The Potential of Lasers as Deterrents to Protect Birds in the Alberta Oil Sands and Other Areas
of Human-Bird Conflict

by

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Abstract

Human population growth, urbanization, and industrialization are rapidly increasing the potential for human-wildlife conflict throughout the world. Such conflict is often mitigated by attempting to deter wildlife from the affected areas, but wildlife frequently habituate to deterrent devices, which makes them less effective over time. Birds are both susceptible to conflict with people and likely to habituate to deterrents, and this causes ongoing conflict that can threaten the livelihoods of people (e.g., agriculture and aquaculture), the safety of bird populations (e.g., offshore drilling platforms, oil spills, and industrial sites), and also human safety (e.g., aircraft strikes). One such conflict occurs in the oil sands region of northern Alberta, which is located beneath a continental flyway for waterfowl. Because the ponds produced by oil sands mining contain bitumen and other toxic substances, oil sands operators are legally required to prevent birds from landing on them. Efforts are made to deter birds with elaborate systems based mainly on high-intensity acoustic stimuli. In spite of this effort, recent standardized monitoring has revealed that tens of thousands of birds still land on tailings ponds annually.

Birds rely heavily on vision and a greater focus on visual deterrents could increase the efficacy of existing deterrent systems, particularly if visual stimuli have high ecological relevance and exploit the sensory systems of birds. Lasers may fill both of these criteria, and also have the advantage of being visible at night when most birds migrate. Several authors have advocated use of lasers as bird deterrents, but there are few published tests of their efficacy on wild birds and none are based in an ecological framework. I advanced this field by exposing birds to lasers in relation to three variables that I predicted would be important to laser saliency; laser colour (green *vs.* violet), season of exposure (spring *vs.* fall) and the foraging mode of the targeted water-associated birds (divers, dabblers, and waders). I also examined the environmental

covariates of ambient light, time of day (morning *vs*. evening), weather (fair *vs*. inclement), and the distance between the laser source and target bird(s). Fieldwork was conducted in and near Edmonton, AB on natural and man-made ponds where I found wild water-associated birds. These included several species of ducks, geese (Family *Anatidae*), and shorebirds (primarily, Family *Charadriidae*). In each of several hundred trials, one or more birds was exposed to a moving laser beam trained on the adjacent water, and I recorded whether or not the bird(s) exhibited an escape response by flying away or diving beneath the surface of the water.

I found that green lasers were more likely to generate escape responses than violet ones, both lasers were less effective as ambient light increased, and birds were more responsive in morning and spring compared to evening and fall. There was no difference between dabbling and diving birds in their response to lasers, but I was unable to compare the responses of waders due to small sample sizes. The distance of the target bird(s) from the laser source did not affect their responsiveness, supporting the efficacy of lasers as bird deterrents over large spatial scales. Based on complementary information from the literature, I propose that lasers are effective as deterrents for water-associated birds that frequent the oil sands region, that they may be made even more effective by pairing them with a relevant acoustic stimulus, and that the use of violet lasers during dark conditions may lessen the habituation by birds as compared to the use of green lasers alone. These results and their potential extensions could support best practices for bird protection in the oil sands region and, potentially, many other contexts involving conflict between people and birds.

Preface

This thesis is an original work by Ffion Cassidy. A version of the Abstract has been published in the final report of the *Research on Avian Protection Project*. Publication is intended for Chapter 2 with co-author C.C. St Clair. The research project, of which this thesis is a part, received research ethics approval from the University of Alberta Research Ethics Board for "Small-scale deterrent methods for protecting birds at industrial sites," Protocol Number 766/04/13, which was approved on 26 April 2012.

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Chapter 1: General Introduction

The potential for human-wildlife conflict grows rapidly with increased global industrialization, especially where intense human use overlaps with high concentrations of wildlife, and this conflict can have negative consequences for both people and wildlife. Birds commonly conflict with humans because of their presence in virtually all habitats, their high mobility, and the diversity of resources they exploit. Historically this conflict has taken the form of crop depredation and associated economic loss (reviewed by De Grazio 1978), but conflict can also compromise human safety (e.g., bird strikes at airports; Thorpe 2003, 2005, 2010) and the enjoyment of recreational areas (e.g., via soiling of parks and golf courses; Conover & Chasko 1985). At the same time, birds can be harmed by a myriad of human activities that cause habitat destruction or degradation (Scharlemann, Green & Balmford 2004). In some contexts, overlap of human activities and birds can cause harm to both groups. A familiar example of this phenomenon occurs via birdstrikes with airplanes (Thorpe 2003, 2005), but such conflict also occurs whenever bird species that are potentially harmed by anthropogenic activity are protected by legislation. In Canada, the Migratory Birds Convention Act (renewed in 1994) prohibits the taking of migratory birds except under permit, and many provinces have additional legislation that prohibits contact between wildlife and substances known to be hazardous to them (e.g., Alberta's Environmental Protection and Enhancement Act 2000). Rare species are additionally protected in by the federal Species at Risk Act (2002).

Whether to protect humans and their assets or to accommodate legislated requirements for bird protection, a variety of bird deterrents is employed to reduce the prevalence and severity of human-bird conflict (reviewed by Draulans 1987; Bomford & O'Brien 1990; Clark 1998;

Lehoux & Bordage 2000; Gilsdorf, Hygnstrom & VerCauteren 2002; Conover 2002). Deterrent types range from traditional scarecrows to elaborate automated and electronic systems that are intended to cover dozens of km^2. Typically, deterrents employ an aversive stimulus designed to dissuade birds from using an area. Deterrents may target any sensory modality, but most large systems emphasize acoustic deterrents such as propane cannons (e.g., Martin & Martin 1984; Cummings, Knittle & Guarino 1986; Ronconi & St. Clair 2006; Steensma *et al.* 2009) or amplified broadcasts of electronic sounds (e.g., Heinrich & Craven 1990; Berge *et al.* 2007). The electronic systems have the advantage of employing a diversity of sound types, which is assumed to reduce habituation by birds, and deploying them at tremendous volumes to cover large areas (e.g., Matkovich *et al.* 2010; LRAD Corporation, www.lradx.com). Most of the modern, large-scale deterrent systems use marine radar to detect approaching birds and then deploy deterrents, often within land- or water-based zones that correspond to the airspace in which bird detections occurred (e.g., Matkovich *et al.* 2010; St. Clair 2014). Many studies have provided evidence that radar is an effective method for detecting birds in flight (e.g., Cooper *et al.* 1991; Gauthreaux & Belser 2003) and there is also evidence that such on-demand systems are more effective at deterring birds than traditional methods of deployment based on random or variable intervals (Ronconi & St. Clair 2006). However, there are surprisingly few peer-reviewed studies of these integrated systems, despite widespread use in a variety of industrial contexts.

The urgent need for more information about the efficacy of bird deterrent systems was highlighted recently in the oil sands region of Alberta where a series of mass landing events resulted in the mortality of hundreds of birds. The first of these occurred in early spring, 2008, at a site where deterrent systems were not yet in place (R. v. Syncrude Canada Ltd. 2010). The responsible company was convicted under both federal and provincial laws (R. v. Syncrude

Canada Ltd. 2010), but two more landing events occurred subsequently (fall 2010, 2014) at locations with deterrents in place. The first two of these landing events stimulated lasting media attention (Nelson *et al.* 2014) and intensive, ongoing scrutiny of industry practices for bird deterrence.

The large potential for human-bird conflict in the oil sands region was recognized by biologists decades ago (e.g., Boag & Lewin 1980, Gulley 1980) because the area is located beneath a major flyway for migratory birds en route to and from the Peace-Athabasca Delta. In this region, 150 km to the north of the oil sands mines, up to 1.5 million migratory birds from all five major flyways in North America converge each spring and fall (Butterworth *et al.* 2002). As a result of bitumen extraction activities, the oil sands area contains over 180 km^2 of industrial water storage ponds spread over an area of 700 km^2 (St. Clair 2014). Birds travelling through this region may seek out waterbodies on which to rest and forage, particularly in the early spring and late fall when winter storms may encourage abrupt landings (Gulley 1980) and warm water effluent from the mining process may provide the only available open water (Boag *et al.* 1975, Gulley 1980). Unfortunately, many of these ponds contain floating bitumen and other toxic substances (reviewed by Allen, 2008), which is the reason oil sands operators are obliged by legislation to prevent birds from landing on them.

The obligation to prevent bird landings on oil sands tailings ponds prompted some investigation decades ago into the best methods for keeping birds out of high-risk areas (Gulley, 1980; Boag and Lewin 1980). For most of the first 30 years of operation, the industry standard for deterrents consisted of human effigies (Boag and Lewin 1980) and propane cannons, already popular in agricultural contexts (e.g., Stephen 1961) placed on shores or floating platforms at a spacing of approximately 400 m (Golder 2000). In 2003, a new operator introduced the first

radar-activated deterrent system (Ronconi & St. Clair 2006) and such systems are now used at all seven lease sites in the region (St. Clair 2014). Several sites employ long-range acoustic devices with sound intensities capable of reaching several km into the adjacent landscape (St. Clair *et al.* 2012). Despite these practices, a recently-standardized monitoring program estimates that tens of thousands of birds land on these industrial ponds annually, although less than 1% of these birds appears to die as a result (St. Clair *et al.* 2013).

As part of the creative sentence awarded following the conviction in 2010 (R. v. Syncrude Canada Ltd., 2010), the collaborative, multidisciplinary *Research on Avian Protection Project* (RAPP) was initiated with the purpose of increasing bird protection in the oil sands region of Alberta. The work contained in this thesis is part of that project and was initiated to address two specific objectives of RAPP: (i) conduct field studies and supporting analyses and (ii) recommend best practices for bird protection by the mineable oil sands industry. This thesis contributes to these objectives by emphasizing ecological and evolutionary attributes of bird sensory systems. In particular, I set out to complement the current industrial emphasis on acoustic deterrents with more information about how visual deterrents could be used over the large temporal and spatial scales, and diverse avian assemblages that characterize the oil sands region.

My work rests on the premise that the success of any deterrent system depends on one or both of (a) a sustained neophobic reaction to novel stimuli, and (b) the use of stimuli that are ecologically relevant, such as predator and distress calls. Both attributes are well-known requirements for effective deterrent systems (reviewed by Conover 2002), but they also address principles of learning theory (summarized by Domjan 2006). In addition to these principles, the use of multiple sensory modalities characterizes many 'honest' signals in animal communication

(reviewed by Bro-Jørgensen 2010) and the same principle is recognized by some authors in the deterrent literature (e.g., Conover 2002; Lecker & Parsons 2013). Despite this overlapping theory, deterrent technology makes surprisingly little explicit use of information about the sensory ecology and evolved sensitivities of birds. Greater use of this information in rigorous, mechanistic experiments could rapidly increase the efficacy of deterrent systems.

Visual deterrents are a logical target for investigation because birds have highly developed visual systems upon which they rely to assess risk in their environment (Fernández-Juricic, Erichsen & Kacelnick 2004). Visual deterrents with potential relevance to the oil sands industry are challenged by the large spatial scale of operations (St. Clair *et al.* 2013), the recurrent temporal pulses of migrating birds each spring and fall (Butterworth 2002), the tendency for many species to migrate at night (Newton 2007) and the problem of habituation which afflicts both resident and migratory species (Ronconi and St. Clair 2006). Traditional visual deterrents consisting of human effigies likely have little sustained effect on birds (Conover 2002), which has prompted some operators to experiment with flashing lights (reviewed by Golder 2000), mechanical falcons (Ronconi and St. Clair 2006), and other devices including mylar ribbons, flagging tape, balloons, hawk-resembling kites, and flares (C. C. St. Clair, personal communication). In some other contexts of bird deterrence, optical lasers have been used (Glahn *et* al. 2000; Blackwell, Bernhardt & Dolbeer 2002; Sherman & Barras 2004; Baxter 2007) and these have recently been installed as part of the automated, radar-activated deterrent systems used in the oil sands (DeTect, Inc.; www.detect-inc.com). Lasers offer tremendous potential advantages in this context because their columnated beams can be seen over large distances, they are most visible at night, and they can be moved to create a sense of motion that may reduce the tendency for habituation.

One additional attribute of lasers that is potentially important to bird deterrence is their ability to project a variety of colours. Birds have excellent colour vision, in part due to the four colour-sensitive cones in their eyes which allow them to detect wavelengths on the electromagnetic spectrum which are outside the visual range of humans (reviewed by Cuthill *et al.* 2000). In some species the photoreceptor which detects the shortest wavelengths has peak sensitivities in the ultraviolet (UV) range, and most birds probably have at least some sensitivity to UV wavelengths (reviewed by Hunt & Peichl 2014). Birds use visual signals for foraging (e.g., Cazetta, Schaefer & Galetti 2009), mate choice (e.g., Bennett *et al.* 1996) navigation (e.g., Nießner *et al.* 2011), and predator detection purposes (e.g., Fernández-Juricic *et al.* 2004). There are inter-specific differences in the peak spectral sensitivities for each of the four cones types, and these may be linked to the unique requirements of the ecological and life history strategies of each species (Hart 2001). For example, penguins, whose aquatic environment is devoid of long light wavelengths (red), have almost no wavelength discrimination in the red part of the spectrum but excellent discrimination in the blue green part of the spectrum (Bowmaker & Martin 1985). Although it has been suggested that colour may be a factor in laser response (Lustick 1973; Blackwell, Bernhardt & Dolbeer 2002), no real effort has been made to investigate until now, partly because some laser colours such as violet have only recently become commercially available as handheld devices (S. Bowes, Laserglow Technologies, personal communication). Similarly, there has been almost no exploration of the many other ecological factors that are likely to influence the efficacy of lasers, such as foraging mode, season, time of day, weather conditions, social context, and levels of ambient light.

In Chapter 2, I present the results of hundreds of field trials that were designed to identify the biological attributes and environmental conditions that affect the efficacy of lasers as bird

deterrents. There I introduce the hypotheses on which I based my experimental design and report the effects of the several covariates I measured. In Chapter 3, I expand on why identifying the most salient visual stimuli for use in multi-modal deterrent systems is likely to advance bird protection not only in the oil sands, but also in other contexts that induce human-wildlife conflict. With this work, I also hope to reduce the current reliance on high-intensity audio deterrents, thereby reducing their associated ecological costs of acoustic pollution.

Chapter 2: Response of water-associated birds to lasers varies among seasons, times of day, laser colours and ambient light[1]

Introduction

Human-wildlife conflict is prevalent in areas where high wildlife use coincides with concentrated human activity. Birds, partly because they are ubiquitous and highly mobile, are particularly prone to such conflicts. These conflicts can compromise human safety (e.g., collisions with aircraft; Thorpe 2010; reviewed in Matyjasiak 2008), reduce economic gains (e.g., crop and aquaculture depredation; reviewed in Draulans 1987; Canavelli *et al.* 2014), lessen enjoyment of natural areas (e.g., soiling of recreation areas; (Conover & Chasko 1985) and impose legal liabilities (e.g., exposure of protected species to toxic substances; e.g., R. v. Syncrude Canada Ltd. 2010). Water-associated birds may additionally be involved in conflict because they often occur in large flocks, range widely, and thrive in habitats created or disturbed by people. Many of these species are also migratory, which can create a paradoxical situation in North America where even hyper-abundant species that are prone to conflict with people (e.g., Canada geese, *Branta canadensis*; reviewed by Smith *et al.* 1999 and others) are protected by legislation (Migratory Birds Convention Act 1994). This situation imposes a widespread need for methods that can dissuade birds from using areas where they might cause conflict for people without harming the birds in the process.

The most conventional method for discouraging bird use of large areas of habitat is to deter them with aversive stimuli using one or more of visual, acoustic, olfactory or tactile modalities (reviewed by Conover 2002). Acoustic deterrents, such as propane cannons and bioacoustic playback from speakers, are the most prevalent type of deterrents because they are

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[1] This chapter will be submitted for potential publication to the *Journal of Applied Ecology* and is formatted in accordance with its conventions and instructions to authors.

easy to deploy, can be detected over large areas and remain effective at night. However, even acoustic deterrents are highly prone to habituation, especially if the stimuli lack relevance to the target species (reviewed by Bomford & O'Brien 1990; Conover 2002). Habituation results in a reduced response over time, and occurs after repeated exposure to even an initially aversive stimulus if it is not followed with further consequences (Domjan 2006). Deployment of acoustic deterrents over large spatial scales imposes the additional problem of noise pollution (e.g., Bayne, Habib & Boutin 2008; Slabbekoorn & Ripmeester 2008; Francis, Ortega & Cruz 2011). Both problems can be reduced with integrated systems that detect approaching birds with marine radar and then deploy deterrents in target zones as needed (Ronconi & St. Clair 2006), and such "on-demand" systems now prevail at many industrial sites (e.g., St. Clair 2014). Unfortunately, radar is ill-suited to detecting birds flying during stormy weather (Vicen-Bueno *et al*. 2010) and at low altitudes (Loots 2014), both of which correlate with landings by migrating birds (Newton 2007). Consequently, deterrents do not yet prevent extensive agricultural damage (Canavelli *et al*. 2014), the presence of bird flocks at airports around the world (Dolbeer *et al*. 2000) or landings by tens of thousands of birds on industrial ponds associated with oil sands extraction (St. Clair 2014).

Greater efficacy of bird deterrent systems might be achieved by making more use of visual stimuli, and dozens of commercial devices have been developed for this purpose (Harris & Davis 1998; Gorenzel & Salmon 2008). Visual deterrents include effigies of humans and predatory animals with various degrees of realism as well as objects designed to emphasize the most salient cue of a would-be predator, such as eyes or motion. Most visual deterrents are limited by detectability to small spatial scales and daylight use, but optical lasers have been promoted as visual bird deterrents (e.g., Lustick 1973) partly because they have the potential to

overcome both factors. Lasers have gained much popularity because they are known to produce aversive responses for some species and contexts (Baxter 2007; Blackwell *et al*. 2002; Werner & Clark 2006; Blackwell *et al*. 2002; Soutdat-Soucaze & Ferri 1997; Glahn *et al.* 2000), but not all birds exhibit an aversive or sustained response (Glahn *et al.* 2000; Homan *et al.* 2010; Blackwell *et al.* 2002). It is difficult to generalize these results among species or contexts because these studies employed a diversity of laser equipment (e.g., colour, power) and deployment methods (continuous, pulsing beams, motion) and typically targeted birds in captivity or habitats that had been highly modified by people. The lack of general patterns for responsiveness of birds to lasers lessens the efficacy they might otherwise achieve as a complement to other deterrent systems.

A promising avenue for refining the use of lasers as bird deterrents is to emulate the emphasis on salience that has been applied to explain avian responses to visual stimuli in other contexts, both basic (e.g., Bennet *et al.* 1997; Davidson, Clayton & Thornton 2014) and applied (e.g., Martin, 2011; Blackwell *et al.* 2012). In sensory ecology, salience describes the ability of a stimulus to elicit a response, usually because it targets pre-existing adaptations to prevailing ecological conditions (e.g., Bowmaker & Martin 1985; Martin 2011; Davidson, Clayton & Thornton 2014). Because birds have sophisticated visual systems (Goldsmith, 1990) that are used to assess risk (Fernández-Juricic *et al.* 2004), visual deterrents are likely to have generally high salience. Birds are especially sensitive to the colour of visual cues (e.g., Kear 1964; Oppenheim 1968; Willson, Graff & Whelan 1990; Schmidt & Schaefer 2004; Cazetta, Schaefer & Geletti 2009) and they also appear to respond behaviourally to the colour of light (Prayitno *et al.* 1997). In addition to the human visual range, many bird species can detect UV signals and may use both emitted (e.g., to navigate) and reflected UV light (e.g., to identify food or assess mates; reviewed by Cuthill *et al.* 2000). Despite the broad application of lasers to bird deterrence and the

appreciation of stimuli salience in other contexts, no study has examined variation in the responses of birds to lasers within such a framework.

The aim of this study was to examine the responses of water-associated birds to lasers while manipulating or measuring several other variables that we predicted would increase the likelihood of eliciting an escape response. We placed a primary emphasis on three variables; laser colour (green and violet), foraging mode (diving, dabbling and wading), and season (spring and fall). We predicted that species that forage under water (divers) would be more sensitive to the shorter wavelengths that prevail there (violet), especially during the breeding season (spring) when threatening stimuli could signal either or both of competitors or greater risk to vulnerable young. In addition to these three targeted variables, we recorded the covariates light, time of day (morning and evening), weather (inclement or fair) and the distance between the laser sources and target. We predicted that lasers would be more likely to elicit an escape response under lower light levels (because they would have greater contrast), in the morning (when birds tend to be more active), during fair weather (when flight is less costly) and at short distances (over which lasers may be more intense).

Materials and Methods

Field trials were conducted at twelve natural and man-made water bodies or pond complexes in and near Edmonton, Canada (53°32′N 113°30′W), using several species of water-associated birds (Table 1). These locations were mostly man-man recreational ponds or wetlands used for stormwater management and ranged in size from 1.7 to 10.5 ha. Two sites were located at civic water outflows on the North Saskatchewan River, and a small number of trials were carried out at natural lakes (~3 km^2) outside city limits.

To minimize habituation or sensitization resulting from repeated exposure to lasers, we avoided reuse of sites with small, single ponds on consecutive days. Three large sites were used up to four days in a row once per season. Within visits to a site, we avoided repeated exposures of birds by moving along the shore in a consistent direction and avoiding sites where treated birds were observed to have landed. We positioned ourselves on shorelines as close to the water as was practical, typically between 1 and 20 m from the water edge and between 0 and 10 m above the water surface.

We conducted trials during crepuscular periods when light levels were low enough for lasers to be visible, but high enough to detect birds, measure the distance to them, and assess their responses. Before initiating a trial, we identified the species, and numbers of target birds in the group using binoculars (Viper HD 15x50, Vortex Optics, Middleton, USA) or a spotting scope (Diascope 85FL, Zeiss, Oberkochen, Germany), and measured the distance between the laser operator and target with a rangefinder (Fusion 1600 12x50, Bushnell Corporation, Overland Park, USA). We grouped target birds into foraging guilds according to their method of locomotion in water while foraging and designated them as divers, dabblers, or waders.

For each trial, we subjected target birds to one of two types of portable Class 3B lasers; the Electra Pro-250 violet diode laser (405 nm, 250 mW) or the Aries-250 green DPSS laser (532 nm, 250 mW) (both obtained from Laserglow Technologies, Toronto, Canada; specifications available at www.laserglow.com). Lasers were directed by hand and trials began by turning on the laser device while pointing the beam at the ground near the feet of the laser operator. We then moved the beam along the ground or water towards the target to within about five bird-lengths, after which we moved the laser back and forth with a similar span.

Bird response was recorded on an ordinal scale from 0 (no response) to 3 (bird flushed) or 4 (bird dove; Table 2). To simplify analysis and the management implications of our results, we condensed these categories to a binary classification that distinguished an escape response (1) from a non-escape response or no response (0; Table 2). Lasers were trained near birds for up to five seconds after which a zero was recorded if the bird or bird group exhibited no over reaction. We avoided directing the lasers directly at the eyes of target birds and did not conduct trials where the directed or reflected beam could reach unintended human subjects beyond our targets. We conducted trials in fall (September and October), 2012 and 2013, and spring (April and May), 2013 and 2014. In spring, we did not target birds that had offspring present.

In addition to the covariates of trial distance and the size of bird groups described above, we either measured weather variables (temperature, wind speed and direction) via a portable weather station (Kestrel 4000NV, Loftopia LLC, Birmingham MI, USA) or estimated them on an ordinal scale (cloud cover, precipitation) at the start of each sampling period. Observers noted the time at the start of each laser trial and measured ambient light level immediately afterwards (Flash Master L-358, Sekonic, Tokyo, Japan). Later, we classified trials conducted during precipitation or winds > 10 kph as having occurred during "inclement weather" and divided the timing of trials into morning (AM) and evening (PM).

We used logistic regression to examine the effect of foraging guild, laser colour, season, time of day, and weather on bird response to lasers over a range of ambient light and observer distances. Analyses were performed in R 3.1.1 (R Core Team 2014) using the lme4 package function glmer (Bates *et al.* 2014). We included site as a random effect in all models to account for possible non-independence resulting from physical features of ponds, such as size or distance to cover, which may have influenced bird responses. Continuous variables (ambient light, and

distance) were standardized prior to analysis (mean = 0, SD = 1). Because we obtained few trials

of waders in spring, we examined the responses of those birds separately from divers and

dabblers, did not include any trials conducted in the spring, and did not evaluate the effect of

weather (which was similarly fair in all trials).

We identified a final model with the method of purposeful model selection outlined by

(Hosmer, Lemeshow, & Sturdivant 2013). Specifically, we evaluated each main effect in a

univariate model, retained those with P-values ≤ 0.25, evaluated all liberally-significant variables

in a single model and retained those that were either significant at $P \leq 0.05$ or altered the

coefficients of other variables by $\geq 20\%$. We then added each biologically relevant two-way

interaction one at a time, retaining those with $P \leq 0.05$. We assessed model fit by calculating the

marginal and conditional R^2 value in R using package MuMIn function r.squaredGLMM (Barton

2014), following the method of Nakagawa & Schielzeth (2013) and conducting the Hosmer-

Lemeshow goodness-of-fit statistic.

Results

We conducted 791 trials on birds that were distributed opportunistically among our *a*

priori explanatory variables of laser colour, season, and foraging group, with more trials

conducted with green lasers (62% of trials), in the fall (61% of trials), and on dabbling birds

(68% of trials; Table 1). Additional differences in sample sizes occurred among our categorical

covariates, and evenings (54% of trials) and calm weather (76% of trials) were sampled more

often. For the continuous variables, light levels ranged from $0.57 - 9,490$ lux (mean = $372.35 \pm$

1150.01 SD,) and distances ranged from $4 - 250$ meters (mean = 65.8 ± 39.9 SD). The number of

trials conducted at each site ranged from 3 to 260 with 75% of trials occurring at three large

wetland complexes that had been constructed for storm water management.

The final model describing the responses to lasers of divers and dabblers identified five significant variables (likelihood ratio $X^2 = 116.33$, df $= 5$, $P < 0.001$; Table 3) and produced a good fit to the data (Conditional $R^2_{GLMM} = 0.343$, Marginal $R^2_{GLMM} = 0.257$; H-L $= 11.41$, $P = 0.18$). Expressed as odds ratios for exhibiting an escape response, birds were 70% more likely to respond in spring relative to fall and about 60% more likely to respond in mornings relative to evenings (Table 3). Green lasers were generally more effective than violet lasers and this difference was greatest at intermediate light levels. Increasing ambient light reduced responsiveness generally and this effect was even more pronounced for violet lasers (Table 3, Figure 1). The final model did not contain foraging guild, trial distance, or weather, suggesting that these variables did not influence bird probabilities of exhibiting escape responses over the ranges of values we tested. However, birds that forage by diving exhibited different escape responses when they were startled; loons and grebes always dove (15/15 trials), whereas diving ducks usually flew away (39/44 trials).

For wading birds subjected to lasers in the fall, only laser colour and ambient light significantly predicted escape responses (likelihood ratio $X^2 = 5.81$, df $= 2$, $P = 0.06$; Table 3). Similar to the divers and dabblers, wading birds were about more likely to respond to green lasers than violet ones, and responsiveness to both devices decreased with increasing ambient light (Table 3). This model also provided a good fit to the data (Conditional $R^2_{GLMM} = 0.21$, Marginal $R^2_{GLMM} = 0.1944$; H-L test $= 8.65$, $P = 0.37$).

We used the predicted probabilities from the final model for divers and dabblers to identify the threshold in light levels below which birds were less than 50% likely to respond to lasers with an escape response. Such values might be used to guide the use of lasers in the context of bird deterrence. Our model predicted that this threshold would occur at light levels

below 21.8 lux for green lasers, but only 2.3 lux for violet lasers (Figure 1). For reference, a value of 0.1 lux corresponds to the light of a full moon, 11 lux to twilight, and 107 lux to a very dark, overcast day. In contrast to the rapid reduction in bird responsiveness with increasing ambient light, bird response was not affected by the distance from the laser operator, and this lack of effect was consistent across both foraging guilds and laser colour (Figure 2).

Discussion

We examined how bird responses to targeted laser beams were affected by three variables that are relevant to the use of lasers as bird deterrents: foraging mode of the bird, season, and laser colour. Based on the concept of sensory salience and a coarse categorization of birds using the ecological variable of primary foraging mode, we had predicted the proportion of escape responses would increase for trials using one or more of violet lasers, diving birds, and spring. We also offered predictions for the variables of ambient light, time of day, weather, and distance, such that lasers would be more likely to elicit an escape response under lower light levels (because they would have greater contrast), in the morning (when birds tend to be more active), during fair weather (when flight is less costly) and short distances (over which the light from lasers may be more intense). Our results did not support many of our predictions clearly, but they may, nonetheless, offer some useful implications for wildlife managers who use lasers to deter birds. We found that green lasers were more likely to generate escape responses than violet ones, both lasers were less effective as ambient light increased, and dabbling and diving birds were more responsive in morning and spring compared to evening and fall.

Contrary to our prediction that the violet laser would elicit more escape responses owing to the shorter wavelengths of its light, the green laser generated a higher proportion of escape responses over the range of ambient light levels that we tested. Birds continued to respond to the

green laser at higher light levels when there was no response to the violet laser, although at the highest light levels we tested, neither laser elicited startle responses. Despite the greater responsiveness of birds to green lasers, we cannot know if they were responding to different wavelengths because the two laser colours also had different beam structures. Green lasers were constructed with diode pumps (i.e., DPSS lasers), which creates a wider beam of higher quality relative to the simple diode construction of the violet laser (S. Browers, Laserglow Technologies, Ltd). A third potential explanation for the greater responsiveness of birds to the green lasers is the peak sensitivity of the associated retinal cells. The visual range of birds typically includes wavelengths from 320 – 700 nm (Maier 1994), but additional species-specific differences in colour perception and sensitivity are present in photoreceptors and their associated oil droplets (Ödeen & Håstad 2003; Hunt & Peichl 2014). As for people, for which high sensitivity to green light contributes to the sensation that green lasers are about 20x brighter than violet ones (as described in Bowmaker 1981), birds may simply be more sensitive to green light. Although birds are expected to be most responsive to light that overlaps with peaks in their visual sensitivities (Blackwell *et al.* 2012), these values are not known for many of the species we tested. The overlapping, but unknown, effects of laser colour, beam structure, and retinal sensitivity makes it difficult to know why birds were more responsive to green lasers.

The known variation in spectral sensitivity among species is the reason we predicted that divers, which forage underwater, would be more sensitive to lasers, especially violet ones. We found no such differences between dabblers and divers and could not examine the relative tendencies of waders due to lack of replication. The similarity between dabbler and diver responses may have resulted because foraging mode is not relevant to responses to lasers or because our division among taxa was too coarse to detect what differences might exist. The latter

possibility is suggested by both the substantial differences in visual fields, vigilance behaviour (Guillemain *et al.* 2002) and risk aversion (Ackerman, Eadie & Moore 2006) that have been documented within dabbling ducks, and the differences in behavioural responses we observed within diving birds. In our experiments, diving birds in the order *Podicipediformes* (which includes loons [Family *Gaviidae*] and grebes [Family *Podicipedidae*]) always dove when they exhibited an escape response to a laser, whereas the diving ducks (Family *Anatidae*) usually flew away. The tendency for loons and grebes to dive in response to deterrents might increase their vulnerability to floating hazards at industrial sites (St. Clair 2014), but repeated use of deterrents is expected to reduce the probability that water-associated birds, including loons and grebes, would land at a site in the first place.

As we had predicted, birds were more responsive as ambient light declined, but their likelihood of an escape response did not change with trial distance. The greater effect of both laser colours under lower levels of ambient light presumably stemmed from increasing contrast between the areas illuminated by the lasers and the surrounding surfaces. This predicted effect of ambient light on laser efficacy (e.g., Lustick, 1973) is the reason that their efficacy is expected to decline above 1200 lux of ambient light (Soudat-Soucaze & Ferri 1997; Glahn *et al.* 2000), although these values have not previously been corroborated with field tests. Contrast is one of the most important components of visual discrimination (Jameson & Hurvich 1964) and can be detected even in the absence of colour vision (Osorio, Miklosi & Gonda 1999). The non-effect of distance on escape responses suggests that our Class 3B lasers retained similar intensity at distances up to about 160m. Lasers are designed to achieve highly collimated beams that do not diffuse with distance and we could see the green laser at distances exceeding 1 km (CCSC personal observation). Successful deterrence of birds has been anecdotally reported at distances

up to 2.5 km (Soudat-Soucaze & Ferri 1997). These visual ranges potentially makes lasers effective as bird deterrents even over the large spatial scales that characterize hazardous industrial ponds in the oil sands region.

Among the three temporal variables we tested, we found that birds were more responsive in the morning and spring, but did not vary in responsiveness across the range of weather conditions we tested. For the divers and dabblers that were tested in both seasons, birds were more likely to exhibit escape responses in the spring. Greater responsiveness then may have resulted from higher levels of competition and aggression in the breeding season among conspecifics (e.g., Titman 1983) or from the greater vulnerability to predators due to reproductive behaviours and conspicuous plumage (reviewed by Lima 2009). Dabblers and divers were also more responsive to lasers in the morning than in the evening, perhaps because many species of waterfowl are more active then (e.g., Winner 1972) or because the contrast afforded by the lasers was exaggerated by the preceding period of darkness. Finally, neither dabblers nor divers showed a reduction in response to lasers during inclement weather relative to fair conditions. We lacked sufficient samples to examine this effect in waders and the limited range of weather conditions over which we conducted our trials could underestimate the effects of weather. Although migrating birds are not much impeded by light wind and rain, they are much more likely to land and even perish during extreme weather events (reviewed by Newton 2007). Thus, extremely harsh weather might have reduced their willingness to fly away in response to laser stimuli. Conversely, birds are hypothetically more responsive to lasers during stormy weather because their beams would be reflected by particles of moisture and dust that are suspended in the air, increasing the visibility of the light paths (Soudat-Soucaze & Ferri 1997).

Our study had some limitations that should be addressed with subsequent work. First, our results based on landed birds should be expanded to address birds in flight, which may exhibit greater responsiveness. Similarly, directing lasers on substrates that provide more contrast, such as ground cover and vertical vegetation, may elicit greater responses by birds. Third, more work on wading birds is warranted, partly because this group does not appear to be as responsive to acoustic deterrents (Ronconi & St. Clair 2006) and their cryptic colouration makes them difficult to detect and target with visual deterrents that have more limited spatial ranges. Finally, the potential for birds to habituate to lasers should be examined. Though there are few studies that explicitly examine habituation, they suggest that the aversive response of captive Canada geese to lasers is sustained even after repeated exposure (Blackwell, Bernhardt & Dolbeer 2002; Werner & Clark 2006). The avoidance shown by captive mallards, however, was extinguished after 20 minutes of exposure to a red laser (Blackwell, Bernhardt & Dolbeer 2002), therefore more work is needed to determine the generality of any habituation effect. Because lasers can be manipulated easily to vary their position, power intensity, colour, and constancy (e.g., pulsed vs. constant), and also remain visible over very large distances, they have much potential to overcome the problems of habituation that characterize most visual deterrents (e.g., Stickley, Mott & King 1995; Andelt, Woolley & Hopper 1997; reviewed by Gilsdorf, Hygnstrom & VerCauteren 2002).

Despite these limitations, our results offer several insights that are potentially useful to wildlife managers tasked with deterring birds to prevent harm to people or wildlife. First, our final model for dabblers and divers offers a coarse predictive tool for eliciting an escape responses from landed birds. It showed that the most important variable was laser colour; green lasers were over six times more effective than violet lasers overall. However, even green lasers

were limited by high levels of ambient light. The predicted probability of 50% for an escape response occurred at an ambient light of 21.8 lux which, for reference, would be between the ambient light levels at twilight (~11 lux) and on a very dark, overcast day (~107 lux). The modest effects of season and time of day, and the absence of effects for foraging guild, weather, and trial distance support the widespread applicability of green lasers for bird deterrence. Like other deterrents, lasers may achieve greater efficacy if they are complemented with an additional sensory modality (e.g., auditory stimuli), especially if the two modalities can be paired to emulate a single aversive stimulus, such as an approaching flying object. Such pairings might be possible in unmanned aerial vehicles, which invite investigation as bird deterrents, especially at dangerous industrial sites (St. Clair 2014). As technology continues to change and new deterrent devices become possible it is important to that these new devices adhere to the principles of ecological salience and behaviour theory, and that efficacy is continuously assessed using robust scientific methods.

Tables and Figures

Table 1: Proportion of individuals that responded by flying or diving following exposure to green *vs.* violet lasers in trials conducted in the spring and fall between 2012 and 2014 at water bodies in and near Edmonton, AB. Birds are grouped by primary foraging modes and listed by species followed by the number of individuals treated (N), the percent of trials conducted in spring, the percent of the trials that generated an escape response for each of green and violet trials and, in parentheses, the number of trials conducted with each laser colour. Bold rows show group subtotals and grand total

Guild / Species	Latin name	N	% Spring	% Responded Green (N_{green})	% Responded Violet (N_{violet})
Dabblers		**536**	**35**	**35 (344)**	**22 (192)**
Mallard	*Anas platyrhynchos*	203	31	44 (140)	33 (63)
Canada goose	*Branta canadensis*	148	55	26 (84)	17 (64)
American wigeon	*Anas americana*	66	29	35 (48)	22 (18)
Blue-winged teal	*Anas discors*	43	33	18 (22)	14 (21)
American coot	*Fulica americana*	23	13	0 (13)	0 (10)
Northern shoveler	*Anas clypeata*	21	29	45 (11)	10 (10)
Other dabblers[2]		32	17	38 (26)	33 (6)
Divers		**191**	**60**	**38 (110)**	**22 (81)**
Lesser scaup	*Aythya affinis*	107	53	22 (54)	17 (53)
Red-necked grebe	*Podiceps grisegena*	26	81	42 (12)	36 (14)
Common goldeneye	*Bucephala clangula*	25	64	75 (16)	33 (9)
Other divers[3]		33	60	46 (28)	20 (5)
Waders		**64**	**0**	**15 (39)**	**12 (25)**
Greater yellowlegs	*Tringa melanoleuca*	35	0	15 (20)	13 (15)
Other waders[4]		29	0	16 (19)	10 (10)
Total		**791**	**62**	**34**	**21**

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[2] Other dabblers included: Northern pintail, *Anas acuta* (7); gadwall, *Anas strepera* (5); green-winged teal, *Anas crecca* (4); tundra swan, *Cygnus columbianus* (2); unknown dabbler (14)

[3] Other divers included: common merganser, *Mergus merganser* (7); pied-billed grebe, *Podilymbus podiceps* (6); bufflehead, *Bucephala albeola* (5); common loon, *Gavia immer* (4); redhead, *Aythya americana* (2); hooded merganser, *Lophodytes cucullatus* (2), ruddy duck, *Oxyura jamaicensis* (1); unknown diver (4)

[4] Other waders included: lesser yellowlegs, *Tringa flavipes* (15); killdeer, *Charadrius vociferus* (2); unknown wader (12)

Table 2: Categories of bird responses to laser beams were measured in the field with an ordinal scale and condensed to binary categories for analysis and interpretation based on the presence (1) or absence (0) of escape behavior.

Behaviour	Ordinal scale	Binary response
No response	0	
Change in direction	1	0
Startle response with flapping and/or rapid movement <10m	2	
Flying > 10m	3	1
Diving	4	

Table 3: Results from logistic regression models identifying the significant covariates predicting escape responses of water-associated birds exposed to lasers directed on adjacent water surfaces. Exposure trials occurred in two seasons (spring and fall), with two laser colours (green and violet), under varying levels of ambient light and times of day (early AM or late PM). For each categorical variable, the reference group is provided in parentheses. Subsequent columns provide the estimated model coefficient, standard error, *P*-value, and odds ratio, which is bounded by its 95% confidence interval. Separate models were constructed for divers and dabblers *vs*. waders, for which season and weather variables were not evaluated.

				95% CI for Odds Ratio		
	B	SE	*P*	Lower	Odds Ratio	Upper
Dabblers and Divers						
(Intercept)	-2.74	0.38	<0.001	0.03	0.06	0.14
Season Spring (Fall)	0.52	0.20	0.01	1.14	1.68	2.46
Laser Green (Violet)	1.89	0.30	<0.001	3.65	6.62	12.01
Ambient light	-1.36	0.23	<0.001	0.16	0.26	0.40
Time of day AM (PM)	0.47	0.19	0.01	1.11	1.60	2.32
Laser Green * Ambient light (Violet)	0.51	0.26	0.05	1.00	1.67	2.79
Waders						
(Intercept)	-2.76	0.80	<0.001	0.01	0.06	0.30
Laser Green (Violet)	1.15	0.91	0.21	0.53	3.15	18.60
Ambient light	-0.97	0.44	0.03	0.16	0.38	0.89
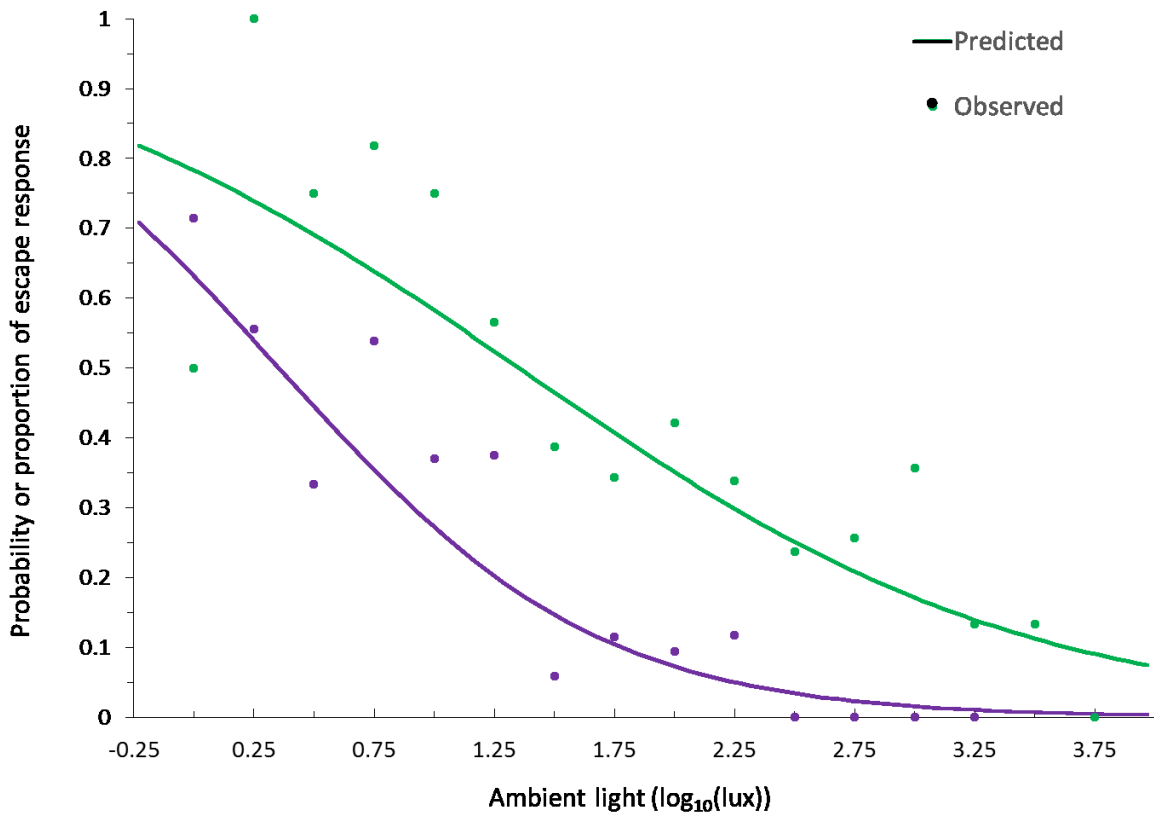
Figure 1: Predicted probabilities of an escape response by birds that dive or dabble to forage when exposed to green *vs*. violet lasers as a function of increasing ambient light. The actual proportion of positive responses are plotted for each bin of 0.25 light units (log$_{10}$[lux]).

Figure 2: Average distance from observer to target birds in trials resulting in an escape response (1) and no response (0) for dabbling, diving, and wading water-associated birds treated with green and violet lasers. Error bars show standard deviations.

Chapter 3: General Discussion
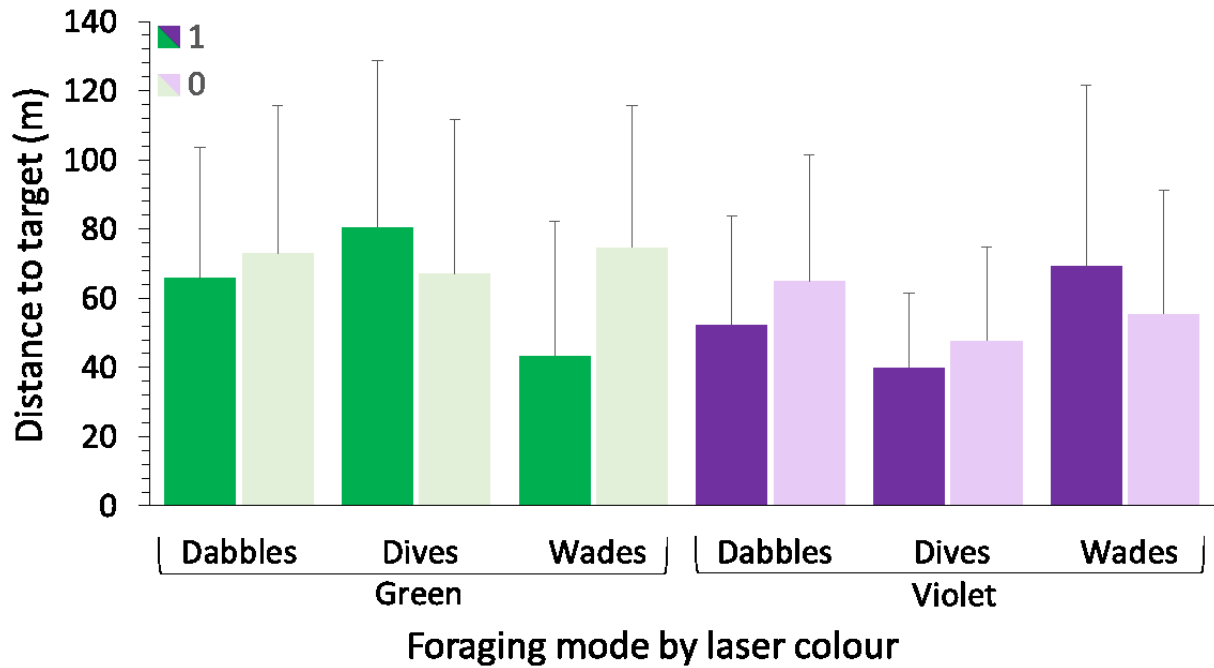
The purpose of this thesis was to contribute information for improving bird protection in the oil sands region of Alberta, as part of the *Research on Avian Protection Project* funded by a court order (R v Syncrude 2010; St. Clair 2014). My part of that project was to (i) conduct field studies on visual deterrents, and (ii) translate my results to support best practices for bird protection in the mineable oil sands region of northeastern Alberta, Canada. There, current practices to protect birds from toxic mining effluent rely mainly on high-intensity acoustic deterrents. Those deterrents do not prevent tens of thousands of birds from landing on the tailings ponds anyway, according to the results of a recently-standardized monitoring program (reviewed by St. Clair 2014). Because legislation obliges the oil sands operators to take all reasonable precautions to prevent such landings, there is a pressing need for more research to identify the most effective bird deterrents.

Greater efficacy of bird deterrents may depend on increasing the use of visual stimuli, which have received little attention by the industry over the past several decades. The human effigies tested by Boag & Lewin (1980) remained the most common form of visual deterrent (reviewed by Golder 2000) until the development of integrated deterrent systems about ten years ago (Ronconi & St. Clair 2006), but there has been no systematic study of these subsequent innovations. No work in the peer-reviewed literature has focused on the issue of visual deterrents in the region in the past 35 years, despite awareness in the broader literature on bird deterrence of the importance of multi-modal deterrents that target two or more sensory systems (Conover 2002). This lack of development of visual deterrents is surprising because birds make extensive use of vision (reviewed by Jones, Pierce & Ward 2007) and species-specific visual

sensitivities are being explored in other management contexts to prevent collisions between birds and anthropogenic objects (e.g., Klem 2009; Martin 2011; Blackwell *et al.* 2012).

My thesis addressed one type of visual deterrent, optical lasers, which have shown promising but inconsistent, results as bird deterrents (Chapter 2). I conducted hundreds of field trials testing the response of water-associated birds to lasers. By examining variables that I expected would be relevant to management decisions, I found that: (i) green lasers were six times more likely to elicit an escape response by birds than violet ones; (ii) birds were about 70% more responsive in the spring season than fall; (iii) birds were 60% more responsive in mornings than evenings; and (iv) higher ambient light levels reduced the probability of an escape response, especially for violet lasers. Bird responses did not differ by foraging guild (divers vs. dabblers), trial distances, or weather conditions. However, among diving birds, loons and grebes always escaped laser stimuli by diving, whereas diving ducks usually flew away. This study is the first to address such a diversity of factors in the responses to lasers by wild birds.

The second objective of this thesis was to translate my results into management recommendations that support best practices for bird protection in the oil sands region. I explored the conditions under which lasers were more or less effective within the range of conditions defined by my study trials (Chapter 2). Some of these results might reasonably be extended to contexts I was not able to study directly. One plausible extension stems from my finding that violet lasers were generally less effective than green lasers, but bird responses became more similar as ambient light declined. It is possible that violet lasers could provide an effective complement to green lasers under the darkest conditions and might reduce the propensity birds have to habituate to any stimulus that does not change over time (reviewed by Conover 2002). In addition to unpredictable changes in laser colour, erratic changes in the

position of the beam would make the stimulus dynamic, which is known to reduce the speed of habituation in many learning contexts (Domjan 2006). Because lasers provide a visual stimulus alone, they are likely to be more effective deterrents if they are paired with sound to address multiple sensory modalities (*sensu* Conover 2002). Different sounds might be used with alternative visual stimuli during daylight to reduce habituation in both periods. Further research should experiment with a variety of sight-sound pairings and determine their effects on bird responses.

Identifying the most salient visual stimuli for use in multi-modal deterrent systems is likely to advance bird protection not only in the oil sands, but also in other contexts that induce human-wildlife conflict. Because more salient stimuli are likely to cause more intense responses (*sensu* Blackwell et al. 2012) and less likely to produce habituation (Conover 2002), targeting such systems should be adopted as a best practice by this and other industries that threaten birds. The same principle applies to contexts where human safety can be compromised by failure to deter birds, which applies to the problem of bird strike at airports worldwide (Thorpe 2003, 2005, 2010; reviewed by Matyjasiak 2008). Robust experimentation and publication in peer-reviewed, open-source venues could advance deterrent practices rapidly in several other conflict domains, including agricultural (e.g., Canavelli *et al.* 2014), aquaculture (e.g., Dorr *et al.* 2012; Marzano, Carss & Cheyne 2013), offshore drilling platforms (e.g., Burke, Montevecchi & Wiese 2012) and oil spills (e.g., Ronconi *et al.* 2004).

Beyond best practices for bird deterrence, each of the contexts where bird-human conflict occurs would, ideally, also advance practices for providing alternative habitat to maintain bird populations. This complement is especially important for species that are already exhibiting population declines because of habitat loss and other human activities (Dolman & Sutherland

1995). Such an approach may be warranted in the oil sands region, which is directly beneath a migratory flyway to and from the Peace-Athabasca Delta, in turn used by up to 1.5 million birds in spring and fall (Butterworth *et al.*, 2002). Because it is unrealistic to prevent bird landings throughout the oil sands region, it may be important to identify alternative safe areas for landing, especially during early spring when adjacent water bodies are still frozen (Ronconi & St. Clair 2006). Such areas might be developed in natural freshwater ponds (Ronconi 2006), but few of these remain amid the active mining area (St. Clair *et al.*, 2013). Thus, safe landing sites might target the types of ponds, such as those containing recycle water, that do not appear to pose health risks to birds (Beck, Smits & St. Clair 2014). Areas of relative safety might even be provided in parts of the largest tailings ponds that are distant from current outflow pipes where fresh tailings could be contained with booms (St. Clair *et al.* 2011; St. Clair 2014). In the oil sands region and elsewhere with comparable risks, an integrated approach that deters birds from some areas, while allowing them to land in others, is most likely to achieve the ultimate goal of increasing bird protection.

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