Testing Infrared Technology to Locate Active Migratory Bird Nests

by

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COMMITTEE APPROVAL

The members of Brian Gustafson's Thesis Committee certify that they have read the thesis titled Testing Infrared Technology to Locate Active Migratory Bird Nests and recommend that it be accepted as fulfilling the thesis requirements for the Degree of Master of Science in Environment and Management:

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Abstract

The *Migratory Birds Convention Act of 1994* prohibits the destruction of migratory bird nests (incidental take), requiring industry to avoid activities that may put nesting birds at risk. Active nest surveys currently used by industry to avoid incidental take are not endorsed by Environment and Climate Change Canada due to a low probability of nest detection and the risk for surveyor caused incidental take. Active nest surveys with a hand-held infrared (IR) device could be an alternative less invasive and more effective method of detecting active bird nests than standard nest-searching methods. My research tested the effectiveness of an IR device in detecting simulated and real active nests across varied nesting habitats and nesting strategies. I concluded that the detection of active nests is possible with IR, although detection is not consistent across all habitat types or nesting strategies. The mean Maximum Detectable Distance (MDD) for all simulated and real active nests tested was 28.1 ± 2.1 m. Mid-story cup nests ($n = 7$) were detected during active nest surveys, mostly in shrub edge habitats ($n = 5$) followed by deciduous ($n = 1$), and coniferous ($n = 1$) forest types. There is potential in the future use of IR to non-invasively detect active nests; additional research with reduced biases (e.g., simulated nest insulation) and a more sensitive IR unit is needed to determine the most suitable approach. A comparison of active nest detections with the IR unit to standard search methods using behaviour cues would determine if using IR is a more effective approach to detect active nests.

Keywords: Active nest survey, incidental take, infrared imagery, migratory birds, nesting birds.

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Introduction

The destruction of bird nests has global scale impacts especially when it involves migratory species that span continents through their life cycle. Birds provide many environmental services that support the functioning of natural and human systems suggesting that a loss or decline of successful nests results in economic hardships in other connected systems. In British Columbia, provincial and federal legislation provide protection for birds and their nests against willful destruction. Bird nesting occurs at the same time that logging companies plan to harvest trees and construction companies plan to build infrastructure so incentive exists to navigate the legislation and avoid the destruction of bird nests. The survey procedures commonly used by industry to locate active bird nests and avoid destruction are not without issue, as they are criticized for contributing to nest failure and having low rates of nest detection. Technological advancements in hand held infrared (IR) sensing devices show promise for decreasing surveyor caused nest failure (incidental take) and improving nest detection rates. Prior to my research, IR was untested for this specific application.

In order to test IR for detecting active bird nests, all similar research was reviewed to discover where known limitations exist to develop methods that could overcome shortfalls. Research questions were developed followed by objectives and methods to conduct the research and analyze data to answer the research questions.

Migratory Birds in Canada and Incidental Take

Avian mortality as a result of anthropogenic activities (incidental take) has a global scale impact when it comes to biodiversity loss and the reduction of beneficial ecosystem services provided by birds. Pollination, pest control, seed dispersal, and nutrient cycling (Longcore & Smith, 2013) are just a few of the services provided to provision and support ecosystem and human functions. The economic value of these services are significant as Whelan, Sekercioglu, & Wenny (2015) report; bird provided pest control in coffee plantations can increase crop values from US $44/ha to US $310/ha. Every service that birds provide can be correlated with a value so, as the loss of birds increases around the world so does financial investments to artificially reproduce these lost services (i.e. the use of pesticides to control pests that birds would regularly consume). With an estimated 269 million birds and 2 million nests destroyed annually in Canada through human related activities (Figure 1) the economic impact of the loss of services provided by birds, while hard to quantify, is significant. Many birds migrate on an international scale so losses in one geographic location are felt throughout the migratory range. Although cats, buildings and power generation are the top contributors to avian mortality, industrial operations such as agriculture, forestry, and oil and gas operations represent a major cumulative impact to populations (Calvert et al., 2013).

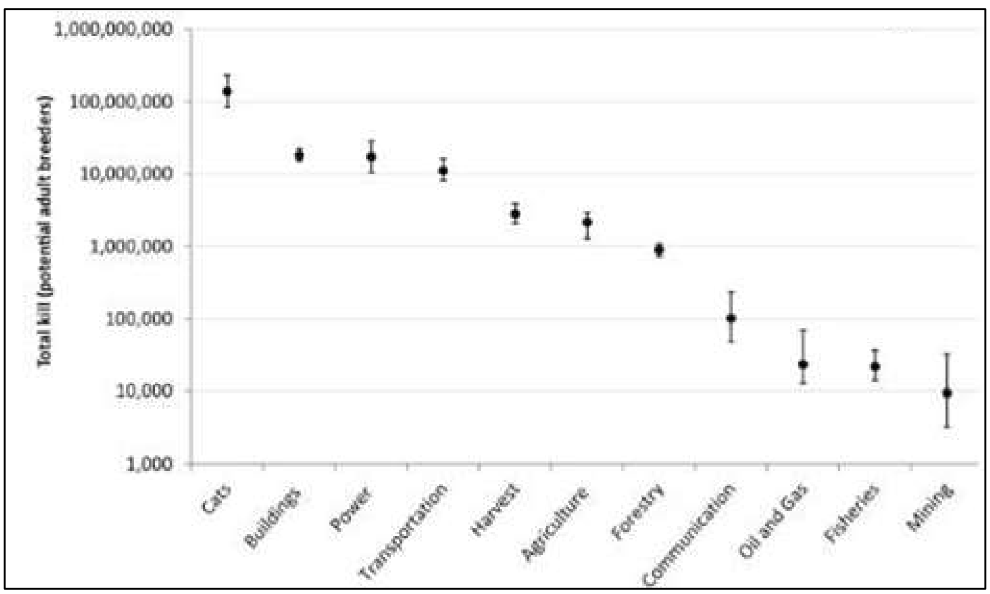


Figure 1. Avian mortality estimates per human-related activity (median with 90% confidence limits) (Calvert et al., 2013)

The *Migratory Birds Convention Act*, 1994 (*MBCA*) (Government of Canada, 1994) prohibits the intentional destruction (i.e., direct take) and unintentional destruction or disturbance (i.e., incidental take) of migratory birds and their nests. While the *MBCA* offers federal protection to migratory birds and their nests the BC *Wildlife Act* (Government of BC, 1996) provincially prohibits the destruction of any occupied bird nest, not just migratory species. Given the documented level of avian mortality caused by industrial activity (Calvert et al., 2013), it is evident that industrial operations are exposed to legal liabilities under the *MBCA* and the BC *Wildlife Act.* To avoid these liabilities, industry will either conduct disturbance activities (e.g., vegetation clearing) outside of the nesting season or, when delaying work is not possible, conduct active nest surveys to identify nests and avoid destruction. Standard active nest survey protocols are restricted by acceptable environmental conditions (e.g., temperature and precipitation) and do not yield 100% detection rates which often results in rushed surveys (pers. obs) and destroyed nests despite best efforts to locate and avoid nests. The development of tools to more readily identify active nests and reduce industrial impacts on birds is a priority.

Standard Active Nest Surveys

To avoid the destruction of birds and their nests, industry commonly employs active nest searching techniques prior to conducting high risk activities (e.g., tree clearing) during the nesting season. These surveys are not reliable in detecting all of the nests in an area and can contribute to nest failure. Standard techniques for active nest surveys are based on industry best practices and standards put forth by provincial regulators, such as the Sensitive Species Inventory Guidelines produced by the Government of Alberta (2013). Survey methods require ornithologists to walk transects within a pre-defined work area to visually identify nests with the assistance of audio playbacks and bird nesting cues, such as; male birds singing, adults carrying food, adults carrying nesting materials, defensive behavior, and distracting displays. Repeated visits are required depending on the complexity of habitats the are being surveyed. Surveys of this type are difficult to standardize due to biases rooted in the previous experiences of the surveyors and can result in nest failure (Rodewald 2004).

Rodewald (2004) suggested that active nest surveyors use two main strategies for searching for active nests, following parent bird behavior and searching substrate for nests. Nests can also be discovered by plain luck and by flushing adults off active nests. Biases are tied to these different survey strategies as Rodewald (2004) reported; behavioral based methods can yield nest discovery to higher elevations off the ground (10 m) whereas substrate searchers will yield lower elevation discoveries (7.5 m) and rely on flushing adults and luck bias discovery to much lower elevations (3.5 to 4.2 m). Rodewald (2004) further concluded that nests discovered by flushing adults (5% of nests) are much more likely (up to 70%) to fail, suggesting that standard active nest surveys inherently result in surveyor caused incidental take.

In an attempt to defend nests from predation, many bird species will employ deceptive nest defences which can range from sneaking away from the nest as a predator approaches to loud vocal or elaborate physical displays intended to lure predators away from active nests (Smith & Edwards, 2018). The threat of predation that a surveyor poses will, in many cases, result in triggering these deceptive behaviours flushing parent(s) from a nest, leaving eggs without incubation (pers. obs.). Prolonged adult absence from nests can affect hatching success (Ospina, Merrill, & Benson, 2018). Searchers will not only flush nesting birds, the presence of searchers trying to pinpoint nest locations can also prolong the return of birds to a nest. The other danger while trying to pinpoint nest locations, primarily when looking for ground nests, is stepping on the nest and destroying the eggs or nestlings. Being able to pinpoint the location of a nest from a distance, by using IR, could reduce the risk of flushing, prolonged absence and nest destruction (surveyor caused incidental take).

While active nest surveys are a common industry practice, the technique is not endorsed by Environment and Climate Change Canada (ECCC) as an effective mitigation for avoiding incidental take since active nest searches are criticized for being invasive to nesting birds and ineffective in locating all active nests (ECCC, n.d). Active nest searches typically result in some active nests being identified; however, cryptic nesters such as cavity nesting and tree top nesting species are often missed. Dohms & Huang (2017) tested standard active nests surveys and discovered that *"in forested sites searching for cavity nesters, at the third visit the proportion of detected nests was on average 80%, but can be as low as 30% in some cases. Further, nest detectability may be even lower for other forest birds, such as those nesting in the canopy, due to their low visibility."* These findings suggest that a large amount of time (up to 10.8 hr/ha in riparian habitats (Dohms & Huang, 2017)) is required to find all active nests in an area, an amount of time which is not always feasible when working on an active construction site, given schedule and financial constraints. A new technique for locating nests that is less invasive and yields better results with less effort is required to reduce incidental take and minimize legal liabilities for development activities occurring during bird nesting seasons. Using IR technology to locate nests by detecting the heat emitted by the nesting birds or eggs has potential to be the more effective and less invasive option.

IR Technology and Application

Infrared radiation is emitted by anything that has a temperature above absolute zero (McCafferty, 2013) and is detectible by infrared sensing devices. This technology has the potential to effectively detect nesting avian species' body heat or warm incubated eggs. Incubation is the process of using body heat to influence the development of the embryo in the egg so birds incubating eggs in their nests provide a constant temperature (i.e., heat) that should be detectable by an infrared camera. IR has been used in avian research since the 1960s mostly as a method of non-invasively detecting surface temperatures in captive birds (McCafferty, 2013). IR also has a history of use in research with a variety of other taxonomic groups.

IR technology has been used for a variety of applications across a range taxa and biological sciences for; disease detection, detecting reproductive status, researching thermoregulation, analysis of animal behaviour, and detection of animals and estimating population size (Cilulko, Janiszewski, Bogdaszewski, & Szczygielska, 2013). Through these different applications of IR, the literature review conducted by Cilulko et al., (2013) lists discovered limitations;

- Weather conditions, specifically solar radiation;
- Distance from IR device to the object;
- Field of view, influences exposure to solar radiation;
- Obstructive vegetation between the object and IR device;
- Thermal retention properties of animal fur, skin, feathers or hair;
- Stressors influencing thermoregulation;
- Blood circulation or lack of blood circulation in some body parts;
- Animal behaviours that can affect the ability to detect heat; and
- Cost of purchasing IR units.

The limitations listed above are similarly reported in avian specific applications but there are also some applications used in research similar to searching for active bird nest that supported progressing with my research. In a recent research project, IR was used to search for nests of passerine birds in Iowa where the researchers noted that there was potential in IR for locating nests, but IR was not particularly effective in this specific application as reflected solar radiation and thick vegetation obstructed nest detection (Stephenson, 2017). Galligan, Bakken, and Lima (2003) also reported positive results in the detection of grassland species with IR and suggested that early morning, prior to sunrise, provided the best conditions for nest detection. In another study, active nest searches were conducted in Alberta using an IR camera mounted to a drone; this research is still ongoing but early phases show promise for the method (N. Bartok Pers. Comms, 2019). IR was also successfully used to locate birds during a study in Australia where night roosting birds were located and studied non-invasively (Mitchell & Clarke, 2019). As IR technology becomes more readily available, research into the efficacy of IR as a tool for avian detection has increased despite the identified limitations.

While there are limitations to IR technology, IR is less invasive as it allows for nest observations at a distance (McCafferty 2013). Application-specific testing is required to determine the functionality in conducting on the ground, active nest surveys and develop techniques that overcome the shortfalls of IR, such as difficulty in locating active nests as a result of background false positive detections, obstruction from vegetation, and efficient nest insulation (Boonstra et al., 1995). Boonstra et al. (1995) suggested that timing surveys in the early morning would aid in providing a scenario with the greatest temperature gradient between nest and ambient temperatures which will likely address most of these identified limitations.

Research Objectives

The objective of my research was to test IR imagery for locating active bird nests and quantitatively analyze the collected data to answer the question: can infrared imagery be used to locate active bird nests across a range of nesting strategies and habitat types?

In order to answer this question, the Maximum Detectible Distance (MDD) of nests was determined through simulated nests tests and real active nests surveys with an IR device. Simulated nest tests were conducted with nest location known to the surveyor and surveys for active nests were conducted with the IR device to test the ability of the device to detect active real nests, where the location of the nest was unknown. Previous research aided in overcoming the known shortfalls in IR technology. Surveys were conducted in the early morning to address issues of solar influence and background false positives and redundancy was built into the survey techniques to overcome obstructing vegetation that would limit detection. Questions that emerged through research and data collection included:

1. Is there a difference between the MDD of simulated and real nests?
2. Does habitat type influence nest detection?
3. Do nesting strategies vary in detectability?
4. Do the settings used on the IR device have an influence on nest detection?
5. Is the distance that a nest is initially detected different from the MDD?

I predicted that there would be minimal difference between real and simulated nest MDD because reasonable care was taken simulate the different nesting strategies, though tree top nest did pose a challenge for simulation. Habitats were suspected to influence detectability as obstructing, low-elevation, vegetation species and forest structure varied across habitat. It was suspected that nest detection would be possible from a greater distance in habitats with less obstructing vegetation.

Previous related publications and conversations with researchers gave initial hope for the use of IR technology for locating active nests; however, challenges were known especially with detecting active ground nests. It was suspected that cavity nests would be easier to detect than ground nests because of the likelihood of reduced obstructing vegetation higher off the ground, and particularly that grassland ground nests would likely be the most difficult to detect (Stephenson, 2017). The biggest unknown going into this research was whether tree top cup nests would be possible to detect by IR as there was no specific previous research around this strategy.

With some initial experimentation with the FLIR® device selected for use in my research, I expected that there would be significant variability in the setting of the device therefore, a variety of device settings were tested. With the known issue of vegetation obstructing the detection of heat I expected that the detection of a nest would depend on aligning a view of the nest with no obstruction so the distance that the nest was initially detected would likely be shorter than the MDD of the nest.

In the path of achieving the objectives of my research, I first needed to decide how I would test the IR unit to lead to a determination of the unit's effectiveness in detecting active bird nests. I then needed to select locations to test simulated nest detections and survey for active real nests. The sites selected needed to be representative of a variety of habitat conditions that would support a range of nesting strategies. A suitable IR device that was appropriate for the application was acquired based on durability and functionality. Techniques for testing the MDD of simulated nests and surveying for active real nests were determined through past experience and background research. Methods for simulating the different nesting strategies were devised followed by determining data fields for later analysis. Conclusions were drawn following the quantitative analysis of mean MDD data from the different nest simulations and real nest searches.

Methods

Testing Phase and Survey Phase

MDD measurement data for the different selected habitat types and nesting strategies were collected in two different phases of my research—testing and surveying—in the spring of 2019 (May to July) during the most active period for bird nesting in the region. During the testing phase, I used simulated nests comprised of gel heat packs to imitate the heat produced by birds incubating eggs. The methods used for simulation varied across the different nesting strategies to overcome differing logistical challenges and details regarding the heat packs are described further in the Nest Simulation section that follows. The data collected during the testing phase were used to increase the sample size for my research. By using simulated nests, less time was spent looking for real nests to conduct tests for MDD on so, the focus could be put on determining the ability of the IR device to detect nests, or something similar to a nest. Additionally, using simulated nests while testing the FLIR® device reduced the likelihood of disturbing real nests resulting in incidental take.

The regional nesting period for my study area is between mid-April and mid-August (ECCC, n.d.). Simulated nest trials were conducted within this period to ensure similar environmental conditions as when active nest searches would be conducted. Ambient temperature was of particular concern when conducting searches as it was hypothesized that ambient temperature would have an impact on the detectability of nests with IR due to the difference in temperature gradients between nests and the surrounding environment. In the colder months (e.g., earlier in the nesting period), the temperature gradient between the active nest or simulated nest would be much greater than in the summer months when ambient temperatures are closer to that of an active nest. Testing in colder months would likely give skewed results of nest detection because of the greater gradient of temperatures between ambient and bird body or incubating temperature.

IR detection is more successful in the morning when there is less interference from solar influence on vegetation, soils and other features (Galligan et al., 2003). Based on this information, I primarily conducted testing of both simulated nest detection and IR active nest surveys prior to sunrise starting at as early as 5:30 am and going to as late as 8:30 am. Overcast days can yield optimal conditions where solar influence does not create background noise that would obstruct active nest detection (Galligan et al., 2003). Therefore, when conditions allowed (i.e. cloud cover limiting solar influence), active nest searches and testing continued past sunrise.

Ambient temperature was taken using a digital Bios DT131 thermometer prior to starting the tests and surveys. Since all surveys and test sessions commenced prior to sunrise or occurred in conditions with obscured solar influence, shielding the thermometer from solar interference was not of concern. The thermometer was suspended in vegetation at heights between 1 m and 1.5 m to get an ambient temperature reading.

In total, 67 nest simulation scenarios were tested: 25 tree top nests, 14 mid-story nests and 28 ground nests. No cavity nests were simulated during testing, but seven active cavity nests discovered using nesting cues were used in the testing phase. An additional five active real nests were discovered during surveys (using nesting cues) that were also used to test the device: four mid-story cup nests and one tree top nest.

The IR survey phase was a structured process of covering a transect area with sweeps with the IR device in attempt to locate active nests. No simulated nests were used in this phase as the focus was on detecting real active nests that were unknown to the surveyor (B. Gustafson). Following the detection of an active nest, the maximum distance that the nest could be detected with the IR device was measured (MDD). Details on the method used to conduct surveys is presented in the IR Survey section that follows. A total of seven active real nests were detected with the IR device in the survey phase.

Site Selection

Diverse habitats that provide opportunities for not only a variety of bird nesting strategies but also an abundance of bird species were sought out to conduct simulated nest testing and IR active nest searches. My research was conducted in the Columbia Valley near Golden, British Columbia (Figure 2). The Columbia Wetlands is a RAMSAR designated wetland of international importance and is an integral part of the Pacific Flyway. As many as 163 different bird species are known to migrate through this area (Darvill, 2020) with many staying to breed. Within the region, there is a variety of wetland, upland forest and grassland habitat that provides variability in site conditions and nesting habitats. This variety of ecosystems and habitat types within the Columbia Valley provide for a diversity of avian species using different nesting strategies, making this area ideal for my research. Seven different locations in close proximity to Golden were identified for data collection.

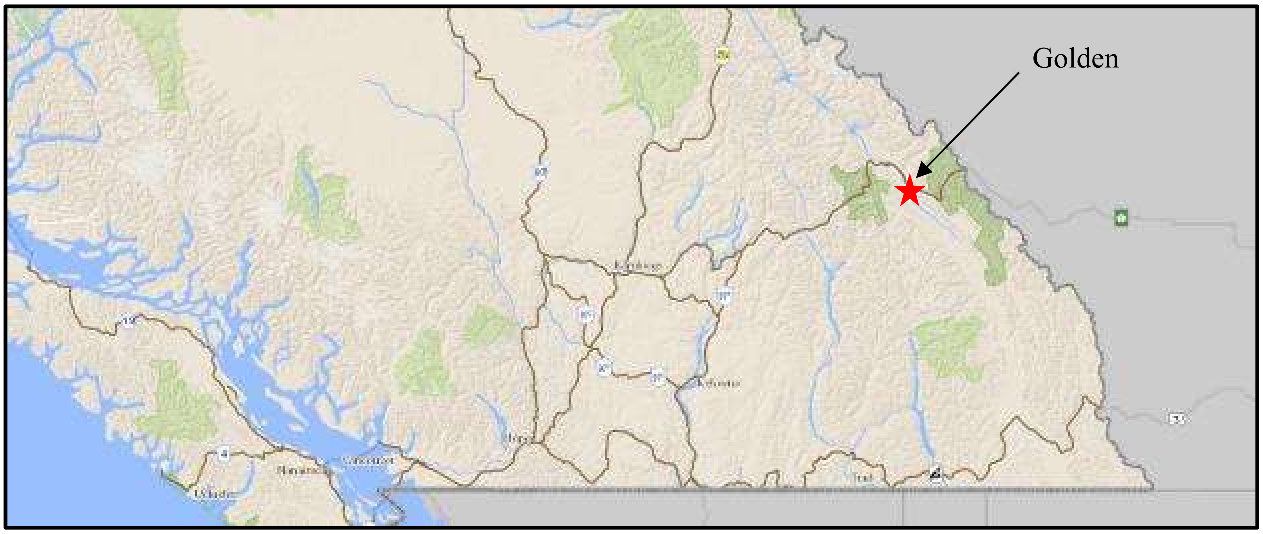


Figure 2. Overview map of southern British Columbia. The red star indicates Golden, the general location of this research.

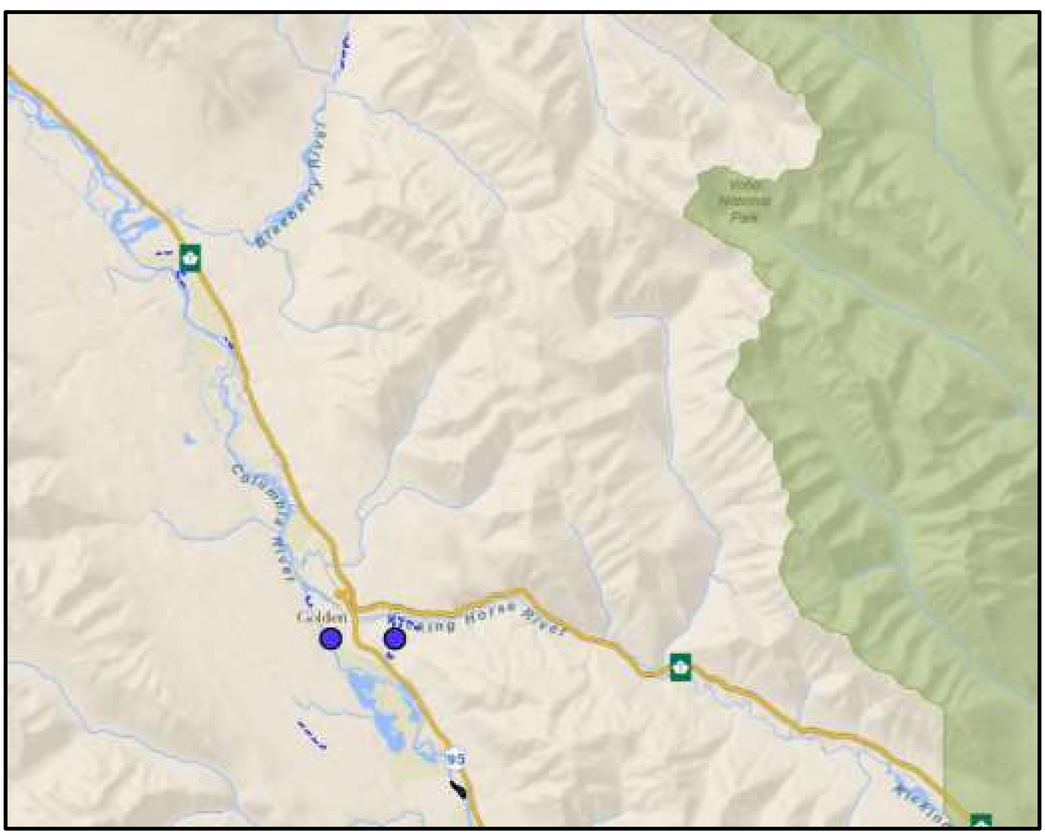
Study Site/Habitat Descriptions

The seven selected research locations were used to conduct simulated nest testing and IR active nest surveys. Sites were located throughout the Golden area extending 20 km to the northeast of Golden into the Blaeberry Valley, 8 km south of Golden to the Nicholson Bridge and 5 km west to the Moonraker trail network (Figure 2;

Figure ***3.*** Overview map of locations around Golden used for the testing and survey phases of the research. Blue hatched lines indicate surevey transects and purple dots indicate testing sites

*Table **1***). Test sites and survey transects were selected based on several factors: known bird abundance, ecosystem variability, access, and nesting habitat diversity. Some locations were used for simulated nest testing and others were used for IR active nest surveys. The majority of the transects surveyed followed existing trails or old roads. The selection of the research locations was intended to focus on areas with easy access that have a wide variety of habitats and diverse bird use to maximize the probability of detecting active nests. Photos of the representative site conditions are presented in Appendix A.

Site conditions were important for site selection especially when looking for cavity nests as trembling aspen *(Populus tremuloides)* are common tree species used by cavity nesting birds (Li & Martin, 1991); therefore, forest stands containing a high frequency of trembling aspen and other deciduous species were sought out to conduct IR active nesting surveys and test for cavity nest detection.



Habitats were categorized into deciduous, coniferous, or mixed forest as well as shrub edge which provided the basis for determining difference in MDD across habitat types.

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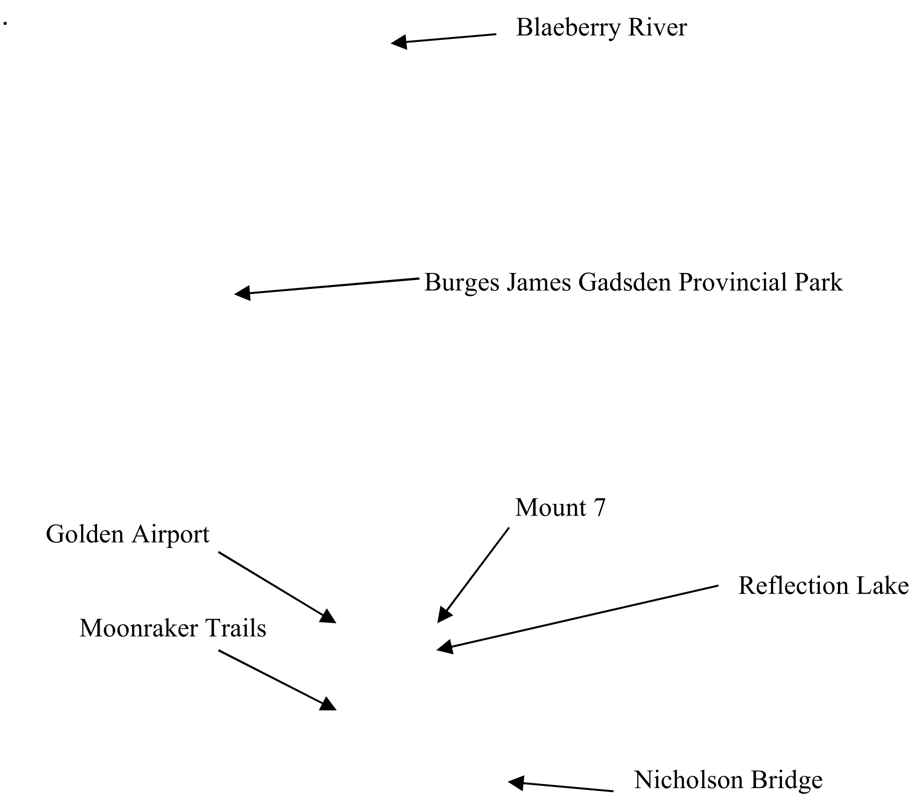

Figure 3. Overview map of locations around Golden used for the testing and survey phases of the research. Blue hatched lines indicate surevey transects and purple dots indicate testing sites

Table 1. Summary of research location information.

Survey Locations	**Species Richness**[1]	**Ecosystem**[2]	**Habitat Features**	**Habitat Categories** [3]	**Nest Types (Searched (s) or Tested (t))**	**Area Surveyed**

Blaeberry River (Figure A 1)	57 species	MSdk	Older forest River banks Shrub understory	M,C,S	Ground (s) Cavity (s) Tree top (s) Mid-story (s)	One transect
Burgess James Gadson PP (Figure A 2)	181 species	MSdk	Young forest Wetlands Open shrubs Forest edges	M,D,S	Ground (s) Cavity (s) Tree top (s) Mid-story (s)	Four transects
Golden Airport (Figure A *3*)	76 species	MSdk	Old forest Wetlands River edge Open fields	S, D	Ground (t) Cavity (t) Mid-story (t)	Simulated nest tests
Moonraker Trails (Figure A 4)	58 species	ICH mk5	Mature forest Riparian features	C, M	Ground (s) Cavity (s) Tree top (s) Mid-story (s)	One transect
Mount 7 (Figure A 5)	33 species	IDF dk5	Mature dry forest Forest edge Thick understory	C,S	Ground (t)(s) Cavity (s) Tree top (t)(s) Mid-story (s)	Three transects Simulated nest tests
Reflection Lake (Figure A 6)	147 species	MSdk	Wetland Emergent vegetation Aspen forest	D,S	Ground (t)(s) Cavity (t)(s) Tree top (s) Mid-story (t)(s)	One transect Simulated nest tests
Nicholson Bridge (Figure A 7)	53 species	ICH mk5	River edge Wetlands Aspen forest Thick shrubs	D,M,S	Ground (t)(s) Cavity (t)(s) Tree top (t)(s) Mid-story (t)(s)	One transect Simulated nest tests

***Notes*:**[1] Species richness taken from nearest e-bird hot spot (eBird, n.d.) and is cumulative from bird checklists through numerous years but is restricted to the months of April to August or the regional bird nesting window.
[2] Biogeoclimatic ecosystem classification from Land Management Handbook 71 (MacKillop, D.J., A.J. Ehman, K.E. Iverson, 2018).
MSdk = Dry Cool Montane Spruce, ICH mk5 = Moist Cool Interior Cedar Hemlock, IDF dk5 = Dry Cool Interior Douglas Fir.
[3] M = mixed forest, D = deciduous forest, C = coniferous forest, S = shrub edge.

Nesting Strategies

Four common nesting strategies were focused on for testing Maximum Detectible Distance (MDD) through simulated nest testing and IR active nest searching. Not all birds nest in the same manner and most have evolved to use specific materials and habitats to best ensure nest success (Yeh, Hauber, & Price, 2007). Birds will nest in areas where food is available, protection is provided from predators and climatic conditions are favorable for incubation and chick survival (Hansell, 2000). Nests can be found nearly anywhere, in a pile of rocks on the ground, in shrubs or small trees, high up in tree tops or on manmade structures (pers. obs). My research focused on four different nesting strategies used by passerine birds and did not target large stick nests, commonly used by large raptors or owls. The four strategies that were targeted include:

- Tree top cup nests;
- Cavity nests;
- Mid-story cup nests; and
- Ground nests.

Tree Top Cup Nests

There are many species, such as the ruby-crowned kinglet (*Regulus calendula*), that nest high (30m+) in tall trees (Cornell Lab of Ornithology, n.d.) making the detection of nests extremely difficult during standard active nest surveys. The nests are relatively small and nesting behaviour can be cryptic, which aids in preventing detection by predators. Searching for the nests of species that use the tree top strategy requires detecting avian behavior cues which can be a challenge given the distance from the tree top bird activity a surveyor on the ground. For example, behaviour cues like the a singing of a male bird indicates to the surveyor that the male is trying to attract a mate (Eriksson & Wallin, 1986) and an assumption is made that there will be active breeding in the area. However, detection during the incubation phase is extremely difficult using standard active nest searching methods as the best way to find a nest is to see an adult return to the nest with food (pers. obs). Returning to the nests is generally done as inconspicuously as possible in order to prevent directing predators to the nest location. Having the ability to locate a nest high up in the canopy of a tree by detecting the heat given off through incubation with an IR device would eliminate guess-work on nest location and would ideally reduce the number of missed nests through standard nest survey techniques. In my research, tree top cup nests refer to cup nests located in the top half of trees. Expected challenges for detecting this nesting strategy included obscuring vegetation (e.g., branches, needles and leaves) and the distance from IR device to nest.

Cavity Nests

Boonstra et al. (1995) had moderate success with attempts to locate active cavity nests with IR citing background false positives from heat retained in loose bark and lichen and challenges with warming ambient daytime temperatures that obscured the search area with false positive readings. Further, they found that active nesting boxes (human made) emitted detectible heat, showing that human constructed active cavity nests could be detected with IR. While there is previous support that active cavity nests could be detected, questions remained regarding probability of detection (false negatives) and potential for false positive detections. For example, will heat be detected on the bole of the tree on the side opposite of the cavity entrance or will heat only be detected when looking directly into the tree cavity? Further complexities exist with secondary cavity users such as small mammals and insects, and determining what species is emitting heat from an active cavity.

Determining the status (active or inactive) of potential nest cavities is often difficult, especially during incubation stages. Observing return trips from a feeding parent, the sounds of excavation in the construction phase or the chirping of hungry nestlings are the sure signs of an active cavity. If the nest is in a stage with little activity, like during incubation, nest status can take long periods of observation to determine. Having the ability to scan a cavity with an IR device and immediately determine its status

(Figure 4) based on the detection of heat would increase the efficiency of nest searches and lead to the protection of more active cavity nests.

Figure 4. Active cavity nest detected in a black cottonwood (*Populus balsamifera*) during the testing phase of this research; the red glow indicates the heat emanating from the cavity. The image was captured by an external display connected to the IR device.

Mid-Story Cup Nests

For my research, I defined mid-story cup nests as open nests that are located in the bottom half of trees and within shrub cover (Figure 5). This nesting strategy is most commonly used among passerine species (Price & Griffith, 2017); therefore, it was assumed to be the most likely and abundant nest type to be discovered during IR surveys. While there is little previous work specifically focusing on IR and mid-story cup nests to reference any shortfalls, I expected difficulty with obstructing vegetation preventing the detection of heat emanating from nests. To overcome this challenge, I incorporated multiple sweeps that overlapped in both horizontal and vertical planes into the survey design for IR active nest surveys to give more opportunity to detect heat escape from nests through obstructing vegetation.

Figure 5. American robin *(Turdus migratorius)* incubating eggs in a mid-story cup nest situated among willow *(Salix spp.)* in a shrub edge habitat.

Ground Nests

Many species nest on the ground including ducks, grouse, shorebirds and some songbirds like the hermit thrush *(Catherus guttatus)* (Allen, 2017), all of which take a variety of different approaches to conceal nests. Boonstra et al. (1995), had difficulty when searching for mallard *(Anas platyrhynchos)* ground nests (**Error! Reference source not found.**) suggesting that emergent vegetation effectively obstructed the infrared emitted by the incubated eggs or the bird itself. I expected that this would remain a challenge for detection with nests in thick vegetation in my study; ground nests that are not as obstructed with vegetation may be more detectable. Ground nests are at more of a risk for surveyor caused incidental take because there is the possibility of stepping on the eggs or chicks while trying to locate the nest. Having the ability to locate nests from a distance with IR would not only prevent the destruction of ground nests by surveyors, it may also reduce the flushing of adults from nests.

Figure 6. Mallard ground nest located in mixed shrubs.

Equipment

My research required an IR device that would be functional in a forested environment and within my budget. With these parameters in mind, I selected the FLIR® Scout iii 640 thermal imaging monocular (Figure 7) for its versatility, durability and cost. The FLIR® brand has been used in similar projects, such as Israel & Reinhard (2017) who searched with unmanned aerial vehicles for lapwing birds, and Stephenson (2017) who searched for grassland and nesting passerine birds. Both of these research projects were conducted in agricultural settings. McCafferty (2013) also listed many applications that have been tested throughout avian sciences using FLIR® devices such as monitoring egg and nest temperatures and monitoring conditions of domestic fowl. Each application can use different devices based on needs and research environment (e.g. lab or forested area). For searching for active nests, a rugged and simple device was needed to ensure durability in varying forest and weather conditions.

The monocular is waterproof and has 4x digital zoom; the technical specifications suggest that a human can be detected at a distance of 1140 m. The unit has a listed sensitivity of <50 mK @ f/1.0, has seven different settings for detection and a five-hour battery life. The operation range of the monocular is -20 to 50ºC and the field of view is 18º by 14º.

Figure 7. FLIR® Scout iii 640 Monocular infrared sensing unit alike what was used in my research. (Image from: https://www.flir.ca/globalassets/imported-assets/image/scoutiii.png).

Options for detection settings include white hot, black hot, Graded Fire and InstAlert™. The white and black hot options along with the Graded Fire settings were not used due to the lack of variability in sensitivity. Within the InstAlert™ settings there is a range of four different sensitivities. Level 1 (L1) will give color to the warmest 5% of objects, Level 2 (L2) to the warmest 10%, Level 3 (L3) to the warmest 15% and Level 4 (L4) to the warmest 20% of objects.

The InstAlert™ settings were used for this research. Level 3 had the most consistent level of acceptable background interference during the testing phase, so this setting was primarily used to conduct active nest IR surveys. Level 4 proved to have too much background detection of objects that would obstruct the detection of active nests (Figure 8). When conducting tree top sweeps, using L3 would result in background interference when put on a steep angle so L2 was frequently used for tree top nest sweeps.

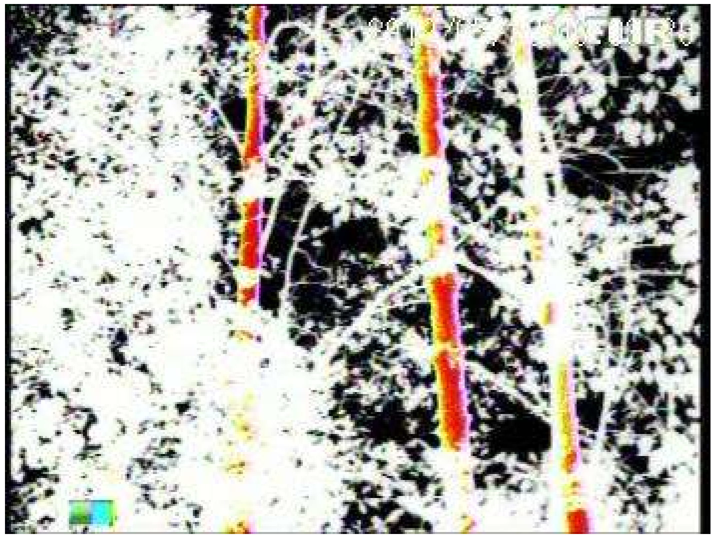

Figure 8. Screen shot from FLIR Scout iii 640 handheld monocular on the L4 setting with red glow from aspen trees showing excessive background noise obstructing nest detection.

In my research, Maximum Detection Distance (MDD) was the metric used to determine difference in detectability across nesting habitats and strategies. To determine MDD, distances between detected nests and the surveyor were measured using a Nikon Aculon handheld laser rangefinder, accurate to the nearest meter. During the testing phase, a fluorescent orange field notebook was placed beside the simulated nest for quick measurement reference with the rangefinder. During surveys, distance was measured off of the nearest tree or surface that would allow measurement with the rangefinder, since placing an object close to an active nest would have increased the potential for nest disturbance.

Nest Simulation

Nesting conditions (incubating female with eggs) were simulated using reusable gel heat packs, which were activated and placed in locations to replicate the different nesting strategies (Figure 9). The

Helly Hansen branded gel pack produced enough heat to simulate egg incubation for just over an hour once activated and was reused on subsequent days following a reactivation process. Two different gel packs of the same brand were used during the testing phase to keep temperatures near incubation temperature. The temperature of the packs was tested using a calibrated Bios DT131 digital thermometer. The gel pack was wrapped around the thermometer and activated with temperatures recorded at approximate 10-minute intervals (Table 2).

Table 2. Temperatures of a gel pack recorded at 10-minute intervals with the Bios DT131 digital thermometer.

Time	Temperature (ºC)
9:57	52.2
10:07	51.3
10:17	49.3
10:28	47.3
10:38	44.1
10:48	40.4
10:58	36.6
11:08	32.4
11:19	30.0
11:29	27.1
11:40	25.0
11:50	24.5

Figure 9. Helly Hansen gel heat pack placed in an old nest used for simulation tests of mid-story cup nests

The heat produced by the gel packs ranged from 52.2º C to 24.4º C over a 113-minute test period with a mean temperature of 38.4º C. Incubation temperatures of most birds is generally between 30 and 40º C with 38 to 39º C being optimal for development (Ospina et al., 2018). The high-end temperature produced following activation of the gel pack is well above the general incubation temperatures; however, the mean temperature falls into the ideal temperature range for incubation within 40 minutes. Activated gel packs were switched out for a new gel pack during simulated nest testing once the heat emitted decreased below the incubation range (after approximately one hour).

In order to test for MDD on simulated nests, a likely nesting scenario was prepared and the heat pack was activated. All simulated nest locations were prepared by the surveyor so the location was known prior to testing detectability. Once a heat pack was activated, the FLIR® unit was used to determine the level of detectability of the simulated nest. All simulated nest detections were tested at 10 m increments, starting at 10 m and progressing to a maximum of 60 m. The surveyor started by scanning the area to determine if heat was detected from the nest simulation by the IR unit. Once detectability was determined the surveyor progressed to the next 10 m interval to again test if the nest simulation was detected. Results were recorded based on three levels of detection; partial, full or no detection (Figure 10). A partial detection was recorded when the simulated nest was detected by a bright white glow through an IR scan. A full detection was noted when a red glow was detected through an IR scan. No detection was recorded when neither a white glow nor a red glow was detected in the IR scan. The different nesting strategies targeted in my research required unique approaches for simulation.

Figure 10. Left, white glow of a heat pack categorized as a partial detection during simulated nest tests. Right, red glow of a heat pack categorized as a full detection. Yellow circle identifies the detected heat pack in each photo.

The ground nests and mid-story cup nests were easily simulated, while the elevated strategies (e.g., cavity and tree top nests) required more inventive approaches for simulation. To simulate ground nesting, a gel pack was placed in likely nesting locations in a variety of habitats to mirror potential real ground nesting scenarios. I utilized my previous experience of searching for and discovering active nests, through standard surveys, to inform the location and scenarios that were used to test ground nests. Activated gel packs were placed at the base of shrubs, in tall grass and emergent wetland vegetation.

The mid-story nesting simulations were conducted by placing activated gel packs into old nests. Where no old, inactive nests were available the gel packs were suspended in the fork of branches. Using old inactive nests for the simulations was preferred because it would give the most accurate representation of real active nest conditions (i.e. nest insulation).

Cavity nests were not simulated as many active cavities were discovered during the testing phase through standard methods of following nesting behaviour cues of cavity nesting species. Additionally, cavity nests proved to be logistically difficult to simulate as most cavities are located high up in trees, which would have required tree climbing to both install and remove heat packs from existing cavities. All active cavity nests were located in deciduous trees and were initially detected by searching using bird behaviour cues, not by searching with the IR camera (Figure 11). Cavity activity status was confirmed by observing adult feeding activity or hearing chicks in the nest.

Figure 11. American robin in secondary cavity nest used to test the detection distance of the IR.

Tree top nest simulations also presented difficulty since heat packs needed to be lifted high into the tree canopy to determine the maximum detectible distance (out to 60 m). A weighted arborist throw-bag was used to drape a rope over a branch high up in a tree, then, the gel pack was tied into the rope and lifted high up into the tree, between 15 m and 20 m off the ground (Figure 12). Both deciduous and coniferous trees were used in these tests.

Figure 12. Throw bag with heat packs used to simulate tree top nests

Data Collection

A digital datasheet was designed so that data could be added to the spreadsheet in the field on an iPad. Data fields for the simulated nest testing phase and IR active nest survey phase were consistent across both phases and included ambient temperature, detectability at 10 m intervals up to 60 m, habitat type, nest type, camera setting, species detected, nest height and general comments. Collected raw data is presented in Appendix B. Data for both simulated and real nests were recorded in the same Microsoft Excel database. Time of survey commencement, weather conditions, temperature, location and general observations or significant discoveries were recorded in a Microsoft Word file for every day of field data collection, during both testing and surveying phases.

IR Surveys

Following the testing of the FLIR® monocular, surveys for active real nests were conducted using a fixed area plot survey method. Survey stations were located along the transects described above at an approximate 30 m spacing to allow for overlap of survey area and insurance that the survey area was within the effective detection range of the IR monocular. Overlap in survey stations was included in the survey design in an attempt to search into vegetation from different angles to address the shortfall identified in previous research where vegetation obscured active nests (Stephenson, 2017). Distance between survey points was measured by pacing 30 m. *Figure **13*** below illustrates the fixed area plot survey method used. When surveying for the range of nesting strategies in complex habitats, attention was paid to the different elevations that nests could exist. Three distinct elevation bands exist that require a separate sweep for active nests with the IR device. First, the ground level was swept looking for ground nests as well as mid-story cup nests. A second sweep was conducted at a higher elevation looking for mid-story cup nests and cavity nests. Depending on the height of the trees present, a third and possibly even a fourth sweep was required to search the top portions of the forest canopy for tree top cup nests. Care was taken during the sweeps to ensure there was overlap in the separate elevation horizons so that no area was left unsurveyed. A depiction of the elevation horizons requiring separate sweeps is shown in Figure 13.

Once a nest was discovered, the distance of initial detection was recorded along with species detected, height of nest, type of nest, ambient temperature, habitat type, sun exposure and whether the nest was discovered with the IR device or by chance. Nests that were discovered by chance or by use of following nesting cues were also used to sample for MDD. Detection of the nest with the IR device was measured at 10 m intervals, out to 60 m, akin to how testing was done on simulated nests. The level of detection (full, partial or no detection) was recorded at each interval. Once a nest went undetected during distance tests, no further distance intervals were tested.

Where possible, nests (simulated and real) were tested multiple times using the different settings in the InstAlert™ function of the FLIR® device. Active nest testing subsequent to initial IR detection followed random transects but bias was made towards more open and easily walkable tangents.

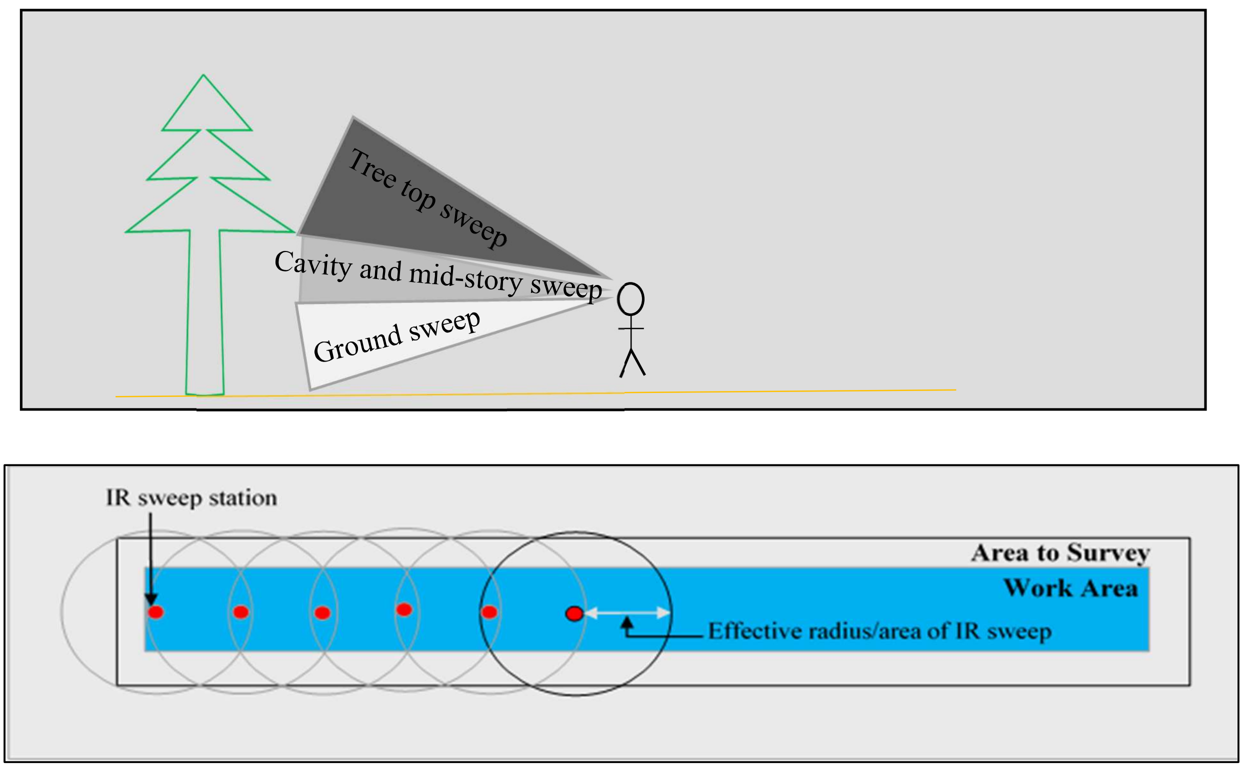

Figure 13. Top: Different elevation categories requiring separate sweeps during IR surveys. Bottom: Illustration of fixed area plot methods based on limited distance of IR's effective range.

Data Analysis

Testing the hypothesis that IR is an effective tool for locating active bird nests.

The data collected in the survey and testing phases of this research was used to quantitatively determine the efficacy of IR surveys. The raw data collected during field survey and testing phases were transcribed into an MS Excel database that was imported into SPSS Statistics software (Version 26) to run all data analysis.

A total of 99 nests, 32 real and 67 simulated, were used to assess patterns in maximum detectable distance across a range of habitat types and nesting strategies. Data were reviewed prior to analysis to remove entries that were not consistent with the focus of this research (e.g. detected stick nests were excluded). Additionally, where cavity nests were suspected but not confirmed to be active (false positive detections), the data were not included in analysis. While interesting and notable, data from the detection of wasp *(Vespida* sp*.)* nests and active tree cavities inhabited by American red squirrels (*Tamiasciurus hudsonicus)* were also removed from the statistical analysis.

T-tests were run for simple comparison of two data sets with equal variances such as the comparison of detected and active nest Maximum Detectable Distances (MDD). Levene's tests were run to determine the equality of variances in all t-tests. Where multiple data sets were being compared, such as the comparison of MDD among habitat types and among nesting strategies, ANOVAs were run to determine significance. Where significance was determined in the ANOVA, a post-hoc Tukey test was run to evaluate pairwise differences. Tests for normality determined that the data were not normally distributed. All error terms are presented in ± standard error.

Results

Detected and Tested Active Nests

Seven active nests (Table 3) of four different species were detected in 1966 minutes of active IR nest survey effort yielding a detection rate of one nest per 218 minutes of effort. Most nests were located in shrub edge habitat (n= 5); no nests were discovered in mixed forest habitats. All of the IR detected active real nests were mid-story nests between 0.5 m and 3 m off the ground. The mean MDD (n=7) of all real nests detected by IR is 22.9 ± 4.7 m.

In addition to the seven IR-detected nests, 25 active nests tests (on nests located using standard methods of nest searching) were conducted to test the utility of IR nest detection (Table 4). The mean MDD for real nest detected by standard methods was 32.8 ± 3.8 m. There was no statistically significant difference detected between mean MDD for nests discovered by IR and the nests discovered by standard methods (t_{30}= -1.3, p = 0.205). The combined mean MDD for all active nests is 30.6 ± 3.2 m.

Table 3. Details of all active real nest discovered during IR (n=7) active nest surveys.

	Scientific Name	Nest Strategy	Maximum Detectible Distance (MDD (m))	Height (m)	Habitat Type
American redstart	*Setophaga ruticilla*	Mid-Story	20	1.0	Shrub Edge
American robin	*Turdus migratorius*	Mid-Story	40	1.0	Shrub Edge
American robin	*Turdus migratorius*	Mid-Story	20	1.0	Shrub Edge
American robin	*Turdus migratorius*	Mid-Story	40	1.5	Shrub Edge

Yellow warbler	*Setophaga petechia*	Mid-Story	10	0.5	Shrub Edge
Yellow warbler	*Setophaga petechia*	Mid-Story	10	0.5	Coniferous
Vireo sp.	*Vireo* sp.	Mid-Story	20	3.0	Deciduous

Table 4. Summary of active real nests (n=25) tested for MDD. The nests on this table were discovered using nesting cues or were tested on subsequent visits to the location following discovery with IR.

Species	Scientific Name	Nest Strategy	Maximum Detectible Distance (MDD (m))	Height (m)	Habitat Type	Setting
Black-capped chickadee[2]	*Poecile atricapillus*	Cavity	0	15.0	Coniferous	L1
Black-capped chickadee[2]	*Poecile atricapillus*	Cavity	0	15.0	Coniferous	L2
Black-capped chickadee[2]	*Poecile atricapillus*	Cavity	0	15.0	Coniferous	L3
Black-headed grosbeak	*Pheucticus melanocephalus*	Mid-Story	10	2.2	Shrub Edge	L3

Species	Scientific Name	Nest Strategy	Maximum Detectible Distance (MDD (m))	Height (m)	Habitat Type	Setting
Yellow warbler[1]	*Setophaga petechia*	Mid-Story	10	0.5	Shrub Edge	L3
Spp. unknown		Cavity	40	20.0	Deciduous	L3
Spp. unknown		Cavity	30	10.0	Deciduous	L3
Spp. unknown		Cavity	40	15.0	Deciduous	L2
Spp. unknown[2]		Cavity	40	20.0	Deciduous	L2
Spp. unknown[2]		Cavity	40	20.0	Deciduous	L3
Northern flicker	*Colaptes auratus*	Cavity	40	18.0	Mixed Forest	L3
Northern flicker[2]	*Colaptes auratus*	Cavity	20	15.0	Deciduous	L1
Northern flicker[2]	*Colaptes auratus*	Cavity	20	15.0	Deciduous	L2
Northern flicker[2]	*Colaptes auratus*	Cavity	50	15.0	Deciduous	L3
Northern flicker	*Colaptes auratus*	Cavity	50	18.0	Deciduous	L1

Species	Scientific Name	Nest Strategy	Maximum Detectible Distance (MDD (m))	Height (m)	Habitat Type	Setting
American robin	*Turdus migratorius*	Mid-Story	30	3.0	Deciduous	L3
European starling[2]	*Sturnus vulgaris*	Tree Top	60	20.0	Coniferous	L1
European starling [2]	*Sturnus vulgaris*	Tree Top	60	20.0	Coniferous	L2
European starling [2]	*Sturnus vulgaris*	Tree Top	60	20.0	Coniferous	L3
American robin	*Turdus migratorius*	Cavity	40	4.0	Deciduous	L2
American robin	*Turdus migratorius*	Cavity	40	4.0	Deciduous	L3
American robin	*Turdus migratorius*	Mid-Story	20	2.5	Mixed Forest	L3
Vireo spp. [1]	*Vireo* sp.	Mid-Story	20	3.0	Deciduous	L3

[1] Nest that were originally detected by IR and were tested for MDD on different tangents.
[2] Multiple attempts to test detection on the same nest.

Maximum Detectible Distance

There was no statistically significant difference detected between the mean MDD for real (n = 32, mean = 30.6 ± 3.2 m) and simulated (n = 67, mean = 26.9 ± 2.6 m) nests tested in my research (t_{97} = -0.851, p = 0.937). The lack of a statically significant difference between real versus simulated nest MDDs allowed for the use of an overall mean MDD in some of the subsequent analyses (n = 99, overall mean MDD = 28.1 ± 2.1 m).

Comparison of MDD per Nesting Strategy

MDDs varied among the nesting strategies ($F_{3,95} = 17.4$, $p = < 0.0001$; Figure 14) with significant pairwise differences indicated between most comparisons with the exception of cavity nests and mid-story nests and cavity nests and tree top nests (Figure 14).

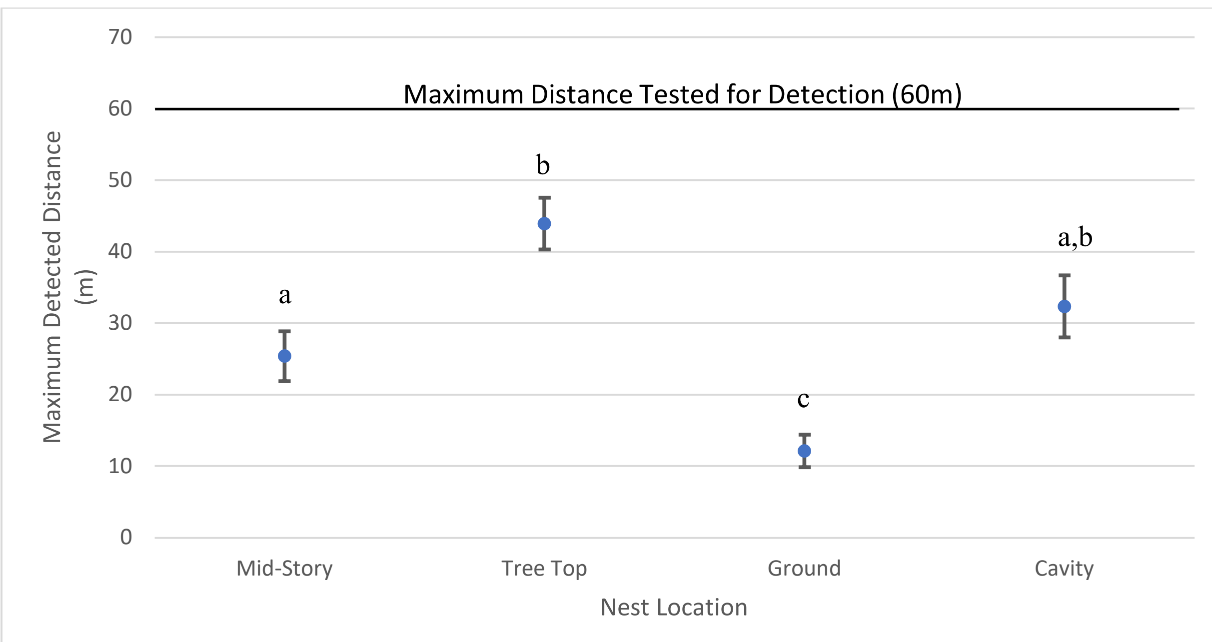

Figure 14. Plotted mean MDD per nesting location with standard error bars (m). Letters above MDD values represent pairwise difference patterns, shared letters show commonality (Tukey post-hoc).

A comparison between real (n=3, mean 60 ± 0 m) and simulated (n=25, mean 42.0 ± 3.9 m) tree top nests was not valid given the difference in sample size and unequal variances. No active real nests were discovered during IR active nest surveys. Real active tree top nests were discovered using standard nest search techniques and the sample size (n=3) is made up of repeated tests of the same nest, all of which were detected to the maximum (60 m) test distance.

There was no difference detected between the mean MDD of real (n=12, mean MDD = 20.8 ± 3.1 m) and simulated (n=14, mean MDD = 29.3 ± 5.8 m) mid-story nests ($t_{24} = 1.225$, $p = 0.233$) giving a combined mean MDD of 25.4 ± 3.5 m.

No valid comparisons existed between real and simulated cavity or ground nests because no simulated cavity nests were tested nor were any active ground nests discovered during IR searches.

MDD Comparison Across Habitat Types

Statistically significant differences in MDD were detected among habitat types ($F_{3,95} = 2.9$, $p = 0.037$; Figure 15). Post-hoc pairwise tests indicated difference between deciduous MDD and shrub edge MDD (Figure 15).

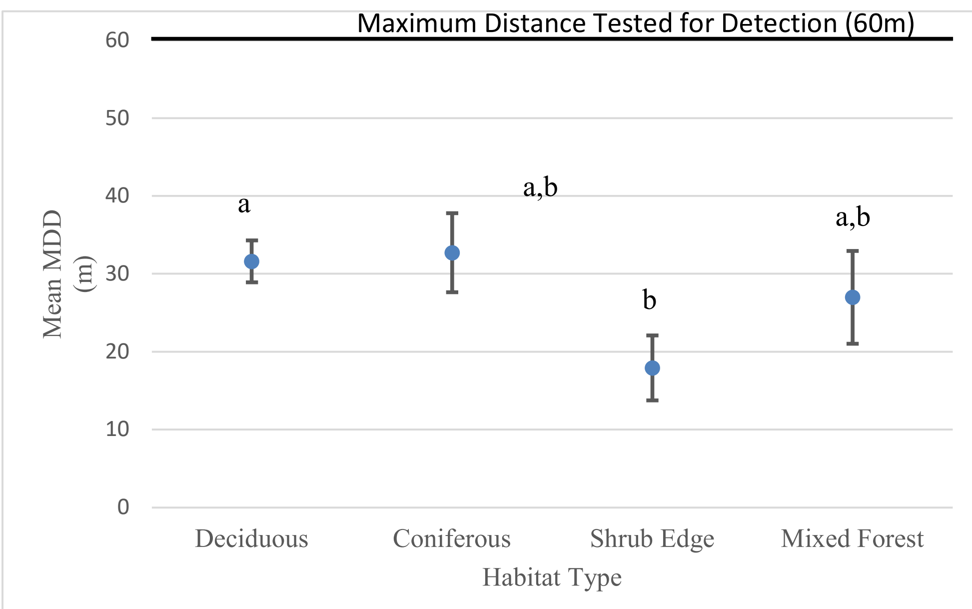

Figure 15. Mean MDD across habitat types. Letters represent significant pairwise differences determined by Tukey post-hoc, shared letters show commonality.

MDD Across IR Camera Sensitivity Settings

Three different sensitivity settings were used throughout the testing and survey phases to determine if there was a difference in active nest detectability across the varied settings. No statistically significant differences in MDD were determined among the three sensitivity levels ($F_{2,96}$= 0.68, p = 0.51): L1 (n = 16 nests, mean MDD = 32.5 ± 5.7 m); L2 (n = 25, mean MDD = 29.6 ± 4.2 m); L3 (n = 58, mean MDD = 26.2 ± 2.6 m).

MDD Compared to Actual Detection Distance (ADD)

The distance from the surveyor to the active nest at the time of detection was recorded prior to testing the MDD, this distance is referred to as the Actual Detection Distance (ADD). No significant statistical difference was determined between ADD (n = 7, mean = 16.4 ± 5.1 m) and MDD (n=7, mean = 22.9 ± 4.7 m) for nests that were discovered with IR (t_{12} = -0.93, p = 0.37).

Discussion

The intention of testing IR for detecting active avian nests in my research was to find an alternative method of locating active nests that is non-invasive (McCafferty, 2013). Ideally, for IR to be an effective and non-invasive alternative to standard active nest surveys prior to forest clearing, active nests should be detectable from the ground to the top of the tallest trees, in all habitat conditions and at a distance that prevents surveyor caused incidental take. Mature trees in BC can reach anywhere from 20 m to 85 m tall, depending on the species (Parish & Thomson, 1994). Therefore, to be truly effective in detecting all nests, IR capabilities must be able detect all nesting strategies in all nesting habitats, including nests high above the ground.

Nest Detection

My research suggested that active passerine nests can be detected by an IR device. However; with the FLIR® 640 Scout iii device that I tested, detection was not consistently reliable across the nesting strategies or habitat types represented in my study area. From the combined dataset of real and simulated nests (n=99), tree top and cavity nest strategies were detectable at the greatest distance, while ground nests had the shortest detection distances. Nests within shrub edge habitats were only detectable at close range, while the detection distances of nests within the other three nesting habitats were greater and not significantly different from each other. Variation in the use of sensitivity settings of the FLIR® device I used did not appear to impact active nest detection; however, the applicability of these results is limited to the use of this particular model of FLIR® device because sensitivity settings vary among other models. No significance was discovered between the distance of the first detection of a nest with IR and the Maximum Detectable Distance (MDD).

Nesting Strategies

Tree Top Nests

Distance from the surveyor to the nest limits the ability to observe nesting behaviours and also reduces the likelihood of triggering defensive nesting behaviours that increase detectability (Smith & Edwards, 2018), so the high mean MDD for tree top nests reported from my research is encouraging as these nest types are often the hardest to detect using standard nest searching methods. However, in my study the active real tree top nests (N=3) sampled for MDD in the dataset were located first using standard nest searching techniques, observing nesting behaviour, not through the IR survey detection. All three of these MDD measurements with the FLIR ® were conducted on the same nest, with different sensitivity settings used for each test, although the nest was detected out to 60 m on each test. So, the effective detection range of the IR device showed some promise when searching for real nests. Likewise, the detection of simulated nests under these conditions showed that the FLIR ® could easily detect the nests at greater distances, although the method of nest simulation that I used may have introduced some bias into the results.

The relatively high distance of detection for simulated nests may have been the result of the heat packs being hoisted into the open air with no insulation, which differs from what would be provided by a real nest. The simulated nests were likely easier to detect with the FLIR ® than real nests because the heat was not surrounded by nest materials and there was less obstructing vegetation than would typically be present with a nest suspended in branches. Future research should incorporate insulation material around simulated nests to reflect more realistic nesting conditions to address the bias introduced from the method used in my research. Although, despite this bias, tree top nests (real or simulated) could be detected using a lower sensitivity setting on the IR device.

Nearly every tree top scan was performed using a lower sensitivity setting on the FLIR ® than the scans within the other nesting categories. When the L3 (higher sensitivity) setting was used in tree tops scans, much of the background would turn red indicating the detection of heat with a steepened pitch of the device. Using a less sensitive setting (L2) alleviated this issue. A lack of statistically significant MDD differences among the sensitivity settings suggested that using a lower sensitivity setting did not affect the ability to detect nests, so the flexibility that the FLIR ® offers in this regard can help with overall nest detection.

During the IR surveys, birds were detectable by the IR device at the tops of trees but were easily obscured by thick branches or the bole of the tree. While IR appeared to be able to detect tree top nests from a large distance, further work is required to confirm these results by increasing the sample size of real active tree top nests. Until this is completed, the use of the FLIR ® device, that I tested, is not a suitable alternative to standard methods for reliably searching for active passerine tree top nests. The results of my research demonstrated potential in the technology that supports the need for further research. However, while nests were not readily detectable with this FLIR® device, birds were detected, which suggests that IR could, at a minimum, assist a trained ornithologist to locate and follow birds with active tree top nests.

Mid-Story Nests

Mid-story nests were the most consistently detectable nest type in both simulated test and IR active nest surveys, mid-story cup nests were the only nesting strategy discovered during IR surveys (n= 7). The height of the nests off the ground can influence the amount of obscuring vegetation, nest insulation and topography that can interfere with detection of heat escaping the nest. The active real nests detected during IR surveys were between 0.5 and 3 m off the ground. This height range allowed the surveyor a downward or slightly above level view into the nest to effectively see the heat signature of the adult incubating eggs and/or the eggs. However, obscuring vegetation was a major limiting factor to the detection of mid-story cup nests using IR. While the initial or Actual Detection Distance (ADD) and the maximum detection distance were not significantly different from each other, the mean ADD was substantially lower, suggesting that vegetation generally obscured nests until the observer was relatively close to the nest.

During MDD tests with the IR device, the location of nests was known to the surveyor, so the search effort was more focused on the nest and bias was likely introduced through the selection of a less obscured view path. This likely resulted in higher MDDs than if the simulated nest locations were unknown to the surveyor; however, it was clear that the IR device can be used effectively when searching for mid-story nests. To improve upon these results, MDD could be tested multiple times on consistent predetermined tangents to remove surveyor introduced bias to a clear view path. While my research shows that mid-story cup nests can be detected by IR, in most cases these detections were made relatively close to the nest. A more sensitive IR device could be used to determine if it has the ability to detect nests from a further distance through obstructing vegetation. In addition, further research using IR to search for simulated nests with locations that are unknown to the surveyor could be conducted.

Cavity Nests

The MDD of cavity nests was comparable to that of tree top and mid-story nests, suggesting the IR device is equally effective at detecting nests under these different strategies. All cavity nests observed (n= 17) during testing were identified using standard nest searching methods and none were initially detected using IR. My original hypothesis for cavity nest detection, based on successes of Boonstra et al. (1995), was that only an active cavity would emit heat. However, nearly every readily observed cavity in trees scanned with the IR device detected the heat escaping, whether it was active or not, making the differentiation of active or inactive cavity nests by using the IR device alone difficult.

These false positive readings from cavity nests were likely from trees retaining heat from the previous day's solar effect through the night and into the morning. Heat retention by trees was not considered in the initial planning of surveys nor was it mentioned in any previous research but should be considered in any future research. A more sensitive device with a graded display of temperature may help with the differentiation of heat emitted by nesting activities compared to the heat retained by the thermal mass.

Ground Nests

Ground nests were the most difficult strategy to detect with the FLIR ® during my research. This is supported by the statistically significant and lower MDD (12.1 ± 2.3 m) compared to other nesting strategies and the fact that no active ground nests were discovered during IR active nest searches. Obstructing vegetation likely restricted the detection of heat emitted from ground nests when using the search methods that I performed. Other methods of IR searching for ground nests, such as the use of aerial mounted IR units can be a more effective search method.

Research conducted by Israel & Reinhard, (2017) showed a 93% success rate of detection for Lapwing *(Vanellus vanellus*) ground nests using a drone with an attached IR device, which gave me promise for the detection of ground nests during my research. However, ground nests were challenging to detect, even in simulations, which is reflected in the low mean MDD and the fact that no active real ground nests were detected during IR surveys. Differences in site conditions likely contributed to the variance in detection success between my research and Israel & Reinhard (2017). My research was conduced in natural forested and riparian (shrub edge) habitats whereas their study was conducted in disturbed agricultural areas with no obstructing vegetation. Ground nests are widely suggested to be the most challenging nests to detect with an IR device, as reported by Boonstra et al. (1995) when looking for mallard (*Anas platyrhynchos)* nests with known locations and in Stephenson's (2017) attempt to locate passerine nests. The results in my research were therefore not surprising given the previous published literature. The use of a drone for an overhead view, as done by Israel & Reinhard (2017) may be a more effective method to employ IR technology when searching for ground nests in open areas.

Nesting Habitats

Difference in habitat conditions can influence nest detectability, suggesting that some habitat types may be more difficult to detect nests in than others. This is due to a varying amount of vegetation obscuring the detection of heat being emitted from nests (Stephenson, 2017). My analysis suggested that nest detection is possible with IR from a greater distance in deciduous, coniferous and mixed forest habitats compared to nest detection in shrub edge habitats. As previously mentioned, the most active real nest detections during IR active nest surveys were within shrub habitats suggesting that more nesting occurred in this habitat type in my study area or that nests were more easily detected in this habitat type, despite a shorter mean MDD. Obstructing vegetation is likely the cause for shorter MDDs in shrub edges. Detections were likely possible at a greater distance in the other habitat types (coniferous, deciduous and mixed forest) because the nesting locations were higher off the ground and not as obscured by understory growth.

Simulated nests provided the ability to increase the sample size and test the functionality of the IR unit while limiting the potential of surveyor caused incidental take. Introduced biases in the testing phase as the surveyor knew the location of the simulations and was able to select locations with less dense obstructing vegetation to allow for measurements at the full MDD testing distance. Two strategies to eliminate this bias in future research are: setting up nesting simulations at locations unknown to the surveyor and testing MDD on predetermined tangents.

The cumulative destruction of nests as a result of industrial activities, such as forest harvesting and oil and gas operations, are significant across Canada (Hobson, Wilson, van Wilgenburg, & Bayne, 2013) in habitats similar to those used in my research. Without consistent and meaningful enforcement of the *MBCA (1994*), industry lacks incentive to avoid contravention of the Act. Further research and investment in IR technology will likely be driven by a need to avoid prosecution and fines associated with direct or incidental take of nests contrary to *MBCA (1994).* The use of IR to detect active nests is promising though more research is needed to solidify the best methods to employ and determine the most suitable device to use. It is possible that a variety of methods, specific to habitat and nesting strategy, may help overcome the limitations identified in my research and work towards reducing the destruction of migratory bird nests.

Recommendations

Infrared devices could help improve nest detection and subsequently reduce the incidental take of bird nests resulting from industrial activities so long as the limitations listed are overcome. Obstructing vegetation is by far the most limiting factor preventing the detection of active nests followed by background heat sources that create false positive nest detections. Eliminating surveyor introduced biases could aid in directing further research to determine the most suitable IR device to use for active nest searching. Comparisons with an ideal IR device should be made with standard search methods to determine the true efficacy of IR sweeps as an alternative method for searching for active avian nests. Better methods, other than the current standard active nest surveys, are needed to make a substantive reduction in the number of birds and bird nests that are lost as a result of industrial activities.

Obstructing vegetation is a common limitation with IR devices searching for nest in all reviewed literature as well as in my research. Structuring IR surveys to overlap and scan the same area multiple times from different directions was intended to overcome this known limitation, however, it was not fully successful. More sensitive units exist that should be tested to overcome obstructive vegetation before IR surveys are fully dismissed as a non-invasive method for locating active bird nests. In addition, the approach of using a drone mounted IR device would change the angle of scanning for heat detection and could increase detection, particularly in tree top and ground nesting strategies.

Ambient temperature did not appear to be a factor restricting the detection of nests because most surveys were conducted in the early morning before sunrise. The effect of sun on vegetation was evident at the end of daily survey periods. Leaves and branches would glow red in the view finder of the IR device immediately following exposure to sunlight creating conflict for discovering real active nests. The retention of heat in trees as a thermal mass influenced the detection of active cavity nests as most cavities appeared to be emitting heat regardless of being active or not. As a result, I reverted to standard methods of searching to determine cavity nest status. A more sensitive and sophisticated IR unit may be able to separate out the temperature of heat emitted through thermal mass retention in comparison to nesting activities.

Beneficial further research should test hidden simulated nest detections with IR, where the location of the simulated nests is unknown to the surveyor. Future testing should also go beyond 60 m to the full distance to the point where detection is not possible to get a better measurement of the actual maximum detectible distance. Heat packs that maintain temperatures between of 30-40º C consistently, to better simulate actual incubation temperatures, should also be used. Simulations should replicate nest insulation to reduce biases of easily detected, non-insulated heat sources as in my research. Additionally, a more sensitive and suitable IR unit should be used to compare detection rates of IR surveys and standard active nest surveys.

While my research did not produce a solution to prevent incidental take with IR nest surveys, it did identify limitations that will aid in directing future research. It is important to keep in mind that the device used in my research was a basic unit. There are many higher-level, more expensive, IR units available on the market that are much more sensitive to detecting heat, it is just a matter of testing more units to find which unit is the most suitable for this application.

Conclusion

Infrared imagery devices show promise for the non-invasive detection of active bird nests. A more effective and non-invasive method for detecting active nests, in comparison to standard nest surveys, would reduce surveyor caused nest disturbance or destruction and provide another tool to surveyors for preventing the incidental take of active bird nests. Currently enforcement of the *MBCA 1994* is not consistent when it comes to incidental take so industry continues to destroy or disturb active bird nests, largely without penalty. Increased and consistent enforcement of the *MBCA* would likely result in more interest to avoid active nests and provide additional opportunities for using IR technology to avoid incidental take.

My research suggests that nests could be detected to the top of some mature trees in interior BC, under the right conditions. However, further research, as technology advances and costs decrease, experimenting with more sensitive IR units could potentially result in increased detection rates over what is represented in my research. While my research does not show IR to be a standalone method for locating active bird nests it does indicate that there is promise in the future use of IR to locate active bird nests and prevent the loss of birds and bird nests. Until the technology is perfected for this application an IR device, such as the one tested in my research, is a beneficial tool that ornithologists could use to assist in the search for active and cryptic nests.

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Appendix A

Photograps showing site conditions of all research locations

Figure A 1. Mixed forest, forest edge and dry creek channel along the Blaeberry River

Figure A 2. Mixed habitats in the Burges James Gadsden Provincial Park. Top left: (1) Braul transect riparian features and shrub edge. Top right (2), Sime 2 transect along the edge of wetlands. Middle two photos: (3,4) shrub edge and riparian feature along Sime 1 transect. Bottom photo: (5) Bergenham transect with thick shrub edges and mature black cottonwood.

Figure A 3. Deciduous leading forest and shrub edge conditions at the airport location.

Figure A 4. Typical mixed mature forest and edge habitat along Cedar Snag transect.

Figure A 5. Transects surveyed at Mount 7 site (transect 1 in top left, transect 2 in top right and transect 3 in bottom middle).

Figure A 6. Regenerating aspen edge near Reflection Lake riparian habitats.

Figure A 7. Typical forest type with small wetland edges in the Nicholson bridge survey area along Columbia River.

Appendix B

Raw Data-Excel Datasheet from Field Data Collection

Date	Time	Ambient Temp	Nest detail	Camera setting	Nest type		10	20	30	40	50	60	HT (m)	Habitat type	Sun	Detection Type (camera/ Observer)
May 14, 2019	7:08	9.2	Gel	L3	Cup	Slightly obscured by shrub vegetation. Approach from the west	Full	Partial	No detect	No detect	No detect	No detect	1.5	Shrub edge	None	Observer
May 15, 2019	6:26	7.5	gel	L3	Cup	Same position, gel pack used, 2x zoom	Full	Full	Full	Partial	Partial	Partial	1.5	Shrub edge	None	Observer
May 15, 2019	6:48	7.5	gel	L3	Cup	Fully obscured	Partial	No detect	No detect	No detect	No detect	No detect	1.5	Shrub edge	None	Observer
May 15, 2019	7:01	7.5	gel	L3	Ground	Edge of shrub field	Partial	Partial	No detect	No detect	No detect	No detect	0	Shrub Edge	None	Observer
May 15, 2019	7:05	7.5	gel	L3	Ground	Full obscured by shrubs	No detect	No detect	No detect	No detect	No detect	No detect	0	Shrub Edge	None	Observer

May 16, 2019	6:40	8.6	gel	L3	Ground	Rain over night, full cloud cover. Partial shrub cover	Full	Full	Full	Partial	Partial	No detect	0	Mixed forest	None	Observer
May 16, 2019	6:05	8.6	gel	L3	Ground	More obscured with distance	Full	Partial	No detect	No detect	No detect	No detect	0	Mixed forest	None	Observer
May 16, 2019	7:15	8.3	gel	L3	Cup	totally open, along hiking trail	Full	Full	Full	Partial	Partial	Partial	1.5	Mixed forest	None	Observer
May 16, 2019	7:25	8.3	gel	L3	Cup	Fully obscured.	Partial	No detect	No detect	No detect	No detect	No detect	1.5	Mixed forest	None	Observer
May 16, 2019	0:00	8.3	gel	L3	cup	Fully obscured by tree branches	Full	Full	Partial	No detect	No detect	No detect	1.5	Mixed forest	None	Observer
May 16, 2019	0:00	8.3	Active raven nest	L3	Stick	Partial obscure, 20 m up spruce tree	Partial	Partial	Partial	No detect	No detect	No detect	20	Mixed forest	None	Observer
May 17, 2019	6:33	8.8	Active flicker cavity	L3	Cavity	Light rain, full cloud cover. Too obscured past 40m. Nest tended to by adult.	Full	Full	Full	Partial	No detect	No detect	18	Mixed forest	None	Observer
May 17, 2019	7:01	8.8	Active squirrel cavity in cottonwood	L3	Cavity	Tall cottonwood. Too obscured past 30m	Full	Full	Partial	No detect	No detect	No detect	22	Mixed forest	None	Observer

May 23, 2019	6:30	9.5	gel	L3	Ground	On ground obscured by reeds and willow	Partial	No detect	No detect	No detect	No detect	No detect	0	Riparian	None	Observer
May 23, 2019	6:41	9.5	Gel	L3	Cup	In old nest 1.5m off ground. Not obscured	Full	Full	Full	Full	Full	Partial	1.5	Shrub Edge	None	Observer
May 23, 2019	7:14	9.5	gel	L3	Cup	3m off ground-un obscured	Full	Full	Full	Full	Full	Full	3	Shrub Edge	None	Observer
May 23, 2019	7:20	9.5	Gel	L3	Cup	Same location 3m off ground- fully obscured	Full	Full	Full	No detect	No detect	No detect	3	Shrub Edge	None	Observer
May 25, 2019	6:22	8.8	Gel	L3	Ground	Obscured by woody debris ans shrub cover	No detect	No detect	No detect	No detect	No detect	No detect	0	Mixed forest	None	Observer
May 25, 2019	6:32	8.8	Gel	L3	Ground	High roll. Full obscure at 40m. Light rain	Full	Full	Partial	No detect	No detect	No detect	0	Mixed forest	None	Observer
May 25, 2019	6:38	8.8	Gel	L3	Ground	Same nest. Different direction for detection. Fully obscured at 20m	Full	No detect	No detect	No detect	No detect	No detect	0	Mixed forest	None	Observer

May 25, 2019	6:52	8.8	Gel	L3	Ground	Closed forest.	Full	Partial	No detect	No detect	No detect	No detect	0	Deciduous	None	Observer
May 25, 2019	7:00	8.8	Gel	L3	Ground	Same location, different direction	Full	Full	No detect	No detect	No detect	No detect	0	Deciduous	None	Observer
May 25, 2019	7:14	8.8	Active cavity- species unknown	L3	Cavity	20m up Act- rain- cavity too small to detect past 40m. Can locate with 4x zoom	Full	Full	Full	Partial	No detect	No detect	20	Deciduous	None	Observer
May 27, 2019	6:19	3.6	Active cavity nest	L3	Cavity	20m up At, lots of background colour due to temp? Hard to detect past 40 due to interference. Well into forest, good line of sight.	Full	Full	Full	Full	No detect	No detect	20	Deciduous	None	Observer

May 27, 2019	6:30	3.6	Active cavity nest	L3	Cavity	10m up At. Obscured by brush past 30m. Some extra background red. Well into forest.	Full	Full	Full	No detect	No detect	No detect	10	Deciduous	None	Observer
May 27, 2019	########	4	Gel	L3	Ground	Within reeds and horsetail	No detect	No detect	No detect	No detect	No detect	No detect	0	Riparian	None	Observer
May 27, 2019	7:04	4	Gel	L3	Cup	In shrub 2m up.	full	Full	No detect	No detect	No detect	No detect	2	Shrub Edge	None	Observer
May 28, 2019	0:00	4.6	Gel	L3	Ground	Edge of open sedge meadow	Full	No detect	No detect	No detect	No detect	No detect	0	Deciduous	None	Observer
May 28, 2019	6:06	4.6	Gel	L3	Ground	Same location, different direction	Full	Partial	No detect	No detect	No detect	No detect	0	Deciduous	None	Observer

May 28, 2019	6:24	4.6	Active cavity nest	L2	Cavity	Active in At- photos at 40m- change to L2 to reduce background noise- unable to see tree on L3 all red. Open minimal obscure, 15m up tree	Full	Full	Full	Partial	No detect	No detect	15	Deciduous	None	Observer
May 28, 2019	6:31	4.2	Active cavity nest	L2	Cavity	20m up at, photos at 40. Too obscured past 40.	Full	Full	Full	Partial	No detect	No detect	20	Deciduous	None	Observer
May 28, 2019	6:44	4.2	Gel	L2	Ground	Opened forest-at.	Full	Full	Partial	No detect	No detect	No detect	0	Deciduous	None	Observer
May 28, 2019	6:53	4.2	Gel	L2	Ground	Open at, too obscured past 30m	Full	Full	No detect	No detect	No detect	No detect	0	Deciduous	None	Observer

May 29, 2019	0:00	4.5	Gel	L2	Ground	Less background, same location. Two modes tested side by side. Open meadow little shrub cover. Sedges obscure.	Full	No detect	No detect	No detect	No detect	No detect	0	Deciduous	None	Observer
May 29, 2019	6:00	4.5	Gel	L3	Ground	Busy background	Full	No detect	No detect	No detect	No detect	No detect	0	Deciduous	None	Observer
May 29, 2019	6:09	4.5	Gel	L2	Cup	Obscured by shrub foliage	Full	No detect	No detect	No detect	No detect	No detect		Deciduous	None	Observer
May 29, 2019	6:09	4.5	Gel	L3	Cup	Tested at same time, more background	Full	No detect	No detect	No detect	No detect	No detect		Deciduous	None	Observer
May 29, 2019	6:20	4.5	Gel	L2	Ground	Same time test. Open meadow. Obscured by grasses	Partial	No detect	No detect					Deciduous	None	Observer
May 29, 2019	6:20	4.5	Gel	L3	Ground	More noise	Full	No detect	No detect					Deciduous	None	Observer

May 29, 2019	6:39	4.5	Gel	L2	Cup	More surface area exposed on gel pack, mod obscured past 20m	Full	Full	No detect					Deciduous	None	Observer
May 29, 2019	6:39	4.5	Gel	L3	Cup	More noise, done at same time	Full	Full	No detect					Deciduous	None	Observer
May 29, 2019	7:02	4.5	Confirmed active cavity nest	L2	Cavity	Secondary user (robin) photos on nest.	Full	Full	Full	Partial	No detect	No detect		Deciduous	None	Observer
May 29, 2019	0:00	4.5	Confirmed active cavity nest	L3	Cavity	Obscured too much past 40m, good line of sight helps longer distance detection.	Full	Full	Full	Partial	No detect	No detect		Deciduous	None	Observer
May 30, 2019	6:05	11.2	Gel pack and throw bag	L2	Tree top	Edge of river at 55m- partial. Low brush cover. Screen goes red with too much angle.	Full	Full	Full	Full	Partial	No detect		Deciduous	None	Observer

May 30, 2019	6:10	11.2	Gel pack and throw bag	L3	Tree top	Same but with L3- more background noise	Full	Full	Full	Full	Partial	No detect		Deciduous	None	Observer
May 30, 2019	6:21	11.2	Gel pack and throw bag	L2	Tree top	Too much background- facing east- photos	No detect	No detect	No detect	No detect	No detect	No detect		Deciduous	None	Observer
May 30, 2019	6:21	11.2	Gel pack and throw bag	L1	Tree top	Eliminate background noise-good detection. Too obscured past 30m.	Full	Full	Full	No detect	No detect	No detect		Deciduous	None	Observer
May 30, 2019	6:32	11.2	Gel pack and throw bag	L1	Tree top	Clear- minimal tree top interference	Full	Full	Full	Full	Partial	No detect		Deciduous	None	Observer
May 30, 2019	6:32	11.2	Gel pack and throw bag	L2	Tree top	More background noise	Full	Full	Full	Full	Partial	No detect		Deciduous	None	Observer
May 30, 2019	6:32	11.2	Gel pack and throw bag	L3	Tree top	Unable to see through background noise	No detect	No detect	No detect	No detect	No detect	No detect		Deciduous	None	Observer
May 30, 2019	7:00	11.2	Gel pack and throw bag	L1	Tree top	Less noise, partially open forest	Full	Full	Full	Full	Full	Partial		Deciduous	None	Observer

May 30, 2019	7:00	11.2	Gel pack and throw bag	L2	Tree top	Too much noise with sharp angle. Good detection with distance	No detect	No detect	Full	Full	Full	Full		Deciduous	None	Observer
May 30, 2019	7:00	11.2	Gel pack and throw bag	L3	Tree top	Too much noise with sharp angle. Good detection with distance	No detect	No detect	No detect	No detect	No detect	Full		Deciduous	None	Observer
May 30, 2019	7:14	11.2	Gel pack and throw bag	L1	Tree top	Same as last but different direction, partially open forest, good sight lines	Full	Full	Full	Full	Partial	No detect		Deciduous	None	Observer
May 30, 2019	7:14	11.2	Gel pack and throw bag	L2	Tree top	Too much noise on steep angle	No detect	No detect	Full	Full	Full	No detect		Deciduous	None	Observer
May 30, 2019	7:14	11.2	Gel pack and throw bag	L3	Tree top	Too much noise on steep	No detect	No detect	No detect	No detect	Full	No detect		Deciduous	None	Observer

May 31, 2019	5:50	10	Active starling nest	L1	Tree top	Active nest in my front yard. Continual feeding returns. Lots of background at 20m	Full	No detect	Full	Full	Full	Partial		Coniferous	None	Observer
May 31, 2019	5:50	10	Active starling nest	L2	Tree top	Too much background up close. Moderate back ground further out.	No detect	No detect	Full	Full	Full	Full		Coniferous	None	Observer
May 31, 2019	5:50	10	Active starling nest	L3	Tree top	Too much background	No detect	No detect	No detect	No detect	Full	Full		Coniferous	None	Observer
May 31, 2019	6:27	10	Gel pack and throw bag	L1	Tree top	Up fd tree. Lots of branches. Detection path along road.	Full	Partial	No detect	No detect	No detect			Coniferous	None	Observer
May 31, 2019	6:27	10	Gel pack and throw bag	L2	Tree top		No detect	Full	No detect	No detect	No detect			Coniferous	None	Observer
May 31, 2019	6:27	10	Gel pack and throw bag	L3	Tree top		No detect	No detect	No detect	No detect	No detect			Coniferous	None	Observer
May 31, 2019	6:42	10	Gel pack and throw bag	L1	Tree top	Same location, different direction	Full	Full	Full	Partial	No detect			Coniferous	None	Observer

May 31, 2019	6:42	10	Gel pack and throw bag	L2	Tree top	Too obscured past 40	Full	Full	Full	Partial	No detect			Coniferous	None	Observer
May 31, 2019	6:42	10	Gel pack and throw bag	L3	Tree top	Too loud upclose	No detect	No detect	Full	Full	No detect			Coniferous	None	Observer
May 31, 2019	7:00	10	Gel pack and throw bag	L1	Tree top	Same location different direction, more trees.	Full	Full	Full	Partial	Partial	No detect		Coniferous	None	Observer
May 31, 2019	7:00	10	Gel pack and throw bag	L2	Tree top		Full	Full	Full	Full	Partial	No detect		Coniferous	None	Observer
May 31, 2019	7:00	10	Gel pack and throw bag	L3	Tree top		Full	Full	Full	Full	Full	No detect		Coniferous	None	Observer
June 3, 2019	5:55	14.2	Gel	L1	Ground	Obscured by horse tail, grass and cat tail.	No detect	No detect	No detect	No detect	No detect	No detect		Riparian	None	Observer
June 3, 2019	5:55	14.2	Gel	L2	Ground	Open riparian edge	No detect	No detect	No detect	No detect	No detect	No detect		Riparian	None	Observer
June 3, 2019	5:55	14.2	Gel	L3	Ground		No detect	No detect	No detect	No detect	No detect	No detect		Riparian	None	Observer
June 3, 2019	6:05	14.2	gel	L1	Ground	Light rain. Obscured by grasses	No detect	No detect	No detect	No detect	No detect	No detect		Riparian	None	Observer
June 3, 2019	6:05	14.2	Gel	L2	Ground		No detect	No detect	No detect	No detect	No detect	No detect		Riparian	None	Observer
June 3, 2019	6:05	14.2	Gel	L3	Ground		No detect	No detect	No detect	No detect	No detect	No detect		Riparian	None	Observer

June 3, 2019	6:29	14.2	Active flicker cavity	L1	Cavity	Active return feeding, discovered without camera	Partial	Partial	No detect	No detect	No detect	No detect		Deciduous	None	Observer
June 3, 2019	6:29	14.2	Active flicker cavity	L2	Cavity	Active return feeding	Partial	Partial	No detect	No detect	No detect	No detect		Deciduous	None	Observer
June 3, 2019	6:29	14.2	Active flicker cavity	L3	Cavity	Active return feeding, glow on bole of tree, could be nest? Much stronger detection with L3.	Full	Full	Full	Full	Partial	No detect		Deciduous	None	Observer
June 5, 2019	6:22	6.7	Gel pack and throw bag	L1	Tree top	Conifer forest-20 m up tree	Full	Full	Full	Full	Partial	Partial		Coniferous	None	Observer
June 5, 2019	6:22	6.7	Gel pack and throw bag	L2	Tree top	Some noise	Full	Full	Full	Full	Partial	Partial		Coniferous	None	Observer
June 5, 2019	6:22	6.7	Gel pack and throw bag	L3	Tree top	Too much noise	No detect	No detect	Full	Full	Full	Full		Coniferous	None	Observer
June 5, 2019	6:30	6.7	Gel	L1	Ground		Partial	No detect	No detect	No detect	No detect	No detect		Coniferous	None	Observer
June 5, 2019	6:30	6.7	Gel	L2	Ground		Partial	No detect	No detect	No detect	No detect	No detect		Coniferous	None	Observer
June 5, 2019	6:30	6.7	Gel	L3	Ground		Full	Partial	No detect	No detect	No detect	No detect		Coniferous	None	Observer

June 6, 2019	5:55	8.6	Active flicker cavity	L1	Cavity	Deciduous forest, rain over night.	Partial	Partial	Partial	Partial	Partial	No detect	18	Deciduous	None	Observer
	5:55	8.6	Active flicker cavity	L2	Cavity	Deciduous forest, rain over night.	Partial	Partial	Partial	Partial	Partial	No detect	18	Deciduous	None	Observer
June 6, 2019	5:55	8.6	Active flicker cavity	L3	Cavity	Deciduous forest, rain over night.	Full	Full	Full	Full	Full	No detect	18	Deciduous	None	Observer
June 8, 2019	8:40	6.7	Active black capped chickadee cavity	L1	Cavity	Bush party trail, regular returns by parents.	No detect	No detect	No detect	No detect	No detect	No detect	15	Coniferous	Minor	Observer
June 8, 2019	8:40	6.7	Active black capped chickadee cavity	L2	Cavity	Adult activity observed, through camera.	No detect	No detect	No detect	No detect	No detect	No detect	15	Coniferous	Minor	Observer
June 8, 2019	8:40	6.7	Active black capped chickadee cavity	L3	Cavity		No detect	No detect	No detect	No detect	No detect	No detect	15	Coniferous	Minor	Observer
June 9, 2019	5:45	4.5	Active common raven nest	L2	Stick	Discovered by camera in the top of tree 40m away. Nest insulates bird from below making detection difficult up close. L3-too much back ground	No detect	No detect	Partial	Full	No detect	No detect	25	Coniferous	None	Camera

						looking steep angle.										
June 10, 2019	6:50	8.2	Active robin nest	L3	Cup	Detected during sweep 30m away. Too obscured past 40m to see. Female sitting on nest	Full	Full	Full	Full	No detect	No detect	1	Riparian	None	Camera
June 10, 2019	7:16	8.2	Robin nest construction	L3	Cup	Nest under construction. 15m away when discovered with 2 birds. Birds left, no further observations possible.		Full					1	Riparian	None	Camera

June 10, 2019	8:30	11	Robin nest-incubation	L3	Cup	Detected during walk back. Tested detection with camera. Very little heat detected due to angle made by nest height. In forest off riparian edge. Within search radius	Full	Partial	No detect	No detect	No detect	No detect	2.5	Mixed forest	Minor	Observer
June 13, 2019	7:07	10.6	Yellow warbler nest-in construction	L3	Cup	Discovered by camera 8m away. Only has heat when adults return with building materials. Cannot detect further because of no consistent adult attendance.	Partial						0.5	Coniferous	None	Camera

June 15, 2019	6:35	8.1	Active yellow warbler nest- chicks	L3	Cup	Chicks in nest. Clear detection. Minor obscure by shrub veg. Look down on nest. 5m away. Too obscured by shrubs to detect past 10m.	Full	No detect	No detect	No detect	No detect	No detect	0.5	Shrub Edge	None	Camera
June 15, 2019	7:40	10.1	Active yellow warbler nest-chicks	L3	Cup	Check different angle for detection	Full	No detect	No detect	No detect	No detect	No detect	0.5	Shrub Edge	Minor	Camera
June 20, 2019	6:10	6	Active wasp nest	L3		5m away for first detection. Very little obscuring veg until 30m away. No obs past 30m, too much shrub and trees in the way.	Full	Full	Full	No detect	No detect	No detect	0.5	Coniferous	None	Camera
June 21, 2019	6:21	9.2	Active black headed grosbeak- chicks in nest	L3	Cup	Nest discovered as walking away from sweep station. Test detection off of nest. Too obscured by shrub to detect at other angles and past 10m.	Full	No detect	No detect	No detect	No detect	No detect	2.2	Shrub Edge	None	Observer

June 24, 2019	6:00	6.2	Cavity-unconfirmed active	L1	Cavity	No confirmed activity-false positive?	Full	Full	No detect	No detect	No detect	No detect	15	Coniferous	None	Observer
June 24, 2019	7:15	6.2	Cup-active-sting on nest	L1	Cup	Vireo spp... on nest. Too obscured by foliage past 20m. Very small nest. Made of lichen.	Full	Partial	No detect	No detect	No detect	No detect	3	Deciduous	None	Camera
June 25, 2019	5:50	5.2	Active robin nest-sitting on ne	L3	Cup	Missed by previous day sweep, bird behaviour indicated likely nest-angle by nest height and branches obscure nest. Looking up at nest.	Full	No detect	No detect	No detect	No detect	No detect	3	Deciduous	None	Observer
June 25, 2019	6:44	5.2	Vireo cup-	L3	Cup	Same nest as yesterdat	Full	Full	No detect	No detect	No detect	No detect	3	Deciduous	None	Camera
June 25, 2019	6:53	5.3	Robin?	L3	Cup	Detected 40m away, on isolated island so can only assume detection would occur closer up.				Full				Riparian	None	Camera
June 25, 2019	7:36	5.2	American redstart-incubating nest	L3	Cup	Detected at 7m, too obscured by shrubs past 25m.	Full	Full	No detect	No detect	No detect	No detect	1	Riparian	None	Camera