The Influence of Intensive Land Use Types on the Foraging Distribution of Ducks Wintering in the Fraser River Delta, British Columbia

by

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Abstract

Current ecological theory states that food and danger considerations underlie patch selection. Foraging sites for the ~ 100,000 ducks wintering on the Fraser River delta, British Columbia, Canada, are embedded in a matrix of suburban and rural land use types. I investigated foraging by American wigeon (*Anas Americana),* mallard (*A. platyrhynchos*)*,* northern pintail (*A. acuta*) and green-winged teal (*A. carolinensis*) to test the hypothesis that features adjacent to foraging sites such as buildings or roads cast a 'shadow of danger' that reduces patch use and thus habitat carrying capacity. I measured patch use with winter-long dropping counts on transects across fields adjacent to residential areas, greenhouses, roads and berry fields. Usage was highest adjacent to greenhouses, lowest adjacent to residential areas, and intermediate adjacent to berry fields and roads. Seasonal usage of a field was steady once begun, began soonest adjacent to greenhouses, and latest adjacent to residential areas. The distribution pattern of droppings across fields showed that ducks avoided residential areas, and foraged close to greenhouses. They showed no strong distribution pattern at berry fields and roads. The measured level of activity (wildlife, people, traffic, noises, lights, etc.) was highest at residential areas and roads, and lowest at greenhouses. Patch use and seasonal usage was lower in fields bordering land uses with higher activity levels. Previous studies on wintering ducks on the Fraser River delta widely report that upland foraging is largely nocturnal, that diurnal use is restricted to roosting on flooded fields, and that crop type strongly influences field usage. In contrast, I found that nocturnal and diurnal foraging were similar, though fields were visited more often at night. Landscape-scale selection of fields was best explained (AIC) by models including field-level measures of danger and greenhouse proximity: neither available energy nor standing water were included in the most informative models. These findings are consistent with the hypothesis that danger from various land use types strongly influences the foraging distribution of wintering ducks.

Keywords: Wintering ecology; predation danger; habitat selection; nocturnal foraging; Fraser River delta; dabbling ducks

to my nieces, Emma, Mia and Lily. May they know that with

hard work and dedication no mountain is too high to climb.

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Chapter 1.

Introduction

The human population has become more urban in recent decades. The percent of people living in urban areas grew from 33% in 1960 to 50% by 2009 (World Health Organization Report). In 2005, more than 330 cities were home to populations of at least one million people (www.mongabay.com). It is projected that by 2030, more than 60% of humans will live in urban areas, if current trends continue (Alberti et al. 2003).

Urban areas range from highly dense urban cores to sparsely inhabited rural landscapes (Clucas and Marzluff 2012). Urban areas can be large; the area of the world's 25 largest cities ranges from 777-8683 km^2 (United Nations World Urbanization Prospects 2011). Further, some cities are located in biologically productive places such as estuaries (Thurman and Burton 2000), river junctions and coastlines. For example, estuaries are occupied by an estimated half billion people worldwide and 53% of Americans live along coastal fringes (http://wps.prenhall.com).

Effects of urban growth result from three processes; population growth in existing urban areas, increased development of rural areas, and expansion of existing urban footprint into surrounding areas (Cohen 2004). This last process involves both alteration and development of existing habitat, resulting in more interfaces with natural areas. Examples of the kinds of effects arising from urban growth are city expansion near lakes, rivers or estuaries that alter water flow by dykes and ditches, productive land being fragmented and altered to suit agriculture and adjoining areas being developed into residential, commercial and industrial areas woven within a road network to service and transport goods and people. Each of these layers produces a source of human activity and provides an interface between urban features and wildlife habitats.

Effects of urbanization can be positive or negative. Although direct loss of habitat through development is detrimental to wildlife, alteration of habitat may enhance habitat for some species, especially those that adapt easily to human activity. Familiar urban wildlife such as pigeons, crows, raccoons and coyotes thrive in highly human-altered landscapes. In contrast, many other species forced into contact with human-altered habitats and associated human activities do not respond well. Large and mid-sized mammal abundance declines from rural to urban core (Saito and Koike 2013) and development of wildlands alters the abundance and community structure of avian communities (Nilon et al. 1995).

Urban ecology is the study of "ecosystems that include humans living in cities and urbanizing landscapes" (Marzluff et al. 2008). Urban areas impact survival, habitat availability and movement of wildlife. For example, millions of migratory birds are killed annually in North America from domestic cat predation and strikes with buildings, cars and power lines (Loss et al. 2013, Calvert et al. 2013). On the other hand, wildlife habitat around cities can be improved by reclaiming marshes, building nestboxes and hunting perches and suppressing fire and human presence (Rosenzweig 2003).

Conservation biology is the scientific study of nature with the aim to evaluate human impacts and develop practical approaches to halt losses of biodiversity. Within the field three areas of inquiry are aimed at understanding how intervention can reverse the damage done by human activity. 'Restoration ecology' aims to recover lost habitat through programs such as reforestation, invasive species removal and fish spawning stream enhancement. 'Rewilding' restores ecosystem function by improving the extent and connectivity between core wilderness areas and reintroducing or protecting apex predators or keystone species. A third branch is 'reclamation ecology' which promotes self-sustaining wildlife populations within the human-altered urban landscape by slowly allowing wildlife to habituate to an unfamiliar interface (Rosenweig 2003). With predicted urban expansion it is particularly pertinent to explore how features of urban landscapes affect persistence of animal populations within the urban setting.

1.1. Theoretical background

To gauge how an expanding urban footprint impacts wildlife populations we require a theoretical construct that will measure the response of animals to their environment. Behavioural ecology has historically been the study of how animals in a natural setting respond to patterns in their environment, with an emphasis on how natural (and sexual) selection underlies the evolution of a behaviour. A core tenet is that animals make 'decisions' about where and when to forage and settle with decision-making processes that have been shaped by natural (and sexual) selection to produce outcomes that maximize fitness.

Behavioural ecology applied to foraging behaviours has given rise to a variety of simple models that assume the aim is to maximize rate of intake. Danger was absent from early foraging models because the currencies for foraging gain and danger differed (Mangel and Clark 1986). Adoption from economic theory of the notion of tradeoffs spurred the incorporation of danger (Mangel and Clark 1986). A tradeoff assumes that an animal cannot do two activities well but can invest in one activity at the expense of another (Sih 1980). By making this tradeoff a forager aims to optimize the investment in one activity and, ultimately, fitness (Lima and Dill 1990). The development of theoretical and empirical tools for exploring such tradeoffs gave danger a strong foothold in foraging theory.

In order to place danger in the tradeoff context a technique is needed that measures how foragers assess danger and how much they invest in alternative activities. The Ideal Free Distribution (IFD) predicts that if individual foragers have perfect information about all patches then they will distribute themselves among patches with variation in resource abundance among patches (Fretwell and Lucas 1970; Abrahams and Dill 1989). The true-to-life limits of this idea were that animals were observed to distribute themselves not according to relative resource abundance but also in accordance with danger in each patch (Abrahams and Dill 1989). One way to incorporate danger into the IFD model is by titrating food and safety (Nonacs and Dill 1990, Todd and Cowie 1990, Kotler and Blaustein 1995). By providing patches artificially enhanced or depleted of food and allowing foragers to visit each patch we can gauge the relative importance of foraging costs and benefits (Brown 1988). This is the premise of

'giving up density' whereby foraging costs are measured using artificial patches while holding all other components of the foraging equation constant except danger. Some researchers have used the distance between an approaching predator and a forager when the forager departs a patch to measure danger (Brown 1988). The flight initiation distance (FID) is a tradeoff between the costs of leaving a patch (energetic costs of flight and missed foraging opportunities) and the benefits of escaping from a predation attempt. Finally, danger varies across space in relation to habitat structure, producing invisible gradients of fear. This 'landscape of fear' (sensu Laundre et al. 2001) is visualized as 'peaks' of danger in areas near dangerous structures and 'valleys' near less dangerous structures.

Foragers respond to human activity much as they respond to other forms of danger (Frid and Dill 2002). As with danger in an unaltered environment, prey that are sensitive to danger will show a stronger spatial or temporal response to cues of human activity that are more dangerous than cues that are less dangerous. Prey may choose to forage during safer times (Buckingham et al. 1999, Knapton et al. 2000) or in safer locations (Allen and Read 2000, de la Torre et al. 2000, Gill et al. 1996, Dyer et al. 2001) when or where human activity is present. A result of managing danger is differential habitat use in space or time in relation to the source of human activity. The response to human activity, therefore, can be viewed as a behavioural tradeoff between foraging and danger from injury or death (Abrams 1993, Hugie and Dill1994, review in Lima 1998).

A variety of behavioural ecology tools can be used to interpret the response of foragers to habitat features. For example, patch residency time, relative patch preference and relative safety between patches can be evaluated using measures of foraging intensity and forager distribution. Quantifying giving up density and the landscape of fear allows for determination of spatial variation in danger. The tradeoff in costs and benefits of spending time in a patch can be evaluated using flight initiation distance and giving up density. These are the tools I will employ to explore patterns of habitat selection by ducks wintering in the rural Fraser River delta of British Columbia.

1.2. Study objective

The broad objective of this study is to apply behavioural ecology tools to understand the response of foraging animals to the presence of human-made structures. Of particular interest is how animals make patch use tradeoffs when faced with structures that vary in danger. Such patch use tradeoffs and cumulative impacts in response to danger from human activity have been explored in wintering waterfowl (Gill 1996, Gill et al. 1996). Ducks provide a suitable model for testing such questions as they are conspicuous, their droppings are produced at a regular rate (Mayhew 1988) providing a record of how much time was spent in each patch, and they show flexibility in small- and large-scale patch use in response to changes in food distributions within and between seasons (Merkens et al 2012). Finally, waterfowl are known to respond in subtle ways to danger both spatially and cumulatively across a wintering season (Gill 1996, Gill et al 1996). Although the nature of responses by foraging animals to varying levels of danger across space is well understood, a handful of studies have examined the behavioural or spatial responses of foraging animals to visual barriers in their habitat (Metcalfe 1984; Pöysä 1987; Donald et al. 2001; Guillemain et al. 2001; Pomeroy et al. 2006). Only a subset of these studies addresses responses to human-made structures (Donald et al. 2001; Pomeroy et al. 2006). As the urban footprint expands into wild areas, the cumulative impacts of human-made visual barriers and their relative danger for foraging animals will continue to be an important area of inquiry. Although broad waterfowl distributions and carrying capacities are well-understood (references in Gill 1996, Gill et al. 1996), little is known about how responsive ducks are to danger, how patch use and cumulative use is influenced by human land use, and how this varies between land uses.

1.3. Study area and study species

The Fraser delta is located on the Pacific Coast of Canada southwest of the city of Vancouver (49° N, 123° W). The Fraser delta is a matrix of upland and offshore waterfowl habitats separated by foreshore dykes. Seaward of the dykes are foreshore marshes containing emergent marsh vegetation (*Typha latifolia, Carex sp. and Schoenoplectus sp.*) above the high tide line, eelgrass (*Zostera marina* and *Z. japonica*.)

beds within the intertidal zone and extensive sand and mudflats extending up to two kilometers from the foreshore marsh into Georgia Strait and along the Fraser river. The upland is an approximately 36,000 hectare matrix of open-soil farmland, <10 large greenhouses (>0.4 ha under glass), roads, highways, rail corridors, residential and commercial areas (the towns of Ladner and Tsawwassen), a small airport, sloughs, ditches, reserves and city parks. A network of ditches, sloughs, pumping stations and flood gates control water at most agricultural fields and the deep water provides escape cover for ducks.

Delta's agricultural area is an important contributor to the British Columbia economy. In an average wintering season (October-April) the approximately 10,000 hectares of open-soil farmland is composed of field vegetables and potatoes (either waste or cover cropped), livestock forage, pasture and grain, berry crop, greenhouses and cultivated or fallow land (Freeman 2004). Over the winter, fields currently in vegetable production are either left bare with substantial crop residue, or planted with a winter cover crop (annual average: 1,200 ha (Bradbeer et al. 2010)). Fields not used for vegetable production contain over-wintering berry crops, grains, grassland set-asides and old-fields. Waste potato, winter cover crops (barley, oats and winter wheat) and forage provide upland feeding areas for waterfowl (Breault and Butler 1992, Bradbeer 2007). Tens of thousands of people live and/or work in the agricultural region of Delta. The majority of the contact between humans and ducks is within agricultural habitat.

The Fraser delta is an internationally recognized wintering site for waterfowl (Butler and Campbell 1987) and supports the highest abundance and diversity of birds of all of Canada's Important Bird Areas (BirdLife International). Its intertidal mudflats and adjacent agricultural area are important wintering areas for several hundred thousand waterfowl on the Pacific Coast of Canada (BirdLife International, Butler and Campbell 1987). Substantial amounts of waterfowl habitat have been identified and secured for waterfowl such as the Important Bird Area program of BirdLife International and RAMSAR designations of Wetlands International, Alaksen National Wildlife Area, George C. Reifel Migratory Bird Sanctuary and Boundary Bay Wildlife Management Area. Waterfowl overwintering in the Delta encounter danger from the activity of both humans and their main avian (bald eagles and peregrine falcons) and mammalian (coyote) predators.

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I focus on the four most abundant grazing ducks (American wigeon (*Anas americana*), northern pintail (*Anas acuta*), mallard (*Anas platyrhynchos*) and green-winged teal (*Anas carolinensis*)) wintering in the Fraser delta and known to use open-soil agriculture inland from the foreshore dykes. I treat these four species as a group for their abundance, heavy reliance on upland habitat through the winter and the similarity in their regional spatial patterns (Duynstee 1995). Many of the studies describing these patterns are not readily available (theses, government reports etc.). In Appendix A I have compiled the many studies of overwintering waterfowl in the Fraser delta. Summarized briefly, these show that between 80-120,000 ducks are present between late summer and early spring (Jury 1981). Numbers build during fall migration in late September and rise through the fall to a peak in January (interannual mean: 80,000 individuals, interannual range: 60-120,000 individuals) at which time numbers decline steadily until spring migration in late March (Butler and Campbell 1987). Ducks feed on eelgrass beds and foreshore marsh vegetation until mid-November at which time they switch to feeding in the uplands at night and resting offshore during the day (Baldwin and Lovvorn 1992). The majority of upland habitat use is at night. While a subset of the population can be found in the uplands during daylight hours, the majority of ducks roost in nearby intertidal and subtidal areas by day.

1.4. Measuring dropping density

Dropping density has been widely used to evaluate waterfowl grazing activity (Ydenberg and Prins 1981, Mayhew 1988, Vickery and Summers 1992, Riddington et al. 1997) and can be used to evaluate grazing intensity (Riddington et al. 1997, Amano et al. 2004), carrying capacity (Riddington et al. 1997, Bradbeer and Halpin 2009) and habitat selection (Mayhew and Houston 1989, Pomeroy et al. 2006). This method is reliable as the rate of waterfowl dropping production is consistent while grazing (Dorozynska 1962), varies marginally between individuals and across time (Owen 1971, Ebbinge et al. 1975, Mayhew 1988), is similar for similar sized species (Barnacle Geese: 1 dropping per 3.62 min (Ebbinge et al. 1975) and White-fronted Geese: 1 dropping per 3.5 min (Owen 1971)) and is not influenced by food consumption volume (Amano et al. 2004 and refs within). Further, droppings are durable (Ydenberg and Prins 1981, see

Chapter 2). For small grazing waterfowl, a dropping represents one duck foraging for 3 minutes (=0.002 duck days).

1.5. Issues and focus of past work

Changing land use practices in Delta are creating the potential for more interactions between human land use and wintering wildlife. Over the last few decades, increasing coverage of blueberry and greenhouse operations and the completion of major highway infrastructure mean duck habitat more frequently interfaces with potentially disruptive intensive land uses. Intensive land use is a sole-purpose land use that is concentrated in high density in a parcel of land. They are predominant and expanding in Fraser delta farmland. Ducks view them as dangerous but danger may vary among intensive land use types. These included large greenhouses (>0.4 ha under glass), mature berry fields (blueberry and cranberry), residential areas (row of houses or school complex) and roads that receive steady traffic day and night. In the delta, large greenhouses, residential areas and busy roads are often placed adjacent to suitable duck foraging habitat. Intensive land use could exclude ducks from using a field if these activities are overly dangerous to ducks. By keeping ducks out of adjacent habitat these intensive land uses may alter the real and/or available area of cropland for grazing waterfowl. Evaluation of cumulative impacts of human land use in agricultural areas that support waterfowl requires an understanding of the interplay between placement of structures, farmland characteristics and response by waterfowl.

Habitat use by waterfowl in the Fraser delta has been the focus of over 35 studies over 3 decades. Most of these studies are technical reports or unpublished, and not easily accessible. I have compiled them in Appendix A as they provide useful background to this study. Most studies emphasized effects of waterfowl food availability and crop characteristics such as grass species composition, energetic content, planting date, commuting distance and alternative foraging opportunities in waterfowl habitat use (e.g. Duynstee 1992, 1995, Buffett 2007, Bradbeer 2007). Danger from anthropogenic structures had been recognized as an influential component in the story of duck habitat use (Duynstee 1995, Buffett 2007) but to date it has not been incorporated into models of habitat use or carrying capacity. Some waterfowl studies in the Fraser delta have

reported patch avoidance (e.g. Delta Farmland and Wildlife Trust 2010, Merkens et al. 2012), however, these studies were not designed to measure duck patch use in response to a variety of prominent intensive land uses. Recently acquired knowledge on how to quantify danger presents the opportunity to compare and contrast duck responses to intensive land use types as well as model relative effects and estimate cumulative impacts.

1.6. Hypotheses and predictions

Foragers are sensitive to cues of danger and human activity and respond by altering spatial use and vigilance. For example, visual barriers caused birds to shift spatial use (Pomeroy et al. 2006) and increase vigilance (Metcalfe 1984; Pöysä 1987; Guillemain et al. 2001), and human activity decreased spatial (Williams and Forbes 1980) and cumulative use of patches (Madsen 1985; Keller 1991) and resources (Gill 1996). This study will apply a behavioural ecology approach to the cumulative spatial responses of foraging waterfowl to an urbanizing agricultural environment. Despite a growing footprint of human land uses in the farmland of the Fraser delta the responses by ducks across a variety of human land uses has yet to be fully explored. In chapter two, I establish the basic patterns of habitat use using the hypothesis that danger from the presence of an intensive land use adjacent to suitable farmland habitat influences spatial and cumulative use of a field. I predict that ducks that are sensitive to danger will spend less time near dangerous intensive land use types. Similarly, they will spend more time across a season near less dangerous intensive land use types. Once the basic patterns of spatial and cumulative use are established I investigate whether variation in light, temperature and anthropogenic activity can explain these patterns. I predict that ducks will spend less time at intensive land use types with higher levels of activity if they equate the activity cues with danger. They should also spend less time at intensive land use types that are brightly lit than those that are less bright. Finally, energetic costs of foraging will be minimized by spending more time in fields that have higher temperature.

Previous studies have established that upland use is largely at night. As activity levels of the major predators in the uplands are higher during the day, nighttime might be a safer time period. Yet, it is not known to what extent day and night use contribute to

the spatial patterns established in chapter two or whether vigilance, another method of measuring predator avoidance behaviour, varies between day and night. In chapter three, I will compare daytime and nighttime habitat use and vigilance levels using the hypothesis that danger is higher during the daytime than nighttime. If ducks detect differences in danger between day and night and between intensive land use types then differences in frequency of visits and overall amount of use would be expected. Similarly, vigilance levels may differ between day and night and among species and sexes if danger varies between day and night.

Understanding the relative role of responses to the presence of land use types and field attributes, such as energetic content, presence of water and commute distance in habitat selection will allow us to better estimate cumulative impacts and carrying capacity. In chapter four, I will explore the relative roles of danger and field attributes in the distribution of duck use at the field scale. I predict that ducks will balance the conflicting demands of food availability, danger, attraction and water sources spending more time in safer areas than more dangerous areas rather than selecting fields based on field attributes. In my final chapter, I summarize the implications of my results to conservation planning in urban landscapes and specifically to the case of waterfowl in the Fraser River delta.

Chapter 2.

Grazing patterns of wintering ducks in fields adjacent to intensive land use types

2.1. Abstract

Anthropogenic activity can have subtle, long-term impacts on the distribution and grazing behaviour of waterfowl. In the human-altered Fraser delta, suitable duck habitat is often adjacent to intensive land use including residential areas, greenhouses, busy roads and berry fields. Using a predation danger framework, I measured the spatial and cumulative response of ducks to the presence of an intensive land use adjacent to suitable habitat. I recorded dropping density in farmfields (N=61) at weekly intervals (October-April 2007-2008 and 2009-2010) in 1 m^2 quadrats on a transect perpendicular to one of four intensive land use types. Response was measured spatially as tolerance of an edge and cumulatively as the dropping density ('intensity of use') in a field. Tolerance and intensity of use were higher at greenhouses than residential areas and intermediate at berry fields and roads. I explored whether these patterns could be explained by variation in light, temperature and activity between the intensive land use types. Light and temperature at the field level did not vary between intensive land use types. Activity was high at residential areas and roads and low at greenhouses. Tolerance and intensity of use declined with increasing activity at all intensive land use types. Ducks respond to activity as dangerous and reflect this in spatial and cumulative habitat selection. By quantifying the response to activity this study has contributed towards a more comprehensive understanding of the factors influencing duck habitat selection not only in the Fraser delta but wherever ducks interface with human activity. I discuss how the use of tolerance values can increase precision of models of waterfowl carrying capacity and habitat availability.

2.2. Introduction

The role of danger is increasingly being recognized as important in time allocation and spatial use decisions (Pomeroy et al. 2006). Where and when animals forage may be driven by danger presented by a habitat. Danger is an inherent property of a habitat produced by a habitat's structure or its conditions. It is the probability of being harmed in a given situation if an individual does not engage in antipredator behaviour (Lank and Ydenberg 2003). Animals generally respond to danger by reducing time spent in dangerous places (Kotler et al. 1991; Kotler 1992; Kotler et al. 1993a) or engaging in antipredator behaviours in places or at times when danger is higher (Kotler et al. 1993a; Brown et al. 1999; Brown and Kotler 2004).

Variation in danger with proximity to habitat structures may alter where and how foragers spend their time. The presence of a structure can produce between-patch variation in danger if danger varies with proximity to the structure. Such structures cause foragers to increase vigilance (Metcalfe 1984; Pöysä 1987; Guillemain et al. 2001, review in Whittingham and Evans 2004), delay response time to an attack (Whittingham et al. 2004), decrease patch use (Madsen 1985; Keller 1991; review in Whittingham and Evans 2004; Pomeroy et al. 2006) and alter flock species composition (Lima and Valone 1991) in areas close to a structure. Each of these responses is a shift in forager behaviour as a result of heightened danger.

Depending on the escape tactic employed (van der Veen and Lindstrom 2000), foragers assess areas near structures as dangerous. If visual obstruction by the structure pre-empts a forager from being able to ensure their safety from a predator in areas near that structure then the structure produces a gradient of danger across space. Predators often use the presence of an opaque structure to conceal their approach allowing sneak attacks on prey foraging in areas close to the structure (Creswell 1994; Dekker and Ydenberg 2004). Using a simple experiment, Pomeroy and colleagues (2006) tested whether areas near visual barriers are assessed by prey as dangerous. By erecting an artificial barrier and measuring resulting shifts in the distribution of foraging western sandpipers, the authors showed that the sandpipers assess areas near a visual barrier as dangerous than areas further away. The shorebirds' assessment of danger

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was further reinforced by higher predator lethality in areas close to a dyke, a naturally occurring visual barrier (Pomeroy et al. 2006).

An anthropogenic edge may also alter habitat selection if its presence casts a shadow of danger into adjacent habitat. In several systems, wintering waterfowl distributions shifted in the presence of a structure adjacent to suitable habitat. Structures that obstruct the view from within a field caused settling in the centre of fields away from edges (Bradbeer 2007) and the percentage of a field's perimeter dominated by visual obstructions reduced daytime field use by ducks (Mayoral 1995) and influenced the percent of a field that was grazed (Duynstee 1992). Mayoral (1995) found that the presence of a large number of roads bordering a field reduced daytime field use. Additionally, if the level of danger differs between anthropogenic edges this will be reflected in different use of patches within a habitat (Gill et al. 1996; Sawyer et al. 2009) and different uses of habitats adjacent to different edges (Dyer et al. 2002; Johnson et al. 2005). Little is known about how foragers alter responses to different anthropogenic edges or which cues from those edges elicit a response.

Investigations of forager's responses to anthropogenic activity have often been measured using short-term spatial redistributions to large perturbation events or by recording the spatial distribution of a population in relation to existing anthropogenic activity. The methods of these studies have been criticized as they often fail to capture the cumulative impacts of anthropogenic activity (Gill et al. 1996). An alternative method is to use a tradeoff approach whereby foragers are trading off danger and foraging opportunity (Lima and Dill 1990). Animals make tradeoffs in responding to danger and modulate their responses along a danger gradient (Frid and Dill 2002). The same responses are evoked by anthropogenic activity, with prey modulating their response with the intensity of danger (Frid and Dill 2002). The resulting variation in accumulated use between patches produces resource depletion patterns that can be used to reveal response of animals to danger and make direct comparisons of relative danger among patches. Further, measuring extent of patch avoidance in relation to the proximity of danger allows for estimates of realized carrying capacity of a habitat (Madsen 1995; Gill et al. 1996; Stillmann et al. 2007). Studies investigating how anthropogenic activity influences forager distributions would benefit from applying a predation danger framework.

The degree of change in cumulative time spent in patches at increasing distance from danger will provide a record of how strongly a forager rates danger associated with a structure. In patches near more dangerous structures, cumulative time spent across a season near that structure will be lower and will increase with distance compared to patches near less dangerous structures. Similarly, in patches near a structure, over time the cumulative time spent will be higher in less dangerous patches than more dangerous patches. Danger from anthropogenic structures may exert a strong influence on forager distributions but this has seldom been considered in models of habitat carrying capacity and cumulative effects. By quantifying these spatial and temporal responses to activity at the appropriate scale I can measure both relative danger of anthropogenic structures and cumulative impacts on habitat carrying capacity.

Waterfowl are sensitive to human-altered landscapes in ways that collectively can have profound impacts on population size and habitat carrying capacity (Madsen 1995; Gill et al. 1996; Stillmann et al. 2007). Studies of wildlife-agriculture interactions have revealed how anthropogenic activity can have subtle, long-term impacts on the distribution and grazing behaviour of waterfowl (Williams and Forbes 1980; Duynstee 1992; Mayoral 1995; Fox and Madsen 1997; Madsen 1998; Buffett 2007). In habitat with anthropogenic activities, waterfowl may spend less time in that habitat, use it later in a season or make less use of patches in close proximity to anthropogenic activity that poses a danger. Anthropogenic activity drives regional patterns of waterfowl distribution in Europe (Madsen 1998; Le Corre et al. 2009) and appears to explain the distribution of Eurasian wigeon (*Anas penelope*) at inland sites, overshadowing strong patterns of food quality (eg. Williams and Forbes 1980). Studies have alluded to the relationship between human land use and waterfowl habitat use patterns but none have measured spatial use in relation to a suite of land uses or the various physical characteristics that comprise human activity.

Changing land use practices in the Fraser delta ('Delta') are creating the potential for more interactions between anthropogenic activity and wintering wildlife. Increasing coverage of blueberry and greenhouse operations in the Fraser delta and completion of major highway infrastructure may alter the real and/or available area of cropland for grazing waterfowl. The majority of waterfowl that use the uplands in winter are ducks that frequently come into contact with human land-use practices in the Fraser delta when

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foraging there. As development expands, waterfowl habitat more frequently interfaces with potentially disruptive intensive land uses.

Intensive land use types are structures that cast a shadow of light, heat and activity into adjacent habitat. Intensive land use types vary in activity composition and extent of intrusion into adjoining habitat; factors which may result in a different degree of danger for waterfowl. Measuring how waterfowl view these land use types and comparing their responses between land use types requires an understanding of the components that make up that activity and how intensity of use may vary relative to other land use types. Intensive land use types are predicted to vary in three important characteristics: activity, light and temperature.

Variation in illumination, temperature and activity between microhabitats can alter danger and thus relative use of microhabitats. Not only do predators hunt more under illumination (Wendt et al. 1991; DeCandido and Allen 2006), prey such as gerbils and pocket mice showed a more pronounced preference to foraging less and spent more foraging time in safer microhabitat near cover than more dangerous open microhabitat under illuminated conditions (Brown et al. 1988, Price et al. 1984, Kotler et al 1991). Kotler and colleagues (1993a) found that gerbils foraged less on colder nights suggesting that low temperature increases the cost of foraging and influences patch use. Therefore, prey rely on light and temperature as indirect cues of danger.

Greenhouses are sources of light, heat and activity. All greenhouses are heated to above ambient temperature and have diurnal business operations but not all greenhouses are lit at night. Residential areas and roads will be sources of nighttime lighting and heat while activity will vary with human daily rhythms. I predict that if lit areas are dangerous, ducks will spend less time in brighter fields and more time in darker fields. Alternately, if darker areas are dangerous then the opposite will occur. If roads, residential areas and greenhouses conduct heat then temperatures will decline with distance from the edge of the land use type. This pattern will be more striking at night when these intensive land use types conduct heat but fields do not. If ducks prefer spending time in areas that are warmer then dropping densities will be higher in warmer areas than cooler areas. If human activity is dangerous then ducks will spend less time in areas with higher activity levels.

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I used Delta's four most abundant overwintering duck species, American wigeon (*Anas americana*), mallard (*Anas platyrhynchos*), northern pintail (*Anas acuta*) and green-winged teal (*Anas carolinensis*) as a group to indicate spatial use because they are abundant, rely heavily on upland habitat through the winter and their regional spatial patterns are well-documented (Duynstee 1995). Between 80-120,000 ducks are present between late summer and early spring (Jury 1981). Ducks arrive in Delta in late summer feeding on eelgrass beds until mid-November at which time they switch to feeding in the uplands at night and loafing offshore during the day (Baldwin and Lovvorn 1992). Duck habitat use decisions within the uplands are not well understood but are simple to measure. Droppings are produced every three minutes while grazing (Mayhew 1988), providing a record of time spent foraging at particular locations. By recording the distribution and density of their droppings I can infer how risky they perceive each land use type to be and how they make foraging decisions on a range of temporal and spatial scales.

This study aims to understand how spatial and cumulative use of a habitat by foraging animals is driven by danger brought about by a rural interface. Using this predation danger framework, I will explore how the presence of an anthropogenic structure like a greenhouse, a residential area, a road or a berry field adjacent to suitable habitat influences the spatial and cumulative use by ducks wintering in Delta. I will measure danger created by four types of intensive land-use by using time spent in a patch to describe the within-field spatial (tolerance) and season-wide (intensity of use) patterns of use in Delta farmland. Dropping density is a useful proxy for time spent in a patch and its consistent rate of production permits the comparison of habitat selection between intensive land use types. Specifically, I will use changes in cumulative mean dropping density with distance from a land use type to test the degree of tolerance ducks have to each of four intensive land use types (residential, road, greenhouse and berry; see *methods*). I will explore the generality of these responses by examining interannual consistency in responses to intensive land use types. Finally, I will examine whether variation in light, temperature or activity are cues of danger by exploring their relationship to tolerance patterns at fields adjacent to greenhouses, residential areas and roads.

2.3. Methods

2.3.1. Study field selection

I measured the grazing distribution of wintering ducks (see below) adjacent to four forms of intensive land use, each of which has recently or is continuing to expand in Delta. The measurements reported here were collected in the autumn and winter of 2007-2008 and 2009-2010. The four land use types are mature (blueberry bushes >1m tall planted in rows and cranberry fields surrounded by containment berms) berry fields (2007-2008: n=7, 2009-2010: n=7), large greenhouses (>0.4 ha under glass) (2007-2008: n=6, 2009-2010: n=5), residential (row of houses or school complexes) (2007-2008: n=8, 2009-2010: n=12) and roads that received steady traffic day and night (mean 49 cars per minute) (2007-2008: n=8; 2009-2010: n=9). Study fields (1) were immediately adjacent to only one of four intensive land use types; (2) contained vegetation known to be grazed by ducks; (3) were at least 30m in length (2007-2008: mean=104m, range=30-270m; 2009-2010: mean=187m, range=30-270m, Table 2.1); and (4) did not contain any obstructions within or adjacent to the field (playground equipment, bleachers, fences, hedgerows >1m tall and forest). Fields were representative of farmland throughout the municipality. Field dimensions and distances from the dyke were calculated using ArcGIS software (version 10, ESRI, Redlands, California). Crop identity was verified using the advice of a local expert (D. Bradbeer, Delta Farmland and Wildlife Trust). I refer to the edge of the field along the intensive land use as the 'edge'. Study fields chosen for each intensive land use type represented the full range of the variables 'field size', 'crop type' and 'distance to dyke' (Table 2.1) to control for between-field variation in food quality and commute distance from the marine roost habitat.

2.3.2. Spatial, seasonal and interannual dropping patterns

Patterns of field use in relation to adjacent intensive land use types were examined using weekly dropping density measurements along transects perpendicular to the edge of the intensive land use. Duck droppings were distinguished from trumpeter swan (*Cygnus buccinator*) and snow goose (*Chen caerulescens*) droppings, the other most abundant waterfowl wintering in upland habitat, by their approximately 2.5cm

length and smaller diameter. I verified the durability of droppings between successive counts by placing a known number of fresh, whole droppings under a wire enclosure on various substrates (grass, mud, submerged in standing water), during time periods consisting of both mainly clear and wet weather. Counts of droppings are widely used to measure usage in waterfowl studies, including in the Fraser delta (Delta Farmland and Wildlife Trust, D. Bradbeer, pers. comm.). In independent tests I found that most droppings could easily be found after 7 days, even when submerged, and even in heavy winter rain and wind.

Each field contained one permanent transect. Transects began at the point of contact between the field and intensive land use edge and ran perpendicular to the land use edge through the centre of the field. Transect lengths varied with length of the field, ranging from 30 to 300m (Table 2.1) and contained 4-10 permanent 1 m^2 quadrats, spaced equally along the transect beginning at the point of contact. Transects were located on subsequent visits using GPS, a compass bearing on permanent landmarks and a 100m tape reel. Quadrats were readily visible by following the outline of footprints and trodden grass from previous visits. Trampling of grass by observers did not appear to influence duck use of transects for three reasons. First, all observers took care not to step inside the permanent quadrats. Secondly, grass height declined uniformly across a field through a combination of winter kill, grazing and trampling by ducks and Snow Geese. In fields with tall grass where trampled transects were more apparent, grazing by ducks was absent likely because tall grass is an inefficient source of food (in both nutritient content and handling time). For turf and bare fields, grass was not tall enough to be trampled. Finally, grazing was somewhat uniform across each field. Droppings were counted inside a portable 1 m^2 frame of PVC pipe placed on the quadrat location. Droppings were removed from each quadrat and the surrounding area (~25cm) in all directions to prevent re-counting on subsequent visits at regular intervals (2007-2008: mean=10.4 days, 2009-2010: mean=7.3 days) from 15 November 2007 to 17 April 2008 and 5 October 2009 to 19 March 2010. A total of 2,960 quadrats were measured over 83 days in 2007-2008 and 5,678 quadrats over 115 days in 2009-2010.

Mean dropping density on each field was estimated for each measurement date by summing the number of droppings counted, and dividing by the number of quadrats. This measure represents the dropping density (droppings m^{-2}) accumulated on that field

in the interval since the previous count date. Density measures were summed over all counts during accumulated during a season to give the total dropping density and compared between intensive land use types. I refer to the total dropping density accumulated over an entire season as intensity of use.

The pattern of dropping density across fields was also of interest. If intensive land use edges are perceived as dangerous, they would cast a shadow of avoidance so that dropping densities increase with increasing distance from that edge. However, fields differed in size and therefore in transect length, and to avoid biases care had to be taken in making these comparisons. Different methods have different biases, and so I used five measures to help assess within-field patterns. Note that as these measures were aimed at assessing within-field patterns, fields in which fewer than 10 droppings were counted across a season (n=14) were omitted.

First, I compared the intensity of use over only the first 30m of each field - the length of the shortest field (termed '30m intensity'). For each field I also took the ratio of this measure to the overall (i.e. density over the entire field) intensity. I termed this 'relative intensity'; Ratios > 1 represent a greater than average density of droppings in areas near the land use edge while ratios < 1 represent a smaller than average density of droppings in areas near the land use edge.

These measures permit comparisons over the same distance from an edge, but do not really capture within-field patterns. To address within-field patterns on a broad scale, I divided each transect into halves adjacent to and far from the intensive land use, and calculated the ratio [dropping density in the adjacent half/dropping density in the distal half; termed 'relative distribution']. Values > 1 indicate tolerance of the field edge adjacent the intensive land use type, while values < 1 indicate avoidance (Table 2.2).

To further assess the spread of dropping densities across a field I fitted a linear equation to the intensity of use accumulated in successive quadrats along the transect from the intensive land use edge. The equation is

$$Y = intercept + A(x)$$

where Y represents intensity of use (total dropping density accumulated along the transect) and x distance across the field of each transect. A negative intercept indicates intolerance of the edge, while a positive intercept indicates tolerance. To scale the intercept to the overall level of use of a field, I also calculated the ratio of intercept to the intensity of use for each field (termed Int/Int, for 'intercept to intensity ratio').

I used a generalized least squares (GLS) model to examine the relationship between 1- intensity of use, 2- 30m intensity, 3- relative intensity, 4- linear term, 5- TERM, 6- relative distribution and intensive land use type in each year. As variance differed between intensive land use types, the GLS model fitted a different variance coefficient to each land use edge.

2.3.3.   Activity measurements

I recorded activity (traffic, people, pets, lights, wildlife etc.) levels within the footprint of the intensive land use at six road, nine residential and five greenhouse fields during both daylight and darkness. Since berry fields are not tended by people in winter and therefore activity was expected to be negligible, they were omitted from measurements (N=7). Fields were chosen for these measures if they provided a convenient, unobtrusive vantage point (1 greenhouse, 2 road and 3 residential fields omitted). Each field's intensive land use was observed for three 3h periods between 16 November, 2010 and 10 February 2011, with observation periods evenly spaced around the 24h clock. Observations were randomly allocated among date, field and time of day.

An observer inside a parked vehicle recorded the time and a description of each activity event, classifying events into six categories: "wildlife" (wild animals and pets, whether alone or escorted by a human), "human" (one or more people walking, running, cycling or standing), "noise" (any noise including horns, construction noise and squeaky machinery), "light" (ranging from a single porchlight to a bank of streetlights; one or multiple lights simultaneously switching on or off), "unusual" (rare events including flapping tarps, rail control arm sounds and lights, flickering or strobing lights, helicopter flyovers and shouting cyclists, etc.), or "traffic" (number of vehicles). During observations with heavy traffic, vehicles were counted in a 5min sample once within every 30min of the 3h observation block. During low traffic periods, each passing vehicle could be

counted throughout the observation. Traffic data were summarized as number of vehicles per minute. Other categories were represented as the number of events per 3 h observation block.

To develop an index value of activity for each field, I log transformed (natural log plus one) the number of events (or the events per minute in the case of "traffic") in each of the six categories, and summed the transformed values for each observation period. Values from the three observations at each field were averaged, and used as the index value for that field. (See Appendix B for details on validation of robustness of the index).

To explore the influence of activity on patterns of spatial use and overall amount of use of a field, I used a general linear model to examine the relationship between 1-tolerance (intercept term) and activity index for each intensive land use type and 2-intensity of use and activity index for each intensive land use type. Dropping transect data were selected for analysis from one of two study years. As dropping data for individual fields were collected in either one or both years and activity data were collected at a subset (n= 20) of those fields in 2010-2011, I selected tolerance and intensity of use values from 2009-2010 and, if no dropping sampling was done at that field in 2009-2010, I selected the 2007-2008 data. The 2009-2010 dropping dataset was preferred as data collection covered more fields and a longer set of study dates in that year. I made post-hoc pairwise contrasts between intensive land use types using Tukey's test.

2.3.4. Light measurements

The light level on each field was measured using a datalogging light meter (*Extech Instruments* model 401036, Nashua, New Hampshire). The meter measured in lux, which represents a peak luminosity function at a wavelength of 555nm (green). This represents the spectral sensitivity to light of the human eye and is comparable to that of birds (Lustick 1973; Beason 2003). In 2009 – 2010 the meter was deployed at least an hour before sunset and collected the following morning at least an hour after sunrise, during which time it logged a measure every 2s. The meter's housing was placed inside a short metal duct to protect the sensor from precipitation. The instrument was placed at two to four quadrats per field at road (n=9 fields, 32 quadrats), residential (n=8 fields, 21

quadrats) and greenhouse (n=5 fields, 13 quadrats) fields, in a rotation defined by a random number generator. Berry fields were omitted from measurements as they did not contain lighting structures. At one greenhouse and four residential fields at which permission to leave the instrument set-up over night was not obtained, an abbreviated set of measures was made in 2010-2011. The meter was handheld, and a set of measures collected at 10m intervals, while facing squarely toward the land use edge. The measures were taken more than 2h after sunset, and more than 2h before sunrise. To control for the effects of moon phase and cloud cover on meter readings, meteorological conditions coinciding with meter data collection were downloaded from Environment Canada's website (http://www.climate.weatheroffice.gc.ca/climateData/hourlydata_e.html). Hourly cloud cover was available on a four point scale: (1) clear, (2) 1-4 tenths cloud cover, (3) 5-9 tenths cloud cover, (4) 10 tenths cloud cover. Logged light data from 2009-2010 was truncated to the period of darkness defined by two minutes after light levels stopped declining following dusk and two minutes before they began to rise the following morning. From these data quadrat mean lux levels were calculated. Data from 2010-2011 consisted of one lux value for each quadrat. Using the mean lux levels at each field collected in both years examined whether average light levels differed between intensive land use types.

2.3.5. Temperature measurements

To explore the possible role of temperature gradients across fields, temperatures were recorded along road (n=8 day and 5 night), residential (n=9 day and 10 night) and greenhouse (n=6 day and 6 night) fields in 2010-2011 that were safe to access day and night. Berry fields were omitted as they did not contain structures that would alter temperature levels. I used a data-logging thermometer (*Maxim* datalogging iButton, Sunnyvale, California) to record temperatures (ºC) at 10m intervals along 90m transects. Daytime and night-time measurements of a given field were not recorded on the same calendar day. The iButton was placed inside a Ziploc bag hung on a wired flag and handled with woollen gloves to prevent the recorder's body heat or contact with the ground from influencing the temperature recording. The iButton was placed outside the field vehicle for at least ten minutes before sampling to acclimate to ambient conditions.

At each sample point, temperature was recorded at 5s intervals over 30s (timed with the world clock in the "clock" app for iPhone 3GS, Apple Inc, Cupertina, California) and averaged.

Temperature values at each distance were represented by the mean of six temperature values logged at that distance. I controlled for the influence of time of day or night and cloud cover on ambient temperature by subtracting quadrat temperature value from temperature at the Vancouver International airport during the same hour (http://www.climate.weatheroffice.gc.ca/climateData/canada_e.html). I examined the change in temperature near the land use edge by subtracting the adjusted temperature at 0m from the adjusted temperature at 20m. Negative values represent a decrease in temperature with distance and vice versa. I used these values to examine the magnitude and direction of temperature changes with distance from the edge and relative patterns both diurnally and between intensive land use types.

All statistical analyses were performed in R version 2.11.1 (R Core Development Team 2011).

2.4. Results

2.4.1. Usage patterns

As reported in Chapter 1, ducks began using upland fields in late October. Usage peaked in January and February, and then fell through the course of March until migration in April. During the three weeks of peak usage, fields accumulated 40.9-54.4 droppings m^{-2} in 2007-2008, and 9.5-14.4 droppings m^{-2} in 2009-2010.

The seasonal pattern of usage of the four intensive land use types is depicted in Figure 2.1. At all intensive land use types, the dropping density accumulated more-or-less steadily throughout the season once grazing began, and the patterns are generally similar in both study seasons. Greenhouse fields were the first to show usage by ducks (mean date of first grazing evidence: November 19), while grazing on residential fields was not initiated until late December (GLS (greenhouse as base level): berry: T= 2.7, SE= 9.8, p= 0.01; residential: T= 1.90, SE= 19.5, p= 0.07; road: T= 1.3, SE= 14.8, p=

0.2). In fact, at two residential fields in 2007-2008 and at seven residential fields in 2009-2010, no droppings at all were ever recorded. Such avoidance was not detected at any other intensive land use type. The initiation of usage of road and berry fields was intermediate.

The grazing intensity on fields adjacent to the four intensive land use types is summarized in Table 2.3 and in Figure 2.2. In both years, greenhouse fields were by far the most intensely used, and residential fields by far the least, with road and berry fields intermediate (Table 2.4). Intensity of use at berry, road and residential fields differed from greenhouse fields (Table 2.4) and did not differ between years (Tables 2.2, 2.4; Figure 2.2; GLS: T= -0.4, SE= 2.4, p=0.7).

The measures used to evaluate the spread of grazing across fields reveal further patterns (Table 2.2). The 30m intensity measure was identical in ranking across intensive land use types and similar in quantity to the whole-field intensity of use. 30m intensity and intensity of use were highest at greenhouse fields, intermediate at road and berry fields and lowest at residential fields. 30m intensity at berry, road and residential fields differed from greenhouse fields (Table 2.5) and did not differ between years (GLS: T= 1.15, SE= 0.18, p=0.26).

Relative intensity (the ratio of 30m intensity to intensity of use) was lower at residential fields compared to greenhouse fields (Table 2.2) indicating a greater intolerance at residential fields (Table 2.6; GLS: T=-3.23, SE=0.22, p=0.003). As before, road fields were intermediate in this respect and berry fields showed high variability (Tables 2.2 and 2.6). Relative intensity values did not vary between years (GLS: T= -0.12, SE= 0.20, p= 0.90; Table 2.6).

Relative distribution (the proportion of total droppings in the adjacent half relative to the distal half of the field) was lower at residential fields compared to greenhouse, road and berry fields (Table 2.2) indicating a greater intolerance at residential fields. Road fields were intermediate in this respect and berry fields showed the highest values and high variability (Tables 2.2 and 2.7). Relative distribution was higher in 2007-2008 than 2009-2010 (GLS: T=2.23, SE= 0.32, p= 0.03; Table 2.7).

From the linear equation, intercepts were most positive in fields adjacent to greenhouses and most negative in fields adjacent to residential areas. The intercept values for berry, road and residential edges differed from greenhouse edges and did not differ between years (GLS: T= 0.76, SE= 6.30, p= 0.45; Table 2.8; Figure 2.3).

The second ratio measure (int/int; intercept over intensity of use) was negative at residential fields and positive at greenhouse, berry and road fields (Table 2.2). The values differed between greenhouse and residential fields and did not differ between years (GLS: T= -1.11, SE= 0.40, p= 0.28; Table 2.9).

The interaction between intensive land use type and field size was highly significant (field size*land use GLM: $F_{(3,61)}$= 6.9, p<0.001). Ducks spent more time at smaller fields near greenhouses and less time at larger fields regardless of intensive land use type. Intensity of use varied by crop type with higher use at forage fields than bare, cover crop or turf fields (GLM: F= 6.8, df= 3, p<0.001).

2.4.2. Activity index

The activity index values are depicted in Figure 2.4. Values differed significantly between intensive land use types (ANOVA: $F_{(2,17)}$= 10.39, p= 0.001, MSE= 17.29) with lowest index values recorded at greenhouses, and similar index values recorded at residential and road edges (Tukey's HSD: greenhouse-residential= 2.75, p= 0.003, greenhouse-road= 3.42, p<0.01, residential-road= 0.7, p= 0.6). The average activity index was 4.08 and ranged from 1.3 to 7.82, with event counts contributing to each index ranging from 13.6 activity events per three hours (a greenhouse edge) to 5783.4 activity events per three hours (a road edge). The 10 most active edges were an equal mix between residential and road edges (mean activity index: residential= 4.6, road= 5.3) while the five least active edges were all greenhouse edges (mean activity index= 1.9).

The activity index on the intensive edge adjacent to a field had a strong influence on the intensity of use. Intensity of use decreased with activity level (GLM: F= 7.7, df= 1, p= 0.02) but did not differ by intensive land use type (GLM: F= 2.2, df= 2, p= 0.1) (Table 2.10, Figure 2.5). Although intercept values declined with increasing activity level, this relationship was not significant for either activity level (GLM: MSE= 5340.8, $F_{1,15}$: 1.69,

p= 0.23) or intensive land use type (GLM: MSE= 3684.5, $F_{2,15}$: 1.17, p= 0.36) (Table 2.11, Figure 2.6).

2.4.3. Light patterns

Mean cloud cover score did not differ between intensive land use types (mean±95% CI: greenhouse= 3.7±0.3, residential= 3.3±0.7, road= 3.3±0.4; ANOVA: $F_{(2,24)}$= 1.1, p= 0.37, MSE= 0.27). After correcting for cloud cover, there was no difference in mean lux values at the field level between the three intensive land use types (mean±95% CI: greenhouse= 3.36±1.3lux, residential= 3.32±1.08lux, road= 2.46±0.23lux; ANOVA: $F_{(2,24)}$= 1.03, p= 0.37, MSE= 2.31). The lack of differences in light conditions between intensive land use types means that light conditions as measured cannot help explain the differences in tolerance or intensity of use between intensive land use types.

2.4.4. Temperature patterns

The difference in temperature between the edge of a field and its interior was in most cases slightly negative (interior cooler) (Day: greenhouse mean= -0.22ºC, range= -1.51-0.56ºC, residential mean= -0.64ºC, range= -2.59-0.70ºC, road mean= -0.042ºC, range= -1.42-0.92ºC; Night: greenhouse mean= -1.31ºC, range= -3.02- -0.08ºC, residential mean= -0.89ºC, range= -3.68-0.50ºC, road mean= -0.45ºC, range= -1.34-0.0ºC.) However, the variation was large, and no significant differences could be detected either between diurnal and nocturnal gradients, or between intensive land use types. (ANOVA: diurnal: $F_{(1,41)}$= 3.72, p= 0.06, MSE= 3.37; intensive land use type: $F_{(2,40)}$= 1.45, p= 0.25, MSE= 1.38).

There was no difference in temperature gradients between intensive land use types during daytime (ANOVA: $F_{(2,20)}$= 1.03, p= 0.37, MSE= 0.79) or nighttime (ANOVA: $F_{(2,17)}$= 0.83, p= 0.45, MSE= 0.91). There was no diurnal variation in temperature gradient at any of the intensive land use types (greenhouse: ANOVA: $F_{(1,9)}$= 3.59, p= 0.09, MSE= 3.21; residential: ANOVA: $F_{(1,17)}$= 0.23, p= 0.64, MSE= 0.30; road: ANOVA: $F_{(1,11)}$= 1.24, p= 0.29, MSE= 0.52). Temperature at road fields was attenuated such that

the gradient was similar day and night and overall change in temperature was smaller than at residential and road fields.

2.5. Discussion

Using a danger framework I examined the response of wintering ducks to the presence of four types of intensive land use in two winters and the possible role of temperature, light and activity levels in producing these patterns. A general set of responses by ducks to the presence of land use types can be inferred from consistent relative patterns of tolerance and intensity of use at each intensive land use type that was observed in both study seasons. In both years, ducks spent more time across the season at greenhouse fields than residential, road or berry fields and spent more time in areas close to greenhouses and more time in areas further from residential areas. Intensive land use types differed in the overall amount of use received but they retained a consistent order of intensity of use between study seasons. Despite higher overall use in the study area in 2007-2008 than 2009-2010, these patterns held. Intensity of use (density of droppings accumulated) at an intensive land use type differed by intensive land use type and was consistent between years. Activity levels were lowest at greenhouse fields and highest at residential and road fields. Ducks foraged less near edges with higher activity levels regardless of intensive land use type. Intensity of use declined with increasing activity levels and was consistent between intensive land use types. The nature of light and temperature attenuation was unable to explain patterns of tolerance or intensity of use.

Ducks showed striking differences in their responses to the presence of residential and greenhouse edges. The data provide evidence that residential areas are dangerous to ducks and greenhouses are relatively safe. If buildings provide attack cover for ambushing predators, as suggested by Pomeroy et al. (2006) for western sandpipers, then ducks should avoid both residential and greenhouse edges in a similar manner. Heightened danger in fields beside residential areas compared to greenhouses was demonstrated by entire avoidance of most residential fields and, in fields that received use, a late onset of use, a small amount of use and accumulation of the majority of droppings at large distances from the intensive land use. Interestingly,

greenhouse use was more intense and closer than at berry fields, a contiguous open-soil habitat low in disruptive activity level and therefore low in danger. The striking difference in responses to two intensive land use types containing buildings suggests that there may be characteristics of a tall structure besides attack cover that may be important considerations for ducks when choosing suitable habitat. It is likely that the kinds of activities produced by the two building types rather than the visual barrier of the building per se are the cues of danger used by the ducks. As this is the first study to show that the response of foragers can differ between anthropogenic structures, a fruitful line of inquiry would be to further tease apart the relative contribution of visual barriers and activity to habitat selection.

The difference between use of fields adjacent to greenhouses and residential areas is due to intensive land use type and not an artifact of field size. None of the greenhouse fields were absent of duck use even though at least half were shorter in length than the minimum length of residential fields that received duck use (range of greenhouse field lengths: 20-270m; minimum residential field length to show evidence of duck use: 2007-2008: 85m, 2009-2010: 96m). Additionally, ducks spent more time at smaller fields near greenhouses and less time at larger fields regardless of intensive land use type (field size*land use GLM: F= 6.9, df= 3, p<0.001). Many residential fields were a similar size to greenhouse fields that had among the highest intensity of use values in the study and yet received little to no use. Ducks were not only willing to use small greenhouse fields but concentrated their use close to them and used them in higher intensities than any residential fields despite short field lengths precluding the option of foraging further from the intensive land use. Similarly, of the nine fields in two years to never receive evidence of duck use, eight were turf fields; a sward height with high nutritional value (see Chapter 4). This suggests that avoidance of a field cannot be explained by low crop nutritional value.

Intermediate amounts of use and timing of use of fields adjacent to berry fields and roads suggest lower levels of danger in these intensive land use types. Although avoidance responses to roads were not as strong as at residential fields, ducks showed some avoidance of roads (mean intercept at roads: 5.3 cf. residential: -4.9). This is in contrast to stronger responses observed in other systems. In European pink-footed geese, positive relationships were shown between number of goose-use days and

distance from the nearest road (Madsen 1985; Keller 1991) while the proportion of crop depleted at fields near roads was lower than fields further from roads (Gill 1996). Locally, Mayoral (1995) found that presence of a large number of roads bordering a field reduced daytime, but not nighttime, field use by ducks. In Europe, Eurasian wigeon avoided grazing near field edges close to traffic or pedestrians but only on days with abundant activity despite areas closer to the source of anthropogenic activity having higher quality grazing opportunities (Williams and Forbes 1980). In a study of the effects of roads on the behaviour of songbirds nesting in Illinois, densities of horned larks (*Eremophila alpestris*) increased with distance from highways and county roads early in the season and county roads later in the season. Adjacent to berry fields, tolerance values varied considerably. This is expected if berry fields are not dangerous to ducks and therefore their distribution is unrelated to the proximity of the berry field. Instead their distribution may be related to other features unrelated to the berry field which may include suitable grazing substrates, flooded patches or proximity to water features such as sloughs or ditches.

Examining whether tolerance levels influenced the overall amount of use revealed striking differences in the cumulative effects of danger between the intensive land use types. The response to each intensive land use type is distinct. At greenhouses, close use coupled with high intensity of use suggest that ducks view greenhouses as low in danger and that individuals choose to frequently return to these habitats in a given winter. Additionally, greenhouses showed more than twice the intensity of use than berry fields, the next most intensely used intensive land use type (Figure 2.2). In contrast, intolerance and low intensity of use showed evidence that residential areas are dangerous and roads fall intermediate between residential areas and greenhouses. At berry fields, the wide range of tolerance values and the second highest intensity of use suggest that they are neither strongly preferred nor avoided. Despite how common anthropogenic features intersect with natural areas, there is a dearth of studies that compare among the responses of foragers to danger produced by a variety of anthropogenic structures. Investigations of habitat selection in response to structures involved either one form of structure (foreshore dyke; Pomeroy et al. 2006, road; Gill et al. 1996) or comparisons between a safer and a more dangerous structure ('cover' vs 'open'; Brown et al. 1992). This study expands upon previous work by

comparing the relative responses to a variety of structures and then relating those responses to particular characteristics of the structures such as activity or light.

2.5.1. Activity

Activity levels differed by intensive land use type and proved to be important in explaining intensity of use. Activity levels were strikingly lower at greenhouses than residential areas or roads (Figure 2.4). Greenhouse fields made up the five lowest activity values whereas only residential and road fields equally split the top ten highest activity values. Ducks became intolerant with increasing activity level and, across a season ducks showed higher intensity of use at fields whose intensive land use types had lower levels of activity than those with higher levels of activity. This pattern was consistent between intensive land use types suggesting a general pattern of response to activity levels rather than the type of intensive land use producing the activity. This scaled response to activity levels was found in pink-footed geese in Europe. Geese were flushed up by anthropogenic activity from a road more often the closer they foraged to a road. Consequently, cumulative use of fields declined for fields closer to a road (Gill et al. 1996). In many taxa, higher levels of anthropogenic activity result in shifts in abundance and distribution (eg. mule deer (Sawyer et al. 2009), forest birds (Fernandez-Juricic 2000), ducks (Hirons and Thomas 1993)).

Activity level influenced both intensity of use and tolerance levels. I hypothesized that intolerance and low intensity of use at residential areas and high tolerance and high intensity of use at greenhouses could be explained by danger due to activity levels. If ducks are sensitive to activity levels then high levels of activity should be reflected in intolerance and low intensity of use in adjacent fields. This pattern should hold true regardless of intensive land use type. Indeed, ducks were less tolerant of fields with higher activity levels regardless of intensive land use type and spent more time overall at fields with lower activity levels than at fields with higher activity levels. Most duck use of residential fields was intolerant of the residential edge. Many residential fields had a few visits by small numbers of ducks often for the first time late in the season. Both of these patterns can be related to the relatively higher levels of activity at residential areas. Mule deer (*Odocoileus hemionus*) winter habitat selection in Wyoming shifted further away with increasing traffic levels at well pads (Sawyer et al. 2009). Abundance of four

30

species of forest birds in Madrid declined with increasing pedestrian rates on footpaths (Fernandez-Juricic 2000). Numbers of mallard and Eurasian wigeon on reserves in England dropped sharply during periods when shooting was permitted and rose once shooting ceased (Hirons and Thomas 1993). Fields in Scottish farmland where pink-footed geese were frequently disrupted from feeding showed lower cumulative use compared to fields in which disruptive events were less frequent (Gill et al. 1996). Although the study focused only on road activity levels their results suggest that decisions about repeated use of a patch may be influenced by the level of activity. In contrast, fields in Delta adjacent to greenhouses, where activity levels were relatively lower than residential areas or roads, received more use close to the intensive land use and higher intensities of use. Lower activity levels may mean a lower frequency of disruptions, attracting ducks to make repeat visits and producing larger intensity of use values. This lower frequency of disruptions may also entice them to forage closer to the intensive land use than they would to intensive land use types with more frequent disruptions.

Differences in the responses to intensive land use types with similar compositions and activity levels reveal the subtleties of duck perceptions of activity. Despite both residential areas and greenhouses containing buildings, responses and activity levels were in opposition. Responses also differed among intensive land use types with similar levels of activity (i.e. residential and road). These two patterns suggest that ducks avoid buildings that produce high levels of activity which warrants a closer examination of the components of the activity indices. Higher danger at residential areas may be due to the variety and unpredictability of activity events. Residential activity events were spread among the six categories and the events themselves may have been unpredictable in timing and frequency. This may contribute to the intolerant values at residential areas. In contrast, greenhouses had higher intensity of use values and lower activity levels than at any other intensive land use type. The differing intensity of use values at residential areas and roads having similar high activity values may stem from the predictability of those activities. Most activity events at roads are traffic whose levels gradually grow and drop throughout the day. Cars remain on the road surface and move in a predictable, lateral manner and maintain a constant level of noise. Perhaps because of its predictability ducks do not view traffic as a large danger allowing them to

become accustomed to them. In contrast, the less predictable and more varied events at residential areas make them more dangerous than roads despite having comparable levels of activity. A few studies reported that, in large mammals, responses differed across stimuli. Mule deer in Wyoming avoided all types of well pads but chose habitats further from those well pad types with higher traffic levels (Sawyer et al. 2009). Behavioural responses by big-horned sheep (*Ovis canadensis*) differed in response to hikers, mountain bikers and vehicles (Papouchis et al. 2001). Woodland caribou made fewer crossings of roads and seismic lines in winter, when human activity was higher, than in summer (Dyer et al. 2001).

2.5.2. Light and temperature

Neither mean lux value nor change in temperature near the intensive land use varied at any intensive land use type. This result is not surprising given the scale of a field and the properties of light attenuation and temperature conductance. Since light attenuates with the inverse of the squared distance, a 50-500 lux point source would attenuate too rapidly to register on a light meter placed 15-270m away. Relative brightness at a point in space may be less important than how often lighting point sources switch on and off at that edge or how unpredictable those events may be.

2.5.3. Interannual variation

Many factors could produce interannual differences in overall amount of duck use. Whether, when and how many fields received cover crop (less waterfowl food with absence of early-planted cover crop), increased bald eagle (*Haliaeetus leucocephalus*) numbers (higher danger) and climatic patterns (ducks leave the study area during periods of unusually cold weather) could all contribute. Despite a later start to the sampling, 2007-2008 still had greater overall dropping densities. This variation cannot be due to failure to sample places where ducks could be found since I sampled all crop types known to be duck foraging habitat, all regions of the study area and increased the number of fields sampled in the second year.

2.5.4. General Conclusions

The observed responses by ducks to human land-uses represent the population-level manifestations of individual-based responses. A population-level pattern emerges from many responses by many individuals to their environment. Each individual uses a decision rule to respond adaptively to the situation it encounters. Over time as individuals respond to shifts in environmental situations and their internal state the emergent property of the population will be revealed. The response of the population to an environmental situation is therefore the sum of the adaptive decision rules of its individuals. Decisions made by individuals are scaled up to explain patch-specific habitat use patterns (Grimm and Railsback 2005). In this way, the observed responses to activity in the farmland of Delta represent the population-level responses of many individuals acting on adaptations to such cues.

Duck habitat use showed the highest contrasts between residential areas and greenhouses. Spatial use was earliest, highest and closest beside greenhouses while residential fields were either avoided or use was detected late in the season for small periods of time at large distances. Although most residential fields contained turf, the crop type most likely to contain ideal nutritional content, they were avoided in favour of other crop types and intensive land use types. In contrast, one of the highest used fields in 2009-2010 was a turf field adjacent to a greenhouse. The fact that two intensive land use types with similar edge composition (ie buildings) and crop type can produce such strikingly different responses suggests that something other than edge composition, food abundance or quality is driving duck behaviour. Previous work on pink-footed goose response to activity from roads (Gill et al. 1996) paved the way for this research applying spatial patterns of use to compare danger between intensive land use types. This study takes that work further to delve into the components of the activity to understand what causes the response.

2.5.5. Management applications

This study's tolerance values can be applied to inform development mitigation and improve precision of habitat carrying capacity models. Ducks Unlimited Canada has developed a 'TRUEMET' model that calculates the area of habitat available for wintering

ducks to assess progress towards conservation targets. Until now these models had not incorporated danger. I used dropping density data to produce 'buffer' values specific to residential areas and roads. Ducks Unlimited Canada is using these values to subtract from the total area of habitat the area adjacent to all residential and road fields that will experience depressed amounts of ducks use. In this way my results can be reconfigured to inform management activities and produce projections of habitat availability under any number of future development scenarios.

This study has contributed towards a more comprehensive understanding of the factors influencing duck habitat use decisions in Delta. Despite the large body of existing knowledge on the relationship between agriculture and wildlife we are just beginning to understand the role of danger from human land use, possibly the most influential factor in duck patch selection decisions. Now we are able to be more precise about the extent to which ducks are tolerant and intolerant to human land use types, how these landscape features impact carrying capacity and habitat availability and the relative influence of each feature.

Tables and Figures

Table 2.1. Features of study fields in Delta, British Columbia. Year 1 denotes 2007-2008, year 2 denotes 2009-2010.

Field name	Intensive land use	Year	# quadrats	Interquadrat distance (m)	Transect length (m)	Field area (ha)	Crop Type	Distance to dyke (m)
Bates	Berry	1	9	30	270	5.5	forage	1958.1
Bharris1	Berry	1	10	30	300	30.4	bare	16.6
Corey	Berry	1	10	30	300	5.7	cover crop	2484.9
Keulen	Berry	1	6	16	96	5.2	bare	1709.8
Montgomery	Berry	1	10	30	300	17.3	cover crop	47.1
Tharris3	Berry	1	10	30	300	7.5	cover crop	1513.4
Zellweger	Berry	1	10	30	300	22	cover crop	734.1
M Gardens	Greenhouse	1	5	15	75	2.9	forage	486.3
Windset1	Greenhouse	1	7	24	168	11.9	cover crop	1267.4
Windset2	Greenhouse	1	5	15	75	1.1	forage	2018.5
Gipaanda	Greenhouse	1	7	22	154	5.2	forage	1402.3
Houweling	Greenhouse	1	4	10	40	0.9	turf	266.8
Kao Yi	Greenhouse	1	10	30	300	11.3	bare	827.8
London Gate	Residential	1	7	24	168	3.4	forage	2746.7
Beach Grove	Residential	1	6	21	126	1.2	turf	346.8
Bharris4	Residential	1	10	30	300	26.7	bare	2501
Cromie	Residential	1	6	19	114	2.4	turf	1162.8
Diefenbaker	Residential	1	6	17	102	2.3	turf	2311
Goodwin1	Residential	1	9	30	270	5.7	turf	3812.9
Goodwin2	Residential	1	10	30	300	6.3	turf	3814
Imperial	Residential	1	6	16	96	1.3	turf	1427.8
Hamming	Road	1	9	27	243	9	grass	562.5
Bharris3	Road	1	8	30	240	8.9	cover crop	820.9
Bharris2	Road	1	8	26	208	10.3	bare	459.3
Thibeaudier	Road	1	7	25	175	5.7	forage	1815.1
Tharris1	Road	1	8	30	240	8.9	cover crop	820.9

Field name	Intensive land use	Year	# quadrats	Interquadrat distance (m)	Transect length (m)	Field area (ha)	Crop Type	Distance to dyke (m)
Tharris2	Road	1	10	30	300	30.4	cover crop	16.6
Zillman	Road	1	10	30	300	13.9	forage	1507.5
Harris berry	Berry	2	10	30	300	30.4	bare	16.6
Hothi	Berry	2	10	26	260	13.3	cover crop	570.6
Bates	Berry	2	6	22	132	4.0	forage	2070.6
Keulen Berry	Berry	2	6	16	96	5.2	bare	1709.8
Montgomery	Berry	2	10	30	300	17.3	cover crop	47.1
Cory	Berry	2	10	30	300	5.7	cover crop	2484.9
Terpsma	Berry	2	10	30	300	22.1	forage	1375
WindsetE	Greenhouse	2	5	15	75	1.1	forage	2018.5
WindsetN	Greenhouse	2	7	24	168	11.9	bare	1267.4
WindsetS	Greenhouse	2	5	6	30	0.5	forage	2018.5
Gipaanda	Greenhouse	2	10	9	90	8.7	cover crop	1152.8
Kao Yi	Greenhouse	2	10	30	300	11.3	bare	827.8
Beach Grove	Residential	2	6	21	126	1.2	turf	346.8
Burr	Residential	2	9	30	270	11.7	bare	1692.1
Deshaun	Residential	2	10	30	300	13.6	bare	1344.8
Diefenbaker	Residential	2	5	24	120	2.3	turf	2311
Goodwin1	Residential	2	10	30	300	5.7	turf	3812.9
Goodwin2	Residential	2	10	30	300	6.3	turf	3814
Cromie	Residential	2	6	19	114	2.4	turf	1162.8
Highmark	Residential	2	6	22	132	7.5	forage	2342.6
Imperial	Residential	2	6	16	96	1.3	turf	1427.8
London Gate	Residential	2	7	24	168	3.4	forage	2746.7
Arthur-Harris	Residential	2	10	30	300	26.7	bare	2501
Rink	Residential	2	8	26	208	7.7	cover crop	497.3
Harris Deltaport	Road	2	9	30	270	13.7	cover crop	2065.8
Harris Highway N	Road	2	10	30	300	15.1	cover crop	776.5
Harris Highway S	Road	2	9	30	270	6.3	cover crop	443.7
Harris River Road	Road	2	9	26	234	8.9	cover crop	820.9

Field name	Intensive land use	Year	# quadrats	Interquadrat distance (m)	Transect length (m)	Field area (ha)	Crop Type	Distance to dyke (m)
Hessels	Road	2	5	10	50	2.4	forage	78.8
Keulen Road	Road	2	10	30	300	8.5	forage	1534
Wellbrook	Road	2	7	24	168	15.1	cover crop	2014
Zylman	Road	2	10	30	300	13.9	forage	1507.5
Ab Singh	Road	2	10	30	300	12.7	cover crop	2123.1

Table 2.2. Measures used to describe spread of duck grazing patterns within fields adjacent to four intensive land use types in Delta, British Columbia.

	Greenhouse		Berry		Road		Residential	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Intensity of use	84.39	93.73	21.91	26.22	25.78	49.55	7.70	6.98
30m intensity	93.61	107.20	16.95	27.81	17.59	37.51	0.36	0.64
Relative intensity	0.87	0.57	1.38	1.90	1.01	1.19	0.14	0.27
Relative distribution	1.72	2.1	2.50	5.3	1.18	1.4	0.94	0.6
Intercept	77.58	118.44	1.27	48.15	-1.30	16.50	-9.67	10.65
Int/Int	0.47	1.03	1.22	2.97	0.48	1.34	-1.02	0.77

Table 2.3. Cumulative mean dropping density ('intensity of use') in fields adjacent to intensive land use types in Delta, British Columbia in 2007-2008 and 2009-2010. Values are mean dropping densities (droppings m^{-2}) in fields adjacent to four intensive land use types accumulated during the entire winter grazing period.

	2007-2008		2009-2010	
Land use type	Mean (n)	Range	Mean (n)	Range
Greenhouse	79.9 (6)	2.8-275.4	53.0 (5)	3.1-215.6
Berry	31.2 (7)	3.0-86.3	10.8 (7)	0.5-40.2
Road	25.8 (7)	0.1-186.9	8.9 (9)	0.4-35.0
Residential	1.8 (8)	0-16.0	1.0 (12)	0-18.7

Table 2.4.   Generalized Least Squares Model examining the relationship between intensive land use type and seasonal cumulative mean dropping density in 2007-2008 and 2009-2010. Heterogeneity of variance associated with the intensive land use type variable was stabilized using a weighted variance structure and 'berry' as the baseline level with a variance structure that assigned a different variance coefficient to each land use edge (N=61, df=56). Test statistics for intensive land use types denote comparisons against 'berry'. Overall intensity of use of greenhouse fields was higher than berry fields and the intensity of use of residential fields was lower than berry fields. These patterns did not differ between years.

Variable	T	SE	P	Coefficient	Variance Parameter
Greenhouse	2.2	29.1	0.03	64.0	3.7
Road	-2.1	30.4	0.04	-63.2	1.8
Residential	-2.9	28.3	<0.01	-81.4	0.2
Year	-0.4	2.4	0.7	-1.1	N/A

Table 2.5.   Generalized Least Squares Model examining the relationship between intensive land use type and intensity in the first 30m of the transect in 2007-2008 and 2009-2010. Heterogeneity of variance associated with the intensive land use type variable was stabilized using a weighted variance structure and 'greenhouse' as the baseline level (N=61, df=56). Test statistics for intensive land use types denote comparisons against 'greenhouse'. 30m intensity values for berry, road and residential fields were significantly different from greenhouse fields.

Variable	T	SE	P	Coefficient	Variance Parameter
Berry	-2.35	33.13	0.02	-77.80	1.0
Road	-2.37	33.44	0.02	-79.15	1.27
Residential	-2.89	32.33	0.005	-93.51	0.02
Year	1.15	0.18	0.26	0.21	N/A

Table 2.6.   Generalized Least Squares Model examining the relationship between intensive land use type and relative intensity in 2007-2008 and 2009-2010. Heterogeneity of variance associated with the intensive land use type variable was stabilized using a weighted variance structure and 'greenhouse' as the baseline level (N=43, df=38). Test statistics for intensive land use types denote comparisons against 'greenhouse'. Relative intensity values for residential fields were significantly different from greenhouse fields.

Variable	T	SE	P	Coefficient	Variance Parameter
Berry	0.92	0.56	0.37	0.51	1.0
Road	0.38	0.37	0.71	0.14	0.63
Residential	-3.23	0.22	0.003	-0.71	0.16
Year	-0.12	0.20	0.90	-0.03	N/A

Table 2.7. Generalized Least Squares Model examining the relationship between intensive land use type and relative distribution in 2007-2008 and 2009-2010. Heterogeneity of variance associated with the intensive land use type variable was stabilized using a weighted variance structure and 'greenhouse' as the baseline level (N=43, df=38). Test statistics for intensive land use types denote comparisons against 'greenhouse'. Intercept relative to intensity values did not differ from greenhouse values but they were higher in 2007-2008 than 2009-2010.

Variable	T	SE	P	Coefficient	Variance Parameter
Berry	0.51	1.51	0.61	0.77	1.0
Road	-0.79	0.76	0.44	-0.60	0.30
Residential	-1.75	0.66	0.09	-1.16	0.08
Year	2.23	0.32	0.03	0.70	N/A

Table 2.8. Generalized Least Squares Model examining the relationship between intensive land use type and intercept in 2007-2008 and 2009-2010. Heterogeneity of variance associated with the intensive land use type variable was stabilized using a weighted variance structure and 'greenhouse' as the baseline level (N=43, df=38). Test statistics for intensive land use types denote comparisons against 'greenhouse'. Intercept values for berry, road and residential fields were significantly different from greenhouse fields.

Variable	T	SE	P	Coefficient	Variance Parameter
Berry	-1.98	38.48	0.06	-76.35	1.0
Road	-2.18	36.38	0.04	-79.28	0.35
Residential	-2.47	36.33	0.02	-89.55	0.21
Year	0.76	6.30	0.45	4.81	N/A

Table 2.9. Generalized Least Squares Model examining the relationship between intensive land use type and intercept relative to intensity in 2007-2008 and 2009-2010. Heterogeneity of variance associated with the intensive land use type variable was stabilized using a weighted variance structure and 'greenhouse' as the baseline level (N=43, df=38). Test statistics for intensive land use types denote comparisons against 'greenhouse'. Intercept relative to intensity values for residential fields were significantly different from greenhouse fields.

Variable	T	SE	P	Coefficient	Variance Parameter
Berry	0.87	0.87	0.39	0.76	1.0
Road	0.11	0.47	0.92	0.05	0.44
Residential	-2.67	0.52	0.01	-1.40	0.36
Year	-1.11	0.40	0.28	-0.44	N/A

Table 2.10. General Linear Model examining the relationship between activity level and the seasonal cumulative mean dropping density in fields adjacent to intensive land use types (greenhouses, residential areas and roads) in 2007-2008 and 2009-2010 (N=22, df=18). Cumulative mean dropping density declined with increasing activity levels for all intensive land use types.

Variable	DF	MSE	F	P
Activity level	1	17323.6	7.7	0.01
Land use type	2	4961.1	2.2	0.1
Interaction	2	209.8	0.1	0.9

Table 2.11. General Linear Model examining the relationship between activity level and tolerance (intercept of linear model describing mean dropping density accumulated across a field) at three intensive land use types (greenhouses, residential areas and roads) in 2007-2008 and 2009-2010 (N=15, df=11). Tolerance was not influenced by activity levels at all intensive land use types.

Variable	DF	MSE	F	P
Activity level	1	5340.8	1.69	0.23
Land use type	2	3684.5	1.17	0.36
Interaction	2	3082.9	0.97	0.42

Figure 2.1. Phenology of wintering duck grazing intensity at four intensive land use types in Delta, British Columbia, in 2007-2008 (Panel a) and 2009-2010 (Panel b). Shown is cumulative mean dropping density on transects, with the final total on greenhouse transects set to 1 to aid comparison between years. Totals at greenhouse fields in 2007-2008 were 79.9 droppings/m^2 and 53.0 droppings/m^2 in 2009-2010.
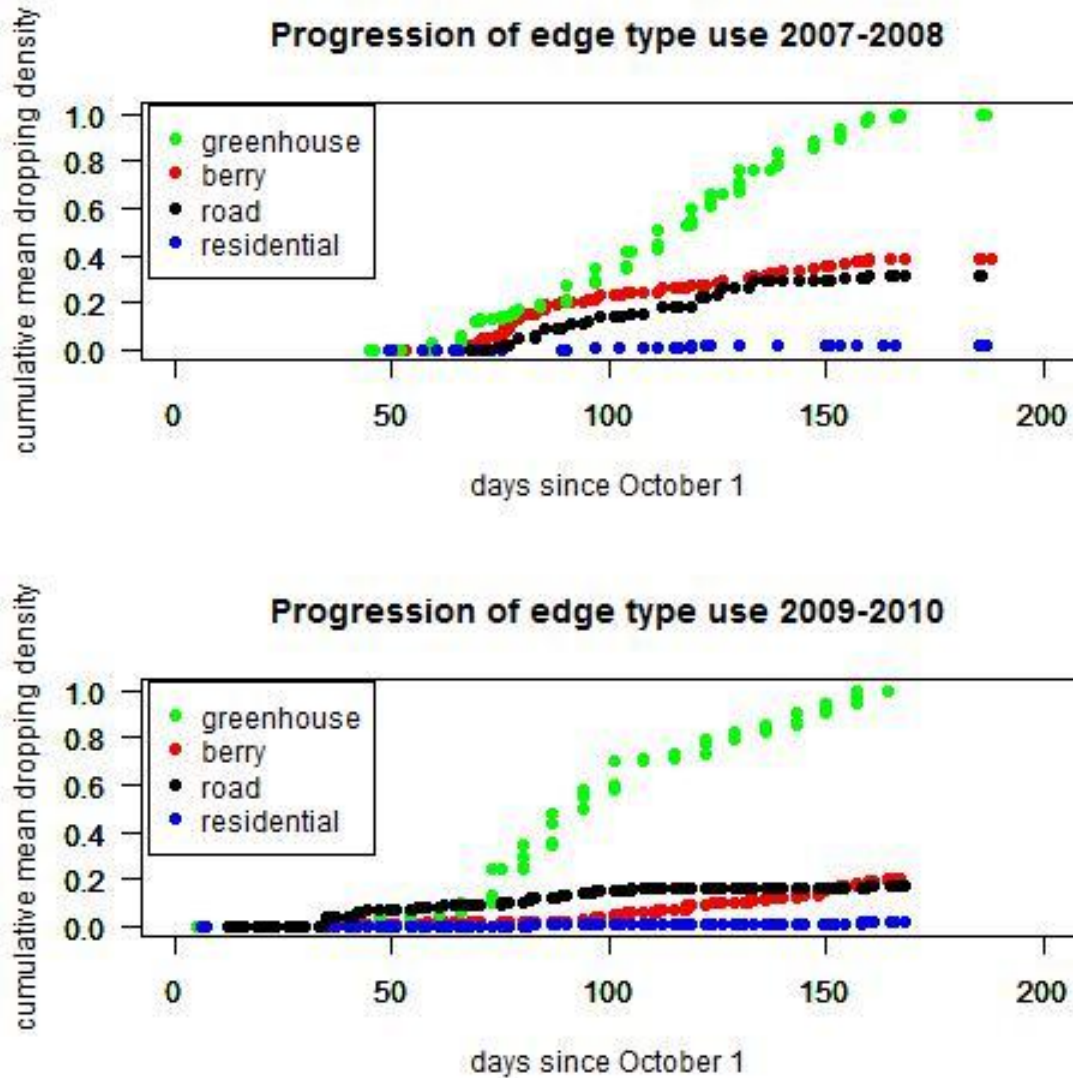
Figure 2.2. Duck grazing intensity of use (cumulative mean dropping density) was higher in fields adjacent to greenhouses than in fields adjacent to residential areas, roads, or berry fields, in 2007-2008 (light grey boxes) and 2009-2010 (shaded). Shown are Box-Cox plots, on a log scale to aid comparisons. Error bars are 95% confidence intervals. A generalized least squares model with a nested varIdent-weighted variance structure was used to examine the relationship between intensity of use and intensive land use type in each year. Overall dropping density differs between years, but the differences between land use types are consistent. Intensity of use was significantly higher at greenhouses than the other intensive land use types and residential was significantly lower than both berry fields and greenhouses.

duck grazing intensity adjacent to four edge types
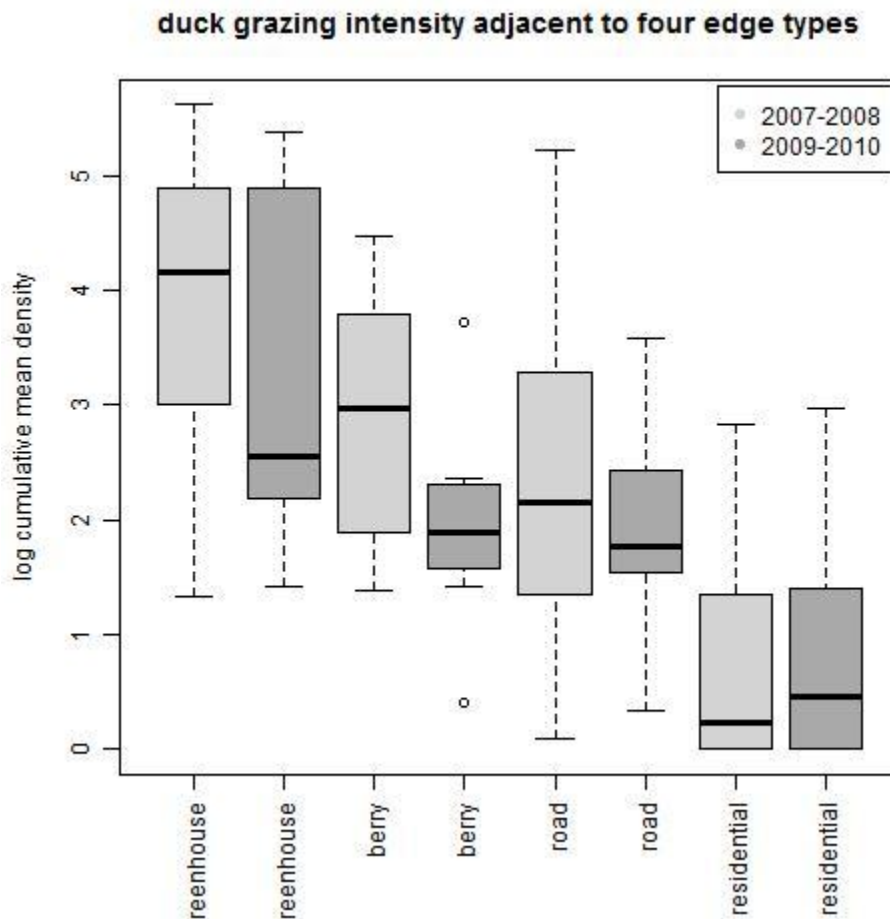
Figure 2.3.   Tolerance (intercept of linear model describing dropping density accumulation across a field) of an intensive land use type by grazing ducks varies on fields adjacent to different intensive land use types, with the differences consistent between years (2007-2008 (light grey boxes) and 2009-2010 (shaded)). Shown are Box-Cox plots. Error bars are 95% confidence intervals. Tolerance was higher at fields adjacent to greenhouses and berry fields compared with residential areas. The intercept values for berry, road and residential edges differed significantly from greenhouse edges.
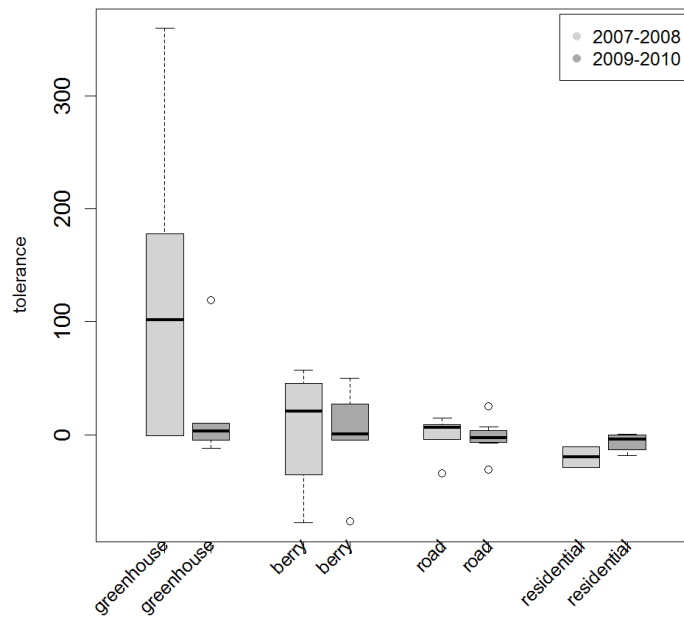
Figure 2.4.   Activity levels at three intensive land use types (greenhouses (N=6), residential areas (N=10) and roads (N=6)) in Delta, British Columbia, in winter 2010-2011. Shown are Box-Cox plots. Error bars are 95% confidence intervals. 'Activity index' is a composite of the number of activity events in six categories; lights, traffic, people and pets, noise, wildlife and other.
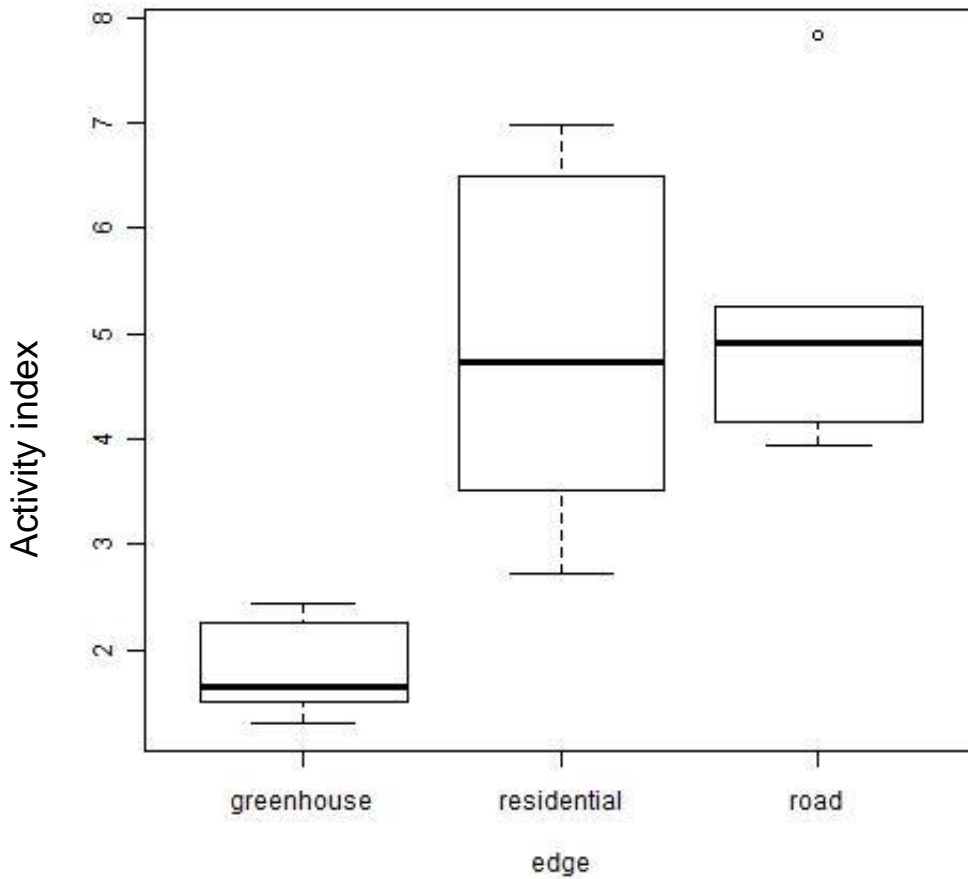
Figure 2.5. Intensity of use (mean dropping density accumulation) of a field by grazing ducks declined with increasing activity levels at three intensive land use types (greenhouses (green dots), roads (black dots) and residential areas (blue dots)). The y axis is log-transformed to aid visualization. 'Activity index' is a composite of the number of activity events in six categories; lights, traffic, people and pets, noise, wildlife and other. A general linear model was used to examine the relationship between intensity of use and activity level for each intensive land use type.
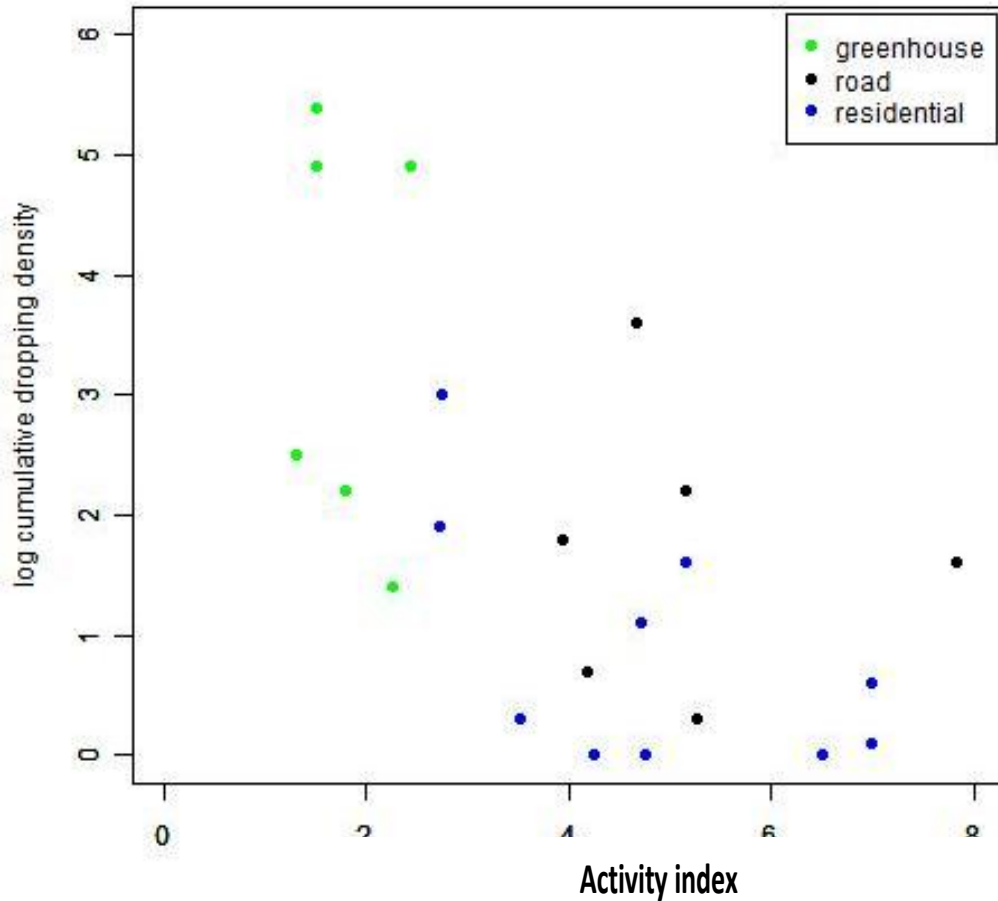
Figure 2.6. Tolerance (intercept of linear model describing dropping density accumulation across a field) of an intensive land use type by grazing ducks with activity level at three intensive land use types (greenhouses (green dots), residential areas (blue dots) and roads (black dots)). 'Activity' is a composite index of the number of activity events in six categories; lights, traffic, people and pets, noise, wildlife and other. A generalised least squares model was used to examine the relationship between tolerance and activity level for each intensive land use type. Tolerance was not explained by activity level at any land use type.
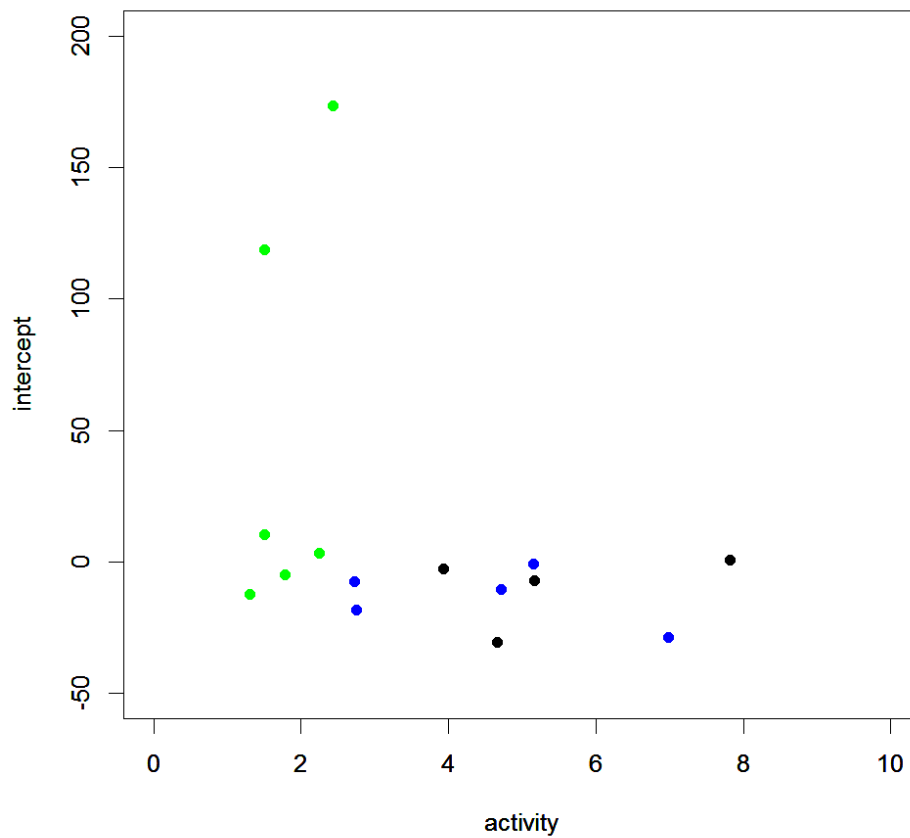
Chapter 3.

Day and night anti-predator behaviour of ducks wintering in Delta, BC

This chapter is co-authored with Lysanne Snijders of Wageningen University.

Abstract

Habitat selection may vary between time periods and between habitats if prey respond to cues that vary across time and space. Variation in danger between day and night and between patches will then be reflected in spatial use and vigilance. Prey can respond to danger by using more dangerous habitats at safer times or by increasing vigilance. In the Fraser delta, duck use of farmland habitat adjacent to intensive forms of land use varies spatially and cumulatively while overall use is higher at night than during the day. Whether vigilance and field use adjacent to these intensive land use types varies between night and day is not understood. We investigated differences between day and night in spatial and behavioural responses to three intensive land use types. Dropping density was measured on transects perpendicular to an intensive land use during both nocturnal and diurnal periods. We measured vigilance in each species and between sexes using focal observations both day and night. Quadrats were visited more often during night than day, but counter to previous work, dropping densities were similar. Vigilance levels were not higher during the day compared to the night but mallard vigilance levels were higher during the night. Additionally, males spent more time vigilant than females during the day, but were similar at night. We discuss possible causes of the apparent shift to similar day and night upland foraging in the context of changing predator pressure and sampling methods.

3.1. Introduction

Many animal species show strong differences in their activity level and/or distribution between day and night time. At one extreme, individuals may be completely inactive and sleep or hide during the day (e.g. many owls (Martin 2010), bats and marsupial mammals (Roots 2006)) or night (e.g. chimpanzees, Stanford 1998), while at the other extreme activity is unaffected by the diel cycle (e.g. reindeer and ptarmigans in summer and winter, van Oort et al. 2005). Other species, such as some waterfowl (see below), appear flexible in their diel patterning, while most show some degree of difference between night and day in their behaviour and distribution. For example, two gerbil species (*Gerbillus pyramidum* and *G. allenbyi*) in Israel switched between two desert micro-habitats night and day (references in Kotler 1984) revealing day and night contrasts in both distribution and timing of use.

Habitat selection may rely on the use of cues that equate to danger. Prey may rely on cues of danger such as amount of cover or moonlight (Price et al. 1984) when deciding when to use a habitat. Desert gerbils spent less time in more dangerous open areas (in the presence of predators that hunt in the open), opting instead to spend time near protective cover (Price et al. 1984; Brown et al. 1988; Kotler et al. 1991). In this way, responses to indirect cues of danger may result in temporal or spatial variation in distribution.

Differences in diurnal time allocation across patches may reflect differences in daytime and nighttime relative danger. If abundances or encounter rates of predators differ between day and night, then danger in that patch will change across time. Types and densities of predators may vary between habitats (Svanback and Eklov 2003), across seasons (Brown 1989) and time of day (Kotler et al. 2002). Additionally, lethality may vary with conditions (illumination, habitat structure, predator abundance) or encounter rate with prey may vary spatially or temporally. Diving ducks and greylag geese (*Anser anser*) shifted from diurnal to nocturnal feeding in response to danger (Thornberg 1973; Pedroli 1982 in Hohman and Rave 1990; Kahlert et al. 1996; Merkel et al. 2009). Wintering dunlin (*Calidris alpina*) made greater use of inland habitat at night, when their main predator was absent (Shepherd 2001). By varying across time, danger can alter habitat use of prey in both space and time.

Differences in diurnal time allocation may also occur among populations of the same species. Two populations of Eurasian wigeon (*Anas penelope*) in the Netherlands made use of upland grassy areas ('polders') and offshore roosting areas at different times. One population used polders at all times of day and night, whereas most individuals in a second population commuted daily between offshore roosts and polders (Boudewijn et al. 2009). The authors attributed this difference to higher diurnal predator abundance in the latter region. In this way differences in danger in both space and time may have produced differential use of two habitats. Understanding whether variation in habitat use in relation to differences in danger is a general mechanism driving waterfowl distributions elsewhere is an underutilized but important consideration for calculations of carrying capacity and development of flyway monitoring programs.

Besides altering when and where they use habitats to avoid encounters with predators, prey may increase vigilance when and where danger is higher (Metcalfe 1984; Fritz et al. 2002). If danger differs between night and day then foragers should increase their vigilance behaviour during the more dangerous time period relative to the safer time period. Many bird species increase vigilance levels when active during the day compared to the night (Jorde and Owen 1988; Beauchamp 2007). However, an increase in vigilance levels when the surroundings impair visibility has also been reported for several bird species (Metcalfe 1984; Pöysä 1987; Guillemain et al. 2001). Many species of birds increase vigilance (review in Whittingham and Evans 2004) and decrease use of patches in response to visual obstructions. Experimental studies on chaffinches (*Fringilla coelebs*) showed slower reaction times to an attack by a model predator when visual obstruction was greater (Whittingham et al. 2004) and the species composition of ground-feeding flocks near a visual obstruction shifted towards those that use cover as a refuge (Lima and Valone 1991). Greater flamingos (*Phoenicopterus roseus*) were more vigilant at night compared to the day perhaps due to reduced ability to detect approaching predators at night (Beauchamp and McNeil 2003). If danger differs between night and day then foragers should increase their vigilance behaviour during the more dangerous time period relative to the safer time period. Such 'encounter avoidance' is used by prey to minimize danger (Lima 1998; Shepherd 2001; Pomeroy 2006).

The Fraser River delta (herein called 'Delta') in southwestern British Columbia (49˚ N, 123º W) is a matrix of suitable waterfowl habitats including foreshore marshes, eelgrass beds and, inland from an extensive dyke system (herein called 'uplands'), managed grasslands and sloughs. The area supports about one hundred thousand wintering American wigeon (*Anas americana*), mallard (*Anas platyrhynchos*) and Northern pintail (*Anas acuta*) (Hirst and Easthope 1981). Duck numbers build during fall migration. At first they rely on the marine habitat foraging primarily on eelgrass and marsh vegetation (Lovvorn and Baldwin 1996). In mid-November they make a shift in their spatial patterns spending a large proportion of their time in the uplands foraging on grasses and waste crops. Most of the ducks use the uplands at night and roost offshore during daylight hours (Lovvorn and Baldwin 1996, Jury 1981). Ducks move to the uplands after dusk and return offshore before dawn (Jury 1981). A subset of the population is found in the uplands during the day. The most important waterfowl predators in the delta, the peregrine falcon (*Falco peregrinus*) and the bald eagle (*Haliaeetus leucocephalus*) (H. Middleton, unpubl. data; Elliott et al. 2011), are active during the day. Additionally, hunting regulations restrict duck-hunting activities to the months of October through January during daylight hours and within the foreshore marsh and upland areas away from dwellings. To avoid encounters and thus reduce danger, waterfowl may choose to visit upland areas populated by predators and waterfowl hunters primarily at night (Merkel and Mosbech 2008) and spend the daytime offshore. A five-fold rise in upland daytime use in February to early March may be a response to depletion of marine food sources or the closure of hunting season (Jury 1981). To date a connection has not been examined between these diurnal cycles of danger and the reported diurnal patterns of upland use by ducks.

Duck spatial use of suitable upland habitat is also influenced by the presence of intensive land use types. In Delta, large greenhouses, residential areas and busy roads are often placed adjacent to suitable duck foraging habitat. The presence of a habitat structure imposes a specific amount of danger such that, all else being equal, they should spend more time further from more dangerous structures and less time near those structures and vice versa at less dangerous structures. Chapter two examined whether the presence of one of these land-uses casts a shadow of avoidance onto suitable habitat by measuring spatial use of fields. Ducks spent less time near residential

areas and roads than greenhouses and they spent more time across a winter adjacent to greenhouses than the other intensive land use types suggesting greenhouses are lower in danger than other intensive land use types. This lower danger may be related to the amount of anthropogenic activity occurring in the intensive land use type. Residential areas and roads had similar high levels of anthropogenic activity and greenhouses had low activity (Chapter 2). As a reflection of the diurnal cycle of human schedules, there should be lower activity levels at residential areas and roads at night compared to day. As greenhouses are industrial operations with longer hours of operation, day and night activity levels should be similar. If higher activity levels equate with higher danger then ducks should show a higher preference for using residential areas and roads at night when activity levels are lower than during the day but no difference at greenhouses, where activity levels are more similar day and night. It is not understood whether the relative contribution to overall use in a 24-hour period at an intensive land use type is disproportionately represented by daytime or nighttime use.

Our objectives were to examine whether duck habitat selection and vigilance differed between day and night in fields adjacent to intensive land uses and compare our findings to previous research showing higher nighttime use of upland habitat. We compared, between nocturnal and diurnal periods, the overall frequency and intensity of visits to upland fields, as well as the vigilance levels of foraging ducks during nocturnal and diurnal periods.

3.2. Methods

3.2.1. Study area and dropping transects

We focused on intensive forms of land use, each of which has recently or is continuing to expand in Delta. These included large greenhouses (>0.4ha under glass, n=4), residential areas (row of houses or school complex, n=4) and roads that receive steady traffic day and night (n=5). Study fields (1) were immediately adjacent to only one of these three intensive land uses, (2) contained vegetation known to be grazed by ducks, (3) were at least 30m in length and (4) did not contain any obstructions within or adjacent to the field (playground equipment, bleachers, fences, hedgerows >1m tall,

power lines and forest). Fields were included in analyses only if ducks occupied them at least one day or night during the study period.

The measurements reported here were collected between mid November 2010 and March 2011. We measured dropping density in transects on fields adjacent to greenhouses (n=30), residential areas (n=22) and roads (n=27). Transects began at the point of contact between the field and the edge of the intensive land use type and ran perpendicular to the intensive land use edge through the centre of the field. Transects comprised 5 – 10 1 m² quadrats spaced equally along the transect beginning at the point of contact. To avoid any influences from the adjoining field the final quadrat was set at least one inter-quadrat interval from the opposite edge. Each quadrat was marked by a coloured plastic flag on a 0.5m tall wire stake placed 5m from the quadrat. There were a total of 118 quadrats and, across all study dates, a total of 890 quadrat measurements were made. Droppings were counted inside a portable 1 m^2 frame of PVC pipe placed on the quadrat location. To make comparisons between daytime and nighttime field use we counted droppings in each quadrat following the daytime and the nighttime portion of a 24 hour period. Each transect was set out for 24 consecutive hours. Once a transect was set up we allowed one daylight period to elapse and then collected dropping counts within one hour of sunset. We removed duck droppings from each quadrat and the surrounding area (~25cm in all directions) and left the quadrats allowing one nighttime period to elapse. Within one hour of sunrise we returned to count droppings produced during the nighttime period and dismantled the transect. The transect was then moved to a different field for the following 24 hour period. Transects were placed in fields where ducks were located foraging the previous day and thus were repeated on three to eleven 24 hour periods in each field. Sampling by observers did not influence field use as care was taken to ensure no ducks were present on fields when transects were set up, dismantled or measured.

3.2.2.   Focal observations

Focal observations were conducted between 04:00 and 22:00 between 27 November, 2010 and 26 February, 2011. The focus until 1 January, 2011 was on ducks using fields adjacent to the three intensive land use types. However, because of low duck abundance, after 1 January, 2011 we focused on ducks in all types of fields

regardless of the presence of one of the three intensive land use types. Suitable individuals were located using searches by car and incidental sightings. Selection of individuals within a flock for focal observations (Altmann 1974) was done in an *ad hoc* manner, restricted by visibility. Day-time observations were conducted with a 20x60 spotting scope and night-time observations with a 5X42 Infra Red Night Vision Device (Yukon Advanced Optics). Eight behavioural categories were dictated into an audio recorder: foraging, vigilance, moving (swimming or walking), comfort, alert, resting, social and not visible (Table 3.1). For each focal observation we noted the time period (day or night), study field, group size, species (American wigeon, mallard, northern pintail), sex and week (weeks since December 1). On average, individuals were observed for 264s (range= 60-530 s; n=418), corrected for time not visible. Observations of less than 60s were excluded as too short. We quantified behaviour by scoring the behaviour on the audio recording at 5s intervals. From this we calculated the proportion of time spent vigilant by dividing the number of 5s intervals that scored a vigilance event by the number of 5s intervals in the focal observation. Of the 418 focal observations, 306 were recorded during the day and 112 at night. To ensure observer presence did not influence vigilance, observers remained in the vehicle throughout the observation and parked such that the nearest distance to a focal individual exceeded 200m.

3.2.3. Statistical analyses for dropping transects

For each quadrat we made separate day-time and night-time calculations of both the proportion visited and cumulative mean dropping density. Proportion visited was calculated as the number of times at least one dropping was found divided by the number of times the quadrat was measured. Cumulative mean dropping density was calculated as the number of droppings found in the quadrat on all visits divided by the number of times the quadrat was measured. We compared day and night values of proportion visited and cumulative mean dropping density within and between intensive land use types.

On average, the daylight period lasted eight to nine hours, while nights lasted fifteen to sixteen hours. To account for this difference we calculated a diurnality index (after Hoogenboom et al. 1984) for each transect. First, we weighted the dropping densities by the number daylight and dark hours by dividing the dropping densities for

day and night by the number of daylight and dark hours, respectively, on the sampling date. The index is the difference between weighted day and night dropping density divided by the sum of weighted day and night dropping density. The index ranges from -1 (all nighttime use) to 1 (all daytime use), with 0 indicating no difference.

As data were generally not normally distributed, we employed Wilcoxon Signed Rank Test for comparisons of diurnal and nocturnal proportion visited and cumulative mean dropping density across all intensive land use types. We examined whether 1-proportion visited and cumulative mean dropping density differed between day and night and between intensive land use types and 2- whether diurnality index differed between intensive land use types using Kruskal-Wallis Tests followed by Mann-Whitney U tests for *post hoc* pair-wise comparisons. In all analyses, p-values and confidence intervals were estimated using Monte Carlo simulations (100,000 runs) to control for differences in sample size and a Bonferroni correction ($\alpha = 0.05/3$) was applied for pair-wise comparisons. Normality and homogeneity of variances was tested with Shapiro-Wilk and Levene's test based on the median. Proportion visited for both day and night was arcsine transformed to achieve homogeneity of variance.

3.2.4.   Statistical analysis for focal observations

Proportion of time spent on each behavioural category was determined for each focal individual. Because birds can increase detection probability of predators by increasing scan rate (Metcalfe 1984, Hart and Lendrem 1984), we used the proportion of time spent vigilant. Comparisons of proportion of time spent vigilant between day and night were analyzed for all species together and between species. To control for between-field differences and nesting of fields within week, week and location were included as random factors in both models. The role of light (day vs. night), week and location on proportion of time spent vigilant was analysed by means of a General Linear Model (GLM) with type IV sums of squares. Finally, differences in proportion of time spent vigilant between sexes for all three species were compared for day and night since, in all species, male plumage is more conspicuous than that of females. A multi-factor interaction was included for species * time of day. As data were generally not normally distributed we employed Kruskal-Wallis tests followed by Mann-Whitney U tests for group comparisons. Presence or absence of a normal distribution and homogeneity

of variances was tested with Shapiro-Wilk and Levene's test based on the median, respectively. Normality was determined by testing the residuals of each model. Proportion of time spent vigilant was transformed on three occasions; twice to achieve homogeneity of variance for the group comparisons (species comparison: Log(Log(arcsine(x)+0.5)+0.5) and sex comparison: Log(arcsine(x)+0.5)) and once to achieve normality for the GLM (Log(arcsine(x)+0.5)).

We used SPSS 17.0 (IBM, New York) for all analyses.

3.3. Results

3.3.1. Use of quadrats by time period

Overall use of quadrats was low. No droppings were ever found in 56% of 118 quadrats, comprising 28 of 40 quadrats (70%) in fields adjacent to residential areas, 27 of 49 quadrats (55%) adjacent to roads, and 11 of 29 quadrats (38%) adjacent to greenhouses.

The overall proportion visited was higher at night compared to day (Z=-2.0, P=0.04, df=1, n=118, Table 3.2, Figure 3.1). Quadrats on transects adjacent to roads (Z=-2.25, P=0.02, df=1) and greenhouses were visited more often during the night than during the day (Z=-1.9, P=0.05, df=1) (Table 3.2, Figure 3.1). There was no difference in proportion visited between night and day at quadrats on transects adjacent to residential areas (Z= -0.6, P=0.6, df=1, Figure 3.1). There were no differences between day and night cumulative mean dropping density when all quadrats were lumped together (Z=-1.7, P=0.1, df=1). Cumulative mean dropping density was higher at night than day at roads (Z=-2.0, P=0.04, df=1) but did not differ between day and night at greenhouses (Z=0.001, P=1.0, df=1) or residential areas (Z= -0.83, P=0.44, df=1; Table 3.2).

3.3.2. Proportion visited day and night and diurnality index between intensive land use types

Five percent of quadrats (N=6 quadrats) were visited both day and night. Four percent of quadrats (N=5 quadrats) received a visit only during the day and 9% of

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quadrats (N=11 quadrats) received a visit only at night in a given 24h period. The remaining 82% of quadrats (N= 98 quadrats) received no visits on any day or night that was measured. When we inspected the number of times at least one quadrat on a given transect received a visit in all the 24h periods it was sampled ('transect-night' in Table 3.3), 13% received visits both day and night, 14% and 16% received a visit either day or night, respectively, and 57% received no visits at all. For each transect, 42% had at least one visit both day and night, 15% and 8% had at least one visit either day or night, respectively, and 35% never received any visits (Table 3.3).

The diurnality index showed higher overall use of fields at night than during the day (mean= -0.7; Figure 3.2). Diurnality indices did not differ significantly by intensive land use type (mean diurnality index: greenhouses=-0.6, roads=-0.95, residential areas=0.6; Kruskal-Wallis Chi-square= 4.7, df= 2, p= 0.1). Dropping density diurnality indices were more diurnal at residential areas compared to roads (Wilcoxon test W= 426, p= 0.03) but did not differ between greenhouses and residential areas (Wilcoxon test W= 462, p= 0.1) or between greenhouses and roads (Wilcoxon test W= 1059, p= 0.4, Figure 3.2).

3.3.3. Day and night vigilance

Due to practical constraints of locating observable individuals at night, nearly three times more ducks were observed during the day (n=306) than during the night (n=112). Proportion of time spent vigilant did not differ between day and night (F= 0.56, df= 1, p= 0.46; Tables 3.4 and 3.5) nor between species (F= 0.22, df= 1, p= 0.64; Tables 3.4 and 3.6). Vigilance declined with week and differed between fields ('location': Table 3.5). The interaction time of day * species was not important in the species group model (Table 3.6).

3.3.4. Male and female vigilance

During the day, males spent more time vigilant than females (Z=-2.76, P(two-tailed)<0.01; Table 3.4). There was no difference within species in male-female differences in vigilance during the day (wigeon: Z= -1.86, P(two-tailed)= 0.06, mallard: Z= -1.81, P(two-tailed) =0.07, pintail: Z= -0.88, P(two-tailed)=0.38; Table 3.4).

Combining all species, there were no differences between the sexes in vigilance at night (Z= -0.31, P=0.8; Tables 3.4 and 3.5). Neither wigeon nor mallard showed differences between the sexes in vigilance at night (wigeon: Z= -0.77, P(two-tailed)= 0.44, mallard: Z= -0.27, P(two-tailed)=0.79). In mallard, lack of between-sex difference at night may result from both sexes increasing their vigilance levels at night while male American wigeon reduced time spent vigilant at night compared to day (Figure 3.3). Between-sex differences in night vigilance values for Northern pintail could not be explored as only one female pintail was observed at night.

3.4. Discussion

Previous studies on wintering ducks in Delta report that upland foraging is largely nocturnal (Jury 1981, Lovvorn and Baldwin 1995). In contrast, we found that nocturnal and diurnal dropping densities were similar, though fields were visited more often at night. Similarly, we found no differences in proportion of time spent vigilant between night and day or between species.

3.4.1. Encounter avoidance

It has long been recognized that nocturnal field use by ducks is higher than diurnal use in Delta. Previous studies reported a greater number of ducks counted in fields at night than day in the study area (eg. Jury 1981, Lovvorn and Baldwin 1995). In contrast with this historical pattern, in our study, upland use did not differ between day and night. Although there was a higher proportion of quadrats visited at night and average diurnality index values were more nocturnal than diurnal, dropping density did not differ between day and night. There are three possible explanations for this difference. Firstly, a decline in hunting pressure in southern British Columbia between the 1980's to present (BC migratory game bird permits issued: ~28,000 in 1980 to ~6,000 in 2010, BC MFLNRO) means fewer hunters in the uplands during the day. If fewer hunters mean that upland areas are safer than in the past then perhaps over time daytime upland use has increased to match that of nighttime. Secondly, different methods of measuring upland use by previous studies may prevent our results from being directly comparable. Day and night relative use was measured using either radio-

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telemetry (Lovvorn and Baldwin 1996) or aerial surveys of total population numbers paired with day and night ground surveys (Jury 1981). If ground surveys provide a different estimate of field use than dropping densities then estimates from this study may not be comparable. Finally, numbers of diurnal predators such as bald eagles (Bower 2009; Elliot *et al.* 2011) and peregrine falcons have been increasing in Delta over the past few decades (Ydenberg et al. 2004). More diurnal predators should increase daytime danger. However, this pattern will have the opposite direction to what was observed by promoting higher nighttime use when diurnal predators are not present.

Despite a lack of difference between overall day and night upland use, closer inspection of each intensive land use type revealed higher cumulative mean dropping density values in quadrats at residential and road fields at night than during daylight hours. These findings fit with the prediction of higher nighttime use of intensive land use types that are more dangerous during the day. In previous work (Chapter 2), it was shown that the level of activity from a variety of sources was higher at residential areas and roads than at greenhouses. After categorizing timing of activity events by day and night it was discovered that activity levels were higher during the day than at night across intensive land use types (H. Middleton, unpubl. data). Higher levels of activity within the intensive land use types during the day and at fields beside residential areas and roads fit with observed patterns of upland use primarily at night at these land use types when danger is lower. Several studies report avoidance of dangerous habitat at more dangerous times. Gerbils in the Negev Desert and pocket mice foraged less and spent more foraging time in safer microhabitat near cover than more dangerous open microhabitat (Price et al. 1984; Brown et al. 1988; Kotler et al. 1991). These patterns were more pronounced under illumination suggesting danger is higher under illumination. Differential use of habitats by prey between time periods is a common pattern where danger varies temporally.

Although cumulative mean dropping density did not differ between day and night, a greater number of quadrats received visits during the night than day. With nights lasting longer than days we expected both nighttime proportion visited and cumulative mean dropping density to be higher than during the day. Equal proportion visited but higher nighttime cumulative mean dropping density may arise if the number of ducks in a given field was higher during the day compared to night. Ducks may have stayed in a

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given field for the same duration of time during day and night but used the relatively longer nocturnal period to visit more than one field. This is unlikely since several local waterfowl studies (Lovvorn and Baldwin 1996; Eamer 1985; Jury 1981; Butler 1992) report that upland duck numbers were higher or at least the same at night compared to day. A second explanation is that ducks made visits to a larger number of fields during the night, hence the higher proportion visited values, but stayed for shorter periods than during the day. This would result in similar cumulative mean dropping density values. Ducks may feel more vulnerable flying during the day compared to night. There are a suite of conditions under which waterfowl make more frequent movements. More frequent flights occurred under rainless, windy conditions than dry, calm conditions (Hirst and Easthope 1981) and more daytime movements between fields following the closure of hunting season (Jury 1981). Anecdotally, while collecting activity observations (Chapter 2) we observed more duck flights per hour during the day than at night (H. Middleton, unpubl. data). A third explanation is that individuals forage closer together during the day than at night. The lower nighttime proportion visited could result from a decreased chance of a condensed flock using the patch containing the transect than a more dispersed flock. Beauchamp (2007) reported that, in several species, individuals adjust spacing between day and night; increasing space in 35% of cases and decreasing space in 35% of cases. Forming condensed groups during daytime foraging was often noted during the present study. Condensed daytime formations could help ducks closely monitor their neighbours' behaviour and their response to possible approaching dangers (Bahr and Bekoff 1999; Packer and Abrams 1990). Watching your neighbors may be less useful at night either because raptors are less active or night vision is poor (Helfman 1993 in Beauchamp 2007). Finally, a lower defecation rate at night compared to day would result in equal numbers of droppings detected day and night. Unfortunately, not much is known about duck inter-dropping interval at night (Mayhew 1988) although dropping rate is known to be consistent while foraging (Dorozynska 1962; Amano et al. 2004). Future studies of waterfowl habitat selection in the Fraser delta should continue the day and night theme to determine whether the patterns describe hold in subsequent winters.

After controlling for the number of available hours using the diurnality index, variance in these values were too large to conclude that ducks spent more time in

uplands day or night. There were subtle differences in day and night preferences between the intensive land use types. Diurnality indices did not differ between quadrats in greenhouse fields and either road fields or residential fields but quadrat use was more diurnal at residential areas compared to roads. More visits to quadrats during the night than day may be explained by the level and types of activity events at these intensive land use types. At roads, activity levels were high, but the components of those activities were predictable in nature (Chapter 2) and levels were lower at night than during the day. At greenhouses, activity levels were lowest of all three intensive land use types (Chapter 2) and low both day and night. After experiencing predictable or low activity levels, ducks may be more apt to make repeated visits and move into such fields through the course of a night. Shifts in use of a habitat in response to level of disturbance is a common pattern (Belanger and Bedard 1989; Hirons and Thomas 1993; Madsen 1998). There is also evidence that populations can show plasticity in diurnal use of a habitat. Gerbils shift from more dangerous 'open' habitat to safer 'bush' habitat when danger or mortality are increased experimentally (Kotler 1992). A study of Eurasian wigeon in the Netherlands revealed two populations that differed in habitat selection; one population commuted between a roosting area on a large lake and upland grazing area and another resident population spent all of their time in the upland grazing area. The authors speculated that the difference in habitat selection was in response to higher numbers of predators and human activity in the upland area used by the commuting population (Boudewijn et al. 2009). Ducks in the Fraser delta may have shifted their upland use from a pattern resembling the Dutch commuter strategy to one closer to the resident strategy.

Foraging at night may allow ducks to top up energetic needs not met during the day. Eurasian wigeon require around 14 hours (Mayhew 1988) and mallard around 9 hours of undisturbed foraging to meet their daily energy needs. With only 8 hours of daylight available in mid-winter in Delta, American wigeon in our study area may use night foraging to top up energetic shortfalls of day-time foraging (*supplementary hypothesis*; McNeil et al. 1992). However, this seems unlikely as ducks in Delta have been reported as feeding primarily at night and resting during the day (Lovvorn and Baldwin 1996; Eamer 1985; Jury 1981). Additionally, we observed mallards actively

foraging at different hours through the night. Waterfowl nocturnal activity patterns vary greatly even between waterfowl taxa (Jorde and Owen 1988).

A lower incidence of upland use, also seen in 2008-2009 (Chapter 2), reduced the sample size of used quadrats and abundance of focal individuals. We suspect this reflects a redistribution of ducks to other parts of their range. One factor may be a higher than average density of predators in the study area. In February 2011, Delta's bald eagle numbers were three times higher than normal (1400 individuals) (D. Hancock quoted by K. Pemberton, 2011). Winter bald eagle numbers in the region are known to be largely a response to food concentrations (Blood and Anweiler 1994) such as presence of large duck concentrations and the Delta landfill. The failed salmon run further north in 2010 may have drawn large numbers of bald eagles to Delta in search of prey. Danger from large numbers of day-active predators could have forced a large proportion of ducks away from the study area thus decreasing use of the uplands. If high predator numbers had forced ducks to rely primarily on the uplands at night there would have been a strong night-use-preference. However, duck upland use was low during both day and night, as predicted if local numbers were low. Another factor could be an early cold spell in November 2011 (Environment Canada 2011) forcing large numbers of ducks further south or west into the Gulf Islands early in the winter season. During 25 days of ice cover in winter 1990-91, duck numbers dropped from about 80,000 to nearly 0 and did not fully recover that winter. The population relies on alternative southern foraging areas during harsh weather in about 13% of winters (Lovvorn and Baldwin 1996). Regardless of cause, lower duck use of the uplands limited our sample sizes and incidence of use.

3.4.2. Vigilance patterns

A second behaviour employed to reduce predator encounters is increased vigilance. Night-time foraging could be a strategy to avoid intense daytime activity (*preference hypothesis*: McNeil et al. 1992; Burger and Gochfield 1991) and diurnally active predators (Jorde and Owen 1988; Kahlert et al. 1996; Shepherd 2001; Beauchamp 2007). At night, detectability of predators will be lower due to reduced visibility (Beauchamp and McNeil 2003). Feeding when detectability is lower may be more dangerous and require greater time spent on vigilance to minimize danger. However, we did not detect a reduction in proportion of time spent vigilant during the

night. There were no differences in proportion of time spent vigilant between day and night for the population or between species much as there was no difference in upland use measured via cumulative mean dropping density. Ducks may select safer habitat during the day compared to night and so they can maintain similar time spent on vigilance. Our study fields were visited less often during the day and a given field was infrequently used both night and day suggesting ducks are selecting different patches day and night. Similarly, proportion of time spent vigilant differed between fields suggesting fields differed in danger. Many bird species change how they use a field day and night. While feeding, differences in distance to shore and even differences in choice of habitat are observed (Shepherd 2001, Beauchamp 2007). Anatinae often select deeper water areas during the day, which are good for loafing, and might choose more shallow water, during the night, which are better for foraging (Paulus 1984b in Paulus 1988).

Male ducks spent a greater proportion of their time vigilant during the day compared to females, but both sexes spent a greater proportion of their time vigilant during the night compared to day. Selective mortality of brightly coloured mallard males over dull females by hunters could have played a role in selecting this behaviour (Metz and Ankney 1991). Male mallards showed more vigilance behaviour than females in their normal (bright) plumage, but not in their eclipse (dull) plumage (Lendrem 1983). However, Guillemain et al. (2002) did not find differences between the vigilance levels of cryptic and brightly coloured male Eurasian wigeon. Although males spent a greater proportion of their time vigilant than females by day, both sexes spent a greater proportion of their time vigilant at night, which supports the finding that vigilance in all species were higher at night. It would be interesting to test whether during the day 'being seen' is of greater influence on vigilance while at night 'not seeing' has a greater impact on time spent on vigilance.

3.4.3.   Conclusions

This study showed that anti-predator behaviour can be different day and night. Fields were used more often at night but not more intensively than during the day. Additionally, male ducks spent a greater proportion of their time vigilant during the day compared to females but not at night. Often studies focus only on day-time observations

to draw conclusions about overall duck behaviour. A review by Beauchamp (2007) of 128 bird studies and 42 mammal studies concluded that foraging day or night has an influence on vigilance, but also on group formation and other factors within one species.

This study provides another example of how, across taxa, danger tradeoffs are reflected in differential habitat selection and that those differences may shift in time along with changes in the intensity of danger. Future waterfowl studies in the Fraser delta should continue to investigate the relative day and night use of uplands with a particular focus on whether changes in seasonal food abundance (depletion of eelgrass beds) or the phenology of bald eagles and hunters exert a stronger influence.

Tables and Figures

Table 3.1. Descriptions of discrete behavioural categories used during duck focal observations in Delta, British Columbia during winter 2010-2011.

Behaviour category	Description
Foraging	Feeding in water, surface and subsurface feeding from water, feeding in fields, foraging from fields
Moving	Swimming, aquatic locomotion not directly associated with feeding, walking, terrestrial locomotion not directly associated with feeding, flying
Comfort	Maintenance activities such as preening, stretching or bathing
Resting	Head held close to body or tucked onto back
Vigilance	Head at or above horizontal without a stretched neck and not in any other behavioural state
Alert	Head at or above horizontal with a stretched neck and not in any other behavioural state
Social	Interacting with other ducks, calling, fighting and courtship behaviours
Out of Sight	Not visible but was later visible

Table 3.2. Duck dropping counts from quadrats on paired nocturnal and diurnal transects in Delta, British Columbia, in winter 2010-2011. Values were calculated as proportion visited (number of times at least one dropping was found divided by the number of times the quadrat was measured) and dropping density (cumulative mean number of droppings found in the quadrat).

Proportion Visited

	Night			Day		
	greenhouse	residential	road	greenhouse	residential	road
Mean	0.16	0.03	0.15	0.11	0.04	0.08
Range	0-0.45	0-0.20	0-0.83	0-0.50	0-0.29	0-0.50

Dropping Density

	Night			Day		
	greenhouse	residential	road	greenhouse	residential	road
Mean	0.64	0.11	0.48	0.65	0.09	0.18
Range	0-5.46	0-1.4	0-7.33	0-3.91	0-1.8	0-2.33

Table 3.3. Proportion visited (number of times at least one dropping was found divided by the number of times the quadrat was measured) by ducks to fields adjacent to intensive land use types (greenhouses, residential areas and roads) in Delta, British Columbia in winter 2010-2011. Values represent the number of quadrats, transect-nights (the number of 24 hour periods with at least one visit to a transect) and the number of transects with at least one visit in: both day and night, night only, day only and neither day nor night.

	# quadrats			Transect-nights			Transects		
	Greenhouse	Residential	Road	Greenhouse	Residential	Road	Greenhouse	Residential	Road
Both	14	3	26	8	2	14	3	2	6
Day only	12	7	20	3	5	8	0	2	2
Night only	26	4	51	6	1	11	1	0	1
Neither	152	204	371	12	15	26	0	0	9

Table 3.4.　　Proportion of time spent vigilant by ducks wintering in Delta, British Columbia, 2010-2011. Sample sizes in brackets.

	Female		Male	
	Day (151)	**Night (43)**	**Day (158)**	**Night (55)**
Mean	0.11	0.23	0.14	0.23
Range	0-0.97	0-0.82	0-0.90	0-0.77

	American Wigeon		Mallard		Northern Pintail	
	Day (137)	**Night (38)**	**Day (150)**	**Night (67)**	**Day (18)**	**Night (7)**
Mean	0.11	0.16	0.14	0.26	0.14	0.26
Range	0-0.56	0-0.81	0-0.97	0-0.82	0-0.71	0.05-0.56

Table 3.5.　　Relationship between proportion of time spent vigilant (arcsin transformed) and time period (day or night) for ducks wintering in Delta, British Columbia, using a General Linear Model with nested random factors week and location (field identity). Proportion of time spent vigilant did not differ between day and night. (N= 418.)

Variable	SSE	DF	MSE	F	P
Intercept	0.51	1	0.51	10.71	0.004
Time Period	0.01	1	0.01	0.56	0.46
Week	0.63	7	0.09	6.48	0.001
Location	0.87	17	0.05	3.71	0.001

Table 3.6.   Relationship between proportion of time spent vigilant (arcsin transformed) and time period (day or night) in American wigeon (N=176), mallard (N=217) and northern pintail (N=25) wintering in Delta, British Columbia, winter 2010-2011, using a General Linear Model with nested random factors week and location (field identity). Proportion of time spent vigilant did not differ day or night or between species. (N=418.)

Variable	SSE	DF	MSE	F	P
Intercept	0.51	1	0.35	9.29	0.006
Location	0.83	17	0.05	3.51	0.001
Time Period	0.003	1	0.003	0.22	0.64
Week	0.64	7	0.09	6.54	0.001
Species	0.02	2	0.01	0.69	0.50
Time Period*Species	0.003	2	0.001	0.10	0.91

Figure 3.1.   Difference between nocturnal and diurnal proportion visited (number of times ≥1dropping present divided by the number of times surveyed) to quadrats in fields adjacent to residential area, roads and greenhouses. Quadrats on transects adjacent to roads (Mann-Whitney U test: Z=-2.25, P=0.02, df=1) and greenhouses were visited more often during the night than during the day (Z=-1.9, P=0.05, df=1). There was no difference in proportion visited between night and day at quadrats on transects adjacent to residential areas (Z= -0.6, P=0.6, df=1). Boxplots show median and interquartile range with whiskers representing maximum and minimum values.
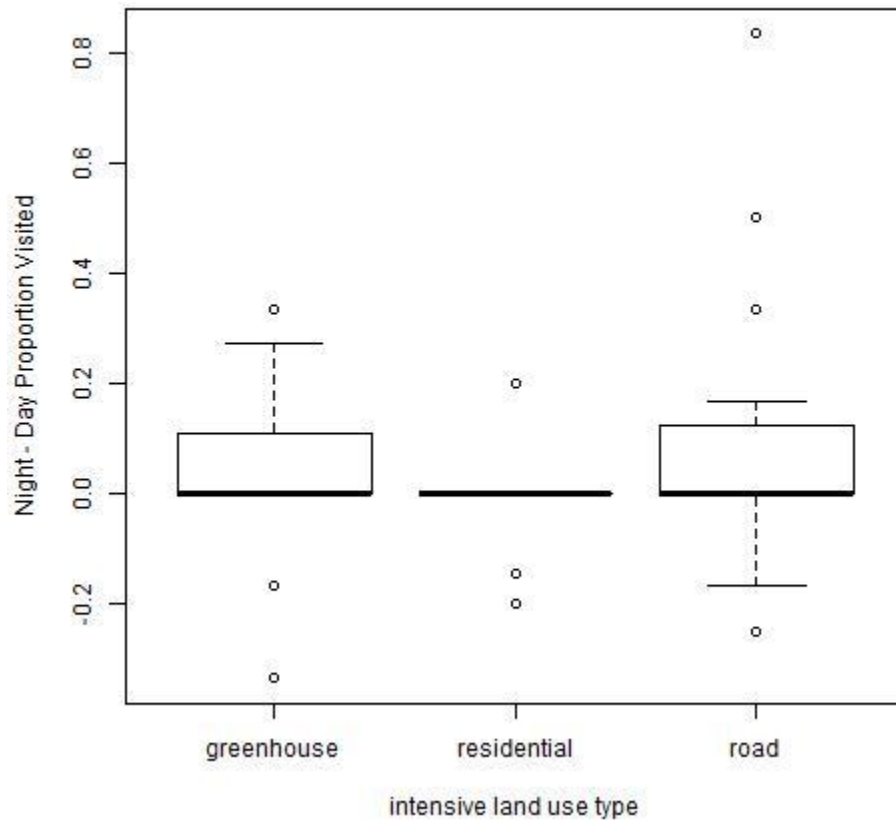
Figure 3.2.   Diurnality index of duck mean dropping density in habitat adjacent to one of three intensive land use types in Delta, British Columbia. The index is the difference between day and night 'dropping density' divided by the sum of day and night 'dropping density'. Positive values denote higher daytime dropping densities than nighttime dropping densities and negative values denote higher nighttime dropping densities than daytime dropping densities. Diurnality indices did not differ significantly by intensive land use type (Kruskal-Wallis Chi-square= 4.7, df= 2, p= 0.1) Diurnality indices were more diurnal at residential areas compared to roads (Wilcoxon test W= 426, p= 0.03) and did not differ between greenhouses and either residential areas (Wilcoxon test W= 462, p= 0.1) or roads (Wilcoxon test W= 1059, p= 0.4). Boxplots show median and interquartile range with whiskers representing maximum and minimum values.
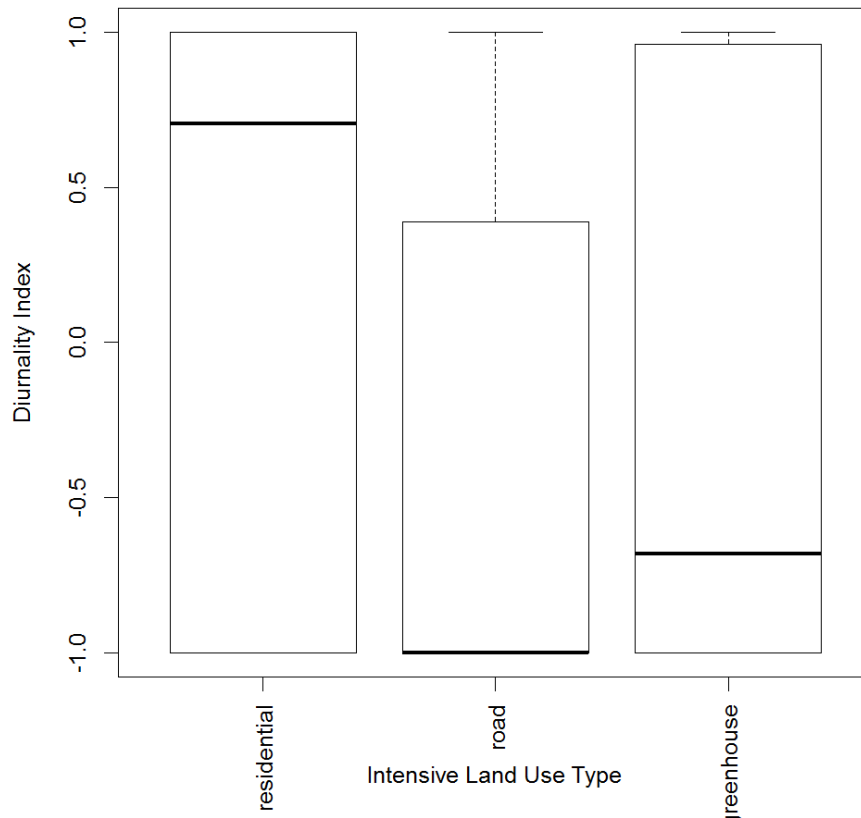
Figure 3.3.   Proportion of time spent vigilant by male and female ducks in daytime and nighttime. Male American wigeon (Kruskal-Wallis test: Z=-1.86, P<0.1, r=-0.16, N=138) and male mallards (Z=-1.81, P<0.1, r=-0.15, N=150) tended to spend more time vigilant than females during the day but not at night. With all species lumped, males spent a higher proportion of time vigilant during the day compared to females (Z=-2.76, P<0.01). Boxplots show median and interquartile range with whiskers representing maximum and minimum values.
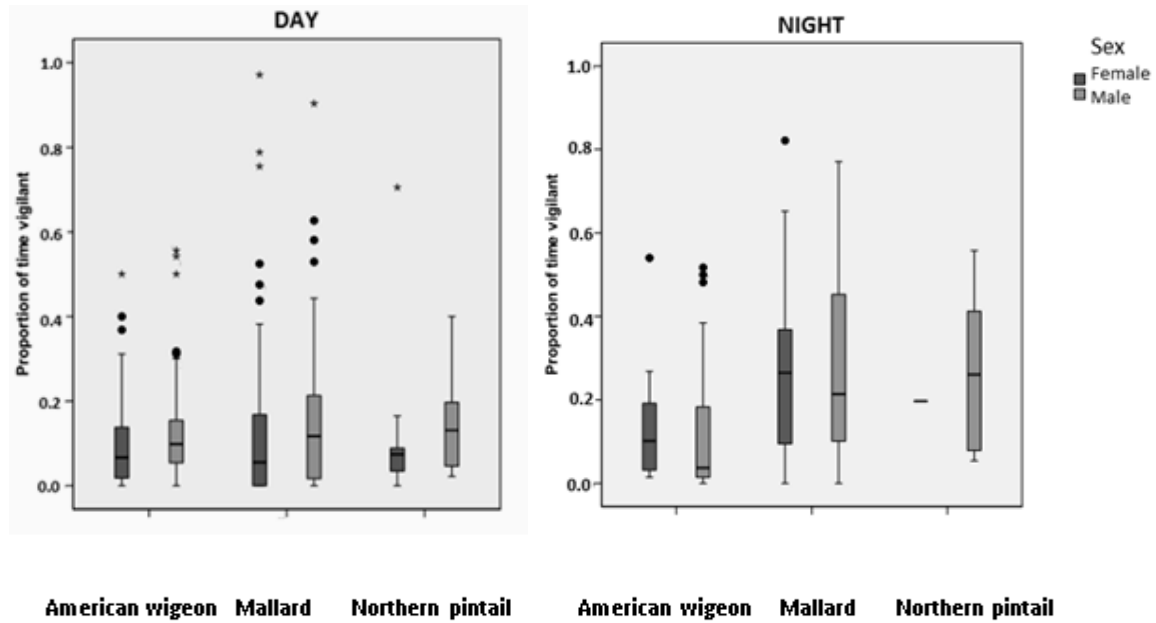
Chapter 4.

Factors influencing field selection by wintering ducks in Delta, BC

Abstract

Habitat selection is influenced by competing inputs including food availability, danger and energetic costs. In the Fraser delta, wintering ducks navigate a matrix of suitable farmland habitat embedded in human intensive land uses. Previous habitat selection research has emphasized field characteristics despite recognition of the importance of danger from intensive land use. To date the relative influence of both danger and field characteristics has not been examined. I investigated whether food availability, danger (distance to nearest busy road, number of buildings within 250m, amount of field perimeter comprised of roads), distance to a greenhouse, distance to nearest roost or the presence of standing water influenced field selection by wintering ducks. Field-level dropping densities were collected on diagonal transects in mid-December 2011. Field characteristics were measured using published values (metabolizable energy content of a crop) and GIS ('danger' variables, distance to a greenhouse and presence of water). Dropping densities were highly variable between fields. Dropping densities were more strongly influenced by the proximity to buildings, roads and greenhouses than the presence of water or food availability. I discuss the merits of including danger in future models of habitat selection and designing future development to mitigate impacts to foraging waterfowl.

4.1. Introduction

Habitat selection is a hierarchical process of behavioural decisions that result in unequal use of available habitats (Jones 2001). Where animals spend their time is influenced by a variety of competing inputs including the availability of food and other nutrients (Dumont et al. 2000), spatial variation in danger (references in Brown and Kotler 2007) and energetic costs of travelling to a habitat (van Gils and Tijsen 2007; Dumont et al. 1998). Animals trade-off the relative importance of each input and the resulting spatial variation in habitat selection reflects the relative influences of these inputs.

Prey are seldom found evenly distributed across a habitat. Disproportionate use of a habitat can be a reflection of danger in a habitat and is a pattern seen across taxa (insects (eg. larval damselflies and caddisflies: references in Lima and Dill 1990), birds (eg. redshanks: Quinn and Creswell 2012 and western sandpipers (*Calidris mauri*): Pomeroy 2006), fish (eg. coho salmon (*Oncorhynchus kisutch*): Dill and Fraser 1984 and black surfperch (*Embiotoca jacksoni*): Schmitt and Holbrook 1985) and mammals (eg. elk (*Cervus elaphus*): Ripple and Beschta 2003 and gerbils (*Gerbillus pyramidum* and *G. allenbyi*): Brown and Kotler 2004)). Danger is the probability of being harmed or captured in a habitat and is an emergent property of a habitat (Lank and Ydenberg 2003). Prey that are sensitive to danger will shift their use of a habitat spending less time in places with greater danger in favour of places with lower danger (Lima and Dill 1990). Danger sensitivity allows prey to assess danger in each habitat both to evaluate the quality of each habitat and the importance of danger relative to other inputs. Quantifying relative use allows us to both evaluate levels of danger in each habitat and the relative importance of each input.

The contribution of danger to habitat selection can be measured by examining a forager's response to danger produced by human or related activity. If foragers are sensitive to danger then they will spend less time in more dangerous patches than less dangerous patches (Brown and Kotler 2007). For waterfowl, danger increases with the frequency of activity events and results in differential patch use in response to the proximity of the danger source (Gill et al. 1996). Existing knowledge about duck habitat

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use can be strengthened by adding the influence of danger in models alongside the influence of field-level characteristics.

The presence of anthropogenic structures may cause spatial variation in danger across patches. This spatial variation can produce differential use of habitats. When danger increases due to the presence of a structure, foragers spend less time in habitats adjacent to these structures and more time in habitats without these structures. Waterfowl in Europe spent less time in habitats or patches close to roads (Gill 1996), walking paths (Williams and Forbes 1980), and, in the Fraser delta, fields adjacent to residential areas and busy roads (chapter 2). Danger may be increased because these structures pose visual barriers obstructing a forager's view of an approaching predator. Birds decrease use of patches and increase vigilance (review in Whittingham and Evans 2004) in response to visual obstructions. Experimental studies on chaffinches (*Fringilla coelebs*) showed slower reaction times to an attack by a model predator when visual obstruction was greater (Whittingham et al. 2004) and the species composition of ground-feeding flocks near a visual obstruction shifted towards species that seek protective cover (Lima and Valone 1991). Western sandpipers (*Calidris mauri*) avoided opaque artificial barriers (Pomeroy et al. 2006) and skylark (*Alauda arvensis*) numbers were lower in fields with tall structures around the perimeter (Donald et al. 2001). Previously, (Chapter 2) I showed that the spread of use across a field was shifted to areas further from some visual barriers (residential areas) and closer to other visual barriers (greenhouses). Responses to varying danger from anthropogenic structures results in disproportionate habitat use and ultimately changes in carrying capacity of habitats near anthropogenic structures.

The intertidal mudflats and adjacent agricultural area of the Fraser delta are the most important wintering area for several hundred thousand waterfowl on the Pacific Coast of Canada (BirdLife International; Butler and Campbell 1987). Delta's agricultural area provides rich foraging and roosting habitat (Breault and Butler 1992) and is an important contributor to the British Columbia economy (Metro Vancouver 2007). Ongoing infrastructural development is increasing the frequency of interfaces between human land use and suitable waterfowl habitat. Structures adjacent to agricultural habitat provide the potential to introduce danger that can alter habitat quality.

Existing knowledge of duck habitat selection decisions in the Fraser delta have focused on the influence of features at the field-level such as food availability (eg. Duynstee 1995; Bradbeer and Halpin 2009; Merkens et al. 2012), the presence of standing water (von Kanel 1981; Hirst and Easthope 1981; Mayhew and Houston 1989; Haase et al. 1999; Eamer 1985) and distance from the foreshore dykes (Merkens et al. 2012). Danger has been long recognized as a potentially strong influence on duck field use decisions (Duynstee 1992; Buffett 2007) but has not yet been incorporated into habitat selection models. Previous work (Chapter 2) has uncovered that duck spatial and cumulative use decisions at the patch scale are influenced by danger from intensive land use types. This study takes a broader-scale approach by examining field-level habitat selection by ducks in response to both danger from intensive land use types and field-level characteristics previously known to influence habitat selection.

Ducks wintering in the Fraser delta rely primarily on crops such as grass and potato for food. Grass quality (Mayhew and Houston 1999), grass biomass (Vickery et al. 1997) and danger (Prins and Ydenberg 1985) all influence duck habitat selection and have been the focus of studies of duck grazing patterns in the Fraser delta. Most studies have placed emphasis on effects of energy and crop characteristics such as grass species composition, energetic content, crop plant date, proximity to foreshore roost and alternate foraging opportunities in waterfowl habitat use (eg. Duynstee 1992, 1995, Buffett 2007; Bradbeer and Halpin 2009; Merkens et al. 2012). Duck use (percent of field grazed and duck-use days) decreases with planting date (Duynstee 1995; Bradbeer and Halpin 2009) and increases with proximity to foreshore roost (Merkens et al. 2012) and percent orchard grass composition (Merkens et al. 2012).

Many populations of waterfowl minimize commute distance between roosting and foraging sites. European goose populations minimize commute costs by foraging within 2-5 km of the roost (Gill 1996; Vickery and Gill 1999). Grazing evidence by greater white-fronted geese (*Anser albifrons*) in Europe is greatest on winter wheat fields close to the roost (Amano et al. 2007). In the Fraser delta, grazing extent in the uplands spreads from areas near the foreshore dyke and in the northwest portion of the study area (Figure 4.1) early in the season to areas further south and east by late March (H. Middleton, unpubl. data). The spread inland may reveal the costs of commuting to underutilized patches. Cumulative waterfowl grazing evidence in the Fraser delta is

consistently highest close to the foreshore dyke (Merkens et al. 2012). Energetic costs related to flying from roosting to feeding sites have been suggested as a possible explanation (McKay et al. 1996).

Repeated grazing maintains foraging patches at ideal grazing conditions (high protein to fibre ratio). Sites grazed by barnacle geese (*Branta leucopsis*) in the Netherlands contained higher crude protein which declined when grazing ceased (Prins and Ydenberg 1985). Barnacle geese use was also higher on sites with higher primary production (Ydenberg and Prins 1985). In the Fraser delta, waterfowl returned to patches grazed within the previous few days (Jury 1981; Duynstee 1992). Waterfowl appear to select the same patch on subsequent days likely because selecting a new patch each calendar day is costly both energetically and nutritionally (van Eerden 1997).

Presence of standing water on the surface of a field increases use by waterfowl (von Kanel 1981; Hirst and Easthope 1981; Mayhew and Houston 1989; Haase et al. 1999; Eamer 1985). Ducks in the Fraser delta prefer flooded fields (Hirst and Easthope 1981). Presence of standing water explained 25% of the variation in waterfowl grazing (Duynstee 1992). Nearby sloughs or ditches that provide water deep enough to dive in may provide added safety via an escape option from aerial and terrestrial predators (Mayhew and Houston 1989). Standing water provides access to fluid to aid digestion (Bossenmaier and Marshall 1958; Mayhew and Houston 1989; Duynstee 1992) and may slow down or prevent a silent attack by ground predators such as coyotes, waterfowl hunters or domestic cats and dogs.

The potential for the presence of a greenhouse to alter habitat selection by ducks has only begun to be understood. At the patch level, ducks have been shown to spend more time near greenhouses and show greater cumulative use near greenhouses than other intensive land use types (Chapter 2). Should the greenhouse footprint expand in coming years it is important to be able to model habitat selection at the field scale in relation to the location of greenhouses in the upland habitat.

As field size increases the parameters of the field relevant to duck habitat choice change. Larger fields represent larger patches of energy. With increasing size, sightlines and take-off space improves, and with them relative safety. In Europe, field size was

shown to be an important factor influencing waterfowl patch selection (Gill 1996; McKay et al. 1996; Haase et al. 1999).

The cumulative effect of danger from land uses on duck habitat use is beginning to be explored in the Fraser delta. Ducks spend less time across a season in fields adjacent to residential areas or busy roads than those adjacent to greenhouses or berry fields. Similarly, patches within those fields adjacent to roads and residential areas are used less than patches further from the edge within the field (Chapter 2). These cumulative and spatial use patterns were explained by the number of activity events (Chapter 2). Danger arises from the activity of people and wildlife in addition to the density of buildings and proximity of roads in the vicinity of the field (Mayoral 1995; Gill et al. 1996). Areas with a higher density of anthropogenic structures not only present higher levels of danger but also hinder sightlines important to detecting and evading predators. A tall or dense structure may obstruct a forager's view of an approaching predator while a habitat patch producing frequent or sudden events such as lights, traffic or pedestrians may disrupt or startle foragers. Many species of birds increase vigilance (review in Whittingham and Evans 2004) and decrease use of patches in response to visual obstructions. The perimeter of a field is an amalgamation of a variety of edge components from buildings to roads to short or tall vegetation to powerpoles and dyke berms. The shape of a field can impact sightlines such that a narrow, long field with tall hedgerows may be avoided as sightlines are poor throughout but a large, wide field bordered by short vegetation is favoured. Sightlines within a field can vary such that areas with poor sightlines are avoided in favour of those where an approaching predator can be detected.

Evaluation of cumulative impacts of human land use in agricultural areas that support waterfowl requires an understanding of the interplay between placement of structures, farmland characteristics and response by waterfowl. Modeling relative impacts of danger and farmland characteristics allow assessment of cumulative impacts on habitat availability. Evaluation of landscape-specific effects of human land use decisions and farmland management are necessary to understand relative impacts of land use decisions and aid in land use planning and development mitigation.

I hypothesize that ducks use danger, the presence of standing water and field attributes such as distance from the roost and crop energy content to make field selection decisions. If danger from intensive land use types underlies duck field use decisions then they will spend less time in fields in close proximity to sources of danger such as roads and residential areas and more time in fields further from danger. I have previously shown that danger associated with greenhouses is low and that ducks spend more time at fields beside greenhouses than other intensive land use types (Chapter 2). Therefore, I predict that this pattern will hold at a larger spatial scale such that ducks will spend more time in fields that are closer to greenhouses than in fields further away. As deep water provides an escape route from predators, I hypothesize that fields near standing water will receive higher duck use than those without standing water nearby. Similarly, if ducks are selecting fields according to their attributes then field use will increase with energy content, size and proximity to the foreshore dyke.

I used an information theoretic approach to directly compete the major hypotheses used to explain patterns of duck habitat selection. I examined the relationship between the intensity of habitat use and energy, danger, proximity to a greenhouse and presence of water in the Fraser delta.

4.2. Methods

4.2.1. Study landscape

The lower Fraser River delta in southwestern British Columbia (49° N, 123° W) is a matrix of upland and offshore waterfowl habitats separated by foreshore dykes. Seaward of the dykes are foreshore marshes containing emergent marsh vegetation (*Typha latifolia, Carex sp. and Schoenoplectus sp.*) above the high tide line, eelgrass (*Zostera marina* and *Z. japonica.*) beds within the intertidal zone and extensive sand and mudflats extending up to 2km from the foreshore marsh into Georgia Strait and along the Fraser River. The approximately 36,000 hectare upland is a matrix of open soil farmland habitats suitable to waterfowl embedded within intensive land use including two residential and commercial areas (the towns of Ladner and Tsawwassen), 3 highways, a port delivery road, a railline and ~10 large (>0.4ha under glass) commercial

greenhouses. A network of ditches, sloughs, pumping stations and flood gates control water at most agricultural fields and the deep water provides escape cover for ducks. The region produces potato, beans and berry fruits in addition to 14-18% of the farmland being devoted to pasture, hay and silage production (Merkens et al. 2012). Potato crop residue, winter cover crops (barley, oats and winter wheat) and livestock forage provide upland feeding areas for waterfowl (Breault and Butler 1992; Bradbeer 2007). Over the winter, fields are either left bare with substantial crop residue, or planted with a winter cover crop (annual average= ~1,200 hectares (Bradbeer et al. 2010)). Substantial amounts of waterfowl habitat is set aside within internationally (Important Bird Area program of BirdLife International and RAMSAR designations of Wetlands International), nationally (Alaksen National Wildlife Area) and provincially (George C. Reifel Migratory Bird Sanctuary, Boundary Bay Wildlife Management Area, Agricultural Land Reserve) designated reserves.

I restricted the study area to the western portion of the Fraser delta (Figure 4.1). This permitted adequate sampling within a 7 day window with limited field staff as well as collaboration with habitat use measurements conducted by Delta Farmland and Wildlife Trust.

4.2.2. Study species

I focused on the four most abundant grazing ducks (American wigeon (*Anas americana*), northern pintail (*Anas acuta*), mallard (*Anas platyrhynchos*) and green-winged teal (*Anas carolinensis*)) wintering in the Fraser delta and known to use open-soil agricultural land inland from the foreshore dykes (herein called 'uplands'). Numbers build during fall migration in late September and rise through the fall to a peak in January (interannual mean: 80,000 individuals, interannual range: 60-120,000 individuals) at which time numbers decline steadily until spring migration in late March (Butler and Campbell 1987). The third week of December typically contains the peak of duck field use in the study area. They rely primarily on intertidal eelgrass beds and foreshore marsh vegetation until mid-November when they switch to rely primarily on extensive upland grass and fields with crop residue. The majority of upland habitat use is at night (Chapter 3, Appendix A). While a subset of the population can be found in the uplands

during daylight hours, the majority of ducks roost in nearby intertidal and subtidal areas by day (Appendix A).

To determine the appropriate sampling time window, I examined the seasonal phenology of dropping production for the period of peak dropping production. The peak period of use provides the greatest opportunity to sample the largest number of duck habitat selection decisions at the greatest number of fields in a short window of time. Using cumulative mean dropping density values from two previous winters (2007-2008 and 2009-2010) across all study fields, I inspected the values in one week blocks to select the week between November and March in which dropping production was greatest. Despite interannual variation in the overall amount of upland use (Chapter 2), for both study years, peak dropping production occurred in the third week of December. Thus, data were collected between December 15, 2011 and December 22, 2011.

4.2.3.   Study field selection

All open-soil fields were divided into those representing suitable duck foraging habitat and those that did not. I selected only those fields representing habitat. Each contained a crop known to be used by foraging ducks such as grass, turf and waste potato ('bare'). Of those fields that contained grass, 33 fields were randomly selected and represented a full range of planting dates and grass types. Bare fields were identified by ground-truthing existing crop cover data. Thirty bare fields were selected using a random number generator and, of those, 6 were selected for sampling to ensure sampling coverage was spread evenly across the study area. These 6 bare fields all contained potato residue. I selected 4 turf fields closest to open soil agriculture and therefore most likely to receive duck use. They included a baseball diamond, a city park and two schoolyards. Overall, 33 grass fields, 6 bare fields and 4 turf fields were sampled approximately representing the proportion of these fields in the study area.

4.2.4.   Dropping density measurements

Duck use was measured using a transect running diagonally across the field with 9-10 permanent circular quadrats (shorter fields could contain only 9 quadrats). Quadrats were placed 30m apart at least 30m from the edge of the field and marked with

a ~30cm tall bamboo stake. Each quadrat was delineated by a large, portable plastic hoop of 1.17 m^2 area centred over the stake and removed after each sampling visit. I removed all droppings within each quadrat and returned 7 days later to count droppings produced during that 7 day period. Mean dropping density for each field was calculated as total droppings divided by number of quadrats.

4.2.5.   Field attributes

Fields were either rectangular or triangular. Structural composition of each of the 3-4 edges of each field was measured by estimating the proportion of each edge comprised of short (grass, shrub or man-made structures <2m tall) and tall structures (grass, shrub, trees or man-made structures >2m tall). For edges containing more than one composition category (eg. 100% road, 50% tall trees, 30% short grass) I calculated a sightlines score as proportion of the field perimeter composed of tall structures (Table 4.1).

Field energy content was determined using true metabolizable energy ('TME', kcal/kg) of a crop multiplied by field area. TME values were derived from values calculated by Ducks Unlimited Canada for their 'TRUEMET' carrying capacity model (B. Harrison, Ducks Unlimited Canada, unpubl. data). Potato crop residue TME values were applied to bare fields and grass TME values to fields containing grasses other than turf. For turf fields I applied TME value for perennial rye grass (*Lolium perenne*, Thomas et al. 2007), the most common turf grass species in the region, at the typical turf sward height of 4.2-6.3cm. I multiplied TME by biomass values supplied by an equation

$$Biomass(g/m2) = 4.214(Score) + 40.75$$

relating biomass to grass drop disc (Holmes 1974) scores (D. Bradbeer, pers. comm.). Seasonal average sward height measurements taken in 2007-2008 and 2009-2010 (H. Middleton, unpubl. data) were used to calculate biomass. Field area (ha) was derived from field attributes calculated by Ducks Unlimited Canada from Agriculture Canada field boundary data. For bare, grass and turf fields, total available energy in a field was calculated as density of TME multiplied by field area (Table 4.1).

Danger was quantified using a suite of three variables; activity, distance to a busy road and a perimeter road value. Activity approximated residential influence and was measured as the number of buildings (excluding greenhouses) located within 250m of the centre of the field using arcGIS. A building was a freestanding space enclosed by at least four walls and a roof (eg. a single family home, a barn or a garden shed). For larger buildings such as schools, apartment buildings and municipal buildings, each wing was assigned as a building. Distance to a busy road was calculated as the shortest linear distance from the centre of the field to the nearest of 4 roads that had steady traffic both day and night using the Point Distance tool in *ET Geowizard* extension in arcGIS. The perimeter road value was proportion of the total perimeter composed of roads by inspecting *GoogleEarth* images (Table 4.1).

Commuting cost to a field was calculated as the shortest linear distance from the centre of the field to a dyke, which represents the edge of the marine roosting area, using *ET Geowizard*. Distance to a greenhouse was described by measuring the shortest linear distance from the centre of the field to the nearest of 6 large greenhouses using *ET Geowizard*. Presence of water was calculated as whether a deep ditch, slough, pond or the dyke was within an average field length (~300m) of the study field by inspecting *GoogleEarth* images and ground-truthing. The presence of deep water was selected since standing water in the fields was frozen due to sub-zero temperatures during the study period (Table 4.1).

4.2.6.   Model testing and selection

Although commuting cost was deemed an important variable, it was dropped as commuting cost was collinear with presence of water (Pearson correlation: r_p=-0.5), distance to a greenhouse (r_p=-0.38) and distance to a busy road (r_p=0.35) and therefore not an independent variable. With greater distance from the dyke, road density increases and field size decreases resulting in high collinearity. Similarly, large greenhouses are only located close to the dyke contributing to low variance in this parameter. Finally, as water on the foreshore side of the dyke was considered a major water body in presence of water, fields further inland had lower presence of water scores, resulting in collinearity with commuting cost. Sightlines was dropped due to highly collinearity with activity (r_p=-0.43). Fields with buildings beside them had more tall structures on their perimeter than

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places with few or no buildings causing sightlines values to drop with increasing numbers of buildings. Perimeter road (r_p=0.35) was collinear with sightlines since sightlines improved with increasing roads on the perimeter. Field area was used to calculate total energy content of a field and was dropped since it was positively collinear with energy (r_p=0.99) and shown low correlation with dropping density (r_p=-0.07).

I used general linear models and an information-theoretic approach to investigate whether mean dropping density was influenced by danger, distance to a greenhouse, presence of water, energy or combinations of these variables (Burnham and Anderson 2002). Nineteen *a priori* candidate models were chosen that represented alternative hypotheses describing duck distributions (Table 4.2). Models included distance to nearest road, perimeter road and activity, distance to a greenhouse, presence of water and energy as individual, additive, and interactive effects. I tested the influence of all two-way interactions in the global model. The interaction between perimeter road and distance to a greenhouse had a large influence on the model fit and was included in the candidate set. To represent additive effects of danger on duck spatial use I included or excluded the three danger variables as a single group in the candidate models (after Zydelis et al. 2006). The danger variable included distance to a busy road, activity and perimeter road. Variables were tested for normality (Shapiro-Wilk's test) and homogeneity of variance (testing model residuals against fitted values). Variables were normally distributed and homoscedastic.

I calculated Akaike's Information Criterion corrected for small sample size (AIC_c) for each model from the maximum likelihood deviance (deviance = -2 x log-likelihood). Models were ranked according to their AIC_c score, calculated as the difference between a model's AIC_c value and that of the best supported model in the candidate set. Support for each model was given by the Akaike weight (AIC_w), which represents the probability of the model given the data in relation to all other models in the candidate set. Parameter likelihoods for each explanatory variable were calculated to assess an individual variable's relative importance within the candidate model set. Because we included or excluded danger variables as a group, the parameter likelihood values for these variables are constrained to be identical. R^2 values summarize the proportion of total variance accounted for by the variables in each model and model averaging was used to determine parameter estimates.

Analyses were performed in the R platform (R Development Core Team 2011).

4.3. Results

Mean dropping density was highly variable between fields (mean density = 2.4 droppings/quadrat, range = 0-47.5 droppings/quadrat, n=43). The best-supported model included the three danger variables plus distance to a greenhouse and the interaction of perimeter road with distance to a greenhouse (Table 4.3). The next most parsimonious model included the danger variables plus distance to a greenhouse, presence of water and the interaction term with delta AIC_c of 1.41 relative to the best supported model and with a model weight of half that of the best supported model (w_i=0.25). Models containing energy neither ranked among the top two models (Table 4.3) nor fell within 2 deltaAIC$_c$ values. Model fit, based on R^2, and model support, based on deltaAIC$_c$ values, were high when both the danger variables and distance to a greenhouse variable were included and fell dramatically when they were removed, indicating that these four attributes explained most of the variation in mean dropping density. Similarly, summed Akaike weights for both distance to a greenhouse and danger variables were nearly 1 (Table 4.4).

Patterns of mean dropping density followed the danger predictions by decreasing with increasing danger. Mean dropping density increased as fields: 1- were further from a busy road, 2- had lower activity values (smaller numbers of nearby buildings) and 3- had a smaller proportion of the perimeter comprised of roads (Table 4.4). Also following prediction, fields closer to greenhouses had higher dropping densities than fields further away (Table 4.4). The interaction of perimeter road by distance to a greenhouse showed that in fields absent of roads, dropping densities were higher in fields near a greenhouse than further away. But, as a field's perimeter became more dominated by roads, the use of fields near greenhouses declined (Figure 4.2). Model averaging (weighted parameter estimates and associated unconditional standard errors) indicated that none of the variables in the top candidate model were reliable predictors of mean dropping density in a field (Table 4.4). Mean dropping density declined with distance to a busy road and perimeter road, although the 95% CI broadly overlapped zero. Similarly, the relationship with distance to a greenhouse and the interaction term were both flat and the 95% CI

overlapped zero. The parameter likelihood for presence of water demonstrated a negative relationship to mean dropping density. Although presence of water was the only variable with a parameter estimate considerably higher than a 95% CI from zero, the parameter likelihood was low (Table 4.4). Energy content of a field explained no additional variance in mean dropping density in a field. The relatively small energy parameter likelihood and R^2 value suggested that energy had no important effect on mean dropping density (Table 4.4).

4.4. Discussion

Danger and presence of a greenhouse were the primary determinants of dropping densities in the Fraser delta. Duck mean dropping density was more strongly influenced by the proximity to buildings, roads and greenhouses than the presence of water or food availability. Interestingly, presence of a road adjacent to a field had a dampening effect on the attraction to greenhouses but duck use was higher in fields near a greenhouse with no surrounding roads. Field energy content and the presence of water were generally poor predictors of mean dropping density. I did not detect an effect of field energy content on the amount of use by ducks and model averaging for the presence of water were low. This initial test of the relative effects of field parameters suggests that avoidance of danger and attraction to greenhouses are primary determinants of duck distributions in the Fraser delta during the peak period of upland use.

Variables that garnered the most support in explaining patterns of mean dropping density are those describing danger. Occurrence of the danger variables in the top two models coupled with their high parameter likelihoods speak to the important role of danger in patterns of field selection. Use of a field increased the further it was situated from a busy road, as seen in several goose species that winter in Europe. In northern England, fields where pink-footed geese could forage further from a road were depleted to a greater extent than those where they could not avoid foraging near a road (Gill 1996). Daytime occurrence of pink-footed and greylag geese was higher in fields further from roads (Newton and Campbell 1973) and the distance to a busy road for fields that were used was further than the distance from the centre of random fields to roads (Keller

1991). In the Fraser delta, mean dropping density also showed to be influenced by the amount of roads on a field's perimeter. The interaction term showed that if one or more edges of a field contained a road the amount of use of a field was more strongly driven by avoidance of a road than attraction to a greenhouse.

The number of buildings within 250m of a field (activity) was negatively related to mean dropping density. I showed previously (Chapter 2) that the presence of a residential area strongly impacted both where ducks spent their time in a field and their cumulative use across a wintering season. Inclusion of activity in the danger models made an important contribution to the models (Table 4.2). Ducks appear to select habitat by responding to building density. Taken with the findings from previous chapters, a high density of buildings of any kind in the vicinity of a field can have as much of a negative influence on field use as a residential edge. In northern England, field use by brent geese (*Branta bernicla*) and greylag geese (*Anser anser*) was higher in fields located greater than 550m and 120m from the nearest building, respectively (Vickery et al. 1997). In this study, the cause of low cumulative use of fields adjacent to a residential area was interpreted as a response to high levels of danger from a variety of disruptive sources (Chapter 2). Pink-footed geese are susceptible to high levels of anthropogenic activity (Madsen 1985) while greylag geese are intolerant of anthropogenic activity from humans and cars. Regardless of the cause, two independent datasets (Chapter 2, this Chapter) demonstrated that waterfowl responded negatively to the presence of residential buildings.

Until recently, studies of waterfowl habitat use in the Fraser delta had focused largely on relating field use to landscape attributes. Danger was absent from these studies but several studies have alluded to its influence. A waterfowl carrying capacity study in the Fraser delta incorporated buffers to account for observed edge avoidance in calculations of the coverage and height of grass required to sustain the population (Buffett 2007). Buffett subtracted 25% of each field's area from his carrying capacity models, representing the four edges of each field observed to be absent of grazing evidence. Similarly, Duynstee (1992) and Mayoral (1995) observed that lower grazing evidence could be attributed *post hoc* to the presence of edges containing taller structures or roads. These observations inspired the hypothesis that habitat selection may be influenced by considerations of relative danger. My modeling approach tested

the relative strength of the various landscape attributes and danger in influencing habitat selection using an independent dataset. This one-year study found stronger support for the role of danger than for other landscape attributes that traditionally were used to explain habitat selection such as energy and presence of standing water. Observing a similar relationship between selection patterns and presence of a greenhouse in the present model as that found in the first data chapter lends additional support to the strength of this relationship.

Models of duck habitat use in the Fraser delta may strengthen with the inclusion of danger variables. One previous approach (Merkens et al. 2012) used spring damage estimates to inform patterns of field use by waterfowl in relation to forage availability and landscape attributes including crop composition, commute distance, field area and conditions that promote formation of standing water. Using an information-theoretic approach they found that the availability of alternate food sources and the forage value of grass within a field best explained the proportion of a field to be grazed. Absent from these models was consideration of danger from anthropogenic sources. Although landscape attributes such as energy were included in my candidate set, the models containing danger received greater support, highlighting danger's potential importance in field use patterns. The best supported model in Merkens et al. (2012) explained 13% of the variation in the proportion of the field grazed while the best supported model in my study, containing danger and distance to a greenhouse, explained 41% of the variation in mean dropping density. My study suggests inclusion of danger variables could explain additional variation not accounted for by landscape attributes alone. This follows the findings in a review by Werner and Peacor (2003) where indirect effects of danger on prey are stronger than density effects. Further study is required to confirm the comparative strength of the danger variables' explanatory power.

Duck habitat selection was altered by the proximity of a greenhouse. In this model, the direction of the effect of a greenhouse on duck habitat selection is not immediately clear (distance to greenhouse: weighted estimate = 0.1, unconditional SE = 0.1). However, three findings lend confidence towards birds selecting for areas near greenhouses. First, the top models all contained the greenhouse term and the models explained more information when the greenhouse parameter was included (Table 4.4). Second, in previous work (Chapter 2) I found that birds spent more time at fields beside

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a greenhouse than beside other intensive land use types and more time in patches near the greenhouse. Finally, levels of activity were also previously found to be lower at greenhouses (Chapter 2). Put together, all three of these factors point to greenhouses being an area of lower danger therefore being areas birds select rather than avoid.

Greater habitat use near greenhouses may be a product of balancing avoidance of busy roads and residential areas and minimizing commute costs. Habitat selection was more strongly explained by the incidence of roads, buildings and greenhouses than nearby water and food availability. If ducks are trading off the different landscape attributes including busy roads, buildings and greenhouses then where they choose to settle is at intermediate distances from the foreshore dyke and residential boundary. The intersection of those decisions falls in the central part of the study area which is where most greenhouses are found. Greenhouses are located at intermediate distances from both the foreshore dykes and residential areas (Figure 4.1). Residential areas contain all but one of the roads that are busy at night. Greenhouses are located at intermediate distances from the foreshore dykes and have lower levels of activity and as a result appear to be selected for by ducks.

Not only do greenhouses lie at the intersection of tradeoffs, each variable was correlated with another, complicating the interpretation of results. Firstly, all but one of the busy roads was situated far from the dyke. Distance to a busy road was a strong indicator of mean dropping density. By selecting fields according to distance from a road ducks are also selecting fields in relation to the distance from the roost. Generally, selecting fields away from roads means also selecting places closer to the dyke. Secondly, field area decreased with commuting cost (D. Bradbeer, pers. comm.). Field area was strongly correlated with energy since field area was used to calculate energy. Since fields were larger closer to the dyke and larger fields contain more energy, fields closer to the roost will have more energy than fields further inland. However, the fact that energy was not good at explaining patterns of habitat selection suggests that field area, energy and commuting cost are less important. Finally, sightlines was correlated with activity. Poor sightlines are found in fields close to large numbers of buildings since they produce a visual barrier. Birds spending time near buildings will experience higher levels of danger from both poor sightlines and raised activity levels. Less obstructed sightlines will be found in places beside contiguous crops or roads where detection of danger will

be improved. As with the central locations of greenhouses, the above patterns point to a general pattern of selecting fields that form a tradeoff between the pull of danger and commute distance.

The interaction between distance to a greenhouse and perimeter roads was important in explaining mean dropping density in a field. At fields without roads on the perimeter, mean dropping density was higher for fields closer to a greenhouse than further away. This pattern is comparable to that seen for the distance to a greenhouse variable in this model. I showed previously (Chapter 2) that cumulative mean dropping density was higher in fields adjacent to greenhouses than adjacent to other intensive land use types and densities were higher in patches near a greenhouse than patches further away. However, this relationship was at a within-field scale. For fields with a road on one or two of its edges a decline in mean dropping density with distance from a greenhouse disappeared. In these situations, mean dropping density increased with distance from a greenhouse. A road on one or two sides of a field resulted in a shift away from the greenhouse in favour of avoidance of the road. Fields with one road on the perimeter had increasing usage with distance from a greenhouse. The lowest usage was at fields with half of their perimeter composed of roads regardless of their distance to a greenhouse. The presence of at least one road elicited a stronger behavioural response in the form of avoidance than attraction to a greenhouse.

Presence of water appeared in the second-best supported candidate model. Despite a low parameter likelihood value, large model average values suggested that presence of water is a good predictor of duck mean dropping density. Ducks are thought to be attracted to water features as they provide an escape route from predators, provide necessary lubrication for digestion of large amounts of plant material (Bossenmaier and Marshall 1958; Mayhew and Houston 1989; Duynstee 1992) and may thwart the silent approach of ground predators. However, the direction of the effect was counter to prediction. Dropping densities were higher in fields without a major water body within one field length. One explanation may be the correlation with commuting cost. Since water oceanward of the dyke was scored as a water source, presence of water values were higher beside the dyke. Commuting cost was dropped due to high correlation with presence of water. As a result, low presence of water values represent fields further from

the dyke and closer to greenhouses which may explain why presence of water fell counter to prediction.

A multitude of local studies and stewardship programs (Duynstee 1992, 1995; Buffett 2007; Bradbeer and Halpin 2009; Merkens et al. 2012) have focussed on the influence of grass species composition (Bradbeer and Halpin 2009; Merkens et al. 2012), grass protein and fibre content (Duynstee 1992, 1995) and plant date (Duynstee 1995; Bradbeer and Halpin 2009) and the presence of alternative feeding opportunities (Merkens et al. 2012) in patterns of duck grazing and local carrying capacity (Duynstee 1992; Buffett 2007). This study showed that true metabolizable energy content of a field was a poor predictor of field selection by wintering ducks in the Fraser delta. Distance to a greenhouse, the influence of danger and presence of water performed better at describing duck distributions during peak upland use. This study represents the first exploration of the relative roles of danger and energy in duck habitat use patterns and will encourage further rigorous explorations of these patterns. As it was shown above that energy variables are able to explain less than a quarter of the variation in habitat use decisions it should be wise to improve model fit with inclusion of variables with more explanatory power.

Although the parameter likelihoods showed a strong contribution from danger and distance to a greenhouse in predictions of mean dropping density in a field, the ability to predict how their values changed through space was low. For example, field use decisions were strongly driven by distance to a busy road but the ability to predict mean dropping density at a given distance from a busy road was low. Low predictability may results from the arrangement of fields in the Fraser delta like a patchwork quilt. Suitable grazing habitat is embedded in a matrix of unsuitable anthropogenic features. As a result, from a duck's perspective, cues of habitat suitability may not smoothly grade from one form to another between fields but change abruptly at the interface with an anthropogenic feature. If habitat was distributed contiguously across the study area, like an unbroken savannah or a mudflat, then a habitat characteristic should grade monotonically at the between-field scale. In the patchwork situation, a cover crop field with ideal grazing conditions may have on its four sides a road, a blueberry field, a forage field and a fallow field. Those adjacent fields differ in factors that describe danger and energy. For any given field, conditions in the present patch are unlikely to be similar

in an adjacent field. Ducks can graze in space along the patch but to move to additional habitat that is similar they need to make movements between fields. An explanation may be that each field appears to the ducks as distinct habitat. Whether the lack of predictability of habitat selection from field to field is a result of the patchwork nature of the fields in the Fraser delta deserves further exploration. Wildlife managers and farmers alike will benefit from a more comprehensive understanding of how duck habitat selection decisions change with distance from anthropogenic features that can and cannot be mitigated.

4.4.1. Management applications

This study examined the relative importance of danger, the presence of a greenhouse and the presence of water in wintering duck distribution patterns in Fraser delta farmland. Although this is the first time these hypotheses have been modelled together, the results verify the suggestions of previous researchers (Buffett 2007; D. Bradbeer, pers. comm.) that danger plays an important role in the overall picture. Further rigorous explorations are warranted to strengthen the evidence for the role of danger in regional habitat use patterns.

The citizens of Delta have largely been resistant to expansion of both greenhouses and transportation corridors within Delta's farmland. Loss of farmland to non-agricultural uses is assumed to represent a loss of wildlife habitat, potential livelihood for farmers, food for the region's human population in addition to increased traffic levels in a rural area. The results of this study provide evidence that counters this assumption about greenhouses. Although the building footprint removes availability to open-soil agriculture, the building pulls birds into the area possibly enhancing habitat availability. Concerns may be valid regarding the recent completion of a major truck route through the study area. This study showed that the presence of at least one road has a negative impact on duck habitat selection through avoidance of areas near the road. Examining the interface between roads and greenhouses, as in the interaction term in the present model, provides an opportunity to compare relative impacts of each land use type. Once a road is introduced on one side of a field with an existing greenhouse edge this counteracts the positive effect of the greenhouse. By examining the interaction between the effect of roads and greenhouses we not only learn that one

variable is more persuasive than another on duck behaviour but that the positive effect of greenhouses can be overshadowed by the negative effect of a road. In fact, ducks appeared to shift their response with the introduction of danger to a field that would normally draw them in. This suggests that avoiding dangerous patches is more persuasive than seeking out places with low danger.

The extent of the influence of greenhouses on duck distributions had not previously been recognized. We can also no longer underestimate the role of greenhouses as they have been shown to be an important influence in duck distribution patterns at both the field and regional scale. Much like danger, the presence of a greenhouse should continue to be incorporated into local duck carrying capacity models.

Upcoming and current development projects in the study area may prove to reduce duck carrying capacity. If the responses to dense buildings and nearby roads demonstrated in this model are a consistent pattern, development plans for the Tsawwassen First Nations land and the completed South Fraser Perimeter Road could result in a reduction in the carrying capacity of the area. Spatial patterns demonstrated in this study can inform how to design developments with low danger and where to place them in relation to valuable duck habitat to help minimize the impacts of such developments.

Tables and Figures

Table 4.1. Mean and range of variables used to investigate patterns of duck mean dropping density in farm fields in Delta, British Columbia in winter 2011.

Variable	Mean	Range
Dropping density	2.4	0-47.5
Distance to greenhouse (m)	1970	295.6-4512
Distance to road (m)	2246	76-5703
Buildings within 250 m	15.3	0-239
Distance to dyke (m)	876.8	106.7-2877
Sightline score	1.8	-3.3-4
Presence of water (0/1)	0.2	0-1
Perimeter roads	0.2	0-0.5
Field area (ha)	17.9	1-116.8
Energy (J/ha)	57360000	31490000-375300000

Table 4.2. Candidate models of distribution of wintering ducks in Delta, British Columbia with the number of independent predictors and hypotheses tested.

Models	Predictors	Hypothesis
Energy	3	Distribution is driven by food abundance
Danger	5	Distribution is driven by danger
Presence of water	3	Birds prefer fields close to water
Distance to greenhouse	3	Birds prefer fields closer to a greenhouse
Energy + Danger	6	Distribution is described by a trade-off between energy and danger
Energy + Presence of water	4	Birds prefer fields near water and with high energy content
Energy + Distance to greenhouse	4	Birds prefer fields with high energy content and near a greenhouse
Danger + Presence of water	6	Distribution is described by a trade-off between danger and proximity to water
Danger + Distance to greenhouse	6	Distribution is described by a trade-off between danger and proximity to a greenhouse
Presence of water + Distance to greenhouse	4	Birds prefer fields near a greenhouse and water
Danger + Presence of water + Dist to Greenhouse	7	Distribution is described by a trade-off between danger and proximity to water and a greenhouse
Energy + Presence of water + Dist to greenhouse	5	Birds prefer fields with high energy content, near water and a greenhouse
Danger + Energy + Presence of water	7	Distribution is described by a trade-off between danger and fields with high energy content close to water
Danger + Energy + Distance to greenhouse	7	Distribution is described by a trade-off between danger and fields with high energy content close to a greenhouse
Danger + Energy + Presence of Water + Dist to greenhouse	8	Distribution is described by a trade-off between danger and fields with high energy content close to water and a greenhouse
Danger + Distance to greenhouse + Perimeter road*Distance to greenhouse	7	Distribution is described by a trade-off between danger and proximity to a greenhouse and interaction between danger and attraction

Model	K					

Danger + Distance to greenhouse + Presence of water + Perimeter road*Dist to greenhouse	8		Distribution is described by a trade-off between danger and proximity to greenhouse and interaction between danger and attraction
Global model	8		All five factors collectively shape distribution
Null	2		Distribution covaries with no predictors

Table 4.3.   Model selection results for candidate general linear mixed models used in the evaluation of the relationship between wintering duck mean dropping density and danger, distance to the nearest greenhouse, presence of a water feature and energy content of a field. The number of parameters (K) includes a parameter for the intercept and residual variance. Deviance is equal to -2 x log-likelihood and was used to calculate AIC_c (Akaike's Information Criterion corrected for small sample size). Competing models were ranked according to ΔAIC_c and Akaike weight ($AIC_c w$). The number of observations used for all models was 43.

Model	K	Deviance	AICc	ΔAICc	AICc w	R²
Danger + Greenhouse + Road*Greenhouse	7	1460.02	168.78	0.00	0.50	0.40
Danger + Greenhouse + Water + Road*Greenhouse	8	1405.96	170.19	1.41	0.25	0.42
Danger + Greenhouse + Water + Energy+ Road*Greenhouse	8	1458.87	171.78	3.00	0.11	0.40
Danger + Greenhouse	6	1701.08	172.48	3.70	0.08	0.30
Danger + Greenhouse + Energy	7	1680.75	174.83	6.05	0.02	0.30
Danger + Greenhouse + Water	7	1697.56	175.26	6.48	0.02	0.30
Null	2	2412.50	177.47	8.70	0.01	0.30
Global Model	8	1677.00	177.77	8.99	0.01	0.31
Greenhouse	3	2358.27	178.81	10.03	0.00	0.02
Water	3	2374.55	179.10	10.33	0.00	0.02
Energy	3	2401.77	179.59	10.82	0.00	0.00
Water + Greenhouse	4	2312.98	180.41	11.64	0.00	0.04
Energy + Greenhouse	4	2324.71	180.63	11.85	0.00	0.04
Energy + Water	4	2368.34	181.43	12.65	0.00	0.02
Danger	5	2270.95	182.19	13.42	0.00	0.06
Energy + Water + Greenhouse	5	2287.35	182.50	13.73	0.00	0.05
Danger + Water	6	2250.14	184.51	15.73	0.00	0.07
Energy + Danger	6	2266.34	184.82	16.04	0.00	0.06
Danger + Energy + Water	7	2245.25	187.28	18.51	0.00	0.07

Table 4.4. Parameter likelihoods, weighted parameter estimates, and unconditional standard errors for each explanatory variable included in the candidate model set. Likelihoods represent the weight of evidence that a parameter explains meaningful variation in the response variable (mean dropping density).

Variable	Parameter likelihood	Weighted estimate	Unconditional SE
Intercept	1.00	-4.56	2.73
Distance to busy road (m)	0.98	0.00	0.01
Perimeter roads	0.98	-2.74	5.84
Activity	0.98	-0.02	0.03
Distance to a greenhouse	0.99	0.01	0.01
Presence of water (0/1)	0.27	-0.88	0.67
Energy (J/ha)	0.12	0.00	0.01
Perimeter road*greenhouse	0.85	0.00	0.00

Figure 4.1.   Study fields within the Fraser delta, British Columbia.
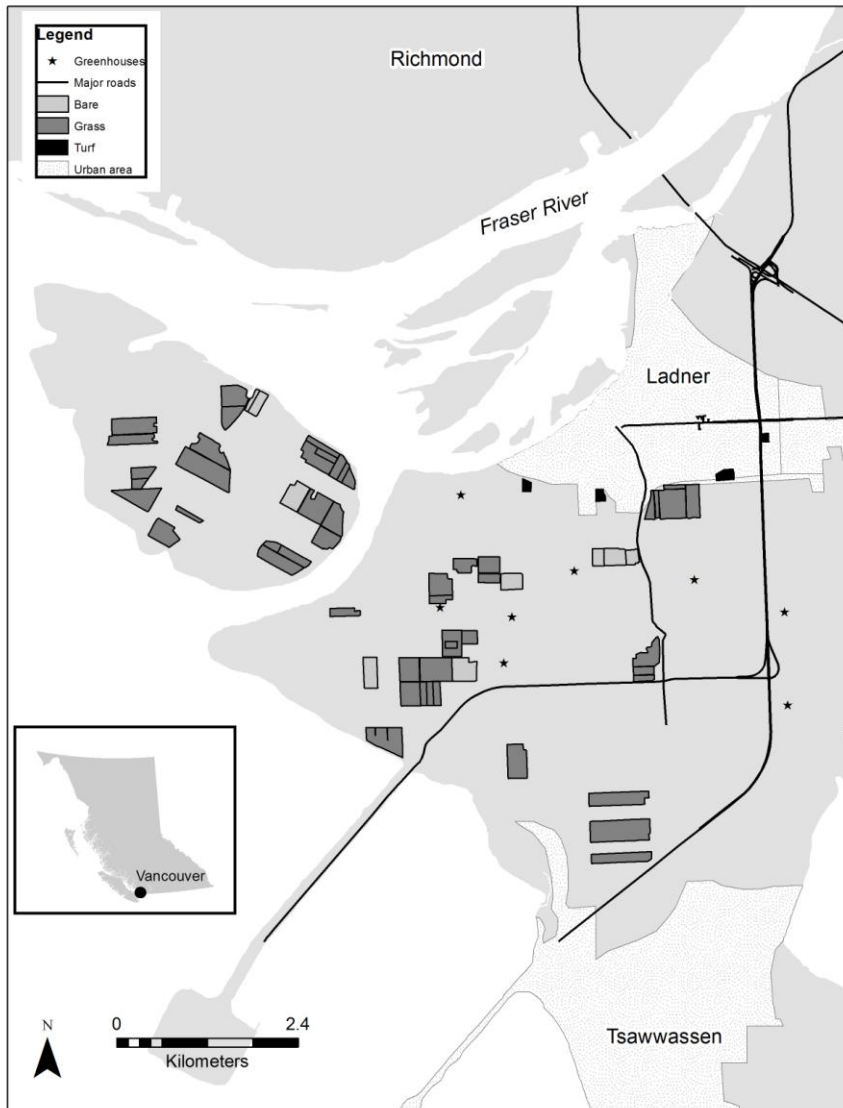
Figure 4.2.   Habitat selection by wintering ducks in response to the proximity to roads and greenhouses in Delta, British Columbia. The relationship between mean dropping density and the interaction between proportion of a field's perimeter comprised of roads and distance to nearest large greenhouse. 'No roads' denotes no roads on the perimeter, 'quarter roads' denotes a road on one of four edges and 'half roads' denotes roads on two edges. The y-axis was log-transformed to aid visualization.
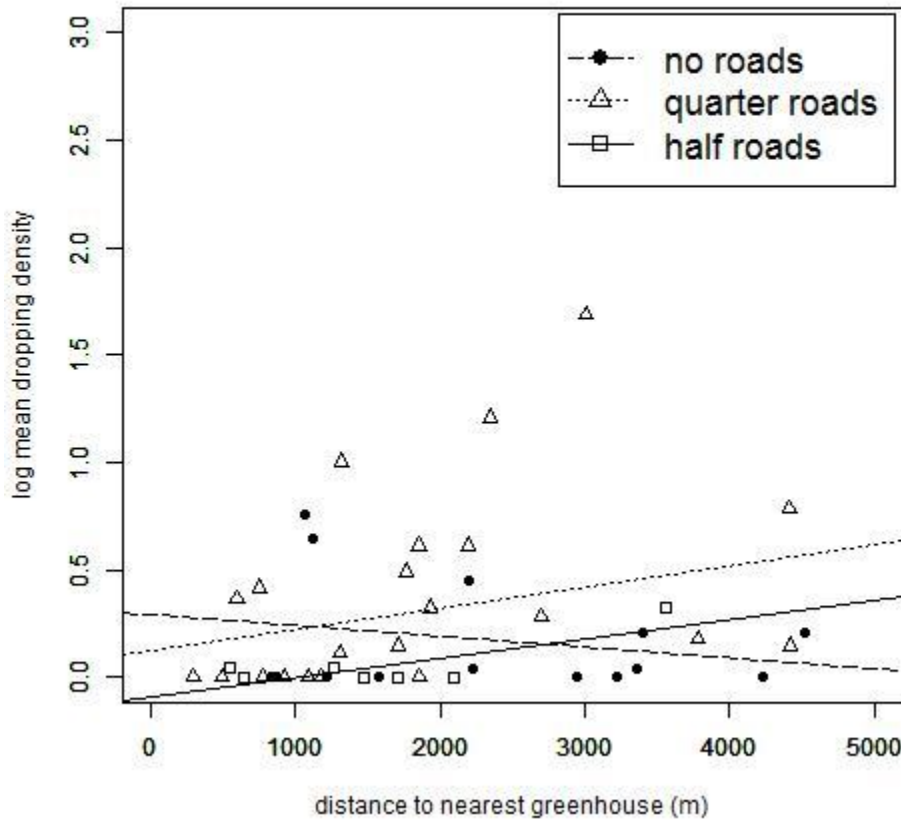
Chapter 5.

Conclusions and Synthesis

This study has contributed towards a more comprehensive understanding of the factors influencing duck habitat selection in the Fraser delta. The findings also speak more generally to how danger from the shadow imposed by an interface with any urban landscape can alter the distributions of foraging animals. Despite the large body of existing knowledge on the relationship between agriculture and wildlife we are just beginning to understand the role of the response to danger from activity, possibly the most influential factor in duck patch selection decisions. Using a predation danger framework and a well-established dropping density method I showed that the presence of some types of intensive land use strongly influenced the foraging distribution of wintering ducks at both the field and landscape scale. We now better understand the relative danger of a suite of intensive land use types and how their presence and placement impact carrying capacity and habitat availability. These findings are further being applied to habitat carrying capacity modelling at the Pacific Flyway scale and will be instrumental in applications such as environmental assessments, habitat mitigation and responses by other species of birds to expanding anthropogenic activities.

The impetus for this study was concern from the citizens of Delta about cumulative impacts of the presence of greenhouses and other intensive land uses on migratory birds. The prevailing assumption was that, in addition to direct loss of habitat from the greenhouse footprint, its presence beside suitable habitat had a negative impact on waterfowl habitat. My unbiased approach of examining patterns of habitat selection in relation to a suite of intensive land use types falsified the existing assumptions. Counter to assumptions, ducks not only used fields adjacent to greenhouses at higher intensities than any other intensive land use type, they spent more time in patches close up than further away. Furthermore, residential areas cast the largest shadow. They were avoided in most cases and those that did show use were

used by small numbers of ducks at the end of the season far away from the intensive land use. Ducks showed some avoidance of fields adjacent to roads and no strong attraction or avoidance of areas beside a berry field. Similarly, greenhouses were the first intensive land use type to show evidence of use each winter while residential areas were the last to be used. These findings underscore the importance of collecting data using an unbiased approach and not using untested, prevailing assumptions to inform management decisions.

The discovery that activity levels were lower at greenhouses than either residential areas or roads and that roads and residential areas had similar, high levels of activity fell counter to prevailing assumptions. The low level of activity at greenhouses explained why intensity of use at greenhouses was higher than at residential areas and roads. High intensity of use at greenhouses may result from infrequent activity events that flush ducks away or from the propensity of ducks to return repeatedly to fields where they can forage undisturbed (or both). This is the first study to measure relative activity levels at a suite of different intensive land use types and perhaps it will inform further understanding of disruptive and attractive cues for ducks. Pairing the dropping density technique with measurements of spatial use (whether dropping density or another kind of species-appropriate measure) can be carried over to other kinds of urban land use in a variety of settings. By taking care to measure cumulative responses to anthropogenic activity and understanding the nature of a species' response to danger, this technique can be applied to systems as far-removed as the response of ungulates to boreal industrial development or forest birds to increased rail traffic.

Given that the intensity of upland use by ducks cycles between day and night and danger is likely different between the time periods due to the diurnal cycle of activity at intensive land use types, I wanted to understand whether the spatial use of fields also varied between night and day at the different intensive land use types. Counter to two previous studies, ducks showed no difference in the intensity of use of upland fields between night and day nor did they differ in proportion of time spent vigilant between day and night. The above findings deserve more focus and it would in particular be important to learn whether the difference lies in the underlying methodologies or a true shift in habitat selection.

This is the first study to compete the major hypotheses currently used to explain patterns of duck habitat use. This study showed that activity and the presence of greenhouses had a larger influence on duck distributions than did field energy content or the presence of standing water. I discovered that ducks respond to cues at the field scale such that conditions outside of a given field have little influence on the decisions made within a field. I encourage further rigorous explorations that compete many of the major hypotheses of activity, plant date, nutrient content and standing water across a winter at both field and regional scales.

In whole, my study progresses the field of foraging ecology beyond the realm of waterfowl wintering in the Fraser delta. I used the theoretical underpinnings of the research by Gill and colleagues on pink-footed geese in Europe (Gill 1996; Gill et al. 2001) but relied upon dropping densities to measure cumulative use which provides a picture of impacts on a seasonal scale. This allowed me to compare responses to a variety of intensive land uses in order to put activity from a variety of intensive land use types in context of one another and the region as a whole. It also permitted expansion of the results to inform carrying capacity models at the most high-profile intensive land use types for conservation groups tasked with managing waterfowl habitats and populations. My study also expands upon 'giving up density' theory by demonstrating that foragers can respond in a manner much like a 'giving up density' to danger arising not only from predators and landscape cues, as in the typical GUD models, but to urban features and anthropogenic activity. It showed that foraging ducks respond to variation in anthropogenic cues using a danger tradeoff (Frid and Dill 2002) and reinforces the flexibility of the GUD technique by being applied to a system far removed from gerbils in the Negev desert. Finally, by measuring the response to a suite of visual barriers and diving deeper into the components of those barriers that correlated with danger I expanded the literature on anthropogenic and environmental cues that correlate with danger.

5.1. Recommendations

A careful understanding of how animals respond spatially and cumulatively to danger allows the results to be applied to a suite of applied situations including land

acquisition, habitat mitigation, refining estimation of carrying capacity and waterfowl deterrence. The methods can also be adjusted to inform the cumulative impacts of a variety of anthropogenic activities beyond the Fraser delta and waterfowl themselves.

Habitat managers can use the preference for greenhouses and the strong avoidance behaviour towards residential areas to their advantage when planning which parcels of land to acquire. If the goal is to maximize duck foraging habitat availability then managers should prioritize the purchase of parcels away from residential areas and busy roads and near a greenhouse, berry field or other contiguous open-soil habitat. In a similar vein, farmers can reduce grazing damage by taking advantage of avoidance of certain intensive land use types by planting cash crops in fields beside residential areas or roads. Several turf fields in the study area with two residential areas were strongly avoided, suggesting this may be possible. Should the footprint of greenhouses expand, this study's findings suggest that direct loss through the building footprint can be partially mitigated by attracting ducks and strategic crop planting. These two strategies could supplement the existing forage compensation program and the strategies of planting lure crops and early seeding of cover crops.

A current application of my results is using the response to the intensive land use types to increase precision of carrying capacity models. Ducks Unlimited Canada has developed a 'TRUEMET' model that calculates the area of habitat available for wintering ducks to assess progress towards conservation targets. Until now these models had not incorporated activity. I used dropping density data to produce 'buffer' values specific to residential areas and roads. Ducks Unlimited Canada is using these values to subtract from the total area of habitat the area adjacent to all residential areas and roads that will experience lower than average amounts of ducks use. In this way my results can be reconfigured to inform management activities and produce projections of habitat availability under any number of future development scenarios. This application is soon to be applied to models at the 'Joint Venture' scale.

Beyond understanding how ducks in fields within the Fraser delta respond to land uses particular to the region, the theory applied and methods developed in this study can be used to model the role of danger in habitat selection under a multitude of types of anthropogenic activities. A sampling of applications include discouraging waterfowl and

other birds from venturing onto airport runways, tailings ponds and landfills by designing the configuration of these intensive land uses to increase danger associated with them. The methods can also be expanded to anthropogenic activity along expanding energy transportation corridors such as rail lines and tanker routes. To ensure that the response to danger is appropriately measured, further investigations should keep an eye to how danger alters spatial use, how danger is a tradeoff among a variety of variables and that more subtle behaviours like cumulative use reflect more profound cumulative impacts.

5.2. Future research

Danger may influence not only when upland use begins but also in what region of their wintering range ducks spend their time. In the winter of 2010-2011 duck use of the study fields was lower than in previous years. That same year, bald eagle numbers were higher than in previous years. These observations suggest that danger affects local abundance of ducks. One key research area would be to explore the role of variation in predator abundance in both the local abundance of ducks across a season and timing of onset or extent of nighttime upland use.

Danger may also drive the timing of the switch from offshore to upland use. Baldwin and Lovvorn (1992) suggested that upland use begins in mid-November when eelgrass availability declined sharply to damage from winter storms and intense grazing. At that same time bald eagle numbers rise. Further studies should explore the connection between the timing of eagle arrival and the switch to upland use. It would be useful to understand whether upland use is a result of ducks switching from the less profitable depleted eelgrass to a more profitable upland grass food source. If this switch is driven by food profitability then the shift should occur when the profitability of eelgrass just dips below that of upland grasses. If the shift is in response to rising danger when eagles arrive then it will be independent of the profitability of the two food sources. If ducks shift to upland use at night to avoid danger from hunters then we would expect them to begin this behaviour as soon as they arrive in the area. But that is not the case. They start this mid-way through the hunting season.

Commuting behaviour, where ducks move between foraging and roosting areas, may be a common pattern not only in the Fraser delta. In the Netherlands there are two wintering populations of Eurasian wigeon that display different temporal patterns of habitat use. A 'commuter' population spends the night on land and the daytime offshore, while a 'resident' population, found further northwest, spends 24 hours on land. This striking difference in temporal habitat use has been documented by the Dutch research group, *Alterra*, in a radiotelemetry study (Boudewijn et al. 2009). Two possible explanations for the differences in behaviour are differences in land-based activity levels between the two sites and differences in danger on land at the two sites. It would also provide an opportunity to explore the role of interannual variation in predator abundance on the propensity of the population to maintain these different strategies.

As human populations grow and cities spread and densify wildlife will face increasing pressure to adapt to the urban environment. Learning how well animals adapt and how best to mitigate for those that do not adapt well is an ongoing task for wildlife managers and city planners. Counter to presumptions, my work showed that not all forms of anthropogenic activity have negative impacts on wildlife. In fact, many species that coexist with urban environments appear to be readily adaptable to the presence of anthropogenic land use, such as ducks and greenhouses. Although the urban footprint will expand it can be mitigated or minimized by a more thoughtful approach and careful understanding of the way wildlife respond to anthropogenic features in their habitat.

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Appendix A.

List of Summarized Studies

1. Burgess, T. E. 1970. Foods and habitat of four Anatinids wintering on the Fraser delta tidal marshes. MSc thesis, University of British Columbia.

2. Jury, D. N. 1981. The health status of waterfowl populations in a designated agricultural area of the Fraser delta. Fish and Wildlife Branch Ministry of Environment Report.

3. Hirst, S. M. and C. A. Easthope 1981. Use of agricultural lands by waterfowl in southwestern British Columbia. Journal of Wildlife Management 45: 454-462.

4. Eamer, J. 1985. Winter habitat for dabbling ducks on Southeastern Vancouver Island British Columbia. MSc thesis, University of British Columbia.

5. Butler, R.W. and R. J. Cannings 1989. Distribution of birds in the intertidal portion of the Fraser River delta, BC. Canadian Wildlife Service Technical Report Series No. 93.

6. unpublished 'Bird Blitzes' 1990-93, conducted by BC Ministry of Fish and Wildlife, Vancouver Natural History Society, Canadian Wildlife Service, Ducks Unlimited.

7. Baldwin, J. R. and J. R. Lovvorn 1992. Abundance, distribution and habitat requirements of American Wigeons, Northern Pintails and Mallards in farmlands. *In*: Abundance, distribution and conservation of birds in the vicinity of Boundary Bay, British Columbia. Canadian Wildlife Service Technical Report Series No. 155.

8. Breault, A. M. and R. W. Butler 1992. Abundance, distribution and habitat requirements of American Wigeons, Northern Pintails and Mallards in farmlands. *In*: Abundance, distribution and conservation of birds in the vicinity of Boundary Bay, British Columbia. Canadian Wildlife Service Technical Report Series No. 155.

9. Duynstee, T. 1992. An investigation into field grazing by wigeon in Delta, British Columbia. Greenfields Project Report.

10. Duynstee, T. 1993. The Greenfields Project Interim Report. Greenfields Project Report.

11. Baldwin, J. R. and J. R. Lovvorn 1994. Expansion of seagrass habitat by the exotic Zostera japonica, and its use by dabbling ducks and brant in Boundary Bay, British Columbia. Marine Ecology Progress Series 103: 119-127.

12. Baldwin, J. R. and J. R. Lovvorn 1994. Habitats and tidal accessibility of the marine foods of dabbling ducks and brant in Boundary Bay. Marine Biology 120: 627- 638.

13. Duynstee, T. 1995. Further investigation into field grazing by wigeon in Delta, British Columbia. Greenfields Project Report.

14. Hatfield, J. P. and G. E. J. Smith 1995. Waterfowl responses to seasonally flooded fields in Alaksen National Wildlife Area, 1980-1991. Canadian Wildlife Service Technical report Series No. 232.

15. Mayoral, C. S. 1995. Waterfowl farmland use in Delta, British Columbia: A remote sensing/GIS analysis. MSc thesis University of British Columbia.

16. Summers, K. 1995. Winter wildlife use of spring cereals in Delta, B.C. November 1994 to March 1995. Greenfields Project Report.

17. Lovvorn, J. R. and J. R. Baldwin 1996. Intertidal and farmland habitats of ducks in the Puget Sound region: a landscape perspective. Biological Conservation 77: 97-114.

18. Summers, K. R., K. Fry and R. McKelvey 1996. Aerial surveys of waterfowl and gulls on the Fraser River delta, 1995-96. Canadian Wildlife Service Technical Report Series No. 260.

19. Smith, D.W., K. Moore, K. Fry, D. Buffett, J. Komaromi and M. Porter 1998. Winter waterfowl use of Westham Island: 1995-1997. Canadian Wildlife Service unpublished report.

20. Butler, R. W. 1999. Winter abundance and distribution of shorebirds and songbirds on farmlands on the Fraser River delta, 1989-1991. Canadian Field Naturalist 113: 390-395.

21. Shepherd, P. 2001. Space use, habitat preferences, and time-activity budgets of nonbreeding dunlin (*Calidris alpina pacifica*) in the Fraser River Delta, B.C. PhD Dissertation, Simon Fraser University.

22. Evans-Ogden, L. J. 2002. Non-breeding shorebirds in a coastal agricultural landscape: winter habitat use and dietary sources. PhD dissertation, Simon Fraser University.

23. Buffett, D. 2006. Classifying agricultural land in an urban landscape with application to waterfowl conservation. MSc thesis, Simon Fraser University.

25. Bradbeer, D. R. 2007. Lesser Snow Geese and agricultural habitat use on the Fraser River delta. MSc thesis, University of British Columbia.

26. Merkens, M, D. R. Bradbeer and C. A. Bishop 2008. Landscape level habitat patterns and field characteristics in relation to winter waterfowl damage to perennial forage crops on the lower Fraser River delta, BC, Canada. DFWT unpublished report.

1. Foods and habitat of four Anatinids wintering on the Fraser delta tidal marshes.

Author: Tom Burgess

Citation: Burgess, T. E. 1970. Foods and habitat of four Anatinids wintering on the Fraser delta tidal marshes. MSc thesis, University of British Columbia.

Sponsoring agencies: University of British Columbia, Canadian Wildlife Service,

Canadian Industries Limited, Alberta Department of Lands and Forests

Date: September to May 1965-67

The earliest known study on waterfowl-habitat associations in the region described the diet of ducks and their use of the marsh and foreshore in the Fraser delta. Burgess studied the relative use of different marsh zones from Iona to Point Roberts and east to the Serpentine-Nicomekl River by the 4 most abundant duck species. Using aerial surveys conducted every 2 weeks to 2 months from September to May 1965-1967 he described spatial and seasonal patterns of duck abundance in the region. He used transects to map the area and topography of the marshes and the distribution and abundance of marsh vegetation. He related patterns of marsh vegetation to the diets of ducks collected from each area. He estimated marsh productivity across the region and relate this to duck distributions to provide an index of relative importance of different marsh habitats. Numbers and species composition of ducks fluctuated between years with the largest numbers counted in spring and fall migration. He recognized that ducks wintering in the region made use of both marine and upland habitats and that agricultural areas provided the majority of duck food during the winter. Tidal marshes attracted half of the ducks wintering in the area and were important winter loafing areas. The highest plant productivity occurred in the upper marsh. Duck diets differed with mallard, pintail and teal consuming mostly seeds and wigeon relying mostly on green vegetation.

2. The health status of waterfowl populations in a designated agricultural area of the Fraser delta.

Author: Douglas N. Jury

Citation: Jury, D. N. 1981. The health status of waterfowl populations in a designated agricultural area of the Fraser delta. Fish and Wildlife Branch Ministry of Environment Report

Sponsoring agencies: Fish and Wildlife Branch Ministry of Environment, Crop Protection Branch Ministry of Agriculture and Food, Canadian Wildlife Service.

Date: fall and winter 1980-81

Jury studied the effects of Delta agricultural practices on duck health. He described the abundance and distribution of ducks in the upland and foreshore of Delta, Surrey and Richmond during fall/winter 1980-1981. Birds were counted from the air across the region twice weekly and from the ground in Richmond, Westham Isl. and Ladner both during the day (6 times) and at night (9 times). He described duck feeding behaviour during the day and night and their distributions relative to crop type, field characteristics and time of day. He also banded many birds to follow their movements. The report included a study of insecticide-related mortality and testing of scare devices. An estimated 80-90,000 ducks and divers were seen in the study area. 4-5,000 ducks were seen during aerial field surveys from Oct to mid-Feb rising to 20-25,000 from mid-Feb to Mar. He suggests this may result from the close of hunting in Jan. During the day, 85% of birds were seen in Boundary Bay and Roberts Bank, 10% in sanctuaries and 5% on farmland. 32% of ducks seen on farmland were in Delta. Night use of farmland was 10 times higher than day use. He estimated that 50,000 ducks could be feeding on the region's farmfields at night. During the day ducks were seen most frequently on ploughed, ploughed potato and pasture fields. Wigeon were mostly seen in homogeneous flocks and fed mostly at night. Banding work showed high local short-term site fidelity.

3. Use of agricultural lands by waterfowl in southwestern British Columbia.

Authors: Stanley M. Hirst and Christopher A. Easthope

Citation: Hirst, S. M. and C. A. Easthope 1981. Use of agricultural lands by waterfowl in southwestern British Columbia. Journal of Wildlife Management 45: 454-462.

Sponsoring agencies: BC Fish and Wildlife Branch under Agricultural Rehabilitation and Development Act.

Date: October to December 1976

Hirst and Easthope studied the distribution and abundance of waterfowl in the Serpentine-Nicomekl floodplain. They examined the relative use of fields and the foreshore in relation to field flooding, crop type and time of day. Fields were visited during the day from October to December 1976. Numbers of waterbirds in each field were tallied to species with a spotting scope or binoculars from outside the field. A section of foreshore was censused concurrently. Field water cover was measured weekly from the air using a three point scale. Weather conditions were also recorded. Finally, they determined diet composition by collecting ducks. Occurrence of waterbirds at any one place showed considerable variation over time. They determined that the numbers of ducks in the foreshore and uplands were negatively correlated suggesting movements between the two areas throughout the day. They found higher numbers of birds in larger fields and flooded fields. Pintails preferred pasture land while wigeon preferred pasture land and potatoes and avoided hay, cereal and vegetable crops. Mallards showed no significant crop preference. Weather affected the behaviour but not the location of waterbirds. Numbers inland and on the foreshore did not differ with the weather conditions. However, more birds were counted on the ground on days with rain and/or strong winds whereas birds made more flights on calmer days. They found no evidence that the distance from the foreshore to the field influenced field use.

4. Winter habitat for dabbling ducks on Southeastern Vancouver Island British Columbia.

Author: Joan Eamer

Citation: Eamer, J. 1985. Winter habitat for dabbling ducks on Southeastern Vancouver Island British Columbia. MSc thesis, University of British Columbia.

Sponsoring agencies: BC Ministry of Environment, Ducks Unlimited Canada and Natural Sciences and Engineering Research Council of Canada

Date: 1979-1980

Eamer examined the importance of coastal and farmland habitats for ducks wintering on Vancouver Island. She described the relative use of farmfields and the foreshore by ducks, their dietary makeup and their foraging behaviour in each habitat. She found a strong negative relationship between foreshore and inshore numbers suggesting that birds move between habitats throughout the day. The number of ducks at inland habitats was positively correlated with the amount of flooding in the field. In fact, flooding accounted for the majority of the variation in field use. Freezing days resulted in higher relative abundance of birds offshore than onshore. She also described the gut contents of birds collected in several shoreline habitats. Because both marine and upland habitats are used as alternate habitats she suggested that a complex of marine and onshore habitat types should be preserved.

5. Distribution of birds in the intertidal portion of the Fraser River delta, British Columbia.

Authors: Rob Butler, Richard Cannings

Citation: Butler, R.W. and R. J. Cannings 1989. Distribution of birds in the intertidal portion of the Fraser River delta, British Columbia. Canadian Wildlife Service Technical Report Series No. 93.

Sponsoring agencies: Canadian Wildlife Service, Vancouver Natural History Society

Date: March 1988-February 1989

Butler and Cannings described the seasonal distribution and abundance of birds in the intertidal habitats of Delta. From October to December, 250,000 birds were seen, comprised mostly of dunlin and ducks. Numbers of birds were lowest from June to September, except during the shorebird migration. Wigeon were the most abundant duck species. The most heavily used sites included the northwest corner of Boundary Bay and the mouth of Mud Bay.

6. Unpublished 'Bird Blitzes'

Investigators: Andre Breault, Kathleen Moore

Sponsoring agencies: BC Ministry of Fish and Wildlife, Vancouver Natural History Society, Canadian Wildlife Service, Ducks Unlimited

Date: fall and winter 1990-1993

The so-called 'Bird Blitzes' were conducted throughout the Fraser delta to determine the extent of farmland use by ducks. Surveys of duck numbers in farmland throughout Delta, Tsawwassen and Cloverdale were used to establish upland waterfowl abundance and species-habitat associations. Crop type, amount of edge, field perimeter and area, extent of field flooding and distance to foreshore were used to examine these associations. Fields were visited twice per month between October and March by the Canadian Wildlife Service, Ducks Unlimited Canada, BC Ministry of Fish and Wildlife and volunteers with the Vancouver Natural History Society. Ducks within those fields were counted and flock species composition estimated. Counts were made during the day and at night coinciding with the high tide. Fields containing no birds were not included in the dataset therefore the results of this study must be interpreted with caution as the data are biased towards fields that contained birds. Despite this shortfall some exploratory analyses were made. The distance to the foreshore was the most important of the measured factors at describing the pattern of field use by ducks. The highest number of duck-days per hectare was in potato fields, while, for wigeon, total field perimeter was the most important factor along with fragmentation index (the ratio of field perimeter to area). Duck abundance was one order of magnitude higher on Westham Island than anywhere else in Delta.

7. Abundance, distribution and habitat requirements of American Wigeons, Northern Pintails and Mallards in farmlands.

Authors: Andre Breault, Rob Butler

Citation: Breault, A. M. and R. W. Butler 1992. Abundance, distribution and habitat requirements of American Wigeons, Northern Pintails and Mallards in farmlands. *In*: Abundance, distribution and conservation of birds in the vicinity of Boundary Bay, British Columbia. Canadian Wildlife Service Technical Report Series No. 155.

Sponsoring agencies: Canadian Wildlife Service, Wildlife Branch, Ministry of Environment, Lands and Parks, B.C. Environment, Lower Mainland Region

Date: September 1989-April 1990 and October 1990-March 1991

Breault & Butler estimated the numbers of ducks using cropland, described the types of farmland used by ducks and the area of cropland required to support their 1992 populations. Fields and foreshore of Delta and Surrey were visited one day and night each week between Sept 1989-Apr 1990 and Oct 1990- Mar 1991. Birds were counted and the species composition of each flock was estimated using a spotting scope and binoculars or a night-vision scope. There were an estimated 115,000 ducks present in the Fraser delta. Wigeon outnumbered pintail and mallard from November to March. Ducks used all five types of fields (pasture, cover crop, potato, corn stubble and ploughed fields). They found no difference between the day and night densities of duck species in the 5 different field types. However, the highest density of wigeon was found in pasture and vegetable fields during the day and vegetable and ploughed fields at night. A given field was used 64.5 days of the year. Given the population size and reliance on farmland at the time of the study, the three populations would be supported by 14302ha of farmland over 150 days, or 75% of the cropland in the Fraser delta. They determined that the best areas for ducks in the Fraser delta are the Serpentine and Nicomekl river drainages, near the northwest corner of Boundary Bay and south of Ladner village.

8. Populations, diet, food availability and food requirements of dabbling ducks in Boundary Bay.

Authors: John R. Baldwin and James R. Lovvorn

Citation: Baldwin, J. R. and J. R. Lovvorn 1992. Abundance, distribution and habitat requirements of American Wigeons, Northern Pintails and Mallards in farmlands. *In*: Abundance, distribution and conservation of birds in the vicinity of Boundary Bay, British Columbia. Canadian Wildlife Service Technical Report Series No. 155.

Sponsoring agencies: CWS, Wildlife Branch, MOELParks, B.C. Envir, Lower Mainland

Date: September 1990 to March 1991

Baldwin and Lovvorn described the diets of 3 duck species, temporal patterns of food availability in the foreshore, estimated population food requirements and suggested whether existing foreshore habitats could sustain existing populations. Populations were estimated by counting ducks from the foreshore dykes every 7-10 days from Sept 1990-Mar 1991 using a spotting scope. Prey abundance was measured by core sampling in the tidal flats and measuring eelgrass coverage on 3 transects. Foraging behaviour was estimated using time budgets once per week from Oct-Dec 1990. Diets were determined by collecting ducks from Oct to Jan on the foreshore. A peak of about 80,000 ducks occurred in mid-Dec totaling 6.7 million duck-use-days in the bay. Wigeon, pintail and mallard composed 48.7%, 37.6% and 12.8% of flocks, respectively. Ducks spent the majority of their time feeding during tides below 2.3m in height and feeding declined to near zero above 2.6m. All ducks fed on eelgrass but each species fed on a different part. Wigeon fed on eelgrass and seaweed, and grass and pasture species in the uplands. Wigeon acquired 42.6% of their food from tidal areas and 57.4% from uplands between

September 1 and March 31. During the fall, wigeon grazed an estimated 83% of the eelgrass biomass (140 tonnes). After late November, most ducks spent the day in the bay and fed in the uplands at night.

9. An investigation into field grazing by wigeon in Delta, British Columbia.

Author: Theresa Duynstee

Citation: Duynstee, T. 1992. An investigation into field grazing by wigeon in Delta, British Columbia. Greenfields Project Report.

Sponsoring agencies: North American Waterfowl Management Plan, University of British Columbia, BC Federation of Agriculture, Canadian Wildlife Service, Ducks Unlimited Canada, Wildlife Habitat Canada

Date: November 1990-March 1991

The Greenfields cover crop program was initiated in response to increasing grazing pressure on winter crops by waterfowl. The cover crop program promoted soil stewardship while examining the distribution of grazing intensity and factors affecting its extent. In 1992, Duynstee published a report on the program's progress. She highlighted the distribution of grazing impacts throughout Delta and the losses that could be attributed to grazing. She also reported on the results of a study examining the changes in chemical composition of grasses throughout the winter and the factors that attract ducks to farmfields. She found that heavily grazed fields were located throughout Delta, but that the pattern of grazing changed throughout the winter, with regrowth on 30% of the heavily grazed fields being regrazed in late winter. By the spring there was a large difference in biomass between the regrazed fields and the fields grazed heavily only in the winter. The drainage capacity of the fields also impacted regrowth with more regrowth on the fields prone to flooding. Grazing also impacted the spring biomass of fields with a difference in biomass between grazed and ungrazed fields of 925-1042 pounds per hectare.

10. The Greenfields Project, Interim Report

Author: Theresa Duynstee, edited by Bill Wareham

Citation: Duynstee, T. 1993. The Greenfields Project Interim Report. Greenfields Project Report

Sponsoring agencies: North American Waterfowl Management Plan, University of British Columbia, BC Federation of Agriculture, Canadian Wildlife Service, Ducks Unlimited Canada, Wildlife Habitat Canada

Date: November 1991-March 1992

Greenfields published a second report outlining cover crop use by wigeon in fall and winter and the extent of available biomass in Delta. Duynstee found that grazing intensity was lower in the winter of 1991-92 than the previous winter with better crop conditions at the end of the winter of 1991-92. The amount of biomass consumed over the winter was about 325 tons or 29% of the available cover crop. Peak removal occurred from mid-November to mid-January. Grazing was impacted by crop planting date with 78% of grazed fields being planted after September 15th. Use of exclosures provided information about changes in crop biomass, protein content and regrowth. From November to February biomass decreased and protein increased. Regrowth of grazed areas were regrazed and had the highest protein content of all available grasses. The total percent of grass area used was related to biomass in the fall, edge effect and plant date. Finally, Duynstee examined factors explaining month to month grazing patterns.

11. Expansion of seagrass habitat by the exotic Zostera japonica , and its use by dabbling ducks and brant in Boundary Bay, British Columbia.

Authors: John Baldwin and James Lovvorn

Citation: Baldwin, J. R. and J. R. Lovvorn 1994. Expansion of seagrass habitat by the exotic Zostera japonica, and its use by dabbling ducks and brant in Boundary Bay, British Columbia. Marine Ecology Progress Series 103: 119-127.

Sponsoring agencies: Canadian Wildlife Service, British Columbia Waterfowl Society, Institute of Wetland and Waterfowl Research and the US Department of Energy

Date: October 1990-December 1991

Baldwin and Lovvorn described the pattern of eelgrass depletion in Boundary Bay and the diurnal foraging patterns of waterbirds. The percent cover of eelgrass decreased by 88-91% from early fall to mid-winter. Duck numbers increased to 80,000 individuals from September to December and then declined. They reported a drop in duck abundance when the area froze in winter. Ducks spent most of their time feeding when the tide was below mean water level and ceased feeding above mean water level. Mean water level correlated well with the upper extent of the japonica bed. Japonica made up the largest component of the diet in all ducks except green-winged teal. Wigeon consumption of japonica comprised mostly the leaves (84% of gut contents). The authors presented the energetic content of japonica and marina parts. They estimated that ducks and brant consumed 364 tonnes of japonica in 1991-92 which comprised 50.2% of above-ground biomass and 42.5% of below-ground biomass.

12. Habitats and tidal accessibility of the marine foods of dabbling ducks and brant in Boundary Bay.

Authors: John R. Baldwin and James R. Lovvorn

Citation: Baldwin, J. R. and J. R. Lovvorn 1994. Habitats and tidal accessibility of the marine foods of dabbling ducks and brant in Boundary Bay. Marine Biology 120: 627-638.

Sponsoring agencies: Canadian Wildlife Service, British Columbia Waterfowl Society, Institute of Wetland and Wildlife Research of Ducks Unlimited, United States Department of Energy

Date: 1994

Baldwin and Lovvorn studied the abundance and distribution of intertidal invertebrates, the diets of the major overwintering duck species and the relative importance of each intertidal habitat for ducks. They measured the distribution of invertebrates and vegetation and characterized sediment types across elevation using transects running across three intertidal habitat zones. Waterfowl abundance was measured by surveying with a spotting scope from the dike every 7-10 days throughout the fall and winter. Time budgets were taken to estimate the time spent feeding at each tide height. Finally, diet of each duck species was determined by collecting ducks in the bay and examining their gut contents. Peak numbers of ducks was reached in December at 80,000 birds, 80% of which were wigeon, mallards and pintail. Most of the foraging time was spent below the mean water line which represented the upper elevational limit of the eelgrass bed. Eelgrass comprised the largest component of the diet for all 3 duck species, although each species specialized on a different part of the plant. They reported on the abundance and distribution of invertebrates with elevation and sediment type. The tide was low enough for ducks to reach the eelgrass bed for 9.6-10 hours a day from October to December.

13. Further investigation into field grazing by wigeon in Delta, British Columbia.

Author: Theresa Duynstee

Citation: Duynstee, T. 1995. Further investigation into field grazing by wigeon in Delta, British Columbia. Greenfields Project Report.

Sponsoring agencies: North American Waterfowl Management Plan, University of British Columbia, BC Federation of Agriculture, Canadian Wildlife Service, Ducks Unlimited Canada, Wildlife Habitat Canada

Date: November –March 1990-1993

Duynstee published a further Greenfields report expanding on the examination of the impacts of grazing on crop characteristics and field parameters that influence grazing. She found that crops planted in August reached higher biomass and reached a greater maximum height than crops planted in October. She found that the amount of biomass removed by grazing did not differ between years, however the peak in the number of hectares grazed differed between years with a peak in December in 1991-92 and in November in 1992-93. There was also a 1% difference between years in the number of fields with less than 25% cover remaining in the spring. This suggests that the amount of grazing did not change between years although the timing of grazing varied.

14. Waterfowl farmland use in Delta, British Columbia: A remote sensing/GIS analysis.

Author: Celia Sanchez Mayoral

Citation: Mayoral, C. S. 1995. Waterfowl farmland use in Delta, British Columbia: A remote sensing/GIS analysis. MSc thesis University of British Columbia.

Sponsoring agencies: University of British Columbia, Canadian Wildlife Service, Spanish Ministry of Education and Science

Date: 1995

Mayoral examined the factors that influenced field use by ducks in Delta. She used a combination of remote sensing, maps and published bird census data to determine the relationship between locational factors and presence/absence of ducks. She focused specifically on field characteristics that influenced duck use including field size and shape, features of the perimeter, crop type, ponding, and distance from shore. Day and night patterns were also explored. She was not able to find relationships between locational variables and duck presence/absence. However, a few factors revealed some interesting patterns. A high density of border trees and large number of roads reduced daytime field use by ducks. The distance from shore negatively influenced day and night presence-absence of wigeon in fields with green growth. One limitation of the study was the classification of fields into only 2 categories; 'green' (pastures, winter cover crops and old fields) and 'non-green' (harvested and ploughed) despite previous studies showing that each species has more complex habitat associations. This oversight likely resulted in a lack of statistical power when examining species-habitat associations. This was the first study to examine the shadow cast by disturbances on field perimeters in Delta.

15. Winter wildlife use of spring cereals in Delta, B.C. November 1994 to March 1995.

Author: Ken Summers

Citation: Summers, K. 1995. Winter wildlife use of spring cereals in Delta, B.C. November 1994 to March 1995. Greenfields Project Report.

Sponsoring agencies: Ducks Unlimited Canada

Date: November 1994 to March 1995

Summers described the use of spring cereal crops by wildlife in Delta. He found that

32 spp of birds used spring cereal fields; 56-68% were waterfowl. The highest densities of waterfowl were found in barley (255 birds/100ha), winter wheat (125 birds/100ha), old barley (44 birds/100ha) and corn stubble fields (29 birds/100ha). The lowest density was in rye grass fields (0.67 birds/100ha). The location of the field in relation to the foreshore significantly influenced bird use while cover type influenced presence-absence (but not density). The most frequent reported behaviour in cereal crops was foraging (>80% foraging), while in old fields 100% of time was spent resting and in corn stubble 70% of time was spent foraging. He concluded that winter cover crops were less attractive to foraging ducks than traditional winter cover fields.

16. Waterfowl responses to seasonally flooded fields in Alaksen National Wildlife Area, 1980-1991.

Authors: John Hatfield and John Smith

Citation: Hatfield, J. P. and G. E. J. Smith 1995. Waterfowl responses to seasonally flooded fields in Alaksen National Wildlife Area, 1980-1991. Canadian Wildlife Service Technical report Series No. 232.

Sponsoring agencies: Canadian Wildlife Service

Date: 1985-1991

Hatfield and Smith described the influence of water cover on field use by waterfowl in Alaksen. This study arose from a winter field flooding program in Alaksen National Wildlife Area from June 1985 to April 1991. Counts of Canada goose, mallard, wigeon, pintail and green-winged teal were made on each field 3 days a week in the morning using binoculars and a spotting scope. Water depth was measured using a permanent depth gauge. The number of ducks in flooded fields was 19 times higher than in the dry field regime. The highest use occurred in flooded fields at high tide. Fields were not used during freezing weather. Water depth influenced use by mallard, wigeon, pintail and teal but not Canada goose. The abundance of each species was observed to peak at different water levels. The authors suggest that the differences in the depth requirements of each species for foraging may have produced this result. For example, the largest numbers of wigeon occurred at depths between 11 and 19cm while the numbers of longer-necked pintail peaked at 15-25cm. Use of flooded fields varied between species with month and year.

17. Intertidal and farmland habitats of ducks in the Puget Sound region: a landscape perspective.

Authors: James. R. Lovvorn and John R. Baldwin

Citation: Lovvorn, J. R. and J. R. Baldwin 1996. Intertidal and farmland habitats of ducks in the Puget Sound region: a landscape perspective. Biological Conservation 77: 97-114.

Sponsoring agencies: Canadian Wildlife Service, British Columbia Waterfowl Society, Ducks Unlimited Institute for Wetland and Waterfowl Research and United States Department of Energy

Date: 1996

Lovvorn and Baldwin examined the importance of intertidal areas with neighbouring farmland in the Puget Sound region. Beginning in late November wigeon rested offshore and in upland flooded sites during the day and foraged in farmland at night. 75% of the regional population of wigeon was located at intertidal sites near farmland. Sites without adjacent farmland had low duck populations. Alternative feeding sites were important in times of severe winter weather which occurred in 13% of years. Often ducks left the area in severe winters. Descriptions of movement patterns were supported by banding and radio-telemetry.

18. Aerial surveys of waterfowl and gulls on the Fraser River delta, 1995-96.

Authors: Ken Summers, Kathleen Fry and Richard McKelvey

Citation: Summers, K. R., K. Fry and R. McKelvey 1996. Aerial surveys of waterfowl and gulls on the Fraser River delta, 1995-96. Canadian Wildlife Service Technical Report Series No. 260

Sponsoring agencies: Canadian Wildlife Service, Ducks Unlimited Canada

Date: fall and winter 1995-96

McKelvey et al. described the distribution and abundance of waterbirds in the waters and foreshore of Delta. This report summarized 14 aerial surveys conducted through the fall and winter 1995-1996 and placed it in context of the surveys done periodically from 1966 to 1993 (listed below). The goal was to monitor population trends in local waterfowl. The estimated number of birds using Boundary Bay and the Fraser River foreshore was higher than in any previous survey year. Average gull numbers were lower than in 1992-93 but with normal range. Between 1966-74 and 1990 waterfowl numbers counted on aerial surveys were decreasing. Numbers increased between 1990 and 1996 suggesting a reversal of the declining trend. Data are compared to counts made in the US on the Pacific flyway.

Other published surveys referenced in this publication:

McKelvey, R. W., D. W. Smith, G. E. J. Smith and R. A. Keller 1985. Aerial surveys of

migratory birds on the Fraser River delta, 1989-90. Canadian Wildlife Service Technical Report Series No. 109.

McKelvey, R. W. and K. R. Summers 1990. Aerial surveys of migratory birds on the Fraser River delta, 1989-90. CWS technical report series No. 109.

Summers, K., P. Hayes and R. McKelvey 1994. Aerial surveys of waterfowl and gulls on the Fraser River delta, 1992-93. CWS technical report series No. 203.

19. Winter abundance and distribution of shorebirds and songbirds on farmlands on the Fraser River delta, 1989-1991.

Author: Rob Butler

Citation: Butler, R. W. 1999. Winter abundance and distribution of shorebirds and songbirds on farmlands on the Fraser River delta, 1989-1991. Canadian Field Naturalist 113: 390-395.

Sponsoring agencies: Canadian Wildlife Service, BC Ministry of Environment, Lands and Parks, Nature Trust of BC, Ducks Unlimited Canada

Date: October 1990-March 1991

Butler described the behaviour and abundance of shorebirds in farmland. Shorebirds roosted in large flocks on the foreshore. Small groups settled in ploughed fields, turf fields and pasture within 2km of the foreshore. Dunlin and black-bellied plover that used fields from November to March foraged in those fields. Butler also summarized the use of hedgerows by songbirds.

20. Winter Waterfowl Use of Westham Island: 1995-1997

Authors: Dave W. Smith, Kathleen Moore, Kathleen Fry, Dan Buffett, Jason Komaromi and Marian Porter

Citation: Smith, D.W., K. Moore, K. Fry, D. Buffett, J. Komaromi and M. Porter 1998. Winter waterfowl use of Westham Island: 1995-1997. Canadian Wildlife Service unpublished report.

Sponsoring agencies: Canadian Wildlife Service, Ducks Unlimited Canada, BC Waterfowl Society

Date: 1995-1998

Smith and colleagues summarized the Westham Island Waterfowl Surveys in which they described the patterns of daytime field use by waterfowl on Westham Island and Brunswick Point and related their use to migration patterns, the hunting season and the presence of the Alaksen National Wildlife Area. Data were collected during the winters 1995-1998. Peak waterfowl numbers were observed between mid-October and late November. More field feeding was observed in years with higher reproductive success, seen in years with higher proportions of juveniles in the flocks. Alaksen received 80% of waterfowl use despite comprising about 25% of the island's area. The use of Alaksen relative to the rest of the island varied monthly and annually with higher use of Alaksen in all months and higher use in the rest of the island from December to March 1998. Wigeon comprised 80% of the ducks using sloughs in Alaksen during the daytime in November and December. During the hunting season waterfowl remained in Alaksen during the day and moved to agricultural land at night. Once the hunting season ended in January, the use of agricultural lands by waterfowl increased. Waterfowl numbers dropped to less than 5,000 birds during severe winter weather in January 1996.

21. Space use, habitat preferences, and time-activity budgets of non-breeding dunlin (*Calidris alpina pacifica*) in the Fraser River Delta, B.C.

Author: Phillippa Shepherd

Citation: Shepherd, P. 2001. Space use, habitat preferences, and time-activity budgets of non-breeding dunlin (*Calidris alpina pacifica*) in the Fraser River Delta, B.C. PhD Dissertation, Simon Fraser University.

Date: winter 1995-1998

Dr Shepherd's PhD research focused on the use of Delta's coastal and upland habitats by dunlin during the winter. She used observations, telemetry, and GIS to document spatial patterns, site fidelity, habitat preferences and time-activity budgets of dunlin during day and night and throughout the tidal cycle. She used radio-telemetry to describe spatial use patterns and site fidelity and related these to patterns of invertebrate prey density and potential predation risk. Dunlin were highly site faithful with home ranges concentrated on areas of high prey density. Dunlin spent most of their foraging time in areas with high prey density. Dunlin used upland habitat both day and night but night use was considerably higher. Dunlin preferred marine habitats but many individuals were found to use both marine and upland habitats. Soil-based agricultural crops ranked highest in terrestrial habitat use. Pasture was preferred likely due to high invertebrate prey density. Dunlin spent an average of at least 15.7 hours foraging which did not differ with time of day or habitat type. At night they spent at least 7.1 hours foraging and at least 2.9 night hours foraging in uplands. She recommends the maintenance of a mosaic of soil-based agricultural crops with an emphasis on their preferred pasture and larger fields if we are to sustain the wintering dunlin population.

22. Non-breeding shorebirds in a coastal agricultural landscape: winter habitat use and dietary sources.

Author: Lesley J. Evans-Ogden

Citation: Evans-Ogden, L. J. 2001. Non-breeding shorebirds in a coastal agricultural landscape: winter habitat use and dietary sources. PhD dissertation, Simon Fraser University.

Sponsoring agencies: Agric. and Agri-Food Canada, NSERC, Envir. Can. Science Horizons, DFWT, SFU, Boundary Bay Conservation Committee, Pacific Field Corn Association, CWS Pacific Coast Joint Venture

Date: 1998-2000

Dr. Evans-Ogden's PhD research focused on the use of agricultural land by 3 species of overwintering shorebirds; dunlin, black-bellied plover and killdeer. She determined patterns of daytime and nighttime farmland use by each species. Using stable isotope analysis she determined that foreshore intertidal was the main dietary source for dunlin (70% of diet) with the remainder acquired from fields. There was wide variation among individuals in the ratio of marine to upland diet with about 5% of adults and 15% of juveniles acquiring 80% or more of their diet from upland habitats. She contends that the loss of open-soil habitat would impact winter survival of all dunlin but especially juveniles, which rely on upland habitats more than do adults. Crop type influenced field use for dunlin and black-bellied plover but killdeer were not selective. Killdeer used smaller fields than did the other species while dunlin and black-bellied plover used fields closer to the dyke. She discusses the role of weather and moon phase in field use. Manure and fertilizer use, laser leveling and time since cultivation increased the use of fields by shorebirds. Each species varied in their extent of day and night use and across the season.

23. Classifying agricultural land in an urban landscape with application to waterfowl conservation.

Author: Dan Buffett

Citation: Buffett, D. 2006. Classifying agricultural land in an urban landscape with application to waterfowl conservation. MSc thesis, Simon Fraser University.

Sponsoring agencies: Ducks Unlimited Canada, Canadian Wildlife Service, Ministry of Environment, Agriculture and Agri-Food Canada.

Date: 2006

Buffett examined the use of remote sensing technology in identifying agricultural crops in Delta and the application of this knowledge to waterfowl conservation. He describes the technical considerations in compiling this kind of dataset using satellite imaging, orthophotos and ground truthing. Using his data on the distributions of crops in Delta and by varying grass nutrient content, grass quantity and disturbance values in a statistical model he was able to determine how much grass is required to sustain the wigeon population. His model showed that more area of fescue grass than orchard grass was required to support wigeon. Grass height influenced the amount of grass needed since as grass height increased a larger area was required to sustain the duck population. He estimated that, for a population of 75,000 wigeon and with grass height at 10cm, the required coverage of grass would be 1450 hectares; just below the current 1500 hectares growing in Delta. He showed that, if a buffer of 25m around the edge of each field is avoided by the ducks as a result of disturbance, there would be a deficit of 618 hectares.

24. Lesser Snow Geese and agricultural habitat use on the Fraser River delta.

Author: Dave Bradbeer

Citation: Bradbeer, D. R. 2007. Lesser Snow Geese and agricultural habitat use on the Fraser River delta. MSc thesis, University of British Columbia.

Date: 2007

Bradbeer studied patterns of agricultural field use on Westham Island and Brunswick Point by snow geese to better understand how changes in crop quality and quantity influence where geese choose to forage. He examined the role of field size, crop type, hunting season, time of year and crop biomass on use of fields by the geese. He used data from the Westham Island Waterfowl Surveys and contemporary data. From 1995 to 2000 geese used the Alaksen National Wildlife Area during the fall and late winter hunting seasons. Fewer geese fed outside Alaksen NWA during open hunting seasons compared to the closed season. Geese used perennial forage, cover crops, potato, and grain. The main determinant of field use was crop type. Nutrient content influenced the order of crop use with those containing the highest concentrations of crude protein (cover crops) and simple carbohydrates (potatoes and barley) being grazed first. Forage contained the highest concentration of indigestible crude fibre and were not used until the higher quality crops were depleted. Crop biomass did not seem to influence crop use patterns because snow geese initially ignored perennial forage fields that contained more biomass than cover crop and potato fields. In March and April snow geese continued to use perennial forage fields, but also grain stubble and cover crop fields likely due to the presence of newly sprouting forbs and grasses. Geese moved outside Alaksen NWA despite an open hunting season in November 2005 likely due to food depletion.

25. Landscape level habitat patterns and field characteristics in relation to winter waterfowl damage to perennial forage crops on the lower Fraser River delta, BC, Canada.

Author: Markus Merkens, David Bradbeer and Christine Bishop

Citation: Merkens, M, D. R. Bradbeer and C. A. Bishop 2008. Landscape level habitat patterns and field characteristics in relation to winter waterfowl damage to perennial forage crops on the lower Fraser River delta, BC, Canada. DFWT unpublished report.

Sponsoring agencies: Delta Farmland and Wildlife Trust, Canadian Wildlife Service, Delta Farmer's Institute, Delta Forage Compensation Steering Committee

Date: 2008

Five years of historical data were analyzed to determine how field characteristics including forage species composition, drainage, field size, proximity to foreshore roosting areas, occurrence of alternative foods and date of last forage harvest affect the level of grazing on forage grass. They visually estimated crop damage at 202 fields in 10% increments 4 times across each of 5 winters. Using an information-theoretic approach they found that the percentage of orchard grass in the forage composition and field size positively influenced the degree of damage a field sustained. Drainage (laser leveling) and distance from foreshore roosts negatively affected the degree of damage. Date of last harvest, drainage (surface), and abundance of unharvested potatoes did not influence damage to forage. However, the presence of alternative feeding areas is likely an important factor in mitigating damage to forage fields. The conversion of crop fields from vegetable/cover crop and forage grass systems to berry production may intensify the occurrence of forage damage.

Appendix B. Validation of robustness of Activity Index

The activity index was built by log transforming (natural log plus one) the number of events (or the events per minute in the case of "traffic") in each of the six categories, and summing the transformed values for each observation period. Values from the three observations at each field were averaged, and used as the index value for that field.

I tested whether this method of calculating the index created biased values as a result of different frequencies of events occurring in each of the six categories. To do so I recalculated each activity index value by omitting the log transformation on the summed number of events for one of the 6 activity categories and recalculating the index (summing all three sampling visits and taking average of the three sampling visits). This recalculation was done 6 times in total; once for each untransformed event category. Next, I ranked all the fields based on the original activity index values from highest (1) to lowest (20) (tied scores indicated by ranks falling between whole numbers) ('baseline' ranks) and then ranked the fields, in turn, by each of the 6 recalculated activity values. I took the average of the 6 recalculated ranks for each field and compared the average to their baseline ranks. The resulting average ranks do not appreciably alter the baseline ranks, concluding that the method used to calculate activity index is not biased (see Table below).

Field name	Activity Index	Baseline Rank	Average Altered Rank
Harris River Road	7.82	1	2.3
Goodwin 1	6.98	2	2.7
Arthur Harris	6.50	3	4.5
Zylman	5.26	4	14.7
Burr	5.15	5.5	8.6
Wellbrook	5.16	5.5	2.8
Cromie	4.75	7	5.4
Diefenbaker	4.71	8	8.9
Ab Singh	4.66	9	10.2
Imperial	4.24	10.5	10.0
Keulen Road	4.17	10.5	13.2

Field name	Activity Index	Baseline Rank	Average Altered Rank
Harris Highway N	3.93	12	5.6
London Gate	3.52	13	14.4
Highmark	2.75	14	13.8
Rink	2.73	15	10.3
M Gardens	2.43	16	19.2
Windset N	2.25	17	15.1
Kao Yi	1.78	18	15.8
Windset E	1.50	19	13.6
Gipaanda	1.30	20	19.7