatments in white-tailed deer are further described in Rutberg et al. (2024) and Rutberg et al. (2013).

2.2.2 Tagging process

All captured deer were fitted with two uniquely numbered medium plastic livestock ear tags (3-7/8" long x 2-1/2" wide, Y-TEX[®] Corporation, Cody, Wyoming) permanently labeled on the

back with "EXPERIMENTAL ANIMAL, DO NOT CONSUME," and a telephone number to call if the animal was accidentally harvested or its carcass found. Ear tags were color coded for treatment type and year (Supplementary Table 1).

PIT tags were injected intramuscularly into the hip/gluteal musculature with trocar syringe applicator. Injection location was selected to mimic the site that a tag would be injected if remotely delivered in conjunction with a PZP vaccine. All tags were scanned with a handheld tag scanner (Agrident Handheld Reader, Merck & Co., Inc., Rahway, NJ) immediately prior to and following insertion into the animal to confirm the unique tag number and determine whether it was functioning properly prior to releasing the animal. To evaluate whether tag size impacts remote readability, approximately half of the PIT tagged animals received a 23.1mm x 3.85mm HDX+ tag that weighs 0.6g, which we refer to as a "large tag", and the others received a 12.0mm x 2.15mm HDX+ tag that weighs 0.1g, which refer to as a "small tag" (OregonRFID, Portland, OR). Each tag has a unique numerical ID sequence and is ISO 11784/11785 compliant ICAR-registered animal tag. To streamline visual assessment in the field and on camera, tag sizes were coordinated with color-coded ear tag groups wherever possible.

2.3 Data collection

2.3.1 Visual observations

From 2019 – 2023, efforts were made to re-sight all treated animals in the study area during organized observations sessions and scheduled PZP-treatment sessions throughout each calendar year. Animal sightings including an animal's location and unique ear tag ID were recorded by field personnel.

2.3.2 Reading PIT tags remotely

To observe and record tagged animals through RFID, we constructed 3 prototype configurations of fixed PIT tag reading stations that were active between March and April 2023, and located in restricted areas of Avalon Nature Preserve. We selected locations where (1) tagged deer were regularly observed, (2) equipment would be safe from potential tampering by park visitors, (3) the landscape was easily accessible for maintenance and unobstructed surveillance by trail cameras, and (4) access to electricity was available as an alternate power source. During the design phase, we considered the station's potential for portability, ability for adult deer to move freely though or around the apparatus, and whether adding multiple antennas was necessary in capturing tag information from multiple tags at a time. Each station, while different in design, consisted of a large triple-loop antenna made with coated braided 12 AWG copper wire housed in plastic tubing or sandwiched between wood framing. Each triple-loop antenna was connected to a tuner and attached to a separately housed datalogger via TwinAx cable. A 12-volt deep cycle marine battery was used to power the system. Batteries were changed every 24 to 48 hours to maintain optimal reader function. All components were housed in weather-resistant storage containers with desiccant packs to further reduce risk of moisture accumulation. (Figures 2, 3).

We tested un-used tags ("dummy tags") in both sizes every 24 to 48 hours at each reader station to confirm the system was functioning properly and assess the approximate read range of each size tag. Small fluorescent survey flags were placed at maximum read range distance to better visually evaluate whether tagged animals were close enough to the reader from trail camera footage.

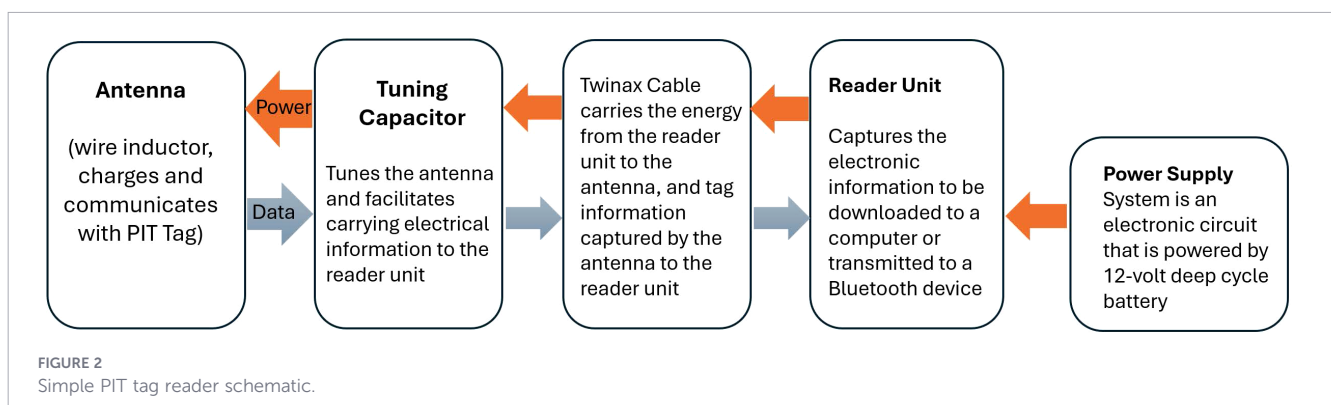
Photo data were used to confirm whether PIT tags were or were not within estimated read range to be captured by the RFID reader. Two Reconyx HyperFire 2TM Covert Infrared trail cameras (Reconyx,

Holmen, WI) were placed at each RFID Reader Station to observe animals from the front and side of the station as a way to cross-check whether animals were present and close enough to the reader to have their tag read. Camera footage was captured on SD cards and downloaded and viewed using Microsoft Photos Application for Windows 10 or Windows Photo Viewer for Windows 8 (Microsoft Corporation). All photos were viewed and tabulated into a workbook in Microsoft Excel, noting the date, time, and quantity of and identification of any animals present in the camera's viewshed. All ear-tagged deer sighted in camera data were cross checked for tag read capture regardless of distance from the antenna to better assess potential read ranges from photo data. Incidence of tag-reading opportunity were recorded as the occurrence of an animal appearing within the estimated read-range from an antenna. Animals leaving the estimated read range and returning were counted as separate incidents. Because the distance between tags and readers was an approximation rather than a precise measurement, we did not assess statistical differences between small tag and large tag captures.

During the data collection period, a NYSDEC-permitted bait station was positioned close to the reader stations to help draw animals to the apparatus and improve opportunities for testing the RFID equipment. Automatic feeders were programmed to release whole corn at the reader station site multiple times throughout the day (Figure 4).

2.3.3 Capturing tag info

The trail cameras placed at the antenna sites were used to provide an indication of tag-reader reliability and individual PIT tag performance. In optimal working conditions, the RFID station will communicate with and capture PIT tag identification each time the tag enters the detection range. Data related to readers' operational status (such as battery life, time and date settings, test tag detections, etc.) and PIT tags within proximity to the reader were downloaded from the reader station datalogger every 12 to 48 hours using the serial port terminal application, CoolTerm for Windows (Roger Meier, <https://freeware.the-meiers.org/>). PIT tag activity was recorded into a text file, where tag identification number, date and time of reading were displayed. These datapoints were cross referenced against tabulated time-marked photo data from the trail cameras to confirm whether tags were captured by the reader when animals were observed within the estimated tag-read range of the reader station antenna.



	Antenna Style	Reader Specs	Power Supply
Reader 1	Single Antenna: Upright horizontal orientation of triple looped 12AWG coated braided copper wire inlayed in a rectangular wooden frame.	Oregon RFID Datalogger Version *5.06	12v deep cycle marine battery
Reader 2	Two independent antennas: upright vertical orientation of triple looped 12AWG coated braided copper wire in flexible plastic tubing in an oval shape, attached to separate rectangular wooden frames	Oregon RFID HDX Multi Antenna Reader with RFM009	12v deep cycle marine battery
Reader 3	Single Antenna: Upright vertical orientation of triple looped 12AWG coated braided copper wire in flexible plastic tubing in an oval shape, attached to a rectangular wooden frame.	Oregon RFID HDX Single Antenna Reader V1.998	12v deep cycle marine battery

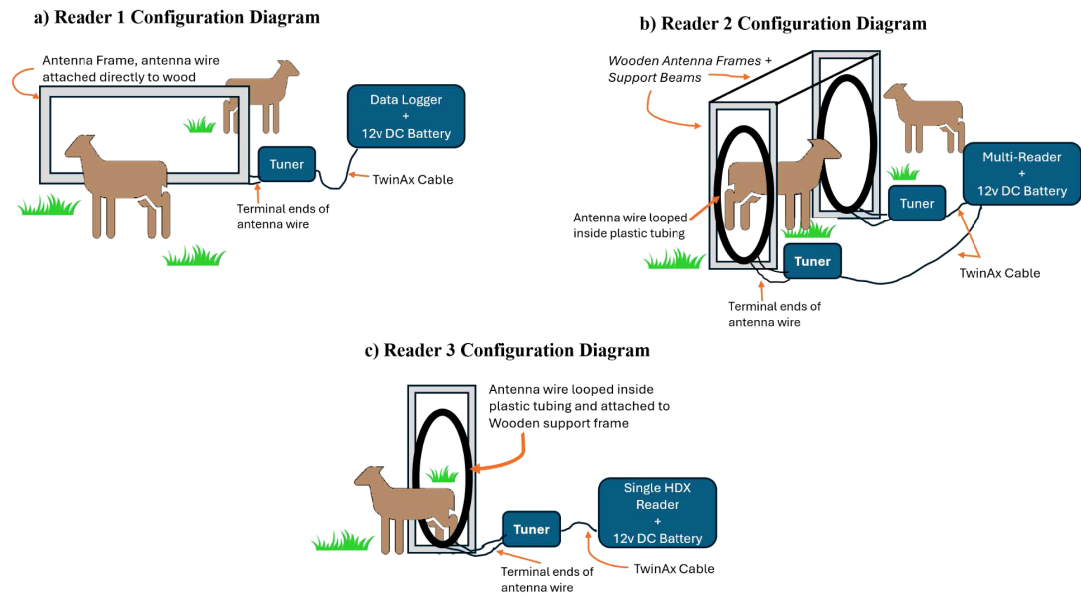


FIGURE 3
Description and diagrams of RFID reader configurations, with components labeled for (a) reader station 1, (b) reader station 2, and (c) reader station 3. All antenna designs accommodate the unrestricted movement of deer through and around the equipment.

3 Results

3.1 Deer treatment & observations

From 2019 through 2021, seventy-five (75) deer were captured and recruited into the study. Of these deer, fifty-one (51) does and one incidentally captured buck were given a PIT tag at the time of capture (Supplementary Table 1). Twenty-two (22) large tags and thirty (30) small tags were deployed. Although we prioritized intramuscular tag injections, ten (10) tags were inadvertently implanted in the subcutaneous tissue. (None of the deer with subcutaneously injected PIT tags appeared in proximity to any reader sites during the data collection period).

3.2 Tag reader performance

Of the fifty-two PIT tagged animals, 7 (12%) showed up on camera within proximity of the RFID reader stations during the data collection period. RFID readers captured 6 of 7 PIT tagged deer successfully. The three RFID reader stations were fully operational from 8 March – 18 April 18 2023, when baiting was permitted under the NYSDEC research permit.

Under optimal conditions when readers had sufficient power supply, large “dummy tags” had an approximate maximum read

range of 90 to 120 centimeters from the center, sides, and corner of the antenna. Small tags could be reliably captured by the reader within proximities of 25 to 50 centimeters of those locations near each antenna (Figure 5). When dummy tag performance fell below this range, the deep cycle marine battery powering the reader was replaced by one with a full charge.

PIT tag reader success was determined by capture of tag information by the reader’s datalogger. To assess reliability of tag captures, we compared the tag capture records on the datalogger of each reader station against photo data evidence of whether deer appeared in proximity of the antenna at the reader locations. A total of 6 individual PIT tags were successfully read at all stations in multiple tag-capture events: Reader 1 (n=12), Reader 2 (n=13), and Reader 3 (n=149), for a cumulative incidence of 174 tag captures (Table 1).

From 16 March to 12 April 2023 camera surveillance confirmed the opportunity for a tag to be read by the reader when a tagged animal appeared within proximity to the antenna. Using this surveillance period, we then divided the number of tag captures by the number of opportunities for tag capture at each location (Table 2). Due to poor camera performance at one of the reader locations (Reader 2), we were ultimately unable to confidently evaluate its reliability beyond the incidence of successful tag reads. Additionally, we omitted datapoints under conditions when the reader was not working properly, such as reporting low power

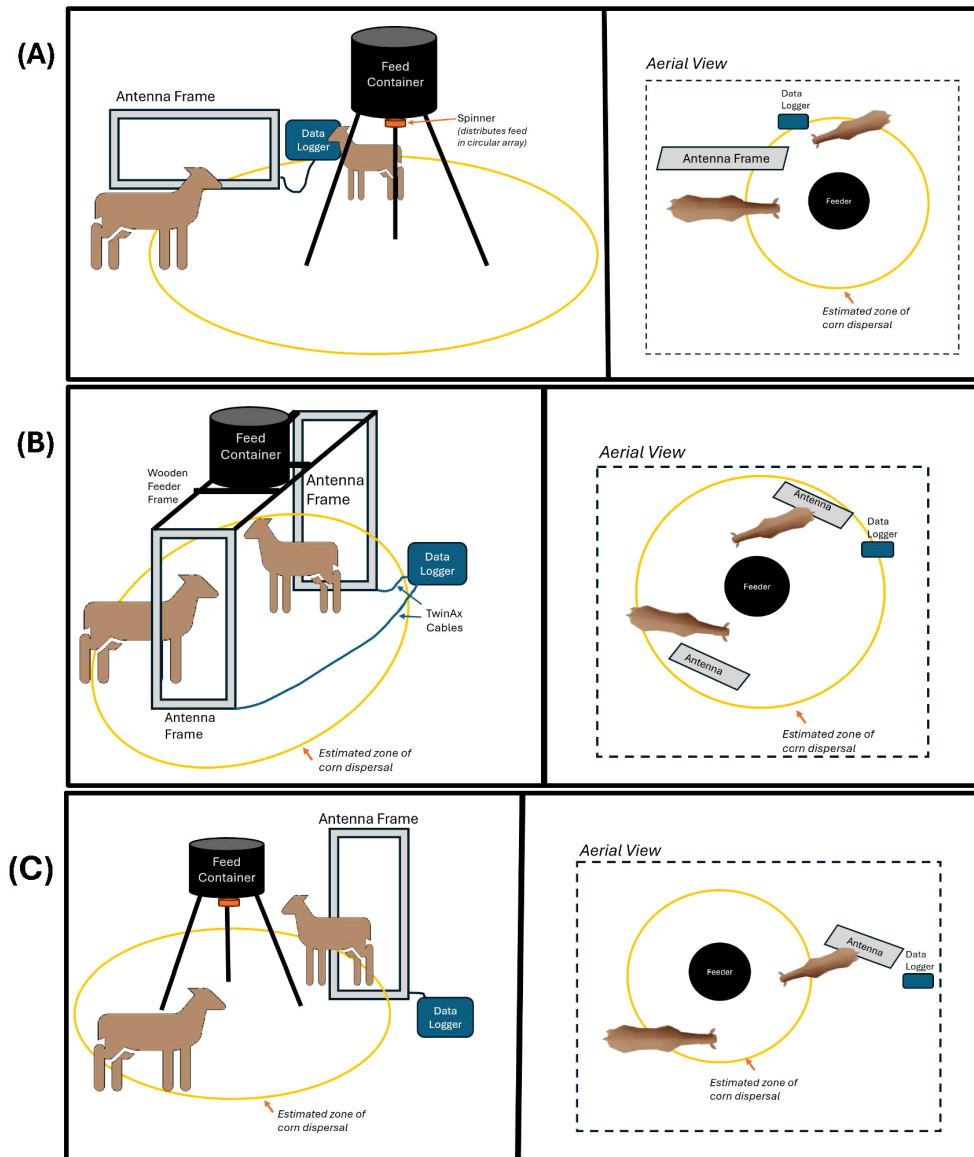


FIGURE 4 Positional diagrams of bait at RFID reader stations. **(A)** Reader 1: single horizontal antenna configuration with standalone automatic corn feeder; **(B)** Reader 2: Multi-antenna configuration with top-mounted automatic corn feeder; **(C)** Reader 3: Single vertical antenna configuration with standalone automatic corn feeder. Yellow line indicates estimated range of corn dispersal from each feeder.

supply or error messaging retrieved from the datalogger at time points where deer may have been present on camera.

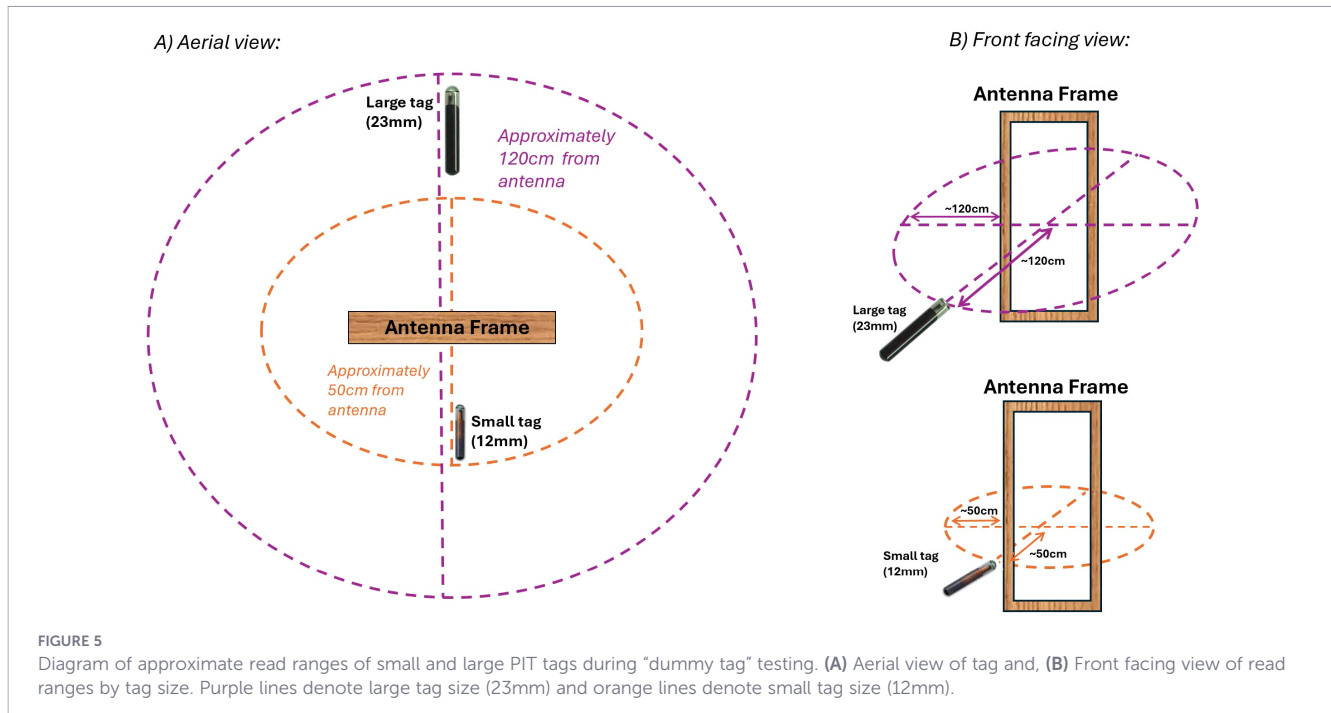
Given the sample size, results indicate that both readers 1 and 3 performed well, but imperfectly, each capturing >75% of tags per read opportunity (visual observation of tagged deer standing within the approximate read range) (Table 3). Reader 1 captured tags 86% of the time per camera surveillance data. While reader 3 had much more animal visitation, the reader failed to capture tags appearing to be within read-range proximity 21 of 91 times (0.23, Table 3). Both Reader 1 and Reader 3 failed to capture a PIT tag on separate occasions during optimal performance conditions, while the animal was standing in the center of the antenna, an ideal location for the reader. One instance involved an animal whose tag was read at a later time, confirming that the tag was present but that the reader did not

capture it. In the second instance, we were unable to confirm whether that animal's tag was present and functioning as this animal never returned within the approximate tag read range again.

3.3 PIT tag retention

All PIT tags captured by the readers were implanted between 3 and 4 years prior to being read, with an average minimum retention of 3.55 years. Of the PIT tags captured (n=6), two were small tags and four were large tags.

An additional study animal not recorded by the RFID reader stations during the data-collection period was found deceased at the preserve. A manual scan of the animal on 21 February 2025 detected and read the indwelling PIT tag in the hip musculature close to the



original injection site (on 7 March 2020) signifying that the tag had been retained in place nearly 5 years.

4 Discussion

The successful implementation of PZP programs in wildlife hinges on the need to identify individual animals for multiple immunocontraceptive treatments over time, while not treating the same animal repeatedly during a single field session. Our investigation of the use of RFID technology to remotely identify individual white-tailed deer brings us one step closer to refining field methods and improving outcomes for both animals and program managers.

Gibbons and Andrews (2004) explain primary considerations for animal marking methods. Such methods should cause no detrimental effects on the study animal; should be permanent or last the duration of the study; be a unique and easily readable code; be comprised of field-hardy components; seek to minimize handling

time; and not be cost prohibitive. Our exploratory field trial indicates that RFID aligns with these criteria. Our findings suggest white tailed deer tolerate and retain PIT tags injected intramuscularly; the tags are easy to administer; and RFID reader stations are durable in outdoor conditions and can remotely detect these tags in real time. Further, when compared to high costs of capture (Bengsen et al., 2021; Hampton et al., 2019), PIT tags may provide an affordable and more field-efficient alternative to ear tagging or collaring.

In contrast to poor PIT tag retention described in other studies (Belser et al., 2017), our data shows multi-year PIT tag retention in wild white tailed deer when injected in the hip/gluteal musculature (minimum average of 3.5 years). This longevity of tag retention suits the identification needs of long-term immunocontraception program efforts. Although our data confirms that PIT tags offer adequate identification for vaccinating and revaccinating deer for at least 3 years, additional years of surveillance with RFID readers would be helpful in examining the longevity of PIT tags beyond this time period to confirm whether tag retention aligns with the reproductive lifespan of free-roaming female white-tailed deer.

While promising, utilizing RFID in wild deer is not without its caveats.

4.1 Importance of PIT tag sizing

Tag size matters for both the comfort and safety of the animal, and the technical capacity of the tags. It is suggested by the manufacturer that the largest sized tag be selected when possible, to improve the range at which it can be read; however, the smaller tag sizes may be more readily delivered by dart, and may better accompany a dose of contraceptive emulsion that also has a pellet set, such as PZP-22, in a single dart. While smaller sized tags are likely to be more comfortable to the animal and readily delivered

TABLE 1 Summary of PIT tags captured by 3 reader configurations during optimal performance conditions from 8 March 2023–18 April 2023.

Reader ID	Reader configuration	Count of PIT tag captures
Reader 1	Single Horizontal Antenna; ORFID Datalogger Version '5.06	12
Reader 2	Two Vertical Antennas; ORFID HDX Multi Antenna Reader with RFM009	13
Reader 3	Single vertical antenna; ORFID HDX Single Antenna Reader V1.998	149
	Total Tag Readings:	174

TABLE 2 Success rates of PIT tag captures by readers during camera surveillance from 16 March 2023–12 April 2023.

Reader ID	Count of PIT tag captures	Count of tag capture opportunities	PIT tag captures/opportunities
Reader 1	6	7	6/7 (0.86)
Reader 2	13	–	Unable to assess
Reader 3	70	91	70/91 (0.77)

remotely, the larger size tags are more likely to read at greater distances to the tag capture device (up to approximately 1.2 min our model builds). A larger sample size is warranted to further evaluate and compare tag size performance. A limitation of remote assessment of PIT tags is attributed to the tag's orientation with respect to the antenna. Given that we did not recapture and scan animals by hand to confirm the tag's location and function, we cannot rule out tag migration as a potential variable in tag performance. However, as described in the results, a postmortem scan of a deceased study animal did confirm the PIT tag's function and location consistent with its initial injection site.

4.2 Access to animals is important

Although 52 PIT tags were deployed during the study, only 7 tagged deer approached the readers within close enough proximity during the data collection period. However, given our promising results on tag retention, it is possible that additional tags could be read in the future by placing reader stations in other areas. We selected reader site locations on restricted portions of the preserve that (1) had known tagged animals in the area, and (2) could provide a safe accessible location to easily maintain the reader equipment and avoid risk of theft or tampering. Because of the secluded nature of our reader site selection, we were unable to assess tag retention or performance in a large portion of study animals, particularly those that do not typically access the properties in which our readers were located. While bait leverage certainly assisted in our ability to lure animals to readers, utilizing this strategy and deploying additional readers across the site in other seasons when food sources may be less abundant could improve reader visitation. Given that many tagged animals reside outside of the park in residential portions of the study area, additional measures to secure and maintain equipment and provide public education should be considered.

While we set out to develop a field methodology for deploying and remotely reading PIT tags in deer, our 3 different reader arrangements provided varied results. This may be due to specific station components and configuration, as well as a station's accessibility to tagged animals. Some animals appeared reluctant to approach the antenna, which impacted our ability to capture more tag reads. We suspect that Reader 3 had more visitation from tagged animals because this location was situated in an area more actively used by multiple groups of deer moving through their respective home ranges; the location is secluded and much less disturbed by public activities and park staff foot traffic; and was previously used as a baited site for animal capture during the initial tagging phase of the study, allowing more time for animals to acclimate to its presence. In the future, deploying antennas or equipment in the field ahead of treatment or data collection efforts, and installing antennas that are camouflaged along paths and trails that deer readily travel through may allow for improved acclimation and visitation.

Camera reliability varied by site, with one reader location having poor camera surveillance due to human error in set-up and maintenance. It is also possible that the age, battery life, and distance of some cameras to the reader influenced the success of surveillance. Interestingly, this location (Reader 2) likely had low animal visitation due to new structural construction projects and property-use changes in the immediate area during our surveillance period.

4.3 Technical challenges

We experienced a variety of equipment related challenges during the construction and testing of our antenna arrays. On-site technical assistance and replacement or repair of reader components from the manufacturer ultimately assisted us in getting 3 arrays that displayed consistent success in dummy tag testing and general function. After testing several power source options (both fixed electricity with an AC adapter and deep cycle marine battery) we found the deep cycle batteries to be the most consistent, though charging and changing of batteries was necessary every 1 to 3 days to maintain optimal tag read ranges. Exploring the use of solar panels to recharge battery-powered readers in remote locations could reduce labor related to frequent battery changes.

Strategies for identifying wildlife often rely on significant photographic, videographic, and acoustic data collection efforts to build robust databases for comparing and confirming individual

TABLE 3 PIT tag retention in deer ($n=6$).

Animal ID (ear tag/PIT tag)	Tag size	Date of tagging	Date of last read	# years tag retained
Pink 5/878	Large	4/21/2019	4/13/2023	3.98
Pink 2/879	Large	4/18/2019	4/18/2023	4.00
White 77/885	Large	2/29/2020	4/17/2023	3.13
Purple 72/155	Small	3/9/2020	4/7/2023	3.08
Pink 4/882	Large	4/19/2019	4/4/2023	3.96
White 82/182	Small	3/2/2020	4/17/2023	3.13

identity, and may not offer real time identification in the field without the advancement of computer-generated learning platforms (Petso et al., 2022). While we re-purposed trail cameras used for monitoring populations for the sake of surveilling the readers and confirming their ability to capture PIT tag information, the use of trail cameras for identification is not practical for real-time identification, nor was it completely reliable. Advances in technology that enable real-time communication with the reader may allow for immediate identification of animals and should be further explored. Since our field work ended, OregonRFID has begun to offer a smart-device application compatible with their newer equipment that allows a handheld device to use Bluetooth to remotely log into a reader station, which could provide rapid real-time animal identification.

4.4 Practical implications & future development

Achieving wildlife population targets in communities where traditional methods are ineffective or publicly unacceptable remains challenging. Reversible, remotely-delivered wildlife fertility control agents such as PZP have been shown to be effective at controlling such populations (Rutberg and Naugle, 2008; Rutberg et al., 2013). However, this approach would be much more practical if paired with methods of individual identification that do not require capture. Similar to studies tracking amphibious animals as described in the introduction, we sought to deploy RFID technology to passively identify larger terrestrial mammals. By developing and refining PIT tag reading stations suitable for deer size, behavior and habitat, coupled with incorporating advances in available technology (e.g., Bluetooth communication to a handheld device linked to the reader) we hope to further explore how to identify deer in real time as they visit the baited reader station during ideal vaccination timelines. This would help improve efficiency in the field, and reduce unnecessary handling of animals through (1) actively identifying new (untagged) deer for eligible for remotely delivered PIT tagging and treatment with PZP, (2) re-identify previously treated deer with appropriate supplemental doses, and (3) consolidate labor related to seasonal PZP-treatment protocols. While this paper does not report on vaccine performance, an understanding of how PZP vaccines are administered in the field provides insight on the advancement of developing and incorporating remote delivery technologies. We treated half of our study cohort with hand-injected vaccines during the chemical capture process, and the other half were treated remotely via opportunistic darting. Considerations for PZP and PZP-22 dosage volumes and dart mechanics in this and previous field studies (Turner et al., 2008; Rutberg et al., 2013) lay the groundwork for remotely-only vaccine delivery.

Incorporating real-time methods for identifying deer will improve field efficiency in treating animals and managing treatment schedules for individuals in tailored fertility control programs. While our study demonstrates the potential for using PIT tags and RFID readers to remotely identify white tailed deer, and Walter et al. (2012) demonstrated dart-delivery of PIT tags, further investigation into

dart delivery of PIT tags in conjunction with a contraceptive agent in a single injection is necessary to further demonstrate a fully remote-delivered immunocontraceptive strategy for deer.

RFID may also prove to be helpful in estimating animal abundance through mark re-sight methods as demonstrated in little brown bats (Waag et al., 2022). Mark re-sight methods utilize readily observable markings of individual animals in an area and compare their presence against observations of both marked and unmarked animals in the population to estimate abundance and population demographics (McClintock, 2011). The use of RFID as the marking strategy could replace the need to capture and ear-tag deer when estimating abundance of female populations. McClintock (2011) further suggests that if the marking method is reliable in identifying individuals in the field, mark re-sight can reduce stress to animals as they can be observed remotely and with minimal disturbance. Through the potential of remotely delivered and remotely read PIT tags, it is possible that marking female deer can be done without capturing them, and further improve upon less-invasive treatment and observation protocols. Further, this could assist PZP program managers at evaluating vaccine impacts on population sizes and dynamics such as age, sex, and movement patterns.

5 Conclusion

Altogether, our study demonstrates proof of concept to a practical challenge in implementing immunocontraception programs for deer. We demonstrate that PIT tags have the potential to offer a long-term (multi-year) form of remote identification in deer and can be implemented successfully in field conditions. Further, utilizing PIT tags in immunocontraception programs is a less invasive and less expensive alternative to capturing animals. Along with further refinement of RFID equipment and utility, additional research on dart-delivery into wild deer in conjunction with immunocontraceptive vaccines is warranted to remove the need to physically handle animals in these types of programs, ultimately reducing negative impacts to animals, and improving animal welfare outcomes, and ease of implementation.

Data availability statement

The original contributions presented in the study are included in the article/[Supplementary Material](#). Further inquiries can be directed to the corresponding author.

Ethics statement

The animal study was approved by Tufts University Institutional Animal Care and Use Committee (IACUC protocol number 2019-01). The study was conducted in accordance with the local legislation and institutional requirements.

Author contributions

KP: Conceptualization, Data curation, Investigation, Methodology, Project administration, Writing – original draft, Writing – review & editing. AR: Conceptualization, Investigation, Supervision, Writing – review & editing.

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