Evaluation of Radar and Cameras as Tools for Automating the Monitoring of Waterbirds at Industrial Sites

By

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Abstract

Conflict occurs between people and birds at industrial sites around the world, where birds can endanger human lives (e.g. airports) and where bird populations are endangered by human activities (e.g. wind farms). Mitigating these conflicts requires accurate detection of birds and measures of their abundance and distribution. At industrial sites, detection of flying birds and the deployment of deterrents are often automated through detection by avian radar. Such sites include the various oil sands mining operations in northern Alberta, where operators are required to protect migrating waterfowl from landing on potentially toxic waste-water ponds. I tested two technologies for detecting birds in this context, one for flying birds (radar), and one for birds that have landed (cameras).

I tested radar to establish its accuracy for detecting flying birds, based on birds detected by paired human observers. I used X-band marine radar and tested two types of radar antennas, one parabolic and one open-array, across a range of conditions at both process-affected water ponds and freshwater ponds. I found that the two antennas failed to detect about half of all detections confirmed by visual observers, both when they were each in operation separately (open-array antenna failed to detect 43% of targets that were confirmed as birds; parabolic antenna failed to detect 56.4% of targets that were confirmed as birds) and when they were in operation together (both antennas operating simultaneously on two radars failed to detect 43% of targets that were confirmed as birds by the visual observers). My results suggest that antenna type, height of radar station, substrate around the station, and site-specific knowledge of target birds should be more explicitly addressed when marine radar is used as part of bird protection programs. A combination of radar types, antennas, and other detection methods may be needed to achieve more comprehensive bird detection strategies at industrial sites.

I also tested cameras to monitor birds in the context of industrial ponds. Birds that have landed on ponds are not detectable by radar, and standardised monitoring by human observers has documented tens of thousands of birds landing annually on oil sands process-affected water ponds. Such counts provide information on bird abundance, but there is considerable variation between observers and sites. To overcome these limitations, I evaluated the potential for cameras to monitor birds on industrial water bodies. I compared counts from high-resolution panoramic photos and photos taken by conventional remote cameras to counts conducted by field observers. I also tested the success of a computer algorithm to process photos automatically.

High-resolution panoramas recorded two-thirds of bird counts recorded simultaneously by field observers, for distances of approximately 500 m from survey stations. Conventional remote cameras recorded two-thirds of birds in photos clearly, but only to a distance of 100 m. Both single-frame SLR panoramas and single-frame wildlife photos failed to capture birds that dove, birds that were behind other birds, and birds with oblique aspects to the camera. The presence of these birds could be revealed by capturing bird motion with multiple photo frames in short succession (time-interval). Automated processing of time-interval photos produced a very high true negative rate (95%), suggesting that it can substantially reduce the time spent by humans to process photos. The combined application of high resolution photos taken at frequent intervals and a specialized bird detection code makes cameras a viable alternative to human observers.

Understanding the distributions and abundance of migratory waterfowl in the oil sands is in the interest of hunters, naturalists and citizens across North America. Radar and cameras can both contribute to this understanding, while simultaneously improving human safety, reducing cost and inter-observer variation, and increasing the duration and frequency of monitoring.

Preface

This thesis is an original work by S. Loots. A version of the Abstract has been published in the final report of the Research on Avian Protection project. Publications are intended for Chapters 2 and 3, with co-author C.C. St Clair. Chapter 3 will be shared with Imperial Oil for internal reporting on the research grant that supported the camera research at their Kearl Compensation Lake. The bird detection computer code used in Chapter 3 was developed and shared by H. Zhang and M. Shakeri.

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Chapter 1 Introduction

1.1. Background

Four major migratory flyways for waterfowl have been identified in North America, and birds from each of these flyways converge at the Peace-Athabasca Delta (Hennan & Munson 1979). This delta in northern Alberta has been recognized internationally as an important area for bird conservation (Ramsar 2013) and over a million birds are believed to use it for breeding and staging each year (Bellrose 1976). The safety of migratory birds using the delta may be compromised by the industrial development occurring just 200 km to the south, in the oil sands region of Alberta (Timoney 2013). In April 2008, the oil sands attracted global attention when around 2000 migrating birds landed on waste bitumen on oil sands process-affected water ponds (Nelson *et al. in press*). These ponds can be fatal to birds if they contact bitumen or fresh tailings (Timoney & Ronconi 2010). The remaining constituents of process-affected water may elicit toxic effects depending on the chemical composition, determined in part by the duration and type of exposure (i.e. feeding, nesting, or resting) of the bird (Beck 2014). Contact of birds with process-affected water is prohibited by provincial and federal laws (MBCA 1994; EPEA 2000; SARA 2002).

The size and number of ponds depends on each operator, but industry together has produced 64ponds, with the combined area of 182 km^2 (OSIP 2013). These range in size from small emergency dump ponds under 1 ha to large ponds with areas up to 10 km^2. The surface area of these ponds provide migratory birds with open water for resting and feeding, which they are especially attracted to in early spring and late fall when natural water bodies in the area may be frozen compared to tailings ponds actively receiving warm waste water (Timoney & Ronconi 2010). Tailings ponds have physical characteristics that inadvertently provide diverse habitat for migratory birds as a result of beached areas, islands, and vegetation.

Wildlife managers in the oil sands apply mitigation measures to minimize harm to migratory birds (Ronconi & St Clair 2006). Despite ongoing deterrent efforts, thousands of birds are landing on tailings ponds each year, though few appear to be dying (St Clair *et al.* 2013). In order to evaluate mitigation measures, the numbers of birds in the area need to be quantified and monitored. Technology has the potential to provide more consistent information than human observers about bird abundance in the region, because it is not subject to observer bias. In this thesis, I explore two bird detection technologies as alternatives to monitoring by human observers.

1.2. Thesis Objectives

The purpose of this thesis was to investigate bird detection by radar and cameras. Both these tools may be useful in automating the monitoring of birds in the oil sands. Radar is currently used in the oil sands by all five operators on seven lease sites, as part of specialized deterrent systems (Ronconi & St Clair 2006). The rationale behind these systems is to reduce habituation by deploying deterrents only when birds are in the area (Stevens *et al.* 2000), because birds have been shown to habituate to auditory deterrents that are used continuously (Bomford & O'Brien 1990).

The effectiveness of these deterrent systems is reliant, in part, on radar successfully detecting birds that are at risk of landing on tailings ponds. Radar does may detect non-target birds not at risk of landing on tailings ponds and deploy deterrents. This may contribute to habituation to deterrents by approaching migratory birds. Radar may also fail to detect target birds, which may result in birds landing on tailings ponds.

The purpose of chapter 2 was to identify rates of bird detection by radar. I conducted observation sessions with X-band radar monitored by radar operators who were paired with field observers, to identify bird targets in the area. I recorded specific attributes of the environment and of bird targets for each bird detection and tested their effects on radar detection rate.

One specific shortcoming of radar deterrent systems is that it cannot detect birds once they have landed. Therefore an additional need exists to monitor pond surfaces at greater spatial resolution than radar provides. In the oil sands, the monitoring of pond surfaces is conducted by human observers, as part of a newly standardized monitoring program, the Oil Sands Bird Contact Monitoring Program (OSBCMP;(St Clair *et al.* 2014). Human observers suffer from inter- and intra- observer variation (Frederick *et al.*

2003), but most importantly, industrial environments are dangerous for people, in both the short and long term (Goldsmith *et al.* 1982; Karra 2005; Verbeek *et al.* 2009).

The purpose of Chapter 3 was to identify the extent to which cameras could replace humans for bird monitoring. I paired camera recording sessions with field observers employing the OSBCMP protocol. I tested digital single-lens reflex (SLR) cameras and wildlife cameras to determine the accuracy with which they detect birds compared to field observers. I also tested automatic processing of photos from stationary cameras.

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Chapter 2 Attributes of Marine Radar Affect Detection of Birds at Industrial Sites[1]

2.1. Introduction

Conflict between people and birds commonly occurs at airports, wind farms, agricultural fields, aquaculture facilities, and other industrial sites (Conover 2010). Such human-wildlife conflict is conventionally defined anthropocentrically by the endangerment of people or property, and supports a multi-billion dollar industry based on bird deterrence. The goals of conflict mitigation overlap with avian conservation for migratory bird species whose protection is mandated by the Migratory Birds Convention, which makes it unlawful in both the US and Canada to kill migratory bird species without a permit (MBTA 1918; MBCA 1994). Consequently, most industries with the potential to harm migratory species use visual and acoustic devices designed to deter birds from the area of conflict (reviewed by (Conover 2010).

As birds readily habituate to auditory deterrents that sound at regular intervals (Bomford & O'Brien 1990), the deterrent industry is moving towards techniques to delay deployment until a target is detected (Stevens *et al.* 2000). In large-scale industrial applications, bird detection typically relies on marine radar, which can detect birds up to several kilometers away (Eastwood 1967; Flock & Green 1974; Gauthreaux & Belser 2003). The use of radar is particularly important for detecting migrating birds (Bigger *et al.* 2006; Klope *et al.* 2009), for which the human observers are limited in space and time (Hutto & Stutzman 2009), as well as under low light conditions (Cooper *et al.* 1991). Radar is especially favoured for monitoring of nocturnal migration because it has a greater range of detection distances relative to other techniques such as audio recordings, moon watching, ceilometry, thermal infra-red illumination, and night-vision imaging (Liechti *et al.* 1995; Williams *et al.* 2001).

The three major radar technologies used in ornithology include weather surveillance radar, tracking radar, and marine surveillance radar (Gauthreaux & Belser 2003; Kunz *et al.* 2007; Robinson *et al.* 2009). Weather radar can define regional or continental movement patterns of birds, but only where weather radars occur at high

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[1] This chapter has been formatted for publication with authors S. Loots and C.C. St Clair.

densities (Dokter *et al.* 2013). Ongoing refinement is improving the fine-scale resolution and accuracy of weather radar for the purposes of monitoring birds (Larkin 2005; O'Neal *et al.* 2010). Tracking radar began with military applications and it is used to track one bird at a time along its flight trajectory and then generalizing individual paths to recognize bird guilds by flight characteristics (Bruderer *et al.* 1995). Marine surveillance radar detects birds with greater spatial resolution than weather surveillance radar (O'Neal *et al.* 2010), and can be used to determine the locations and flight patterns of multiple birds simultaneously. Marine radar is now employed for bird detection at many airports in the industrialized world (Van Belle *et al.* 2007; Dolbeer 2009; Klope *et al.* 2009; Chen *et al.* 2011) and has been used to assess the environmental impacts of wind farms worldwide (Kunz *et al.* 2007). Airports and wind farms mimic many of the conditions under which radar has historically been applied to the study of bird migration. This includes radar deployment for monitoring the airspace over large, flat areas or at ridge-tops, where there are few impediments of topography, human infrastructure, or vegetation to intercept radar signals (Desholm & Laursen 2005; Gerringer 2013).

Several commercial companies now offer comprehensive systems that use marine surveillance radar to detect birds, which triggers computer algorithms to deploy deterrents (Stevens *et al.* 2000). Such systems logically reduce the tendency for birds to habituate to static deterrents. A study testing such a system showed that deployment of all pond deterrents upon confirmation of birds was more effective at deterring birds than acoustic cannons sounding at intervals (Ronconi & St Clair 2006). However, radar has only recently been discussed more generally in the context of bird deterrence (Nohara *et al.* 2007, 2012), and there are no measures of its sensitivity (i.e., the rate of true positives) or specificity (i.e., the rate of true negatives).

Some studies have suggested that false negatives by radar are more likely to occur when birds are below 200 m (Peckford & Taylor 2008) or 500 m (Alerstam *et al.* 2011), but potentially as high as 1200 m (Williams *et al.* 1986), depending on the type of radar, the location of its deployment, and the nature of the birds it aims to detect (Ruth 2007). In the context of industrial deterrence, a preponderance of false negatives at low elevations is worrisome, because those are precisely the birds that are more likely to land (Ronconi & St Clair 2006). Conversely, false positives, which can be caused by the presence of insects and bats (Vaughn 1985; Cooper *et al.* 1991), as well as precipitation (Vicen-Bueno *et al.* 2010), could increase the potential for birds to habituate. In general, the accuracy with which marine radar can detect birds is likely to be affected by antenna type (Williams *et al.* 1986; Gauthreaux & Belser 2003), atmospheric conditions, bird and flock size, bird angle to the radar beam, and flight behavior (Schmaljohann *et al.* 2008; Chilson *et al.* 2012; Beason *et al.* 2013).

More information is urgently needed about radar accuracy in the context of bird deterrence, because radar detection and deterrent systems now operate with unknown efficacy at the lease sites of all five oil sands companies that extract bitumen from sand in northeastern Alberta (St Clair *et al.* 2013). The industry has produced 64ponds containing process-affected water with potentially-toxic mining by-products (Rubinstein *et al.* 1977; Frank *et al.* 2008). These ponds span an area of 182 km^2 (OSIP 2013). For the past 40 years, the industry has been obliged to deter birds from landing on the ponds by minimizing attractants and deploying deterrent systems (reviewed by (St Clair & Ronconi 2009). That task is made more difficult by the proximity of the oil sands to the Peace-Athabasca Delta, which attracts over one million migrating birds annually (Hennan & Munson 1979; USFWS 2013) and potentially including birds from all four of the continental flyways known for waterfowl (Hennan 1972; Butterworth *et al.* 2002). Despite the legal requirement to protect birds from industrial products in the oil sands, a newly-standardized monitoring program has reported tens of thousands of detections of aquatic birds on the surface of process-affected water ponds annually (St Clair *et al.* 2013), suggesting that existing radar-based bird protection systems do not prevent birds from landing.

The purpose of this study was to evaluate the accuracy with which marine radar detects birds approaching sites comparable to process-affected water ponds. Accurate detection is a necessary component of effective bird protection programs in this and other industrial contexts, but the first detectability estimate for bird surveillance by radar was provided only recently (Dokter *et al.* 2013). That work showed that marine radar is more accurate within a range of 1.5 km and for large birds flying at higher elevations, even with the relative advantages of a flat topography and large, ocean-going bird species (Dokter *et al.* 2013). Based on the literature and our own knowledge of radar in the context of the oil sands, we identified three foci for assessing the accuracy of marine radar for detecting birds. Specifically, we predicted that accuracy would be affected by (1) the type of radar antenna, (2) the height of the radar survey station, (3) the substrate over which targets were detected (i.e., land vs. water), and (4) bird characteristics (including body size, flock size and flight altitude).

2.2. Methods

Radar experiments were conducted in spring (May – June) and fall (September – October) of 2012 in the oil sands area north of Fort McMurray, Alberta at both industrial ponds and natural water bodies, as well as in Edmonton, Alberta at natural water bodies in the summer (July and August). Radar observations were conducted at two process-affected water ponds at Shell Albian Sands, the Jackpine Mine MFT pond (57°22’75’’N, 111°36’49’’W) and the Muskeg River Mine Inpit pond (57°26’07’’N, 111°47’85’’W). We also conducted radar observations at the Jackpine Compensation Lake (57°29’62”N, 111°36’85’’W), a constructed freshwater pond designed to compensate for fish habitat lost during the development of the mine. Natural sites in the oil sands included sites adjacent to rivers and lakes at a gradient of elevations. Comparable sites were chosen in Edmonton. Field work in Edmonton was conducted to improve sample sizes, as the number of flying birds in the oil sands area decreased following spring migration.

We used a radar system comparable to industry configurations which consisted of an X-band marine surveillance radar (Furuno 8252, 25kW power output, magnetron-amplified radiation; Electro Marine Communications Inc, Oakville, Ontario, Canada) in a utility trailer with roof-mounted scanner and antenna, powered by two deep-cycle 6V batteries and with the radar range set at 1.5 km. We evaluated the two types of radar antennas currently in use in the oil sands; a parabolic (disc) antenna and a 2 m horizontal open array (t-bar) antenna. The parabolic antenna emitted a narrow radar beam (~ 4°) and was angled at 20° above the horizontal. The open-array antenna emitted a vertical beam of 10° (5° on either side of horizontal); this type of antenna is commonly used for migratory bird research (Nohara *et al.* 2012).

We conducted observation sessions of 1 or 2 hours duration after installing the radar unit adjacent to water bodies across a range of elevations, surrounding landscape types, and bird communities. During each observation session, a trained operator in the radar trailer provided real-time interpretations of the Plan Position Indicator (PPI) radar feed (Larkin 2005). We supplemented this information with the open source software system radR (Taylor *et al.* 2010), which was observed on a second computer screen to increase visual contrast between moving targets and the background. Radar feed was recorded and was examined after observation sessions to confirm detections in cases of operator uncertainty.

We paired the radar operator with visual observers during observation sessions. Visual observers scanned the sky continuously with binoculars (Larkin & Thompson 1980) to confirm detections made by the radar. When possible, visual observers identified birds that were estimated to be within 1.5 km (based on range finder measures of stationary targets), that were not detected by the radar. The radar operator identified targets as birds if they moved with a consistent trajectory for at least two rotations of the antenna. Whenever a bird or flock was detected by the radar or visual observer, the location of the target and the direction to which it was moving were communicated immediately to the other observer. Whenever possible, we had had two radars running simultaneously, each with a different antenna. Late acquisition of the second radar (July 2012) and periodic failure by one of the two radars, resulted in the majority of observations having one radar running alone (80%) and we switched between antennas for alternating observation sessions; visual observers scanned the sky for birds during all sessions.

For each detection, observers recorded which method(s) detected the target (radar, visual observer or both), as well as a suite of covariates that might influence detection probability (Table 2.1). For all detections of a bird or group of birds confirmed by visual observers, we recorded additional information about the detected target: bird guild, flock size, and altitude (Table 2.1). We evaluated radar detection of confirmed bird targets using logistic regression to determine the relative effects of measured covariates. We evaluated the radar detections by the two antennas separately in two models. Detection by the open-array antenna, when it was in operation, was considered one dependent variable. Detection by the parabolic antenna, when it was in operation, was considered another dependent variable. Statistical models were created in SPSS (IBM 2011) using a purposeful, forward-stepwise approach to variable selection (Hosmer & Lemeshow 2000). In brief, the models were constructed by identifying main effects with an $\alpha <= 0.25$ with univariate tests, combining them in a model based on likelihood ratio significance ($\alpha <= 0.05$), adding biologically-relevant two-way interactions, and retaining variables and interaction terms that improved the model significantly ($\alpha <=0.05$).

Finally, we developed two models to evaluate visual observer detection of positive radar detections, one model for detection by each radar antenna. For these models, we considered the visual detection of open-array targets as one response variable, and visual detection of parabolic targets as another response variable. We included several additional covariates (Table 2.1) in these two models predicting visual detection rate, since bird covariates could not be included because they were unknown for cases where radar detected birds that visual observers failed to detect.

2.3. Results

We conducted a total of 160 hours of paired observations with radar and visual observers between April and October 2012 at 13 locations in northern and central Alberta. During these observations, we recorded a total of 4818 detections of a bird or flock with at least one of the three methods (radar with open-array antenna, radar with parabolic antenna, or visual observers). Radar detection by each antenna was compared to visual detections of birds, based on a combination of cases (Table 2.2) when the antenna was in operation alone and cases when both antennas were in operation together on two radars (Table 2.3).

Visual observers detected or confirmed 75.5% of all detections, a higher proportion than was achieved by either the open-array antenna (57% of cases in which it was in operation) or the parabolic antenna (43.6% of cases in which it was in operation). Relative to visual observers, false negatives (failure to detect a target that was detected by another method) occurred twice as frequently for the open-array antenna and 2.6 times as frequently for the parabolic antenna (Table 2.2). There was agreement on bird detections between visual observers and radar less often when the parabolic antenna was used (22.3%) relative to when the open array antenna was used (36%; Table 2.2). When both antenna configurations operated simultaneously on two radars, the antennas seldom agreed on the presence of bird targets (5%;Table 2.3). The parabolic antenna missed one third of the detections made by the open-array (35%), whereas the open-array antenna missed only 17% of those made by the parabolic antenna, and both radar antennas simultaneously failed to identify a large portion of detections by visual observers (43%; Table 2.3).

For cases of positive detection of birds by visual observers, we examined the covariates that determined whether or not the bird was also detected by radar; we did this separately for the two radar antennas. Radar detection with the open-array antenna decreased with increasing survey station height (Table 2.4) as an interaction with broad bird guild, increased when the bird was over the water (Table 2.4), decreased with an interaction between increasing bird elevation and position of bird over the water, varied with an interaction between location and increasing flock size, and varied depending on the location and the bird guild (*Nagelkerke's* $R^2 = 0.30$; $\chi^2 = 245.32$, df = 30, $P < 0.0001$; N = 950; Table 2.4). Radar detection with the parabolic antenna increased with increasing survey station height (Table 2.5), decreased with most locations as bird elevation increased, and increased with an interaction between increasing flock size and bird guild ($R^2 = 0.18$; $\chi^2 = 81.52$, df = 14, $P < 0.0001$; N = 731; Table 2.5).

To know more about the 21% of cases in which each antenna detected birds that the visual observers failed to detect, we evaluated visual detection rate of confirmed radar detections by each of the two antennas. Visual detection of radar targets of the open-array antenna depended on the location, and was influenced by interaction terms between the location and cloud cover, wind intensity, and the presence of a target over water; visual detection also increased in the fall compared to the summer, and increased when the installation height increased in the summer ($R^2 = 0.27$; $\chi^2 = 360.00$, df = 48, $P < 0.0001$; N = 1691; Table 2.6). Visual detection of radar targets of the parabolic antenna also depended on the location and was influenced by interaction terms between location and the position of the target over water, and between location and the intensity of wind. Visual detection decreased with the presence of clouds and the position of the target over water; it also decreased with an interaction term of survey station height and the position of the bird over water ($R^2 = 0.16$; $\chi^2 = 131.65$, df = 32, $P < 0.0001$; N = 1028; Table 2.7). Season was also important for visual detection of parabolic targets, with more positive detections in fall, compared to spring, and fewer positive detections in the summer compared to spring (Table 2.7). Together these two models suggest that visual detections were influenced by the presence of more than 25% clouds in the sky and windy conditions and decreased with increasing survey station height.

2.4. Discussion

The purpose of this study was to determine the attributes that influence the detection of birds by marine radar in the context of bird protection at industrial sites. We conducted sessions with simultaneous observation via radar and people and used human-verified detections of birds as a basis for determining the effects on radar detection of antenna type as well as the characteristics of locations and bird targets. We found that birds were detected more often by human observers who reported 39% more targets than radar fitted with an open-array antenna and 81% more than radar fitted with a parabolic antenna. In a lesser number of observation sessions, radar detected birds that human observers failed to see (21%). We examined the correlates of detection patterns to provide information that could be used to increase the accuracy of radar-based bird surveillance in industrial contexts.

In our study, false negatives were 2 to 2.6 times more likely for radar than people, which is comparable to the rate of approximately 50% detectability for birds by marine radar in a single other study that directly compared an open-array marine radar to visual observers (Dokter *et al.* 2013). The most important contributor to the rate of detection by radar was the type of antenna used. The higher rates of bird detection we found for the open array antenna were presumably caused by its greater beam angle (10° vs. 4° for the parabolic antenna). Others have reported that manufacturer-specified values of beam width can be wider than the actual, operational beam (Hilgerloh *et al.* 2010), but it can also be narrower (Hueppop *et al.* 2006). The relative disadvantage of the narrower beam that characterizes the parabolic antenna can be overcome by installing two antennas at slightly off-set angles (Beason *et al.* 2013), and this technique is currently employed at one oil sands mining company (Nohara *et al.* 2012). Two advantages of parabolic antennas over open-array antennas are that they have less interference as a result of ground clutter (Beason 1978; Chilson *et al.* 2012), and they provide operators with the ability to estimate height of the target (Schmaljohann *et al.* 2008; Chen *et al.* 2011).

In addition to a direct effect on detection rate, antenna type influenced the relative effects of the height of survey stations, the substrate over which the birds flew, and several bird characteristics. Increasing station height relative to the adjacent water body caused a decrease in bird detections by radar when fitted with the open-array antenna (though it depended on the bird guild), and an increase in detections when fitted with the parabolic antenna. At lower survey station heights, the ground clutter immediately around a station is reflected in the lower portion of the wide radar beam, which frees up the majority of the radar beam to detect targets without interference (Beason *et al.* 2013). It is also possible that higher station heights for the open array antenna meant that more birds flew below the radar. By contrast, the positive influence of higher station heights on radar detection with the parabolic antenna is likely due to other location-specific influences. No study has directly examined the effect of survey station height on the likelihood of detection of birds by radar, perhaps because most studies are dedicated to determining the positions of bird flocks in space and time (Williams *et al.* 1986; Schmaljohann *et al.* 2008), and not the proportion of potential targets that are detected.

The substrate over which a bird flew affected the likelihood of detection by radar, but only for the open-array antenna, which was more likely to detect birds when they flew over water than over land. This result is consistent with the finding that detectability by radar increased at high tide (Dokter *et al.* 2013). Because open-array antennas capture a wider swath of sky, they are more affected by surrounding topography than parabolic antennas. For open-array antennas, bird detection might increase over land as false positives, where topographical clutter is more likely, or decrease over land as false negatives, because of automatic filters designed to reduce topographical clutter. The positive effect of water that we detected is likely dependent on calm weather because choppy seas are well-known to create clutter for radar in marine contexts (Kelly *et al.* 2009). The effect of the substrate below the target, whetherwater or land, is clearly relevant to the performance of radar for bird detection, but only one study has discussed the relative effect of these two substrates on radar detection (Dokter *et al.* 2013).

A third major contributor to the performance of radar in our study was the suite of bird characteristics we measured, but these effects were also antenna-specific. With the open-array antenna, waterfowl were more likely to be detected than the other guilds of birds (gulls and terns, land birds, and unknown birds). Moreover, in the analysis comparing humans and open-array antennas, the negative effect of station height on detections was stronger for unidentified birds relative to waterfowl. Finally, the detection of birds via the open-array antenna declined with increasing bird height when the birds were over water. When the radar was fitted with the parabolic antenna, different interactions with bird variables occurred. Land birds were more likely to be detected by the parabolic antenna at higher elevations and in larger flocks. Although we found evidence that bird guild is important to radar performance, the variety and interacting nature of these effects means they are probably context-specific and difficult to generalize for operational purposes. More work is needed to determine the generality of these bird characteristics results, especially since larger birds and larger flocks are both considered in algorithms calculating bird strike risk (Chen *et al.* 2011), and some have reported that radar-based detection increases for larger birds and flock sizes (Gerringer 2013).

We assessed the relatively few instances when radar detected birds that humans did not detect, for their implications for industrial bird protection. We found that these events were more likely during higher cloud cover and wind speeds, which tend to indicate poor weather. It is not surprising that radar, with a range of 1.5 km, may detect birds during foul weather at greater distances than human observers can, but this may not be an advantage in the context of industrial sites. These detections, though true positives, likely included a disproportionate number of birds that were flying at larger distances from the survey station and at higher elevations. Both characteristics make them less likely to land (Ronconi & St Clair 2006) even though their detection may trigger deterrent deployment. A similar problem is potentially created by the high frequency with which radar detected single land birds, such as corvids and non-waterfowl, such as gulls, in our study. This sensitivity presumably means that automated systems deploy deterrents in response to these birds, even though they are unlikely to land and are not targets of the protection programs designed primarily for waterfowl (St Clair *et al.* 2014). In both cases, the unnecessary deployment of deterrents is likely to cause habituation over time and space of waterfowl passing through the region.

In addition to their implications for bird protection in the oil sands region, our results have some potential bearing on the management of radar-based bird protection in other contexts. Many major airports in the world now use marine radar to detect birds (Bridge *et al.* 2011; Chen *et al.* 2011), but there appears to have been little study of the effects on detection accuracy of surrounding topography, survey station height, and bird characteristics. As starting points, bird and flock size are both assumed to increase the 'strike risk' at airports (Chen *et al.* 2011) and the height of bird flocks is known to influence the potential for collisions at airports (Klope *et al.* 2009; Chen *et al.* 2011) and wind farms (Desholm *et al.* 2006). It may be possible to integrate these characteristics to identify broad target classifications for deterrence, even though radar itself cannot distinguish individual species (Gauthreaux & Belser 2003).

As an example of this integrative use of radar, we return to the problem of deterrent deployment by non-target birds in the oil sands, which is likely to cause habituation by target birds. It might be possible to overcome this problem by using a combination of antennas on integrated radars that are installed at different heights. An open array antenna installed on a dike high above a tailings pond with the appropriate ground clutter reduction screen might target only distantly-approaching birds. A pair of parabolic antennas installed at a lower elevation could then localize targets in three-dimensional space. Deployment of deterrents could integrate both sets of detections; birds that are approaching at a distance, as would be expected of migratory birds not intent on landing, and birds that are approaching the perimeter of the pond at low elevations, as would be expected of migratory waterfowl that are intent on landing. This combination could reduce undesired deterrent deployment for birds circling at low elevations immediately over the pond and, simultaneously, for birds flying at high elevations distant from it. Although one system in the region uses dual parabolic antennas (Nohara *et al.* 2012), most systems use open array antennas, and none have the combination we have proposed here.

Several authors have suggested that radar is superior to human observation as a method of bird detection (Bigger *et al.* 2006; Dokter *et al.* 2013), but we have shown that the accuracy of bird-detecting radar is dependent on several factors that have received little study and remain poorly understood. Meanwhile, radar-based bird detection is employed at industrial applications worldwide and deterrent systems are integrated with radar at all five of the multi-national mining companies that operate in the oil sands region of Alberta. There is an urgent need to test and report radar performance in these contexts. We especially encourage companies to avoid relegating radar function to the 'black box' of proprietary software and to test detection accuracy as well as deployment specificity. The oil sands occur in a region of global significance for migratory birds (Ramsar 2013) where over a dozen marine radars have already been installed. These circumstances put significant pressure on the environmental performance of the oil sands industry, but they also position it to become a global leader in radar-based deterrent systems to support best practices in bird protection at industrial sites throughout the world.

Table 2.1. Covariates recorded for each bird observation detected by radar operator and/or visual observers during paired observation sessions conducted twice daily beside various process affected ponds and freshwater ponds.

Covariate	Definition	Variable type	Model covariate was used in	Variable range
Antenna type	Open-array or parabolic	Binary	n/a	-
Site ID	The survey site	Categorical	All	-
Station height	Height of the radar station above adjacent body of water	Continuous	All	0 – 44 m
Substrate beneath target	Whether the target flew over land or over water	Binary	All	-
Weather conditions	< 25% clouds or >25 % clouds in sky	Binary	Visual detection of confirmed radar targets (Table 6 & 7)	-
Wind intensity	Beaufort scale of wind during the observation session	Categorical	Visual detection of confirmed radar targets (Table 6 & 7)	0 – 4
Time	Time of bird/target detection	Continuous	Visual detection of confirmed radar targets (Table 6 & 7)	6:01 – 20:43
Season	Spring, summer, fall	Categorical	Visual detection of confirmed radar targets (Table 6 & 7)	-
Bird altitude	Calculation of bird height from clinometer angle to bird and estimated horizontal distance to bird; both measured by visual observer	Continuous	Radar detection of confirmed visual targets (Tables 4 & 5)	1.5 – 600.7 m
Bird guild	Identification of bird to categories of waterfowl; shorebirds; landbirds; and unknown bird. Identified by visual observer	Categorical	Radar detection of confirmed visual targets (Tables 4 & 5)	-
Number of birds	Number of birds in target group or flock; identified by visual observer	Continuous	Radar detection of confirmed visual targets (Tables 4 & 5)	1-850

Table 2.2. Contingency table comparing detections of birds by visual observers and radar operators during paired observation sessions conducted twice daily at process-affected and freshwater ponds. Radar detections are separated for the type of antenna in use during the observation session. Raw number of detections is presented with the percent of detections for sessions with each antenna type in brackets.

			Visual detection (%)	
	Radar antenna		Yes	No
Radar detection (%)	Open array N = 2820	Yes	1014 (36)	604 (21)
		No	1202 (43)	N/A
	Parabolic N = 2355	Yes	525 (22.3)	503 (21.3)
		No	1327 (56.4)	N/A

Table 2.3. Contingency table comparing detections of birds by two radar systems operating simultaneously, each with a different type of antenna. Observation sessions were conducted by radar operators and visual observers during paired observation sessions conducted twice daily at process-affected and freshwater ponds. Raw number of detections is presented with the percent of detections for sessions with each antenna type in brackets.

	N = 967	**Open array antenna detection (%)**	
		Yes	No
Parabolic antenna detection (%)	Yes	53 (5)	160 (17)
	No	337 (35)	417† (43)

† Visual detections of birds missed by open array and parabolic simultaneously

Table 2.4. Model results for logistic regression of radar detections by the open-array antenna for bird targets that were confirmed by visual observers during paired observation sessions conducted twice daily at process-affected and freshwater ponds. visually confirmed birds.

Covariate	**β**	**S.E.**	**Wald**	**d.f.**	***P***
Survey station height by Bird guild			1.98	4	0.74
gulls & terns vs. waterfowl	-0.048	0.33	0.02	1	0.88
landbirds vs. waterfowl	-0.024	0.29	0.01	1	0.93
shorebirds vs. waterfowl	-79.07	31018.83	0.00	1	1.00
unknown birds vs. waterfowl	0.51	0.45	1.31	1	0.25
Survey station height	4.03	0.82	23.96	1	**<0.001**
Over water by Bird elevation	-0.24	0.11	4.59	1	**0.032**
Over water	1.93	0.27	51.58	1	**0.000**
Bird guild			9.19	4	0.056
gulls & terns vs. waterfowl	-0.024	0.25	0.01	1	0.92
landbirds vs. waterfowl	-0.65	0.25	6.90	1	**0.01**
shorebirds vs. waterfowl	-63.57	25076.56	0.00	1	1.00
unknown birds vs. waterfowl	-0.040	0.41	0.01	1	0.92
Location by Number of birds			11.68	10	0.31
Location by Number of birds	-2.56 to 8.84	0.14 to 13.59	0.42 to 2.77	10	0.096 to 0.52
Location			87.31	9	**<0.001**
Location	-12.77 to 1.53	0.36 to 3.46	6.48 to 42.83	9	**<0.001 to 0.011**
Constant	1.56	0.56	7.83	1	**0.01**

Nagelkerke's $R^2 = 0.30$; $\chi^2 = 245.32$, df = 30, $P < 0.0001$. N = 950.

Table 2.5. Model results for logistic regression of radar detections by the parabolic antenna for bird targets that were confirmed by visual observers during paired observation sessions conducted twice daily at process-affected and freshwater ponds.

Covariate	**β**	**S.E.**	**Wald**	**d.f.**	***P***
Survey station height	0.208	0.115	3.251	1	0.071
Bird elevation by Location			15.83	5	**0.007**
Bird elevation by Location	-3.15 to 0.17	0.18 to 1.42	0.014 to 12.467	10	<0.001 to 0.91
Bird elevation by Bird guid			12.24	4	**0.016**
gulls & terns vs. waterfowl	0.55	0.77	0.51	1	0.48
land birds vs. waterfowl	2.87	0.86	11.06	1	**<0.001**
shorebirds vs. waterfowl	271.21	48167.66	0.00	1	1.0
unknown bird vs. waterfowl	1.49	0.97	2.33	1	0.13
Number of birds by Bird guild			13.34	4	**0.01**
gulls & terns vs. waterfowl	0.52	0.20	6.76	1	**0.009**
land birds vs. waterfowl	0.58	1.60	0.13	1	0.72
shorebirds vs. waterfowl	-22.36	18763.95	0.00	1	1.0
unknown bird vs. waterfowl	-6.22	2.59	5.78	1	**0.016**
Constant	-1.80	0.15	141.29	1	**<0.001**

Nagelkerke's R^2 = 0.18; χ^2 = 81.52, df = 14, P < 0.0001. N = 731.

Table 2.6. Model results for logistic regression of detections by the visual observer for bird targets that were confirmed by radar with an open-array antenna. Observation sessions were conducted twice daily at process-affected and freshwater ponds.

Covariate	**β**	**S.E.**	**Wald**	**d.f.**	***P***
Season			26.16	2	**<0.001**
Season (summer)	20.99	28422.67	0.00	1	1.00
Season (fall)	1.87	0.37	26.16	1	**<0.001**
Location			22.99	13	**0.042**
Location	1.63 to 10.5	0.72 to 3.36	3.33 to 19.31	13	<0.001 to 0.068
Season by Survey station height			11.16	1	**<0.001**
Season (summer) by Survey station height	-3.61	1.08	11.16	1	**<0.001**
Location by Season			34.18	2	**<0.001**
Location by Season	-2.27 to -3.4	0.061	14.02 to 31.15	2	**< 0.001**
Location by Over water			13.84	11	0.24
Location by Over water	-1.79 to 0.62	0.42 to 1.68	0.12 to 8.48	11	0.0004 to 0.73
Cloud cover by Location			35.82	10	**<0.001**
Cloud cover by Location	-1.42 to 1.46	0.33 to 1.16	0.93 to 18.87	10	<0.001 to 0.34
Location by Wind			27.01	9	**0.001**
Location by Wind	-0.43 to 0.8	0.19 to 1.23	0.0048 to 12.10	9	<0.001 to 0.95
Constant	-2.65	0.64	17.35	1	**<0.001**

Nagelkerke's $R^2 = 0.27$; $\chi^2 = 360.00$, df = 48, $P < 0.0001$. N = 1691.

Table 2.7. Model results for logistic regression of detections by the visual observer for bird targets that were confirmed by radar with a parabolic antenna. Observation sessions were conducted twice daily at process-affected and freshwater ponds.

Covariate	**β**	**S.E.**	**Wald**	**d.f.**	***P***
Season			22.15	2	**< 0.001**
Season (summer)	-0.50	0.50	1.02	1	0.31
Season (fall)	0.98	0.33	9.07	1	**0.003**
Location			12.75	10	0.24
Location	-0.68 to 1.81	0.48 to 1.156	0.026 to 6.67	10	0.098 to 0.87
Location by Over water			18.45	10	**0.05**
Location by Over water	-2.94 to 12.03	0.47 to 6.01	0.037 to 4.01	10	0.045 to 0.85
Cloud cover by Over water	-0.74	0.25	8.39	1	**0.004**
Over water by Survey station height	-4.39	2.20	3.99	1	**0.046**
Location by Wind			21.51	8	**0.006**
Location by Wind	-0.68 to 1.67	0.16 to 0.99	0.011 to 8.83	8	0.003 to 0.92
Constant	-1.15	0.44	6.94	1	**0.008**

Nagelkerke's $R^2 = 0.16$; $\chi^2 = 131.65$, df = 32, $P < 0.0001$; Overall % predicted = 64.5. N = 1028.

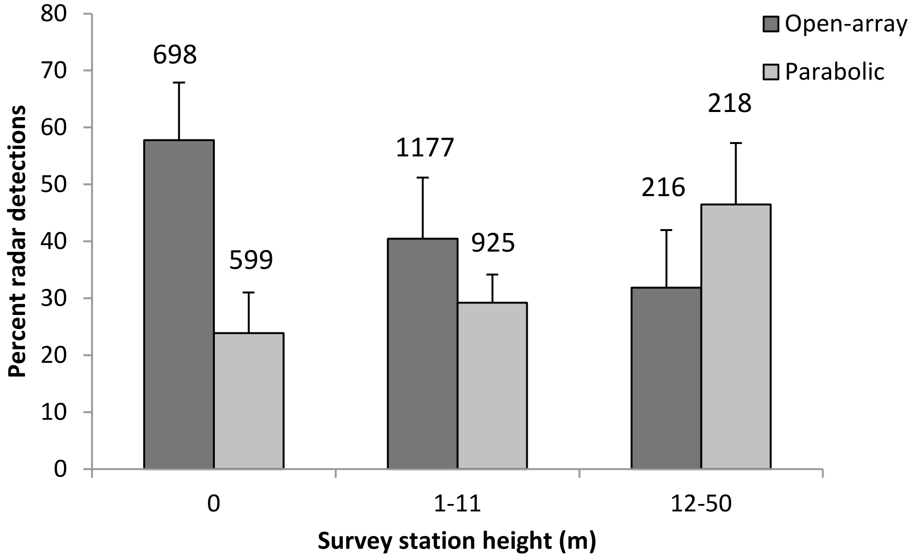

Figure 2.1. Percent detections (± SE) by two radar antennas of bird targets confirmed by visual observers during paired observation sessions, averaged for three survey station height groups. Sample sizes are listed above each category.

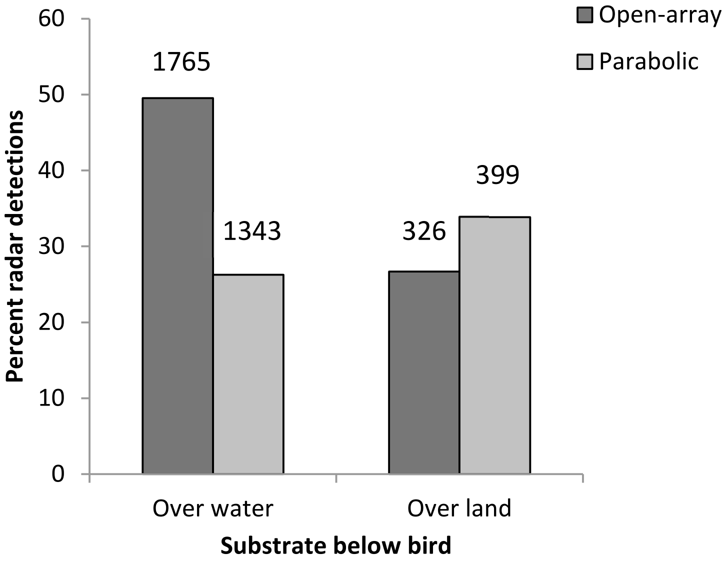

Figure 2.2. Percent detections by two radar antennas of bird targets confirmed by visual observers during paired observation sessions. Detections are separated by the substrate that was below the target. Substrate below the target was categorized as either passing over water or over land. Sample sizes for the total number of visually confirmed targets in each category for each antenna are given above each category.

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Chapter 3 Comparability of Camera and Human Detections of Birds for Standardized Monitoring at Industrial Sites[2]

3.1. Introduction

Mitigating conflict between people and birds at industrial sites around the world requires accurate detection of birds and measures of their abundance and distribution. The need to count birds is particularly critical when legislation obliges industry to prevent birds from coming in contact with human infrastructure. Such situations occur when birds threaten the safety of humans at airports and when migratory birds are attracted to hazardous substances. Risks to birds are heightened when migratory flyways are intercepted by infrastructure, such as electrical lines (Bevanger 1994; Lehman *et al.* 2007), communication towers (Longcore & Smith 2013), lighthouses (Jones & Francis 2003), wind turbines (reviewed by (Drewitt & Langston 2006), and oil and gas infrastructure (Baird 1990; Wells *et al.* 2008). In some cases, infrastructure might also attract migratory species.

Infrastructure that both attracts and exposes birds to hazards is frequently created by the oil and gas industry. In North America, the *Migratory Birds Convention Act* requires that birds are monitored and the number of contacts and mortalities are reported to government officials. Unfortunately, few standards exist for monitoring the effects of infrastructure on birds, despite some claims by industry that they are negligible (Burke *et al.* 2012). For example, conventional terrestrial oil extraction in the US creates pits of waste oil that causes significant, but unquantified, mortalities each year (Flickinger & Bunck 1987; Trail 2006; Ramirez Jr 2010). Similarly, seabirds are attracted to offshore oil structures for resting and foraging opportunities (Fraser *et al.* 2006), but inconsistent monitoring has made it impossible to determine the number of birds affected by the platforms and their waste (Burke *et al.* 2012).

The need to monitor birds at oil-producing facilities attracted international attention recently when approximately 2000birds died after being coated in bitumen, a

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[2] This chapter has been formatted for publication with authors S. Loots and C.C. St Clair.

heavy oil, produced by the oil sands industry in northern Alberta (Nelson *et al. in press*). These events resulted in the creation of a collaborative, standardized monitoring program to count birds that make contact or die, in association with process-affected water. The program targets aquatic birds that forage by diving, dabbling or wading and consists of counting birds that land on 80 designated survey stations on 64 ponds containing process-affected water (St Clair *et al.* 2013). The purpose of the program is to provide information on the distribution and abundance of both live and dead birds that will support iterative improvements to deterrence strategies (St. Clair *et al.* 2014).

Many factors limit the practicality and accuracy of human observers as a means of monitoring birds and other wildlife. Most importantly, many industrial sites are dangerous for human observers, especially in areas that present the greatest risk to birds (Goldsmith *et al.* 1982; Verbeek *et al.* 2009). Even with safe conditions and careful training, observers are limited by the spatial and temporal frequency of monitoring (Farnsworth & Russell 2007). For large sites, the cost of human monitors can be substantial and some oil sands operators have estimated that they spend $2 million per year to support the standardized monitoring program. Finally, unintended variation in counts can result from observer variation owing to experience, training, personal ability, and fatigue, and may manifest as errors in species identification, guild grouping, distance to bird, and counts (Tasker *et al.* 1984; Bajzak & Piatt 1990; Mateos *et al.* 2010).

Each of these limitations – safety, replication, cost, and inter-observer variation – may be reduced with the use of automated techniques. Such approaches have already been applied widely to the censusing of songbirds via acoustic recorders, which provide more objective species identification, increased consistency in population estimates, and reduced disturbance to birds (Farnsworth 2005; Brandes 2008). Others have employed cameras to record bird nests (Rowcliffe & Carbone 2008; Kross & Nelson 2011), document ground-dwelling forest birds (Dinata *et al.* 2008; O'Connell *et al.* 2011) and even measure the foraging behaviour of nocturnal birds (e.g. Santos *et al.* 2008). Ideally, automated recording of birds is supported with automated processing of the vast quantities of data that result (Bardeli *et al.* 2010) to reduce the number of hours that must be spent by humans in manual processing (Harris *et al.* 2010).

Despite these advantages, camera bird monitoring is not yet widespread, potentially because little information is available on the detection rates of cameras, conventional remote cameras have relatively low resolution, and software is not yet available to automate the processing of photos. To address these potential impediments, we developed and tested a remote camera system to match the accuracy afforded by human observers in the standardized monitoring program of the oil sands and explored image resolution, frequency, and processing. Our specific objectives were to (a) determine the count accuracy of panoramic images produced by a high-resolution single-lens reflex (SLR) camera, (b) compare the detection rates of cameras of different resolutions, and (c) estimate the efficiency of a computer program to automate photo-processing.

3.2. Materials and Methods

Study area

We surveyed water bodies for birds on three oil sands lease sites in the Athabasca oil sands area, 40 - 150 km north of Fort McMurray, Alberta, between April and October in 2011 and 2012. We made observations at two types of ponds, process-affected water (hereafter "PAW") ponds and freshwater (hereafter "FW") ponds. PAW ponds ranged in size from 0.075 km^2 to 8.59 km^2 and varied in water chemistry (Allen 2008). All PAW ponds had bird deterrents installed on their shores and, in some cases, on floating platforms. FW ponds were water bodies that served as fisheries compensation lakes or water reservoirs. One compensation lake was used for additional independent camera monitoring and to test configurations for automated operation[3].

Monitoring sessions at both PAW and FW ponds used a newly-standardized monitoring protocol required by the provincial government for all oil sands operators in the region (St. Clair & Loots 2012). In brief, observations were conducted for birds restingon water bodies during 30 min sessions twice daily by observers stationed at the edge of ponds. Monitoring teams consisted of two observers using a spotting scope (Zeiss Victory Diascope 85 T* FL with 20 - 75 x zoom, Carl Zeiss Vision Inc, San

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[3] For a description of the independent camera set up, see Appendix IV.

Diego, California, USA), an integrated range finder and binoculars (Bushnell 10 x 42 Fusion 1600 ARC, Bushnell Outdoor Products Canada, Vaughan, Ontario, Canada), a compass, and a digital data recording device (Samsung Galaxy tablet, Samsung Electronics Canada, Mississauga, Ontario, Canada). During monitoring sessions, observers recorded all unique individuals, indicating the distance, azimuth and number of individuals of each bird species. A subset of the monitoring sessions in 2012 was used to conduct a study of inter-observer variation at five oil sands lease sites (Imperial Oil Ltd.'s Kearl Oil Sands lease; Shell Canada Ltd.'s Muskegg River Mine and Jackpine Mine lease sites; and Syncrude Canada Ltd.'s Mildred Lake and Aurora lease sites). This study was based on simultaneous, but independent, observations by personnel from the University of Alberta (U of A) and industry (Imperial Oil Ltd, Shell Canada Ltd, Syncrude Canada Ltd.).

Count accuracy of SLR panoramas

Cameras were positioned beside observers to photograph ponds for the duration of each 30-min monitoring session. We used a digital SLR camera (Nikon D700 SLR camera with an AF-S Nikkor 70 - 200 mm f2.8 lens and an AF-S Nikon TC-20E III 2x tele-converter, Nikon Canada Head Office, Mississauga, Ontario, Canada) with a resolution of 12.1 megapixels (8.45 µm pixel pitch) and low-light capabilities (ISO 200 - 6400). It was mounted on a tripod attachment (Gigapan EpicPro, Portland, Oregon, USA) which panned the camera to a grid of positions and triggered the camera shutter at each position. The resulting photographs comprised a panorama of the pond surface viewable from the survey station (Figure 3.1).

Each series of photos was combined as a panorama using specialized software (GigaPan Stitch 1.0.0805) and manually examined on a computer screen (iMac 24 inch, 3.4 GHz, Cupertino, California, USA, using Adobe Photoshop CS4, Adobe Systems Inc, San Jose, California, USA) approximately one month after the monitoring session. The same individuals who conducted the field monitoring examined each panoramic photo and counted all visible birds, identifying them to species when possible.

Because it was not possible to directly measure the distance between the camera and birds in the photos, we developed a method for estimating distance using the number of pixels occupied by decoys of mallard ducks (*Anas platyrhyncos*) in a series of photos with known distances to targets. We counted the number of pixels that comprised the decoy at each distance, and derived the relationship between the two sets of numbers ($y = (4*10^7)*x^{-1.944}$; where y = number of pixels, and x = distance in metres; $R^2 = 0.99$). We then counted the pixels for each bird in a subset of the SLR panoramas from a single FW location (Crane Lake) and used this formula to estimate the distance to them. We included only those birds that (a) could be identified to genus, (b) were comparable in size to mallards, and (c) were positioned in the photograph with the side-view we used in our decoy measurements, which comprised 60% of all birds in these reference panoramas.

To evaluate the performance of the SLR panoramas relative to field observers, we paired the number of birds counted by each method, for each observation session. We subtracted the number of birds detected on panoramic photos from the presumed 'true' number derived by field observers and termed this difference 'disagreement'. We analyzed variation in disagreement using a generalized linear mixed model (GLMM) with the program SPSS (IBM SPSS Statistics Version 20, (IBM 2011)). Covariates used during model selection consisted of metrics recorded during each monitoring session, including year, season (spring, summer, and fall), time of day, light index, pond type (FW or PAW), pond size, horizontal and vertical distance from the station to the water, and the meandistance and standard deviation for all birds as recorded by field observers. We added binary covariates to indicate whether or not field observers detected birds designated by foraging guild as dabblers, divers, small waders, large waders, scavengers, and gleaners.

We built models using a forward-stepwise selection procedure (Hosmer & Lemeshow 2000) that consisted of (a) identifying potential main effects using a liberal univariate test ($\alpha <= 0.25$), (b) combining those in a single model and identifying the significant variables ($\alpha <= 0.05$), and then (c) individually adding biologically-relevant two-way interactions and retaining interactions that were significant ($\alpha <= 0.05$) to produce (d) the final reduced model. To facilitate use of the model for predictive purposes, we standardized all continuous variables prior to analysis with a mean of 0 and a standard deviation of 1. We included pond ID as a random effect.

Camera resolution

In addition to the SLR panoramas, we examined the potential to use remote cameras that are conventionally used for wildlife (Reconyx HC600 HyperFire High Output Covert IR, Holmed, Wisconsin, USA; 3.1 megapixel resolution) for bird monitoring. Wildlife cameras were programmed to photograph two FW ponds every 5 minutes for 3 hours after sunrise every day. Using the same manual processing technique as we applied to the SLR photos, we compared counts from wildlife cameras taken on the same days that the pond had been visited by industry monitors. In addition, we determined the relationship between the pixels and distance of target birds recorded by the wildlife cameras using the reference method described for SLR photos above. We analysed a subset of wildlife camera photos to determine the proportion of waterfowl that were clearly discernable within a distance of 100 m, and between 100 m and 200 m.

Automated photo processing

Because the processing of photos manually on a computer is very time consuming, we explored automated analysis via a computer code based on pattern recognition. Specifically, we used a code developed by collaborators (Shakeri & Zhang 2012) written for the program Matlab (R2012a, Mathworks, Natick, Massachusettes, USA), designed for detecting birds. We tested the bird-detection code on recordings from a high-definition video camera (Panasonic HDC TM900; 1080/24p; 3 x 3.05 MP 1/4 .1” 3MOS Sensor, Kadoma, Osaka, Japan) and on photos from the SLR camera, taken in clusters of 20 photos, each one second apart in each of several camera positions. We compared counts from automated processing to manual processing for 10-min video clips (from the video camera) and checked for correlation. We also compared detection of bird presence or absence from automated processing to manual processing of 20-photo clips (from the SLR camera). For the interval photos, we calculated the true positive rate (TPR) and true negative rate (TNR) of detection of bird presence in each clip. We processed the images manually (as above) as our measure of true detections for all automated processing.

3.3. Results

We conducted a total of 243 paired 30-min observation sessions in which birds were recorded simultaneously by U of A field observers and SLR panoramas. We recorded counts of all birds that were visible on the water surface at 14 PAW ponds (52% of observations) and 9 FW ponds; (48% of observations). The majority of birds detected by U of A field observers were within 800 m of the survey stations (95.9 % ± 1.1 SE), across all observation sessions. Both SLR panoramas and field observers detected birds in 47% of sessions (114/243), only field observers recorded detections 22% of sessions, and only SLR panoramas detected birds in 7% of sessions; neither method detected birds in 24% of sessions. In one third of the observation sessions (32%), counts were also made by industry observers.

Count accuracy of SLR panoramas

When averaged among all 243 observation sessions, SLR panoramas recorded significantly fewer birds than U of A field observers (PAW ponds: 2.95 vs. 1.91 birds; $t = -1.94$, $df = 125$, $P = 0.054$; FW ponds: 29.38 vs. 18.32; $t = -5.22$, $df = 116$, $P < 0.0001$). On average panorama counts were 65.0 % (± 13.0 SE) of U of A field counts, with a comparable proportion of counts detected by cameras on FW ponds (66.5% ± 16.5) and PAW ponds (62.2% ± 20.8). SLR panorama counts were more comparable to industry and U of A monitors during paired sessions (Figure 3.2). SLR panorama counts were 3 times that of industry counts on FW ponds, though there were only 6 paired sessions with industry at FW ponds ($N = 6$), however, SLR panoramas counts were not significantly different from industry counts for paired observations at PAW ponds (2.18 vs. 2.17; $t = -0.017$; $df = 70$; $P = 0.99$; Figure 3.2).

The difference between the U of A field counts and panoramic SLR camera counts, was termed “disagreement”, and was modelled using the subtracted counts as a dependent variable in a generalized linear mixed model (for the 180 sessions where one or more birds were detected by field observers). Disagreement, which was normally distributed, increased with the number of birds counted by field observers and by the average distance from them, both as interactions with other covariates (Table 3.1).

Camera resolution

Wildlife cameras had greatly reduced resolution compared to SLR cameras. For example, a medium-sized bird on an SLR photo occupied 100 pixels at 800 m, whereas a medium-sized bird on a wildlife camera photo occupied 100 pixels at only 100 m (Figure 3.3). When we photographed a Double-crested cormorant (*Phalacrocorax auritus*) 261 m away with both cameras, it was clearly discernable on digital SLR photos with an average of 1111 (± 101.9 SE) pixels, but it was only weakly discernable on wildlife camera photos with an average of 38 pixels (± 2.2; Figure 3.4). Despite the reduced resolution of wildlife cameras, daily counts from them were significantly correlated with 30-min industry counts on days with both types of counts (Pearson's Correlation ρ = 0.60; P = 0.014). Wildlife camera photos taken at another location demonstrated that waterfowl were clearly discernable 61.66 % (± 3.9 SE; N = 89) of the time within 100 m but only 13.40 % (± 3.15; N = 68) of the time between 100 and 200 m. For cases with birds in both distance categories, there were significantly more birds discernable within 100 m than between 100 m and 200 m (t = 10.14, df = 49, $P < 0.0001$).

Automated photo processing

The bird-detection code made it possible to automate counts of birds from video recordings, and to automate the binary detection of birds in a very short series of photos from the SLR camera (Figure 3.5). Compared to human observers counting video clips, the bird detection code over-counted some sessions and under-counted others, and counts were only weakly correlated (Pearson's ρ = 0.25; P = 0.029). Detection of bird presence in SLR photo clips from time-interval settings had a low rate of true positives (26.6%), but it could be improved by modifying the code settings to successfully detect about one third of the bird clips (35.7%) with specialized settings. By contrast, the true negative rate of bird detections in SLR photo clips was very high (92.1%), but was also improved with specialized settings (94.4%). The high true negative rate of the code means that photos clips deemed to have no birds can be confidently excluded from manual analysis. Increased sensitivity could likely have been achieved with further adjustments of the code for each position of the SLR camera. The application of this code could reduce the time required for manual processing considerably, particularly when there are few birds on ponds, which occurs at process-affected water ponds.

In one plausible scenario, an SLR camera could be deployed to monitor birds in one position with 40 photos per interval, taken every hour between 0600 and 0900. If the deployment was targeted for spring migration (April, May, June) and fall migration (August, September, October) and photos were taken daily, it would result in a total of 29280 photos, or 732 bursts of photos. The bird detection code could be applied to the entire batch to filter out clips without birds at a success rate of ~95 %, and it would save 19.5, 12.2, and 4.9 hours of manual processing depending on whether 20, 50, or 80 % of the clips contained birds, respectively (Table 3.2). This simulation assumes that manual processing of each 40 photo clip takes 2 min.

3.4. Discussion

The purpose of this research was to establish a camera system that could monitor birds at industrial ponds with accuracy comparable to human observers. Panoramic images produced by a digital SLR camera recorded numbers of birds with comparable accuracy to industry observers. More birds were detected by U of A observers who used optical equipment with greater magnification. About one third of the birds detected by U of A observers within 800 m were not counted on the SLR panoramas because birds were either diving, behind other birds, or in oblique positions. Similarly, about one third of the birds recorded by a wildlife camera could not be clearly distinguished within 100 m. This problem was rectified by taking a series of photos in rapid succession to capture bird motion, which allowed us to process photos via an automated code. The automated code produced a reliable proportion of true negative bird detections.

Camera accuracy and resolution

Panoramic SLR camera counts documented about two-thirds of the birds that were recorded by U of A field observers within 800 m of the observation station, but they generated comparable counts to industry observers, and in some cases exceeded industry observers. Birds that were not included in camera counts were typically not discernable in manual processing because they were diving, positioned with oblique aspects, contrasted weakly with their backgrounds, or were positioned behind other birds. A similar problem occurs with aerial photographs of birds relative to ground counts (Kingsford 1999).

The disagreement between panoramic SLR counts and U of A field observers increased when more birds were detected by field observers and when the average distance to them was greater. Both effects would worsen the problems of detection described above, but field observers might have had higher counts under these circumstances because of estimation error. Because they had to standardize counts to 30 min (whereas those processing SLR images could spend as long as needed), field observers may have over-counted distant birds in high numbers. Increasing the height of a camera could potentially improve camera-based counts, because fewer birds will be obscuring other birds from view. For example, a camera placed at a height of 5 m has an angle of 1.15° to a bird 250 m away; if that camera is raised to 10 m, the same bird is at an angle of 2.29°. The influence of bird behaviour and aspect should be accounted for in camera monitoring applications, and has also been documented to interfere with the processing of aerial images of bird colonies (Trathan 2004; Thaxter & Burton 2009).

The best camera for monitoring waterbirds is determined by the desired range of monitoring. Wildlife cameras were easier to set up and maintain than digital SLR cameras, but their resolution was only 25% (3 MP vs 12.1 MP), resulting in a comparable reduction in the range over which they could reliably detect birds. Whereas the SLR camera counts could detect birds to a distance of about 500 m, and up to 800 m, the wildlife cameras had comparable accuracy within only 100 m. A high-resolution SLR camera may be suitable for monitoring birds at oil spills near shore and at offshore oil platforms where the distance to be surveyed is large. By contrast, those wishing to monitor smaller areas could take advantage of the lower cost, ease of installation, and built-in water-proofing of wildlife cameras. For example, oil pits associated with oil production in the US average 0.4 to 2.0 ha (Ramirez Jr 2010), producing diameters of 63 – 140 m.

Most wildlife camera applications use sensor-activated settings (camera-traps), whereas we operated wildlife cameras only on time-lapse settings. Sensor-activated wildlife cameras are designed for large mammals at close distance ranges (Meek & Pittet 2013), which generally makes them inappropriate for monitoring waterbirds. In one study, time-lapse settings failed to detect up to 30 % of the visits made by medium-sized birds and mammals, but infra-red triggers failed to detect up to 60% of the same visits (Hamel *et al.* (2012), prompting the authors to recommend time-interval settings for smaller animals.

Automated photo processing

Time-interval photos had the advantage of capturing motion, which can increase the rate of true positives when examined by humans or computer algorithms. The panoramic SLR technique captured each portion of the pond in one frame, which only gave us one opportunity to discern each bird. In addition to increasing the likelihood that birds are detected through their motion, time-interval photography also makes it possible to examine bird behaviour.

The true negative rate of our most specialized settings approached 95%, which is conventionally interpreted to mean there is no statistical difference between it and the alternative method (manual processing) for confirmation of true negatives. Such a high rate means the code can already be used as a tool to reduce the number of images that need to be examined, which increases the viability of using it to support camera-based monitoring. Industrial implementation of this method would be most beneficial where the rate of true positives is low, as it is on most process-affected water ponds (St Clair *et al.* 2013). Both sensitivity and specificity of the bird detection code could be refined through development of unique code settings for each camera placement.

Sparsely distributed birds are generally a challenge for automated camera detection in other applications like aerial photography where automated processing results in more false negatives when very few birds are present (Groom *et al.* 2012). Any survey area containing both developed and less developed habitats will demonstrate spatial variation in bird abundance (Milne & Bennett 2013). Our automated bird detection can be tailored to each survey location, and specifically to each camera position, and it can be set to target specific distance ranges of birds.

The benefits and limitations of cameras

Cameras can monitor for extended periods of time, which makes them an ideal method to address temporal variation in bird abundance. The independence between multiple observations in a day has been questioned in bird monitoring studies using point counts (Lele *et al.* 2012). Recording bird activity for an extended period of time would demonstrate not only the degree to which multiple observations in a day are independent from one another, but also (1) the optimal human survey period and duration, if field observers are required, (2) the optimal camera recording period and duration, in order to streamline battery and memory capacities for automated monitoring, and (3) the typical duration of water bird stopovers during migration, on freshwater and industrial ponds.

Long term application of camera-based monitoring may establish the degree to which target birds are affected by the presence of field observers, an effect that has been described for other applications of cameras for wildlife monitoring (O'Connell *et al.* 2011). In acoustic monitoring, records of bird detection are often revisited and can help overcome inevitable observer errors (Brandes 2008; Hutto & Stutzman 2009), and at industrial ponds tangible records of bird detections, or of the absence of bird detections can both overcome inevitable observer errors and increase the transparency of monitoring efforts.

The greatest disadvantages of automated bird monitoring is the difficulty of distinguishing between bird species and the unknown detectability of bird species recorded. This is not just a problem for camera-based monitoring. Other automated techniques for birds (e.g. radar) and wildlife (e.g. infrared-triggered camera traps) also cannot automatically distinguish between multiple species (Gauthreaux 2003; Zaugg *et al.* 2008). A human component remains necessary in these techniques, either in the form of a-priori knowledge of the majority of targets via other detection methods (Peckford & Taylor 2008), or in the form of expert observers who identify to species (or guild) the positive targets produced by automated processing (Zaugg *et al.* 2008; Thaxter & Burton 2009).

Refinement of cameras for shore-based waterbird monitoring should include the development of detection probabilities of the target species so that the resulting abundance estimates can be corrected. Duration of time spent on the water surface likely influences detectability of waterbirds (Cobb *et al.* 1995; Thaxter & Burton 2009). For example, birds that land on water infrequently (e.g. gulls) might be less detectable than birds that remain longer on the water surface (e.g. dabbling and diving birds). Species that are cryptic in colouring or behaviour may also be less detectable (Dinata *et al.* 2008), and this likely applies to shorebirds in both camera and human monitoring. Several studies have emphasized the necessity of species-specific mitigation strategies in industrial environmental impact assessments (Fraser *et al.* 2006; Langton *et al.* 2011; Longcore *et al.* 2013), and therefore it is necessary to know the relative efficacy of target bird detection by any bird monitoring method used.

Table 3.1. Model results for covariates in GLMM that predicted disagreement between bird count from field observers and panoramic cameras during paired sessions.

Covariate	**β**	**S.E.**	**df**	***P***
Intercept	11.81	2.72		<0.0001
Human count <= 800 m	23.70	4.89	1	<0.0001
Average distance of birds x human count	-8.09	1.13	1	<0.0001
Human count x both methods detected birds	-15.27	4.95	1	0.002
Human count x small waders present	5.54	2.59	1	0.033
Average distance of birds x beach in survey area	-4.26	1.13	2	<0.0001
Dabblers present x both methods detected birds	-6.93	3.19	3	0.032

$R_{\text{observed vs predicted}} = 0.78$, $P < 0.0001$; $R^2 = 0.604$

Table 3.2. A calculation of the time that could be reduced for manual processing with the application of the bird detection computer code.

Percent true positives	**True Positive # of photo clips**	**True Negative # of photo clips**[†]	**Time spent manually processing**	**Time saved in minutes (hours)**
20	146	586	4.1	1172 (19.5)
50	366	366	11.4	732 (12.2)
80	586	146	18.7	292 (4.9)

If one camera is positioned in a stationary configuration and programmed to take 40 photos once per hour between 0600 and 0900 for the months in which birds are migrating through the oil sands area (April, May, June, August, September, October). This scenario would result in 732 bursts of 40 photos, for a total of 29280 photos. We assume that each burst of 40 photos can be manually processed in 2 min.

[†] These photos that do not have to be manually reviewed if the bird-detection code is applied to the entire batch of photos

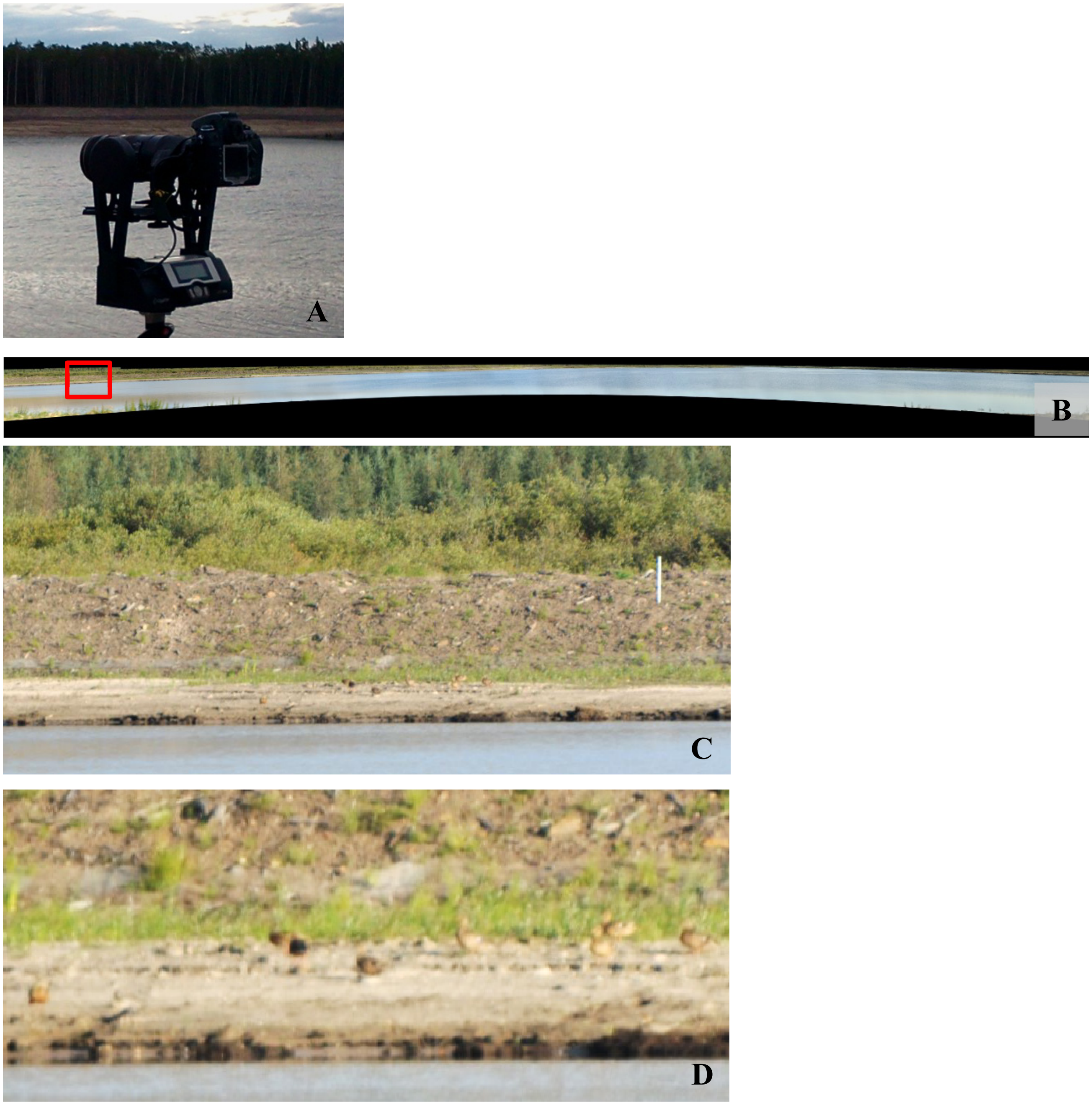

Figure 3.1. Panoramic SLR camera set up.

A digital single lens reflex (SLR) camera mounted on a tripod with a panning attachment (**A**). The panning attachment automatically moved camera to designated positions and the triggered camera shutter to capture a panoramic sequence of photos of entire pond (**B**). An SLR panorama typically photographed the entire pond in around a hundred photos with 2 rows (e.g. Jackpine Compensation Lake photographed with 2 rows and 47 columns), which were subsequently zoomed in to optical (**C**) and digital (**D**) zoom until birds could be distinguished and counted. Shown here is a group of mallard (*Anas platyrhyncos*) ducks 290 m away.

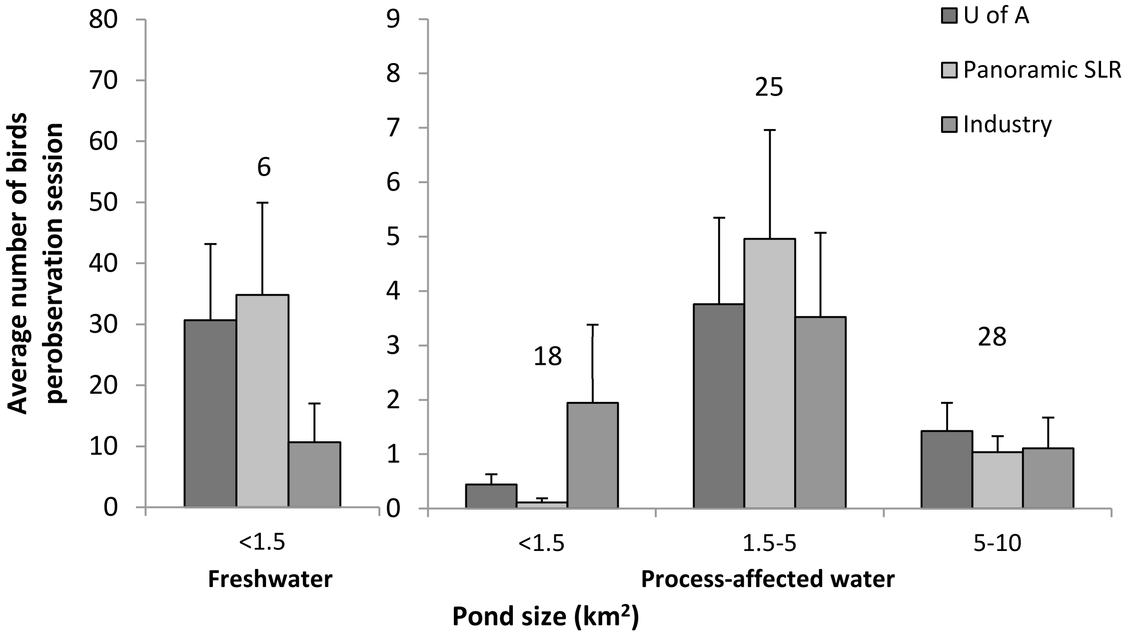

Figure 3.2. Average number of birds counted per observation session (± SE) for University of Alberta (U of A) observers, panoramas taken with an SLR camera, and industry observers at freshwater (FW) and process-affected water (PAW) ponds. Sample size for the number of paired observation sessions is given above each set.

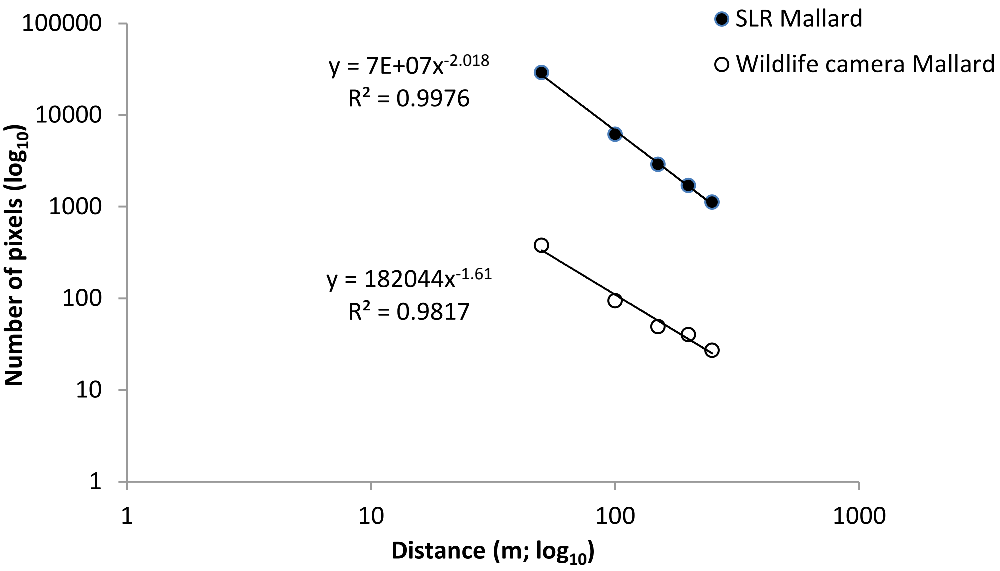

Figure 3.3. Number of pixels with increasing distance for a decoy mallard photographed at measured distances of 50 m intervals from the cameras by a digital SLR and a wildlife camera.

Figure 3.4. Photos from the SLR camera the wildlife camera of Double-crested cormorants (Phalacrocorax auritus) 260 m away from the cameras at Kearl Compensation Lake.

Figure 3.5. Two sets of screen captures by the bird detection code which positively detected landed birds on time-interval SLR photos.

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Chapter 4 General Discussion

The purpose of this thesis was to evaluate two technologies – marine radar and automated cameras – to automate bird detection at industrial sites with the goal of increasing the efficacy of bird protection. Radar is widely used in the oil sands for detecting flying birds in the vicinity of process-affected water (PAW) ponds at distances of up to 2 km from radar stations. In this context, radar is used mainly to trigger deterrent systems, and the accuracy with which it detects birds has not been evaluated. Instead, the detection of birds that fly over and make contact with PAW ponds is assessed with human observers.

Recently, the industry has implemented a standardized monitoring program in which birds are counted daily within designated stations of 500 m radius and 100 m elevation (St Clair *et al.* 2014). This program has revealed that tens of thousands of birds make contact with PAW ponds annually, but the comparability of surveys among operators is limited by site-specific factors and high rates of inter-observer variation (St Clair 2014). Human-based monitoring also exposes monitors to the short and long term dangers of industrial sites.

Radar and automated camera systems have the potential to increase both comprehensiveness and comparability of bird monitoring, ultimately supporting the identification of best practices for bird protection in the oil sands and other industrial contexts. Specifically, cameras could increase the duration, frequency, and coverage of bird monitoring for flying and landed birds, while reducing the risk to human observers. A better understanding of bird detectability with radar could support its role in bird monitoring while increasing the accuracy with which it deploys deterrent devices. Currently, the industry makes no use of automated cameras and limited use of radar for bird monitoring. Implementation of these technologies requires identification of constraints related to their site-specific deployment and measures of the detectability of target birds.

In Chapter 2, I determined that marine radar detects only 50% of the target birds human observers could see in the vicinity of radar stations and that it is prone to errors of both detection (i.e., false positives) and omission (i.e., false negatives). Detection by radar was dependent on type of radar antenna, the height of survey stations, the substrate under the target, and bird characteristics. These effects were often multiplicative, which prevents the use of simple formulae for radar installation. Numerous additional factors may exert context-specific effects on radar accuracy. Because these influences on bird detection by radar have inextricable effects on deterrent efficacy, bird protection could be enhanced by evaluating these factors at each installation site and then adjusting radar configuration to achieve an optimal balance of specificity and sensitivity. However, even at an optimal configuration, false negatives are likely to occur and these birds should be identified and targeted with other detection methods.

The spatial coverage of current radar installations in the oil sands could be increased relatively easily by integrating additional radar antennas that target different portions of the adjacent sky-scape and installing adjacent systems at different elevations (Chapter 2). Existing software could overcome some of the problems of interference to target each radar to particular zones and ranges. These changes could overcome the tendency for current installations to target distant birds flying at high elevations (which are unlikely to land) so as to put more emphasis on birds in close proximity flying at low elevations. Because all five of the multinational companies involved in surface mining in the oil sands use marine radar to deploy deterrent systems, coordinated assessment of radar performance and open communication of findings could foster very rapid improvements in the efficacy of these systems. Presentation of those results in the peer-reviewed literature could be applied to many other industrial contexts, including airports, wind farms, and offshore drilling platforms, to improve bird protection.

In Chapter 3, I determined that high-resolution cameras can be used to monitor birds that have landed on ponds. I improved camera methods iteratively, starting with an SLR camera configured to photograph a panorama of the pond, with one photo per camera position, moving on to video, which offered the benefits of motion, and ending with an SLR camera photographing a more limited portion of the pond on time-interval settings. This last configuration provided the motion necessary for detecting birds with a computer algorithm while minimizing power consumption and data volume. Using this time-interval imagery, I showed that an existing algorithm achieved 95% accuracy of non-detection (i.e. false negatives were < 5%), indicating that it could be used to substantially reduce the time needed to process images, particularly at locations were the frequency of bird visitation is low. The SLR cameras could monitor radii of up to 500 m with detectability comparable to industry observers, but conventional wildlife cameras were accurate to only about 100 m.

Together, the results from my work with cameras showed that high-resolution SLR cameras can achieve counts of birds comparable to industry observers in the standardized monitoring program. For small ponds with reduced radii of coverage, comparable accuracy could be achieved using a series of conventional wildlife cameras, which are much less expensive, more robust, and easier to operate. By setting cameras on both time-lapse (i.e., photos taken at specified intervals) and time-interval (i.e., a 'burst' of photos at each time of deployment), operators could use an existing computer algorithm to process a majority of the resulting images automatically, reducing the total time required for camera-based monitoring to be comparable to that now required by human monitors. Cameras would have the additional advantage of increasing standardization of monitoring and protecting observers from the hazards of working in close proximity to tailings ponds.

The combined findings of the radar and camera work described in this thesis illustrate the complexity of automating the bird detection industrial sites. Neither method can identify individual birds to species automatically, although radar can coarsely distinguish birds of different sizes, and the review of camera images by skilled observers can identify most birds to genus and sometimes species. Although most bird monitoring requires distinction at least to the level of guilds (Hockin *et al.* 1992), monitoring for the purposes of deterrence in the oil sands is currently based only on the presence of a target, making species identification seemingly irrelevant. Yet such identification is essential to the requirements of protection legislated by Species At Risk laws and it could also assist in tailoring mitigation strategies for different types of birds, even as basic as the distinction among divers, dabblers and waders. Achieving, this level of identification will require use of additional methods of ground-truthing (Bigger *et al.* 2006; Peckford & Taylor 2008; Komenda-Zehnder *et al.* 2010) or review of camera-based detections by experts (Zaugg *et al.* 2008; Thaxter & Burton 2009). Additional detection and identification of birds may be achieved with acoustic monitoring, radio-tracking, harmonic radar, and thermal cameras (Bridge *et al.* 2011). The combination of multiple monitoring methods likely remains the best way to achieve the most effective detection of all birds.

Despite the promise of cameras for complementing existing detection strategies, which consists of monitoring of birds with human observers and deterrence based on radar, oil sands operators currently neither use cameras, nor do they systematically evaluate the detection of birds by radar. One reason for refraining from investment in these technologies could be the wide-spread goal in the industry of reducing bird contacts to "zero". This goal promotes reliance on presence/absence information that is easily acquired with both radar systems and human monitoring. Unfortunately, it is impossible to completely prevent landings by the 1.5 million birds that are estimated to migrate over the region each year (Hennan & Munson 1979) and tens of thousands of individuals continue to land anyway (St Clair 2014). In time, industry (and government regulations) will likely acknowledge that "zero contacts" is an unrealistic target. Moreover, the existing detection strategies are limited. Radar is not suited to detecting landed birds and human observers assess only 1/10th of pond area for only 1/48th of the available time. Cameras could increase both the spatial and temporal extent of monitoring to offer several potential advantages to industry and the environment.

For industry, a primary advantage of employing cameras could be the much-needed calibration of radar-based deterrent programs. Cameras could be used to determine the efficacy of existing deterrent strategies on the spatial and temporal scales that are relevant to bird protection. With this information, cameras could also be integrated with deterrents to increase intensity where it is most needed to avoid the broad-scale and costly approach that prevails now across the almost 200 km^2 of PAW ponds. The use of cameras in standardized monitoring could also reduce labour costs, which sums to several million dollars annually for the industry, and employee risk. Environmentally, the integration of cameras with small-scale deterrents could reduce the sound intensity of current integrated systems that project sound pollution several kilometers from their sources and into the adjacent boreal forest (St Clair *et al.* 2011), while causing habituation of birds. Both sets of benefits require quantifying the variation in landings among and within PAW ponds followed by analyses that relate that variation to the suite of temporal and spatial factors that both attract and repel birds.

Bird contact with PAW ponds is just one of several environmental concerns associated with the tailings ponds produced by the minable oil sands industry (Timoney *et al.* 2009). The toxicity of tailings ponds obliges the industry to monitor their environmental effects, which will remain for at least the next 50 years of projected oil sands extraction, and potentially for hundreds of years after mine closures (Wells *et al.* 2008). Already, there is evidence that pollutants from the mining process contaminate downstream waterbodies (Kelly *et al.* 2010) and occur in the eggs of birds that nest in those waterbodies (Hebert *et al.* 2011). Some of these pollutants appear to emanate directly from the ponds via leaking containment (Frank *et al.* 2014). Birds that land on the PAW ponds potentially migrate to destinations throughout North America where they may be consumed by human hunters and other animals (St Clair 2014). These factors make the problem of bird detection and deterrence in the oil sands one of broad relevance that is deserving of much additional research. Development of radar- and camera-based technologies, in particular, will benefit from trans-disciplinary work by biologists, computer scientists, engineers, and economists. That work will require the support of a well-informed public that challenges its elected officials to regulate bird protection with standards that are clear, realistic, evidence-based, and responsive to new information.

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Appendix I: Additional figures and tables for Chapter 2

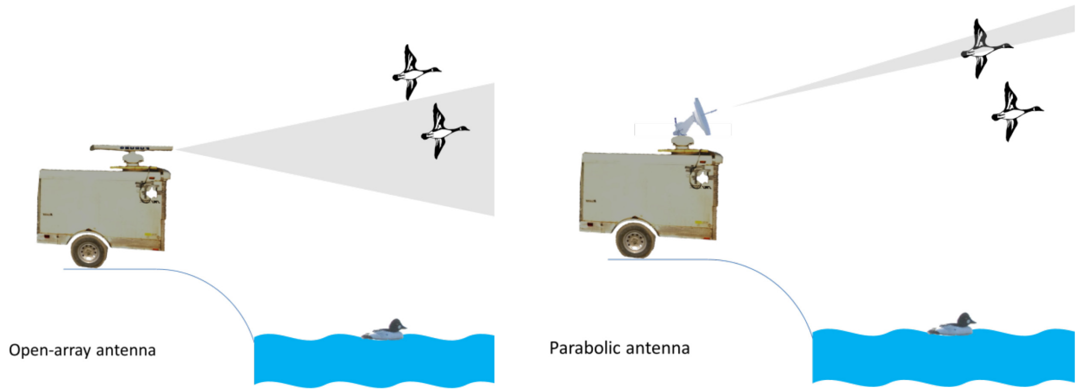

Figure I.1. Configuration of the radar stations at survey sites with each of the two antenna types tested.

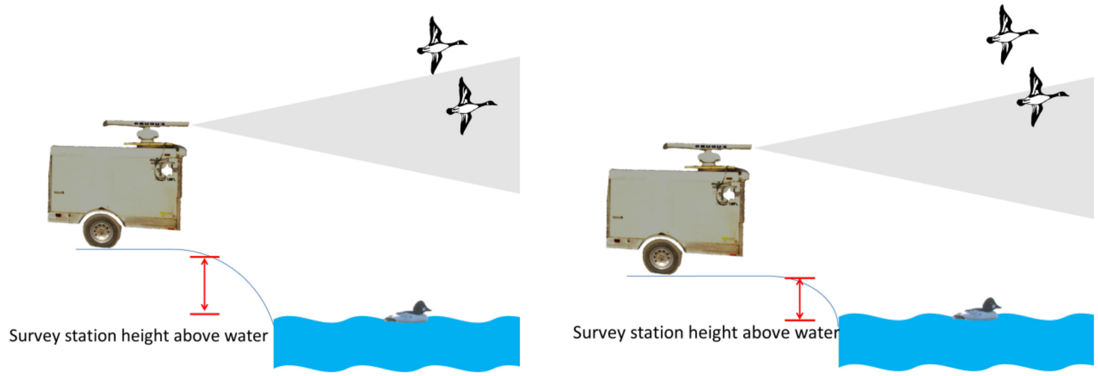

Figure I.2. Configuration of the radar stations at survey sites at different heights of the station above the water body.

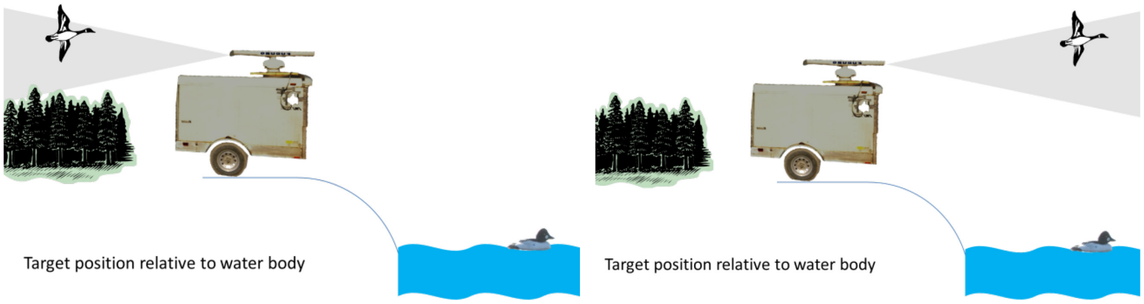

Figure I.3. Configuration of the position where the target was detected, whether the target was flying over water or over land when it was detected.

Table I.1. List of species identified during radar observation sessions by visual observers, separated into broad guilds used in analysis predicting radar detection by each of the two radar antennas.

BirdGroup	Species code	Common name	N	Percent
GullsTerns	BLTE	Black Tern	4	1.1
	BOGU	Bonaparte's Gull	7	1.9
	FRGU	Franklin's Gull	1	0.3
	RBGU	Ring-billed Gull	1	0.3
	UNK BhGull	Unknown Hooded Gull	4	1.1
	UNK Gull	Unknown Gull	291	79.5
	UNK Tern	Unknown Tern	5	1.4
	UNK WhGull	Unknown White-headed Gull	53	14.5
	Total		366	100
Landbirds	AMCR	American Crow	109	8.9
	AMRO	American Robin	1	0.1
	BAEA	Bald Eagle	11	0.9
	BANS	Bank Swallow	11	0.9
	BARS	Barn Swallow	54	4.4
	BBMA	Black-billed Magpie	78	6.4
	BEKI	Belted Kingfisher	2	0.2
	BLJA	Blue Jay	1	0.1
	CCSP	Clay-colored Sparrow	1	0.1
	CEDW	Cedar Waxwing	2	0.2
	CLNU	Clark's Nutcracker	1	0.1
	CORA	Common Raven	208	17
	GOEA	Golden Eagle	4	0.3
	MERL	Merlin	4	0.3
	NOHA	Northern Harrier	3	0.2
	PEFA	Peregrine Falcon	2	0.2
	RBGR	Rose-breasted Grosbeak	1	0.1
	RTHA	Red-tailed Hawk	5	0.4
	RWBL	Red-winged Blackbird	34	2.8
	SMLO	Smith's Longspur	1	0.1
	SNBU	Snow Bunting	2	0.2
	TRES	Tree Swallow	17	1.4
	WETA	Western Tanager	1	0.1
	UNK Blackbird	Unknown Blackbird	10	0.8
	UNK Corvid	Unknown Corvid	44	3.6
	UNK Falcon	Unknown Falcon	1	0.1
	UNK Finch	Unknown Finch	1	0.1
	UNK	Unknown Hummingbird	1	0.1

	Hummingbird			
	UNK Junco	Unknown Junco	2	0.2
	UNK Landbird	Unknown Landbird	59	4.8
	UNK Passerine	Unknown Passerine	437	35.7
	UNK Ptarmigan	Unknown Ptarmigan	1	0.1
	UNK Raptor	Unknown Raptor	54	4.4
	UNK Sparrow	Unknown Sparrow	8	0.7
	UNK Swallow	Unknown Swallow	48	3.9
	UNK Thrush	Unknown Thrush	1	0.1
	Total		1220	100
Shorebirds	GRYE	Greater Yellowlegs	1	1.6
	KILL	Killdeer	2	3.1
	LEYE	Lesser Yellowlegs	5	7.8
	SPSA	Spotted Sandpiper	2	3.1
	WESA	Western Sandpiper	2	3.1
	WISN	Wilson's Snipe	2	3.1
	UNK Sandpiper	Unknown Sandpiper	9	14.1
	UNK Shorebird	Unknown Shorebird	39	60.9
	UNK Snipe	Unknown Snipe	1	1.6
	UNK Yellowlegs	Unknown Yellowlegs	1	1.6
	Total		64	100
Waterfowl/waterbirds	AMCO	American Coot	2	0.2
	AMWI	American Wigeon	24	2.8
	AWPE	American White Pelican	103	12
	BUFF	Bufflehead	10	1.2
	BWTE	Blue-winged Teal	3	0.3
	CAGO	Canada Goose	25	2.9
	CANV	Canvasback	3	0.3
	COGO	Common Goldeneye	18	2.1
	COLO	Common Loon	3	0.3
	COME	Common Merganser	2	0.2
	EAGR	Eared Grebe	1	0.1
	GBHE	Great Blue Heron	5	0.1
	GWFG	Greater White-fronted Goose	2	0.2
	GWTE	Green-winged Teal	2	0.2
	LTDU	Long-tailed Duck	1	0.1
	MALL	Mallard	46	5.4
	NOPI	Northern Pintail	12	1.4
	NSHO	Northern Shoveler	8	0.9
	REDH	Redhead	1	0.1
	RNDU	Ring-necked Duck	1	0.1

	RNGR	Red-necked Grebe	2	0.2
	SACR	Sandhill Crane	3	0.3
	SNGO	Snow Goose	4	0.5
	SUSC	Surf Scoter	1	0.1
	UNK Dabbler	Unknown Dabbler	1	0.1
	UNK Dabbling Duck	Unknown Dabbling Duck	1	0.1
	UNK Diver	Unknown Diver	1	0.1
	UNK Diving Duck	Unknown Diving Duck	16	1.9
	UNK Duck	Unknown Duck	447	52.1
	UNK Goose	Unknown Goose	75	8.7
	UNK Scaup	Unknown Scaup	13	1.5
	UNK Scoter	Unknown Scoter	1	0.1
	UNK Teal	Unknown Teal	2	0.2
	UNK Waterbird	Unknown Waterbird	7	0.8
	UNK Waterfowl	Unknown Waterfowl	16	1.9
	Total		862	100
UNK Bird	UNK Bird	Unknown Bid	192	100

Table I.2. Log likelihood for final model terms in logistic regression model predicting radar detection by the open-array antenna of birds confirmed by visual detection.

Covariate	**Model Log Likelihood**	**Change in -2 Log Likelihood**	**d.f.**	***P***
Bird guild x Survey station height	-541.24	10.86	4	0.028
Survey station height	-549.29	26.95	1	<0.0001
Over water	-567.19	62.74	1	<0.0001
Over water x Bird altitude	-538.46	5.30	1	0.021
Bird guild	-544.38	17.13	4	0.0018
Location x Number of birds	-548.48	25.34	10	0.0047
Location	-586.03	100.43	9	<0.0001

Table I.3. Significance and change in log likelihood for final model terms in logistic regression model predicting radar detection by the parabolic antenna of birds confirmed by visual detection.

Covariate	**Model Log Likelihood**	**Change in -2 Log Likelihood**	**d.f.**	***P***
Survey station height	-295.12	2.94	1	0.086
Bird guild x Bird altitude	-308.57	29.84	4	<0.0001
Location x Bird altitude	-302.33	17.38	5	0.0038
Bird guild x Number of birds	-300.91	14.53	4	0.0058

Table I.4. Significance and change in log likelihood for final model terms in logistic regression model predicting visual detection of targets confirmed by the radar with an open-array antenna.

Covariate	**Model Log Likelihood**	**Change in -2 Log Likelihood**	**d.f.**	***P***
Season	-907.00	35.08	2	<0.0001
Location	-926.28	73.63	13	<0.0001
Season x Survey station height	-899.78	20.63	1	<0.0001
Location x Season	-915.53	52.14	2	<0.0001
Location x Over water	-905.83	32.73	11	0.00058
Cloud cover x Location	-912.27	45.61	10	<0.0001
Location x Wind	-907.10	35.27	9	<0.0001

Table I.5. Significance and change in log likelihood for final model terms in logistic regression model predicting visual detection of targets confirmed by the radar with an open-array antenna.

Covariate	**Model Log Likelihood**	**Change in -2 Log Likelihood**	**d.f.**	***P***
Season	-658.50	24.00	2	<0.0001
Location	-661.79	30.59	10	0.001
Location x Over water	-659.37	25.75	10	0.004
Cloud cover x Over water	-650.75	8.51	1	0.004
Over water x Survey station height	-648.73	4.46	1	0.035
Location x Wind	-658.30	23.60	8	0.003

Appendix II: Additional tables for Chapter 3

Table II.6. Improvement in AIC of the final covariates in model predicting disagreement between panoramic camera counts and field counts

Model	**AIC**	**AICf**	**Change in AIC**
Final	1368.78	-	-
Final - Human count <= 800 m	1368.78	1368.78	0
Final - Average distance of birds x human count	1415.99	1368.78	47.21
Final - Human count x both methods detected birds	1383.13	1368.78	14.35
Final - Human count x small waders present	1376.95	1368.78	8.17
Final - Average distance of birds x beach in survey area	1388.62	1368.78	19.84
Final - Dabblers present x both methods detected birds	1388.46	1368.78	19.68

Appendix III: Camera monitoring station at Kearl Compensation Lake.

I developed a camera monitoring station that ran independently at the Kearl Compensation Lake. The setup was as follows: A Nikon D700 digital single lens reflex (SLR) camera was mounted on a Gigapan Epic Pro panning tripod attachment (Fig. III.1) and was placed inside a refurbished bear bin (Fig. III.1) fitted with plexiglass windows to make it weatherproof. The panning attachment automatically moved the camera to designated positions and triggered camera shutter to capture a panoramic sequence of photos of entire pond. The camera and panning attachment were both powered by AC adaptors connected to a 12V battery. Photos were recorded on a 64GB memory card. The camera station ran independently for up to 2 days at a time, but recorded through the night due to limited panning tripod settings. This memory card will last for 3 days if time-interval settings on the digital SLR camera is used, which would also support the automated processing described in Chapter 3.

This station operated at Kearl Compensation Lake between August and October in 2011 and between June and October in 2012, with a break in July. In 2012 the panoramic settings were modified to reduce overlap and to take 20 photos in a row at each panoramic moment to begin testing of motion capture by interval photos while still photographing the entire Kearl Compensation pond with one camera.

Figure III.4. Camera monitoring station at Kearl Compensation Lake

Appendix IV: Distance of birds on SLR panoramas at Crane Lake

The distances of birds detected by the panoramic SLR technique were calculated using a reference formula and compared to field observers at one freshwater pond.

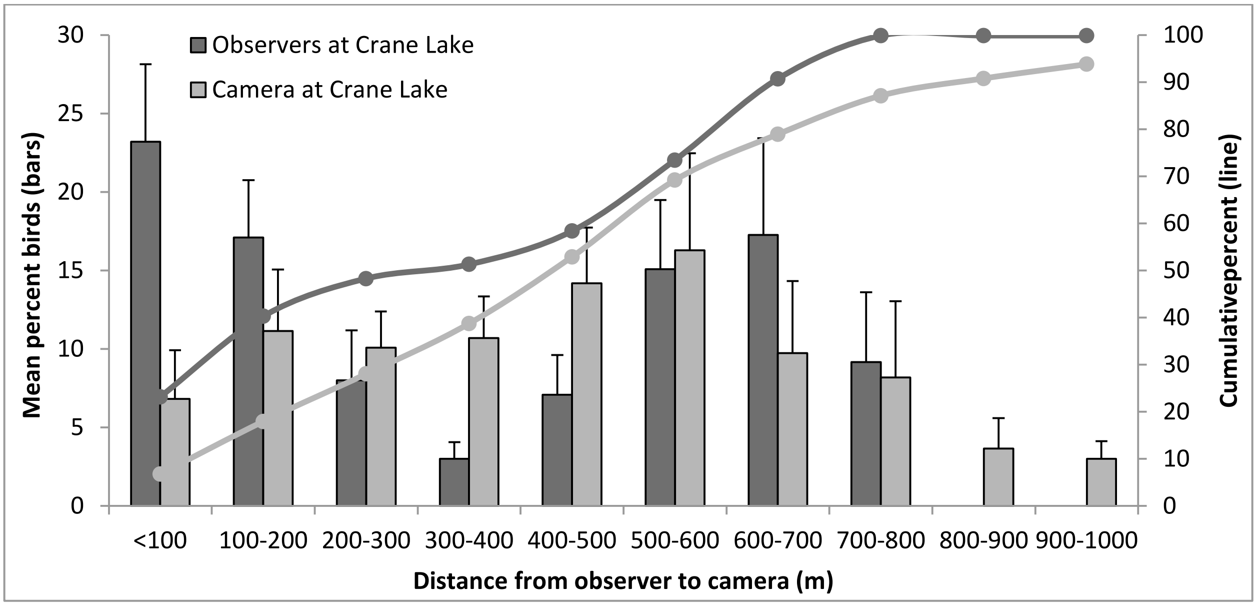

Figure IV.5. Mean percent birds per observation session at Crane Lake in 100m intervals, averaged for each interval. N = 24.

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