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Landscape and field characteristics affecting winter waterfowl grazing damage to agricultural perennial forage crops on the lower Fraser River delta, BC, Canada

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ABSTRACT

The lower Fraser River delta is an important waterfowl staging area on the lower coast of British Columbia, Canada. Since the early 1980s, wintering waterfowl have been causing economically significant damage to perennial forage fields (hay, pasture and silage). We examined the effect of farm management practices and landscape attributes on the extent of grazing damage on a total of 196 perennial forage fields between 2001 and 2005. Multiple regression analysis and an information-theoretic model comparison approach were used to identify field and landscape parameters that account for variation in damage. Rather than limit our evaluation to single-species use of forage crops, we considered the combined grazing impact of a complex of wintering waterfowl, including lesser snow goose (*Chen caerulescens*), American wigeon (*Anas americana*), mallard (*Anas platyrhynchos*), northern pintail (*Anas acuta*), and trumpeter swan (*Cygnus buccinator*) and identified which management practices might mitigate overall grazing damage. Forage species composition and availability of alternative feeding areas had an effect on waterfowl grazing damage to perennial forage fields. Fields with higher proportions of orchard grass showed higher levels of grazing damage; and damage was lower in years when abundant alternative feeding areas (AFAs) in the form of unharvested potatoes were available. Although these factors were found to be important in explaining variation in damage to perennial forage fields, our best model accounted for only 13% of the variation in damage. Mitigation efforts must be comprehensive and consider a wide range of factors that influence damage to perennial forage fields. Although manipulation of field characteristics and management of AFAs can contribute to waterfowl grazing damage mitigation, strategic geographic distribution of AFAs and management of human disturbance in designated AFA areas would further mitigate damage.

1. Introduction

The lower Fraser River delta located in British Columbia, Canada is recognized as an important staging/wintering area for a number of waterfowl species using the Pacific Flyway (Butler and Campbell, 1987). Between October and March, large numbers of American wigeon (*Anas americana*), mallard (*Anas platyrhynchos*), northern pintail (*Anas acuta*), Canada goose (*Branta canadensis*), lesser snow goose (*Chen caerulescens caerulescens*), and trumpeter swan (*Cygnus buccinator*) over winter in the area (Baldwin and Lovvern, 1994; Breault and Butler, 1992; Hirst and Easthope, 1981; Temple et al., 2001). In recent years, winter populations of trumpeter swans and lesser snow geese have been increasing (Pacific Flyway Council, 2006; Moser, 2006).

Although natural foreshore habitats contribute to supporting these waterfowl, agricultural uplands within the delta have, over several decades, become more important as feeding and loafing areas for dabbling ducks, geese and swans. Use of these has increased as natural wetlands have been drained and converted to other uses and agricultural and land use practices have changed along the Pacific Flyway (Baldwin and Lovvern, 1994). Several bird sanctuaries and the Alaksen National Wildlife Area also provide these species with important habitat.

The close juxtaposition of natural habitat, important bird management areas and active farmland has led to a conflict between waterfowl conservation and farming objectives. Winter use of farmland by waterfowl has resulted in substantial damage to economically important crops within the delta. Currently, the most

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heavily impacted crop is perennial forage (hay and pasture) and damage caused by grazing waterfowl represents a considerable cost to many hay and dairy producers in the area. A survey of 85 farmers conducted in 1991 indicated that 4 out of 5 farmers had been impacted by waterfowl crop damage in the three previous years (Klohn Leonoff Ltd. et al., 1992). Crop losses may be reflected in lower forage yields, a reduction in the number of annual forage harvests and destroyed crops requiring reseeding. Farmers are currently provided partial compensation for losses through the Delta Forage Damage Compensation Program. It is unclear what the exact economic impact of waterfowl damage to farms in the area has been, but total compensation payments range from $60,000 to $115,000 annually (Zbeetnoff and McTavish, 2004).

A Forage Damage Committee was established within the lower Fraser River delta in 1999 to examine the conflict, develop an economic model for winter waterfowl foraging damage and identify and evaluate possible mitigation practices. It is suspected that intrinsic field characteristics, landscape level and regional habitat characteristics, waterfowl population numbers and weather may influence forage damage levels. This analysis examines field and landscape level characteristics and their effect on the extent of waterfowl damage to forage fields on the Fraser River delta. Results presented here will be used in the development of an integrated forage management program that could mitigate waterfowl damage.

1.1. Study area

The Fraser River delta lies in the Georgia Depression on the south coast of British Columbia, Canada. Consisting of mostly alluvial soils, the delta is well-known for its highly productive estuarine marshlands and adjacent agricultural lowlands. The area covered by this study includes a substantial portion of the lowland area located south of the south arm of the Fraser River in the Municipalities of Delta and Surrey (Fig. 1). These farmlands are used extensively in the production of a wide range of agricultural products including forage, dairy products, vegetable crops, small berry fruits and greenhouse crops. Approximately 14–18% of the farmland is committed to pasture, hay and silage production annually. Harvest of perennial forage (mowing for hay or silage) occurs between May and October with 3–6 cuts being made on intensively managed fields. Summer cash crops are typically harvested between June and October. Over winter arable fields are either left barren, sometimes with substantial crop residue, or planted with a winter cover crop. A locally funded stewardship program has promoted the establishment of winter cover crops on an average of 3000 acres of the farmland in Delta annually (Bradbeer et al., 2010). Farms in Surrey do not establish cover crops in the absence of the cost share program. During winter, other fields consist of over-wintering berry crops, grains, grassland set-asides and old-fields.

Farmland in this area is almost entirely surrounded by water. The lowland is protected from high water by extensive dykes, flood control gates and pumping stations. Extensive sand- and mudflats are located outside of the dyke in Boundary Bay, along the Georgia Strait and, to some extent, along the Fraser River. These are dominated by eelgrass (*Zostera* sp.) further from shore and emergent marsh vegetation closer to shore (*Typha latifolia*, *Carex* sp. and *Schoenoplectus* sp.) where dabbling ducks, snow geese and swans will forage during low to moderate tides and roost during winter months. Other mudflats are bare, exposing invertebrates to foraging birds.

The area contains 2 bird sanctuaries (Serpentine Wildlife Area and the George C. Reifel Migratory Bird Sanctuary), the federally managed Alaksen National Wildlife Area, and several Provincial Wildlife Management areas, all of which contribute to supporting migratory waterfowl.

Climate for the study area is typically characterized by mild, wet winters and warm, dry summers. Daytime temperatures range from an average of 5 °C in January to 22 °C in July. Most rainfall occurs during the fall and winter months with approximately 1000 mm of precipitation annually. Snowfall is rare and, when it occurs, snow cover typically disappears within several days.

Fig. 1. Study area consisting of Fraser River delta lowlands, British Columbia, Canada.

2. Methods

2.1. Assessing grazing damage

The extent and intensity of waterfowl grazing damage was evaluated through visual estimation at all forage fields included in the study at the end of all 5 winters. Damage estimates were made between 15 and 30 April in all years, after most waterfowl have migrated to northern breeding grounds (Butler and Campbell, 1987). This assessment was the basis for calculating financial compensation for impacts of waterfowl grazing for each field and was carried out by a team of 3–4 surveyors. Surveyors estimated the proportion of each field impacted by waterfowl grazing after collectively walking non-overlapping parallel transects 10–20 m apart through each field. During 2001, the proportion of each field showing grazing damage was estimated. For the remaining years, proportion of field impacted within three levels of grazing damage intensity (light – grazing evident, moderate – half of sward height grazed, intense – grazed to soil level) was estimated using the same methods. We chose to model total area grazed as a measure of waterfowl use regardless of intensity for this analysis because overall area grazed and grazing intensity levels were auto correlated and data on intensity were not collected during the first year of the study.

2.2. Assessment of field and landscape level variables

Based on other studies and personal observations we evaluated a number of variables that may influence field selection by waterfowl. These included: distance from foreshore roosting areas (e.g., Gill, 1996), grass species composition of forage fields (e.g., McKay et al., 2001), standing water (e.g., Mayhew and Houston, 1989) and alternative feeding areas (e.g., Amano et al., 2007). We also assembled data relating to specific farm management decisions and practices that likely affected forage patch value. These related to sward height, standing water, crop palatability and foraging patch size. Farmer records were used to determine: the percentage of orchard grass (*Dactylis glomerata*, a highly palatable and protein rich forage crop species) by weight in the forage seed mix (ORCH); the timing of the last seasonal harvest (HARV); whether surface drainage had been established through digging drainage furrows prior to or during winter (DRAIN); whether the field was contoured through a process called laser leveling (LEVEL); and the field's size in hectares (AREA).

DeltaMap (Corporation of Delta, 2003) was used to measure the distance from the geometric center of each field to the closest dyke, which represented proximity to foreshore roosting areas. Fields were then categorized as being within 1 km or further than 1 km from the dyke (DYKEDIST).

The abundance of alternative feeding areas (AFAs) relative to perennial forage crops on uplands was suspected to be an important factor in affecting forage damage levels between years. AFAs used by wintering waterfowl in the area consisted of winter cover crops, vegetable crop residue fields, and unharvested vegetable and grain crops, particularly potatoes, cabbage, carrots and barley (Bradbeer et al., 2010). Of these AFAs, only area of unharvested potato crops was considered in our analysis given that this varied between years. Although winter cover crops were used extensively by waterfowl and varied in abundance between years, they were not included in any of our candidate models given that the area planted with these lure crops was auto correlated and inversely proportional to area of unharvested potatoes and therefore not an independent variable. Unharvested potatoes were selected over cover crops to model effect of AFAs because of the relatively high density of food energy for waterfowl contained in unharvested potato fields relative to winter cover crops and because we estimated that variation in potato availability during winter best represented total value of AFAs in the landscape. Field observations during the survey years also indicated that waterfowl were strongly attracted by high levels of potato residue. Local farmers were surveyed to determine the total area of potatoes that were not harvested within the study area in each year (POTATO).

Over the 5-year study, 196 individual perennial fields were included in the surveys. The number of fields used in our analysis varied from year to year (2001/02 $N = 85$, 2002/03 $N = 110$, 2003/04 $N = 99$, 2004/05 $N = 95$, 2005/06 $N = 123$). Number of fields increased and declined as specific fields were rotated into and out of perennial forage production.

2.3. Statistical analysis

We quantified relationships between grazing damage and field- and landscape level-characteristics using multiple regression analysis. Data from all five years were pooled into one data set. Individual fields were treated as subjects in a repeated measures analysis where year was the break variable. Proportion of field damaged by waterfowl was used as the response (dependant) variable and field and landscape attributes (Table 1) were evaluated

Table 1
Field and landscape level attributes used to evaluate variation in winter waterfowl grazing damage to perennial forage fields on the Fraser River delta, British Columbia, Canada, 2001–2005. Data presented as average and range for continuous variables, relative occurrence for categorical variables and number of fields per year.

Predictor variable	Description	Units	Data distribution		Source
Orch	Percentage of orchard grass (*Dactylis glomerata*) in the forage mix (continuous)	%	37[a]	0–100[b]	Farmer records
Area	Size of the field (continuous)	ha	8.84[a]	1–30[b]	Agriculture Canada/Farmer records
Potato	Total area of unharvested potatoes left in study area in each survey season (continuous)	ha	57[a]	0–231[b]	Farmer records
Dykedist	Whether a field occurred within 1 km of foreshore, measured to dyke (categorical)	Yes or no	≤1 km: 0[c] >1 km: 1[c,d]	49% [a] 51% [a]	Digitized map; Corporation of Delta
Level	Whether field was laser leveled (categorical)	Yes or no	Yes: 1[c,d] No: 0[c]	49% [a] 51% [a]	Farmer records
Drain	Whether surface drainage had been established on field (categorical)	Yes or no	Yes: 1[c,d] No: 0[c]	35% [a] 65% [a]	Farmer records
Harv	Date of last hay/silage cutting (categorical)	Time period	Before Sept.: 2[c] Sept.: 1[c] After Sept.: 0[c,d]	23% [a] 39% [a] 38% [a]	Farmer records

[a] Averaged across study years.
[b] Range.
[c] Class variable label in analysis.
[d] Class variable set to "0" in regression analysis.

as potential explanatory variables. We used an information-theoretic model comparison approach as described by Burnham and Anderson (2002) to evaluate a total of 14 competing models (Table 2) and to estimate the importance of model parameters.

In the case of categorical model variables, one category was fixed to zero to which the other categories were compared (Table 1). Accordingly, the following categories acted as reference points for all models in which those categorical variables were used: leveling: absence of leveling = 0; distance from dyke: within or equal to 1 km = 0; and surface drainage: absence of drainage structures = 0. In the case of last harvest where 3 categories existed: before September = 2, during September = 1, after September = 0.

Log likelihood values were generated from a maximum likelihood linear regression analysis using a compound symmetry covariance structure. The log likelihood values were used to calculate Akaike's Information Criterion for small sample size (AIC_c) for all 14 candidate models. The model with the lowest AIC_c value was considered the best supported of the candidate models (i.e., the one that incorporated the most variation using the smallest number of estimated parameters). The change in AIC_c (ΔAIC_c) was calculated relative to the best supported model for the remaining models ranked by AIC_c and used to assess the explanatory value of each model. We used Akaike weights (w_i) to compare the relative likelihood of each candidate model (Burnham and Anderson, 2002) and r^2 values as a measure of overall model fit. To assess the importance of each explanatory variable, we summed the Akaike weights of each model that contained the variable of interest. The Akaike weights were used to calculate model-averaged parameter estimates and unconditional standard errors for each explanatory variable. Model-averaged parameter estimates were calculated using the w_i from the entire set of candidate models. We used SPSS 19 (SPSS 2010) to complete the statistical analyses.

3. Results

The greatest waterfowl grazing damage occurred during the winter of 2001 when 75% of perennial forage fields showed evidence of waterfowl grazing relative to 50%, 48%, 34% and 46% in 2002, 2003, 2004 and 2005, respectively. The total estimated area of perennial forage grazed by wintering waterfowl ranged from 139 ha of 893 ha (16%) in 2004 to 328 ha of 874 ha (38%) in 2001 (Fig. 2) and was 25 ± 2% (mean ± SE) across all fields and years. The majority of perennial forage fields had little or no damage (0–20% range) accounting for 53–78% of surveyed fields across all years. Extensive damage (80–100% range) was evident on only 9–26% of surveyed fields.

Table 2
Multiple regression models used to evaluate field and landscape level attributes related to variation in winter waterfowl grazing damage to perennial forage fields on the Fraser River delta, British Columbia, Canada, 2001–2005. Model goodness of fit (r^2), change in Akaike's Information Criterion relative to the most parsimonious model (ΔAIC_c) and Akaike weights (w_i) are listed for 15 models considered. Models are ranked according to ΔAIC_c and top three models were used to derive model-averaged parameter estimates shown in Table 3.

Model	r^2	ΔAIC_c	w_i
Potato + Orch	0.13	0.0	0.4144
Level + Drain + Dykedist + Area + Orch	0.12	1.6	0.1856
Level + Harv + Drain + Dykedist + Area + Orch + Potato (Global)	0.12	1.8	0.1709
Dykedist + Area + Potato	0.12	2.3	0.1292
Dykedist + Orch	0.12	3.5	0.0720
Orch + Harv + Area + Level + Drain + Potato	0.11	5.6	0.0258
Level + Drain + Dykedist + Area + Orch + Harv	0.08	10.9	0.0018
Potato	0.06	15.7	0.0002
Orch + Harv	0.04	19.4	0.0000
Dykedist	0.04	20.7	0.0000
Level + Drain	0.03	22.4	0.0000
Level	0.02	24.3	0.0000
Level + Harv + Drain + Area	0.01	25.6	0.0000
Null (Intercept)	0.00	27.7	0.0000

The data showed distinct trends in waterfowl grazing for several of the field and landscape level variables. Damage tended to be lower in years when greater quantities of potatoes were left on fields over the winter (Fig. 2). Fields closest to foreshore areas, fields that were leveled, larger fields and fields with a higher proportion of orchard grass tended to have greater waterfowl damage (Fig. 3).

AIC analysis indicated that only two of these parameters had sufficient predictive value to be considered as having influence on grazing damage. The most parsimonious (best) model accounting for variation in grazing extent contained POTATO (alternate forage areas) and ORCH (forage quality) (Table 2). This model exhibited the best fit ($r^2 = 0.13$) and a model weight (w_i) of 0.41. The next most parsimonious model included DYKEDIST, AREA, LEVEL, DRAIN, and ORCH, with a ΔAIC_c of 1.6 relative to the most parsimonious model (Table 2). Its model w_i was only half of the best model ($w_i = 0.19$). The global model (including all parameters), had a ΔAIC_c of 1.8 compared to the most parsimonious model, and a model w_i of 0.17 (Table 2) ranking third of all models considered.

The individual parameter w_i indicated that forage quality (ORCH) and availability of alternative forage areas (POTATO) were more important in predicting grazing extent than others (Table 3). The amount of unharvested potatoes in the region tended to reduce grazing damage, as evidenced by its inclusion in the top model and the highest relative parameter w_i ($w_{i\ POTATO} = 0.74$). For every 50 ha of unharvested potatoes in the area, the set of averaged models predicts a 1.5% reduction in grazing extent (Fig. 2). Forage crop composition also had an effect on grazing extent ($w_{i\ ORCH} = 0.70$, Table 3). For every 10% increase in orchard grass content the model predicts a 2.2% increase in grazing extent.

The majority of parameters were not contained within the most parsimonious model. Furthermore, their individual parameter w_i were lower than POTATO and ORCH. Based on this evidence, there was less support for the parameters DYKEDIST ($w_{i\ DYKDIST} = 0.56$), AREA ($w_{i\ AREA} = 0.51$), LEVEL ($w_{i\ LEVEL} = 0.38$), DRAIN ($w_{i\ DRAIN} = 0.38$), and HARV ($w_{i\ HARV} = 0.20$).

4. Discussion

Farm field and landscape level attributes are known to have an effect on habitat selection by wintering waterfowl in many areas where waterfowl conservation and agricultural interests have been in conflict (Hirst and Easthope, 1981; von Kanel, 1981; Mayhew and

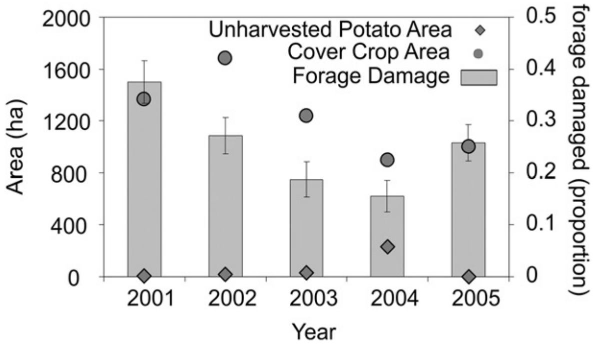

Fig. 2. Waterfowl grazing damage extent to perennial forage crops (gray bars mean ± SE) and availability of unharvested potato fields and winter cover crops on the Fraser River delta, 2001/02–2005/06.

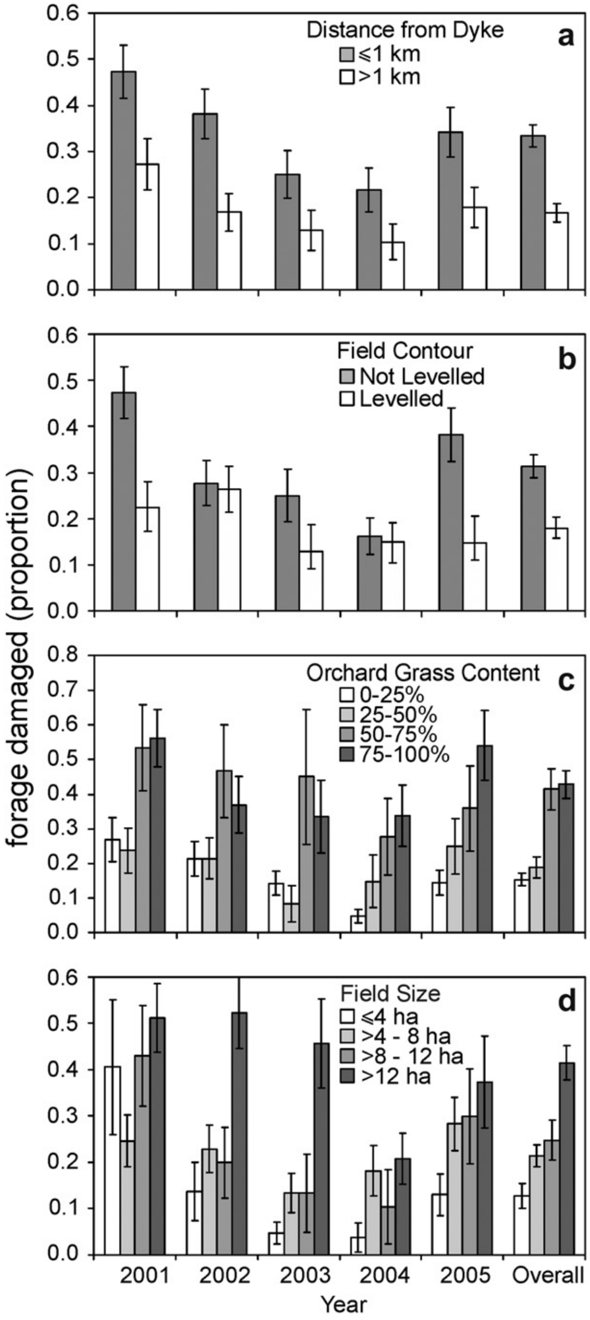

Fig. 3. Mean proportion and standard error of perennial forage field damaged by waterfowl winter grazing on the Fraser River delta as a function of a) distance to foreshore, b) field contour, c) crop composition and d) field size. Data collected over 5 field seasons (2001/02–2005/06).

Houston, 1989; Gill, 1996; McKay et al., 1996, 2001; Riddington et al., 1997; Milsom et al., 1998; Haase et al., 1999; Hassal and Lane, 2001; Cope et al., 2003; Amano et al., 2004). Many studies have identified characteristics that tend to increase or decrease the likelihood of waterfowl use and have provided the basis for waterfowl management programs that can affect foraging habitat selection through field, landscape and disturbance management. Our results show that some standard farm management practices for which suitable alternatives already exist can be manipulated to mitigate damage to perennial forage crops by wintering waterfowl on the Fraser River delta.

Table 3
Summed Akaike weights (w_i), parameter estimates and unconditional standard errors (SE_u) of parameter estimates derived from all candidate models of waterfowl grazing damage to perennial forage fields on the Fraser River delta, British Columbia, Canada, 2001–2005.

Parameter	Summed w_i	Parameter estimate	SE_u
Intercept	1.00	0.0512	0.1097
Potato	0.74	−0.0003	0.0004
Orch	0.70	0.0027	0.0004
Dykedist	0.56	0.0693	0.0663
Area	0.51	0.0085	0.0083
Level (0)	0.38	0.0316	0.0388
Drain (0)	0.38	0.0047	0.0221
Harv (0)	0.20	−0.0033	0.0118
Harv (1)	0.20	−0.0034	0.0010

4.1. Parameters supported by the model

4.1.1. Alternative feeding areas

The influence and management of alternative feeding areas (AFAs) relative to economically important agricultural crops are important factors in minimizing damage in many areas where there is conflict between agriculture and waterfowl management (Vickery et al., 1994; Lane et al., 1998; Prop et al., 1998; Haase et al., 1999; Vickery and Gill, 1999; Paterson and Fuchs, 2001; Cope et al., 2003; Amano et al., 2004, 2007; McKay et al., 2006). In our study area, potato and carrot fields, as well as winter cover crops, provide upland feeding areas for waterfowl (Breault and Butler, 1992; Bradbeer, 2007).

Crop residues have been identified as potentially important AFAs in several areas where winter goose grazing damage is a problem. For instance, sugar beet residue and stubble remains of harvested cereals were important foraging areas for pink-footed geese (*Anser brachyrhynchus*) in eastern England (Gill, 1996) and increasing rice residue in harvested fields was identified as a useful strategy for mitigating damage to winter wheat by white-fronted geese (*Anser albifrons*) in Japan (Amano et al., 2007). Potato, carrot and barley residue are AFAs of significant value to a variety of waterfowl species in our study area, although carrot production has declined locally and is restricted to a small area.

Potato harvest can be made difficult when considerable late summer and early autumn rainfall occurs and farmers must abandon crops when fields become water saturated. Under these conditions potato residue throughout the delta can be substantial. For example, potato acreages that were not harvested totaled 231 acres in 2004, coinciding with the lowest occurrence of waterfowl grazing on local forage fields. During years with high potato abandonment, lesser snow geese (Bradbeer, 2007) were observed feeding almost exclusively on potato fields with very few feeding on winter cover crops or other field types. We believe that the almost complete exclusion of these species from other alternative foraging areas during years of high potato residue tended to reduce the rate of resource depletion of cover crops.

Winter cover crops, composed mainly of fall sown cereals such as wheat, barley, and oats, are used by waterfowl during the wintering period. Cover crops are planted as part of cost-sharing stewardship agreements between local farmers and the Delta Farmland and Wildlife Trust. Since being implemented in the winter of 1990, this stewardship program has supplied winter-feeding habitat to large numbers of over-wintering waterfowl such as snow geese, trumpeter swans, mallard, northern pintail and American wigeon (Duynstee and Wareham, 1993; Porter and Duynstee, 1994; Summers, 1995; Bradbeer et al., 2010). Fields planted with winter cover crops are used extensively by waterfowl and are meant to act as lure crops drawing waterfowl away from perennial forage fields. Cover crop fields show variable amounts of grazing, with winter cereals seeded in late August and early

September supporting the greatest number of waterfowl (Bradbeer et al., 2010). McKay et al. (1994) found that geese preferred winter cereals (equivalent to winter cover crops in our study area) to pasture at the beginning of the inland-feeding season and then switched to pasture later. The energetic value of winter cover crops relative to perennial forage fields for wintering waterfowl has not been assessed in our study area, however, lesser snow geese used a greater proportion of winter cover crop fields relative to perennial forage fields early in the season and switch to perennial forage later in the season (Bradbeer, 2007). Although this is not an indication of the relative importance of the two crop types in contributing to the carrying capacity of farmland for wintering waterfowl, cover crops appear to be an important habitat element and likely exert an influence on the extent of damage encountered on the perennial forage fields by attracting waterfowl.

4.1.2. *Forage species composition*

Forage crops in our study area typically contain a mix of several grass species and usually include clover. One of the most preferred forage grass varieties in our study area is orchard grass. It tends to contain more protein than other forage grasses (orchard grass contains 15–20% crude protein (CP) compared to 11–16% CP in fescue (Zbeetnoff and McTavish, 2004)). We suspect that orchard grass is particularly vulnerable to intense grazing in our study area given its relatively high-protein content. Many studies have shown that some waterfowl species select grasses low in indigestible fibers and high in soluble proteins (Sedinger, 1997; Therkildsen and Madsen, 2000; Hassal and Lane, 2005) which supports our conclusion that higher proportions of orchard grass in forage mixes increases waterfowl grazing damage.

It has been suggested that conversion of crops from those favored by waterfowl to those that are less palatable might reduce the extent of damage to fields. This tactic has been considered for farmland management adjacent to wildlife reserves in the Netherlands (van Eerden, 1990) and has been used in the reverse for the management of alternative feeding area (AFA) reserves for various goose populations in Scotland and England (McKay et al., 2001; Cope et al., 2003). In these cases, goose reserves are planted with more preferred grass varieties in order to lure birds away from agricultural areas.

High orchard grass content in forage mixes tended to increase the extent of waterfowl grazing damage in our study area. Although there are costs associated with switching to less palatable species from an agricultural perspective (e.g., less protein in forage fed to milk producing cows), these may be more than offset by the benefits of effective reduction in waterfowl grazing damage. Nearly 80% of forage producers surveyed in our study area indicated that they changed their grass varieties to include more “tall fescue” and many (nearly 70%) felt that it helped to reduce waterfowl damage (Baumbrough, 2002). Although many growers may have changed forage crop composition, orchard grass is still being used extensively in forage mixes. Orchard grass dominated forage crops accounted for 63% of all forage fields surveyed in the delta over the duration of this study. Our data show that field dominated by orchard grass tended to sustain higher levels of damage compared to forage fields containing other grass species. By reducing the use of orchard grass in perennial forage fields, the relative value of other farmland food sources to wintering waterfowl can be increased.

4.2. *Parameters not supported by modeling*

4.2.1. *Distance from foreshore*

Waterfowl tend to minimize the distance they travel between roosting and feeding areas. Several studies conducted in Europe indicate that wild geese will feed relatively close to their roosts, with most species only venturing an average of 3–5 km inland (Gill, 1996; Vickery and Gill, 1999) and behavioral models presented by Amano et al. (2007) indicate that damage to winter wheat from white-fronted geese can be greater in fields close to roost sites. Boundary Bay and Roberts Bank (Fig. 1) are important roosting and feeding areas for waterfowl in our study area (Lovvorn and Baldwin, 1996). During low to moderate tides they forage on intertidal mudflats and salt marshes immediately adjacent to dyked farmland (Breault and Butler, 1992). Wigeon, pintail, snow geese and trumpeter swans that winter on the Fraser delta will roost on open water. Also, birds moving from roost sites or foreshore habitats to upland habitats will likely choose the first uplands suitable and available to them to minimize energy expenditure. While other studies have confirmed that agricultural fields closest to open ocean water and/or roost sites are most susceptible to waterfowl grazing (Summers and Critchley, 1990; McKay et al., 1996; Gill, 1996), the results of our modeling were unable to support this same conclusion, though the data trended towards less damage in fields more than 1 km from the foreshore dyke. Waterfowl grazing may initially be located close to foreshore roosts, but food depletion throughout winter may force birds to forage further a field.

4.2.2. *Field size*

The extent of waterfowl damage appeared to increase with field size, although many small fields still sustained high levels of damage. Furthermore, our analysis did not provide strong support for this variable. Farm field size has been identified as an important factor related to field selection by waterfowl elsewhere (Gill, 1996; McKay et al., 1996; Haase et al., 1999) and is an essential consideration when establishing AFAs (Milsom et al., 1998; McKay et al., 2001; Vickery and Gill, 1999). Many of the dairy and hay producing farms in our area have been creating larger fields to improve farm efficiency. This increase in efficiency may now be offset by increased levels of waterfowl damage. One recommendation might be to reduce field size, but there is great resistance to this by local growers given their often significant investment in machinery to improve farm efficiency on large fields.

4.2.3. *Standing water and surface drainage*

Winter use of fields by waterfowl is greater when there is standing surface water on the field (von Kanel, 1981; Hirst and Easthope, 1981; Mayhew and Houston, 1989; Haase et al., 1999). Mallard, northern pintail and American wigeon strongly preferred heavily flooded fields on the Fraser River Delta (Hirst and Easthope, 1981) and presence of surface water explained 25% of the variation in the waterfowl grazing in our study area (Duynstee, 1992). Despite these previous findings, our analysis did not indicate that drainage (laser leveling to remove low spots where water ponds or surface drainage channels) influenced the extent of grazing sustained on forage fields.

4.2.4. *Last harvest date*

Last harvest date impacts sward height heading into the winter months. Waterfowl have relatively small digestive tracts and when feeding on grasses tend to select young, short leaves which are higher in protein and lower in indigestible structural fibers (Sedinger, 1997; Therkildsen and Madsen, 2000; Hassal and Lane, 2005). Sward height is a good predictor of field use in many species of waterfowl, with many of the small to medium species selecting shorter swards (Milsom et al., 1998; Vickery and Gill, 1999; Hassal et al., 2001; Durant et al., 2003; Loonen and Bos, 2003; Durrant et al., 2004). Use of grass habitats by brant geese was significantly greater on swards that were ca. 8 cm tall compared to those that were 3–4 cm taller (Milsom et al., 1998). However, larger species of waterfowl may select taller swards, as they are able to maximize dry matter intake and thus protein intake (Durrant et al., 2004).

We included date of last harvest as a proxy for sward height but our data were not able to support this variable as an important predictor of grazing damage. Variations in sward height may have been caused by factors other than date of last harvest, including soil characteristics, drainage, nutrient inputs, grass species, and annual/seasonal variations in temperature, precipitation, and sunlight. Also, because the analysis included grazing from several different size classes of waterfowl species, the relationship between sward height and grazing preference (as evidenced by extent of grazing damage) may not have been apparent. Despite this, grass fields that are cut short just before the arrival of waterfowl may be at greater risk of being grazed, especially by smaller species like wigeon that prefer short swards (Durrant et al., 2004).

4.2.5. *Date of last fertilization*

Fertilizer application influences field use by wintering goose populations in many agricultural areas (Bazely et al., 1991; Percival, 1993; Vickery and Gill, 1999; Hassal and Lane, 2001; Hassal et al., 2001; Paterson and Fuchs, 2001; Bos and Stahl, 2003). For example, preference for fertilized fields was shown for barnacle geese (*Branta leucopsis*) (Bazely et al., 1991; Percival, 1993) and pink-footed geese (*Anser brachyrhynchus*) (Paterson and Fuchs, 2001) and increased rates of spring chemical fertilizer application was positively correlated with brant goose (*Branta bernicla bernicla*) use of pastures (Hassal and Lane, 2001). Only 5% of local perennial forage fields did not receive fertilizer inputs over the five years of our study and many include late season fertilizer applications. One reason for late season manure applications is that local dairy farmers have to store over winter manure accumulations until spring to prevent run-off of nutrients into surrounding ground water. Given on farm storage limitations, most farmers spread manure on fields throughout the growing season and as late as possible in the growing cycle. Delayed fertilization of perennial forage fields (late winter or early spring) or fertilization of sacrificial forage crops or other AFAs, such as winter cover crops, may contribute to the movement of birds from economically important fields to those managed specifically to lure and feed wintering waterfowl.

4.3. *Limitations of study*

Several limitations of this study must be mentioned. The data were collected over five years during which moderate (2001/02, 2002/03, 2005/06) and low levels (2003/04 and 2004/05) of damage were inflicted on forage fields in the area. Independent variable effects are likely attenuated or exacerbated during years when there is greater waterfowl feeding use of forage fields. Also, the study considered the combined impact of five waterfowl species having different requirements, tolerances and preferences. Manipulation of field and landscape level characteristics may affect individual species to varying degrees.

Our study only considered accumulated damage levels apparent at the end of the winter season and did not account for seasonal variation in forage field use and the potential for differences in habitat switching as a function of nutrient availability and temporal changes in species specific nutrient requirements. The intent of the study, however, was to identify management practices that could be used specifically in this study area to reduce damage to perennial forage fields. By modeling area-wide grazing extent in relation to field and landscape level characteristics, factors that influence grazing damage have been identified.

Finally, this study was not able to consider variability in hunting pressure across forage fields. Snow geese and dabbling ducks are hunted annually between October and January, with snow geese being hunted again between February and March (Ministry of Environment, 2009). Hunting can influence habitat use by waterfowl (Fox and Madsen, 1997) but we did not have access to detailed, area-based hunting effort in our study area and were therefore unable to consider how this variable influenced forage damage.

5. Conclusion

Waterfowl grazing on perennial forage fields was influenced most by the species composition of the forage crop and the availability of alternative feeding areas. The extent of damage to economically important forage fields may be mitigated through reducing the use of orchard grass and providing alternative forage. Although these management practices can reduce the relative value of perennial forage fields to waterfowl, implementing them alone will not completely eliminate the waterfowl/perennial forage conflict in the area.

We suggest that attention should be devoted to providing more effective AFAs. Strategic location of large blocks of AFAs that buffer perennial forage areas, particularly those closer to the foreshore, may provide a more useful diversion. Also, old perennial forage fields can be converted into AFAs in their last year of production by increasing their relative value to wintering waterfowl, particularly if they are large fields. Many forage fields are returned to arable land in rotation after a number of years of hay and silage production. The relative value of these fields can be improved through application of chemical or manure fertilizers at appropriate times of the year. Late season fertilizer application has been recommended for AFAs elsewhere (Hassal and Lane, 2001).

Crop residue management and crops grown for waterfowl might provide the best diversionary feeding areas for waterfowl. Although growing vegetable crops specifically as waterfowl food is cost prohibitive, recent observations in this area indicate that they have the capacity to divert waterfowl feeding for extended periods over the winter. We suggest that farmers could be contracted to vary the amount of crop residue left on fields, particularly during years when few unharvested potato fields are left. This can be accomplished by adjusting chain width on potato harvest machines allowing more of the harvested potatoes to be re-deposited on the surface of fields.

One consideration in the design of more effective AFAs is the prevention of waterfowl disturbance on areas committed to them (Milsom et al., 1998; McKay et al., 2001; Vickery and Gill, 1999). We were not able to determine how hunting influenced damage to forage fields in this study because we did not have access to detailed area-based hunting data. However, waterfowl aggregate in areas that are protected from hunting (Fox and Madsen, 1997). On the lower Fraser River delta hunting is restricted to a half hour before sunrise to a half hour after sunset (Ministry of Environment, 2009) and snow geese and American wigeon will feed on forage fields during the night, presumably to avoid exposure to hunters. Creating voluntary no hunt areas that include AFAs and buffers will reduce the likelihood that birds will move from these areas to areas of perennial forage production where hunting is not present. Additionally, forage producers should encourage hunting on their fields, when possible, to deter waterfowl use.

An integrated program designed to disperse waterfowl grazing on the Fraser River delta should include a variety of strategies and tactics. We have identified a number of possible mitigation strategies, however, compensation for lost production and the establishment of more AFAs will likely be the most effective means of reducing the economic impact to local farms. Although AFAs are an important component of the solution, it is unlikely that additional upland permanent waterfowl reserves can be established in the area given that land costs have become cost prohibitive. Seasonal crop management such as winter cover cropping as well as crop residue management may be the only means of providing AFAs. Although our analysis did not identify distance from foreshore roosts, field size, and field drainage as variables that influence forage damage, other studies have shown that these factors can impact waterfowl feeding decisions. Further research should be conducted locally to assess how waterfowl grazing progresses throughout staging and wintering periods in relation to these variables.

Resolution of this forage/waterfowl conflict in this area must preserve sustainable agricultural ***production*** on as much land as possible. Among other considerations, a successful program will need to ensure that: 1) the economic viability of farms is not negatively impacted and 2) it provides options that local farmers are willing to adopt.

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