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CLIMATE CHANGE IMPACTS ON WATERFOWL HABITAT IN WESTERN CANADA

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Introduction

Wetland ecosystems are important not only for producing waterfowl, but because they provide valuable ecosystem services. These include filtration of agricultural and other pollutants (thereby improving quality of ground and even some surface waters), water for livestock and wildlife, opportunities for recreation, a greenhouse gas storage function, and, in addition, such non-market values as visual amenities. The major challenge to the management of wetlands is that private landowners do not and, in most instances, cannot capture all of the values that wetlands provide – their value to society exceeds their value to private landowners. Because of the externalities associated with wetlands and their protection, public policies may be required to protect existing wetland areas and perhaps even restore lost wetlands.

Before implementing public policy to protect and/or restore wetlands, it is first necessary to determine whether existing wetlands area is indeed suboptimal from a social standpoint, and, second, whether government intervention is warranted. Government action to conserve wetlands has a cost, with government intervention warranted only if the costs of policies to conserve wetlands are less than the benefits to society. Further, the policies implemented by the government to protect and/or restore wetlands must be efficient in the sense that they conserve the 'best' wetlands (those providing the greatest benefits) at least cost to the treasury. This may involve the identification of desirable wetland areas to retain and/or restore and the use of auctions to compensate landowners for providing the wetland (Hill et al. 2011). In some situations, the government might wish to leave protection of wetlands to the private sector. Environmental non-governmental organizations (NGOs), such as Ducks Unlimited, can bring together stakeholders (e.g., duck hunters, viewers of migratory waterfowl) to pay landowners for retaining and restoring wetlands. Nonetheless, government policies toward wetlands are important for preserving and enhancing wetland ecosystem services.

The focus of the current report is on wetlands protection in Canada's Prairie Provinces. Our primary concern relates to the conversion of wetlands area into cropland and their value in the provision of habitat for migratory waterfowl. The tradeoff between these alternative uses of wetlands will become even starker should projected climate change reduce annual precipitation in the study region. Although wetland ecosystem services are taken into account, the primary concern is the role of wetlands in providing habitat for migratory waterfowl.

Our analysis begins in the next section with an overview of the study region and the challenges of wetlands protection in this region. Then, in section 2, we examine a bioeconomic model of duck hunting and wetlands protection to demonstrate that, even if the only benefit provided by wetlands relates to their value in producing ducks for hunters, wetlands area in the study region is less than socially optimal. The bioeconomic model is then expanded to include the amenity or ecosystem values provided by wetlands values and the viewing value of migratory waterfowl. Finally, in section 2, we consider what level of wetlands would need to be protected should climate change result in much drier conditions than those experienced during the last century.

In section 3, we turn to the regional impacts of agricultural land use and wetlands retention. We begin that section with a bioeconomic model that is similar to that of section 2. In this case, however, the model is parameterized separately for each province and for each of the strata that are used for surveying waterfowl and wetlands (as discussed in the first section below). We then employ an econometric panel-data model to examine the direct and indirect impacts of wetlands loss on waterfowl populations. The direct impact of wetlands loss is given by the reduction in waterfowl population in the stratum where the wetlands are lost, while the indirect effect relates to the change in populations in other, nearby strata. It turns out that the productivity of wetlands in other strata increases slightly, indicating that there is some accommodation of birds that have lost their primary reproductive habitat and been forced to seek habitat elsewhere. However, the extent of this mitigating effect is small.

Finally, a land-use model is developed for each strata and for the region as a whole. Nine land uses are modeled and positive mathematical programming is used to calibrate the model to observed land uses. The subsequent model is then used to simulate both the impact of climate change on land use (including changes in wetlands) and that of biofuel policies that seek to mitigate global warming. Although the land use model differs significantly from the bioecnomic models that are used in section 2 and subsection 3.2, the results are surprisingly similar in both direction and magnitude. In all cases, our models suggest that greater efforts to protect wetlands are warranted.

This study complements three recent studies of wetlands protection in Canada's grain belt. In one study, Pattison et al. (2011) used an internet survey device to determine the willingness to pay of Manitobans to conserve wetlands. They find that, despite a large annual WTP, the costs of restoring wetlands to their 1968 level would simply not be warranted, although retention and restoration of some wetlands would be socially desirable. Hill et al. (2011), and Yu and Belcher (2011), address the opposite side of the issue—the willingness of landowners to participate in wetlands retention and restoration schemes. Yu and Belcher use a survey instrument to determine the payments farmers would need to participate in a 10-year program to protect wetlands, while Hill et al use an actual reverse auction. Both studies focus on regions in Saskatchewan, and neither provides optimism about society's ability to protect let alone restore wetlands at low costs. Wetland retention and restoration are likely to prove costly, unless spatial targeting also proves cost effective. The current study employs some of these results in a broader investigation of the economics of retaining wetlands in western Canada's grain belt when faced with the threat of global warming.

1. The Prairie Pothole Region of Western Canada

Canada's Prairie Pothole Region (PPR) is part of the pothole region of North America's Great Plains (Figure 1). Although the Canadian PPR represents a mere 10% of North America's waterfowl breeding habitat, the region produces over 50% of the continent's duck population (Baldassarre et al. 1994). Since the PPR also accounts for roughly 60% of Canada's agricultural output (Statistics Canada 2006), intense competition exists between private economic interests and public benefits in this region. Not surprisingly, wetlands and waterfowl numbers have been in decline. As indicated in Figure 2, North American waterfowl populations have fallen from some 35 million when populations first began to be monitored in the early 1950s to almost 15 million by the end of the first decade of the new century – a decline of more than 50 percent (U.S. Fish and Wildlife Service 2010a, 2010b).

Figure 1: Prairie Pothole Region of North America

Source: Northern Prairie Wildlife Research Centre

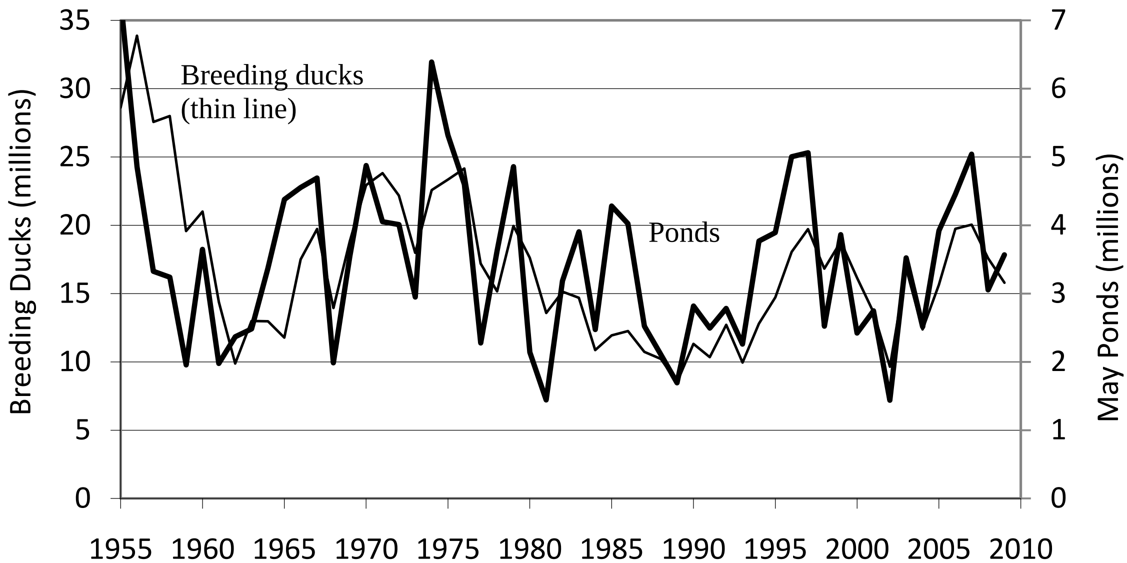

Figure 2: Relationship between Wetlands and Waterfowl in Canada's Grain Belt, 1955-2009

Interestingly, it is the U.S. Fish and Wildlife Service that monitors waterfowl populations. The entire pothole region in Figure 1 is divided into strata, which are used to organize waterfowl population data as land and climate characteristics vary across this vast region. Strata 26 through 40 are located in western Canada's southern grain belt as indicated in Figure 3. Also shown in Figure 3 are 'transects' that biologists use to enumerate waterfowl populations. Transects are laid out in a pattern that avoids double counting of birds, and biologists count birds along the same transects each year to ensure continuity and reliability of samples.

Drought and climate change have been influential factors in bringing about declines in wetlands and thereby waterfowl numbers, but agricultural development and particularly drainage activities by farmers during the 20th century have also significantly reduced wetlands (Watmough and Schmoll 2007). Due to the ecological and economic benefits of preserving wetlands and waterfowl, an empirical examination of the effects of agricultural land use on waterfowl populations is worthwhile, not only for understanding the potential intensity and significance of these effects, but also for gaining insights for management plans that seek to forestall habitat loss and population declines.

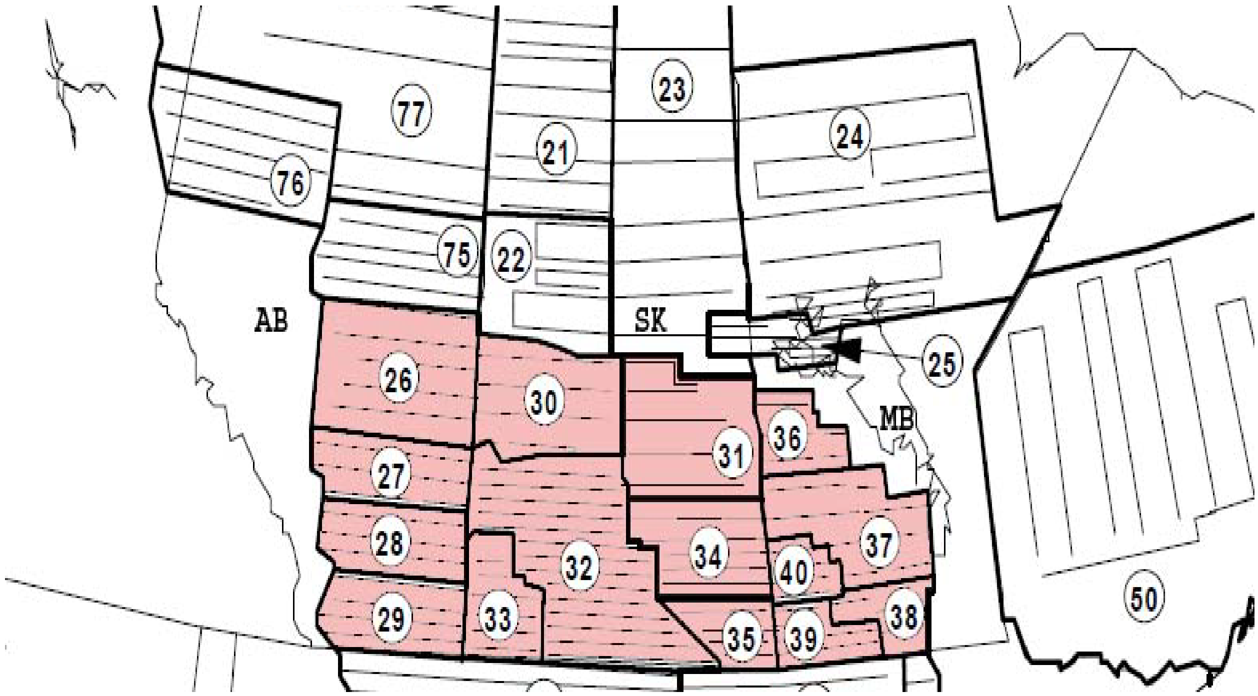

Figure 3: Transects and Strata of the Waterfowl Breeding Population and Habitat Survey
Source: Wilkins and Cooch (1999, p.38); U.S. Fish and Wildlife Service (2010a, p.60)

Consider first the expansion of cropland area. In Figure 4, we provide time series of cropland acreage and waterfowl numbers for the PPR; the data illustrate a possible negative relationship, especially after the 1970s. The picture is a little less clear when we try to break things down into type of cropland and its relationship to wetlands as opposed to duck populations, although the two track fairly closely as indicated in Figure 2.

In Figure 5, we graph seeded area and summerfallow area along with May pond counts for the period 1955-2009. It is not clear that either seeded area or summerfallow explains pond counts. What about the role of agricultural subsidies, which became important beginning in the early 1970s? A plot of agricultural subsidies and wetlands is provided in Figure 6. However, without conducting a regression analysis, it is not clear to what extent the factors in Figures 5 and 6 impact wetlands. Upon regressing May ponds on seeded acreage, summerfallow area and the per cultivated hectare agricultural subsidy, we find that agricultural subsidies do indeed have a negative impact on wetlands, but that the other variables do not. The OLS regression result is as follows (with t-statistics in parentheses):

$$\text{Ponds} = \underset{(2.57)}{7.45} - \underset{(-1.18)}{0.12}\,\text{Seeded} - \underset{(-1.30)}{0.14}\,\text{Fallow} - \underset{(-1.88)}{0.01}\,\text{Subsidy},\ R^2=0.08.$$

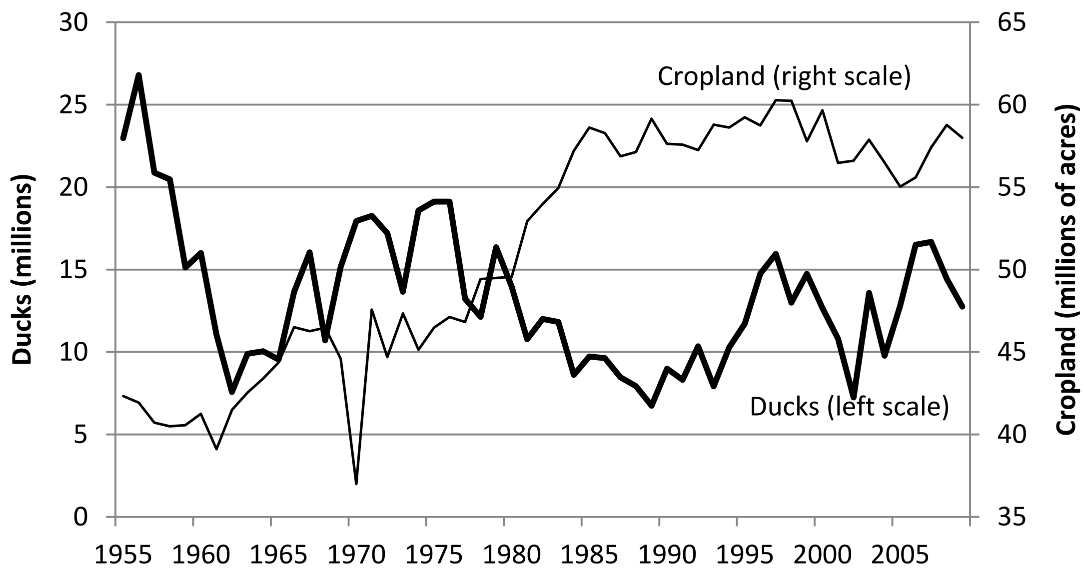

Figure 4: Cropland Acreage and Duck Populations, 1955-2009

Although the signs on the regressors have the expected signs, only the subsidy variable is statistically significant (at the 10% level); the problem is that very little of the variation in wetlands area is explained by agricultural programs or cropped area (seeded plus summerfallow area).

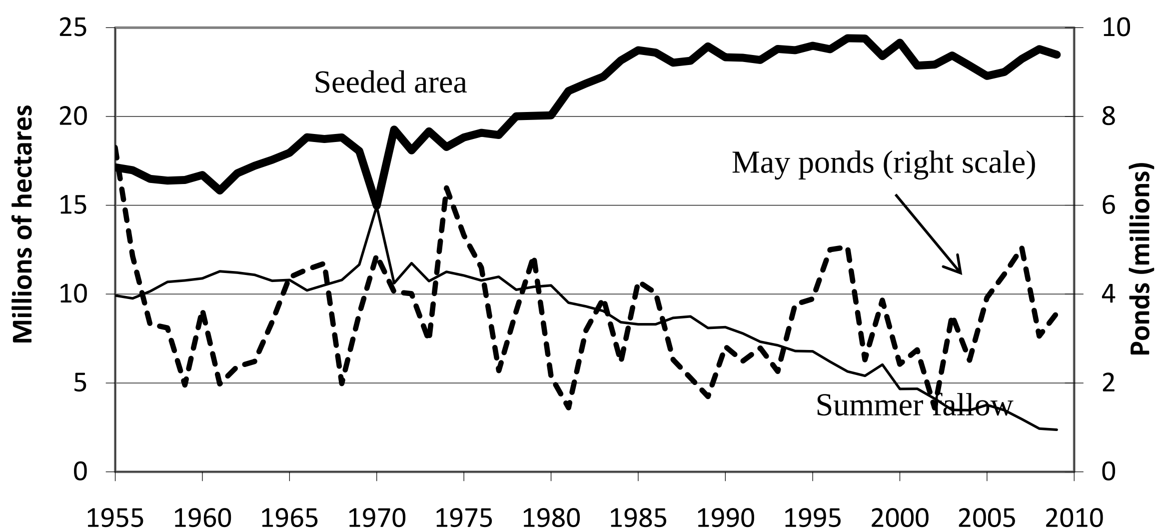

Figure 5: Seeded Area, Area in Summerfallow and Wetlands Area, 1955-2009

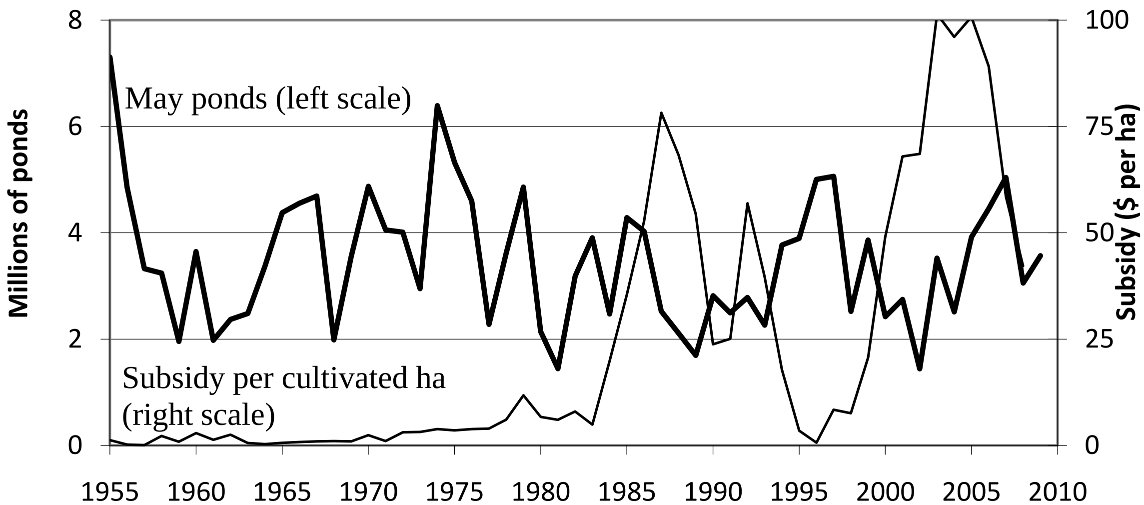

Figure 6: Agricultural Subsidy Level and Wetlands Area, 1955-2009

As indicated in the section on bioeconomic modeling, climate factors are an important factor explaining wetlands area from one year to the next. These factors were ignored in the simple OLS regression provided above. One reason why climate is important relates to the measure used for wetlands, namely, May pond counts. While July ponds are likely more indicative of permanent wetlands, researchers have relied solely on May ponds because they provide a much better statistical explanation of duck populations than July ponds (see, e.g., van Kooten et al. 2011; Hammack and Brown 1974; Brown and Hammack 1973); this is also evident from Figure 2. Indeed, the U.S. Fish and Wildlife Service, the agency that tracks ponds, has altogether stopped using the July ponds measure. Nonetheless, many May ponds are temporary, found in low lying areas on fields, especially pasturelands, and are thus highly correlated with the timing of snow melt and spring precipitation – climate or weather factors.

Weather factors vary considerably across the region, with much drier conditions experienced in the southwest corner of the region (strata 28, 29 and 33) than in the northeast (e.g., strata 34 and 36). Annual and growing season precipitation increase along a line from southwest to northeast, while growing season length and growing degree days generally decline as one travels from south to north. These trends are not linear, however. Nonetheless, sub-region differences in the grain belt are important and need to be taken into account. Fewer wetlands are found in drier regions (e.g, strata 29 and 33), but agriculture also tends to be less intensive except where there is irrigation, which is the case especially in stratum 29. Because these differences in climate impact agricultural land use, it is important to take into account agricultural activities and agricultural rents in the analysis of wetlands and migratory waterfowl. Therefore, the basic bioeconomic model of section 2 is extended to incorporate agricultural rents, and is calibrated on a regional basis in addition to the entire study area. Further, as discussed in the introduction, we rely on econometric analysis and regional and sub-regional land use models to investigate these issues in more detail.

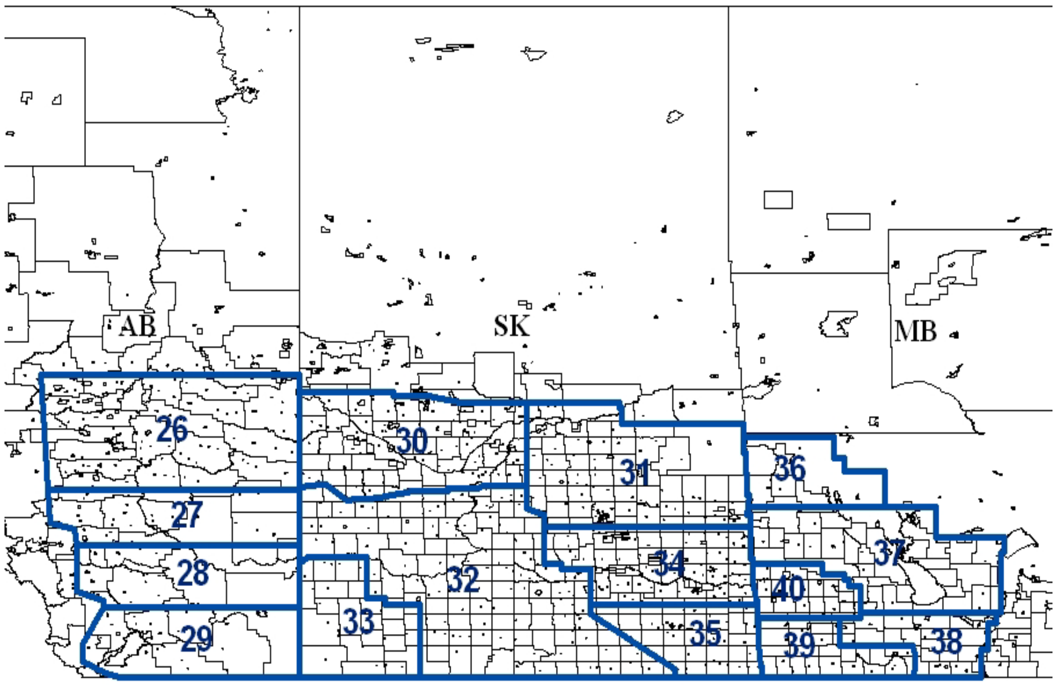

Figure 7: Strata of the Waterfowl Breeding Population and Habitat Survey (thick lines) and Census Consolidated Subdivision Boundaries of the Census of Agriculture (thin lines)

Climate change is expected to result in substantially drier conditions and increased incidents of drought in Canada's grain belt during the 21st Century (Johnson et al. 2005). Indeed, regional climate models predict that temperatures could rise by 1.8°C to 4°C in the prairie pothole region (Johnson et al. 2010). A major casualty will again be North America's duck factory – the pothole region of the southern Prairie Provinces. A drier climate will reduce the number of wetlands, which will have an adverse impact on agricultural ecosystems and the region's ability to produce waterfowl, as is clearly demonstrated by the high correlation between wetlands and breeding duck populations seen in Figure 2.

Wetlands are also impacted by policies that seek to mitigate climate change, particularly policies related to the enhanced production of biofuels. Such policies are like a subsidy but perhaps more insidious. While meant to reduce greenhouse gas emissions associated with climate change, they lead to an increase in food prices that, in turn, hurts the least well off in global society, the very people that mitigation of climate change seeks to protect. Yet, it turns out that such programs might even increase overall greenhouse gas emissions (Crutzen et al.

2008), lead to deforestation and conversion of marginal lands to cropland (Searchinger et al. 2008, 2009), and, in the prairie pothole region, result in the degradation of wetlands. The impacts of both climate change and climate change policies on wetlands are investigated in sections 2 and 3.

Surprisingly, waterfowl management models have tended to focus on the hunting benefits of waterfowl, with wetlands often considered extraneous to the determination of hunting season length and bag limits – the tools of waterfowl management. Recognizing that the majority of hunters are located in the United States while the preponderance of breeding habitat is in Canada, the 1986 North American Waterfowl Management Plan (NAWMP) (U.S. Department of Interior and Environment Canada 1986) was implemented as a mechanism by which the U.S. could compensate Canadian landowners for the positive externality that greater numbers of ponds in Canada provided U.S. hunters.[1] However, NAWMP was criticized for, among other things, simply offsetting the negative impacts of extant Canadian agricultural subsidies (van Kooten 1993b).

A variety of wetland conservation activities have been undertaken by public and private agencies since the 1890s (Porter and van Kooten 1993), but the establishment of the North American Waterfowl Management Plan in 1986 constituted the first continental effort to restore waterfowl populations – to levels seen in the mid 1970s (CWS 2004). Since its inception, over $1.5 billion has been used in conservation efforts across Canada with more than half of these funds directed to the prairies (NAWMP Committee 2009). In the PPR where the overlap between the best waterfowl habitat and the best agricultural lands can be as high as 91 percent (Bethke and Nudds 1995), it is not surprising that the primary conservation strategy is land securement: "The protection of wetland and/or upland habitat through land title transfer or binding long-term (minimum 10-year) conservation agreements with a landowner" (NAWMP Committee 2009). To date, over six million acres have been secured and an additional two million acres targeted over the next 10 years (NAWMP Committee 2009).

2. Bioeconomic Modeling of Wetlands Conservation

In this section, we examine bioeconomic models of wetlands conservation. Gardner Brown and Judd Hammack (1973), hereafter B&H, were the first to use a mathematical bioeconomic

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[1] The focus of NAWMP was not only on provision of ponds. The program provided payments to farmers for providing dense nesting cover on lands that would otherwise be cropped, thereby enhancing the ability of waterfowl to reproduce. Ideally sites are to be fenced to keep out predators, but payments are usually inadequate. See van Kooten and Schmitz (1992) and van Kooten (1993a, 1993b) for a more detailed discussion of these issues.

modeling approach (Clark 1976) to address waterfowl dynamics and wetlands conservation.[2] Such models optimize an economic objective function subject to dynamic technical, biological, socioeconomic and political constraints. B&H (1973) and H&B (1974) chose a model that could be solved analytically to provide insights, but they needed to solve it numerically to determine whether the optimal policy called for more or less wetlands. In their specification, they focused exclusively on duck hunting values, ignoring other waterfowl values and wetland benefits. We begin with a variant of the H&B model, and then expand it, firstly, to include the viewing value of waterfowl and, importantly, the ecological service and other amenity values of wetlands. We then expand the model to include the impact of climate change.

2.1 An Extended Bioeconomic Model of Duck Hunting

B&H (1973) and Brown et al. (1976) specify a discrete bioeconomic optimal control model of duck hunting. They postulate a social planner whose objective is to maximize benefits to hunters minus the costs of providing wetlands:

$$\sum_{t=1}^{T}\left[v(h_t, y_t, Z_t) - C(W_t)\right]\rho^t, \tag{1}$$

where $v(h_t, y_t, Z_t)$ is a function describing the annual benefits derived from duck hunting, which is a function of the number of ducks harvested (h), per capita income of duck hunters (y), and such things as age, gender and outdoor experience that characterize duck hunters (Z); $C(W_t)$ is the annual cost of providing W amount of wetlands (measured by the number of ponds); and $\rho = 1/(1+r)$ is the discount factor with r the discount rate used by the hypothetical planner. The length of the planning horizon is T, and could possibly be infinite. In the H&B model, harvest levels and the number of ponds are decision variables.[3]

H&B's objective function (1) can be extended by bringing in two types of amenity values – one is related to the nonmarket (non-use) benefits of waterfowl, while the other takes into account the ecosystem service and non-use values of wetlands themselves. The modified objective function is:

$$\sum_{t=1}^{T}\left[v(h_t, y_t, Z_t) + \alpha D_t + B(W_t) - C(W_t)\right]\rho^t, \tag{2}$$

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[2] Judd Hammack's PhD dissertation on the subject was subsequently published as a book (Hammack and Brown 1974). Details pertaining to data, estimation of the value of ducks to hunters, and the bioeconomic model are found therein.

[3] H&B multiply $v(.)$ by the number of hunters, the control variable if bag limits and average take per hunter are constant. Here $v(.)$ is simply the benefit to all hunters.

where D_t refers to the population of May breeding ducks in year t, while α is the annual amenity value of a duck, which could be positive for small numbers of ducks and negative for large numbers (e.g., if large numbers lead to crop depredation). To keep things simple, we assume the amenity value is a positive constant. $B(W_t)$ is a wetlands ecosystem benefit function with $\partial B/\partial W_t > 0$ and $\partial^2 B/\partial W_t^2 \leq 0$.

Ducks breed in the prairie pothole region in May and begin the fall flight south in September, which is also the start of hunting season. The fall flight consists of the fraction s_1 of May breeding ducks (D_t) that survive to September, plus their offspring that also survive to September. The latter is given by the recruitment (production) function $g(D_t, W_t)$, where $\partial g/\partial D_t>0$, $\partial^2 g/\partial D_t^2 \leq 0$, $\partial g/\partial W_t>0$, $\partial^2 g/\partial W_t^2 \leq 0$. Equation (2) is maximized subject to the following bioeconomic constraints:

$$D_{t+1} = s_2\,[s_1 D_t + g(D_t, W_t) - \pi\, h_t], \quad (3)$$

$$D_t,\ h_t,\ W_t \geq 0;\ \text{and}\ D_0 > 0,\ W_0 > 0\ \text{given} \quad (4)$$

where D_{t+1} is the number of mature ducks returning to the prairie pothole breeding grounds in year $t+1$, s_1 is the fraction of May breeders surviving to September, s_2 is the fraction of mature ducks that are not killed by hunters and survive to return to the breeding grounds in year $t+1$, and $\pi > 1$ accounts for the loss of ducks that are killed or maimed by hunters but not collected or reported. Conditions (4) are non-negativity requirements and initial conditions regarding the numbers of ducks and ponds.

Applying Bellman's principle of optimality leads to the following recurrence relation known as Bellman's equation (Léonard and van Long 1992, pp.174-176):

$$V_t(h_t, D_t, W_t, \lambda_{t+1}) = \underset{h_t, W_t}{\text{Maximize}} \left\{ \left[v(h_t, y_t, Z_t) + \alpha D_t + B(W_t) - C(W_t) \right] + \rho V_{t+1}(D_{t+1}) \right\}. \quad (5)$$

where V_t is a value function and $\lambda_t = \partial V_t/\partial D_t$ is the shadow price of an additional duck. Equation (5) can be solved using backward recursion based on the assumption that the social planner or authority behaves optimally in the future so that the value at time $t+1$, V_{t+1}, is the best one can do.[4] The first-order conditions are found by first setting $\partial V_t/\partial h_t = 0$ and $\partial V_t/\partial W_t = 0$, and then differentiating both sides of (5) by the state variables D_t (recalling that D_{t+1} is a function of D_t).

Assuming an interior solution, the first-order conditions are:

[4] The backward recursive approach of dynamic programming best lends itself to numerical solutions. In that case, T must be finite and the value $V_T(D_T)$ must be specified.

$$\partial V_t/\partial h_t = \partial v/\partial h_t - \rho\, \lambda_{t+1}\, s_2\, \pi = 0 \tag{6}$$

$$\partial V_t/\partial W_t = B'(W_t) - c + \rho\, \lambda_{t+1}\, s_2\, \partial g/\partial W_t = 0 \tag{7}$$

$$\partial V_t/\partial D_t = \lambda_t = \alpha + \rho\, \lambda_{t+1}\, s_2\, (s_1 + \partial g/\partial D_t) \tag{8}$$

where $c = dC/dW_t$ is the annual opportunity cost of providing an additional pond.[5] Additionally, the state equation (3) must be satisfied; the sufficient conditions for a maximum are guaranteed by Bellman's optimality principle with $\lim_{t\to\infty} \lambda_t\, \rho^t\, D_t = 0$.[6] Equations (6) and (7) constitute a maximum principle, while equation (8) is the co-state equation.

From maximum principle (6), we find that $(1/\pi)\ \partial v/\partial h_t = \rho\ \lambda_{t+1}\ s_2$, which says that hunting should continue until the value of the marginal duck that is harvested (adjusted for the fact that not all birds killed are recovered) equals the user cost of taking that bird (which equals its discounted shadow value adjusted for the fact that not all unharvested ducks survive to breed the following spring). Similarly, from maximum principle (7), we find: $c = B'(W_t) + \rho\ \lambda_{t+1}\ s_2\ \partial g/\partial W_t$. The left-hand side of this expression is the current cost of an additional pond, which is simply the cost of establishing or protecting it. The right-hand side is the marginal benefit of an additional pond, which consists of the sum of two terms. The first term constitutes the current marginal ecosystem service and other amenity values of the pond, $B'(W_t)$. This term is absent from the H&B model as they do not consider nonmarket values of wetlands. The second term is the marginal value of an additional wetland in the production of ducks that return to the breeding ground next year. Note that the shadow value of next year's duck is adjusted by the discount factor ρ and the mortality risk.

The final condition (8) can best be interpreted by re-writing it as $\lambda_t - \alpha = \rho\lambda_{t+1}\ s_2(s_1+\partial g/\partial D_t)$. In the absence of the amenity term α, the discounted future (shadow) value of allowing a duck to escape (adjusted for mortality and the marginal growth in duck population) must equal the current (shadow) value of harvesting that duck, λ_t. From the perspective of the planner, however, the shadow value of the marginal duck to hunters needs to be reduced by α, because the planner needs to take into account the non-use value that a duck provides citizens. This is done by raising the population of waterfowl over that in the case where ducks only have value to hunters – the case considered by H&B. Compared to the hunters-only case, more ducks are allowed to escape to the next year to satisfy both the need to make more birds available to

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[5] The marginal cost of providing an additional pond need not be constant, but could be a function of the number of ponds, so that we would write $c(W_t) = dC/dW_t$.

[6] Notice also that functions $v(.)$ and $g(.)$ are taken to be non changing over time. Further, the last condition says that either it is optimal to drive the duck population to zero at some future time or the present shadow value of an additional duck is zero.

hunters in the future and the non-use value ducks provide.

Substitute $\rho\, \lambda_{t+1}\, s_2$ from (6) and from (7) into (8) to get the following expressions for the current shadow price of waterfowl:

$$\lambda_t = \alpha + \frac{1}{\pi}\left(s_1 + \frac{\partial g}{\partial D_t}\right)\frac{\partial v_t}{\partial h_t} \text{ and} \tag{9}$$

$$\lambda_t = \alpha + \frac{\left[c - B'(W)\right]\left(s_1 + \frac{\partial g}{\partial D_t}\right)}{\frac{\partial g}{\partial W_t}}. \tag{10}$$

Setting (9) equal to (10), and rearranging, gives a relationship similar to (7), but one that more clearly spells out the relationship between ponds and the value of waterfowl:

$$c = \frac{1}{\pi}\frac{\partial v}{\partial h_t}\frac{\partial g}{\partial W_t} + B'(W). \tag{11}$$

The left-hand side of (11) is the (marginal) social cost of providing an additional pond, while the right-hand side is the value of the additional pond in the production of ducks for hunters plus the ecosystem service and non-use benefits it provides.

A steady-state solution is found by letting $\lambda_{t+1}=\lambda_t$ and $D_{t+1}=D_t$, $\forall\, t$. We then find the following three steady-state conditions from equations (6), (7), (8) and (3):

$$B'(W) + \frac{1}{\pi}\frac{\partial v}{\partial h}\frac{\partial g}{\partial W} = c, \tag{12}$$

$$\left(s_1 s_2 + s_2\frac{\partial g}{\partial D} - 1\right) + \frac{\pi\, s_2}{\partial v/\partial h}\alpha = r, \text{ and} \tag{13}$$

$$(1 - s_1 s_2)D = s_2\, g(D, W) - \pi\, h. \tag{14}$$

Once functional forms and associated parameters are chosen, equations (12), (13) and (14) can be solved simultaneously for the optimal waterfowl population and optimal decisions concerning harvests and number of ponds that maximize the social planner's wellbeing. To find the steady-state solutions if the non-use values of wetlands and ducks are ignored, the terms $B'(W)$ in equation (12) and α in (13) would need to be set to zero. This would provide optimal values of our variables in H&B's case where the focus is solely on hunters' benefits.

2.2 Estimating Parameters for the Bioeconomic Waterfowl-Wetlands Model

Hammack and Brown (1974) used information from a survey of duck hunters to estimate a demand function for duck hunting. No other such survey has been conducted in the intervening years. We employ the functional form for demand employed by B&H (1973). However, the parameters of B&H's function are simply too unrealistic for our application nearly forty years later, even if these are adjusted for inflation. Therefore, we proceed as follows.

In 2007, a total of 815,300 duck hunters in the Mississippi, Central and Pacific flyways spent an average of 7.2 days in the field and bagged 15.7 ducks; in 2008, 802,400 hunters harvested an average of 14.8 ducks and spent 7.1 days on the activity (Table 1).[7] Using 1972-2008 data for Alberta, harvests averaged 12.8 ducks per hunter annually. Based on 20 studies, Loomis (2000) finds an average value of a wilderness recreation day to be $39.61 in 1996 US dollars, or $53.83 in 2008 after adjusting for inflation. Assuming duck hunters spend an average of 7 days in the field and harvest 14.5 birds, each bird is then worth approximately $26. Multiply this value by an average harvest of 12.3 million ducks over 2007 and 2008 in the Mississippi, Central and Pacific flyways gives a total benefit of $319.8 million. Assuming that the parameter value on harvest is 0.6, we calculate $v(h) = 70.947\, h^{0.6}$, with $v(h)$ and h measured in millions.

Cortus et al. (2010) calculate the net benefits of wetland retention in Saskatchewan by adapting the gross public benefits of wetland retention from Belcher et al. (2001). Their 'best estimate' of public benefits of wetlands is $81.55 per hectare, while the low estimate is $39.62. We use the low value of wetlands benefits as our base case but conduct sensitivity analysis using the best estimate. These values need to be converted to a per pond measure. Cowardin, Shaffer and Arnold (1995) find that 78% of wetlands in the northern U.S. Great Plains cover 0.41 ha or less. Assuming an exponential distribution, we calculate the average pond to have an area of 0.27 ha.[8] Then the base case value is $10.69 per pond and the higher estimate for sensitivity purposes is $22.01 per pond. For simplicity, it is simply assumed, for simulation purposes, that marginal benefits are constant at $10 and $22 per pond.

The annual cost of restoring a pond is given by the (marginal) opportunity cost of retaining the wetland plus the annualized cost of restoring it. The net opportunity costs of protecting or

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[7] We focus on U.S. hunters because the U.S. Fish and Wildlife Service (2010) contribute to the collection of data in Canada and the U.S. contributes to wetlands protection in Canada under NAWMP.

[8] The cumulative probability function is: $\text{Prob}(x<X) = 1 - e^{-3.693\, x}$. H&B (1974, p.69) indicate that the average size of a pond in the Prairie pothole region was determined to be 0.85 acres or 0.34 hectares.

restoring wetlands equals the reduction in the value of cultivated land or land in its best alternative use. In cases where flooding is common, or where wetlands are permanent, the cost might be zero. Since the least number of ponds in the PPR during the period 1955-2009 was rarely below two million and then only in drought years, we assume this amount of wetlands can be protected at no cost, and that no restoration is required for anything less than two million ponds.

Net returns to agricultural land vary considerably from year to year, from one crop to another, and across the prairie pothole region. This is considered in the extend model that includes climate variables. To derive the net opportunity costs of retaining wetlands in the PPR, Cortus et al. (2010) use a farm level simulation model. They determine the cost of retaining wetlands to be between \$28 and \$41 per hectare, or between \$8 and \$11 per pond.

The marginal cost of protecting any pond beyond two million ponds is also assumed to be constant. We calculate one-time restoration costs to be between \$360 and \$1300 per pond, which we convert to annualized restoration cost of \$12 to \$44 per pond assuming the authority purchases a 30-year easement on the property containing the wetland (see Hansen 2009).

Summing the annualized restoration cost and annual opportunity costs, we find that costs range broadly from \$20 to \$55 per pond. We use a conservative approach and assume the overall annual net (marginal opportunity) cost of keeping a wetland is \$55 per pond, although we employ sensitivity analysis with costs ranging from \$35 to \$65.

B&H (1973), H&B (1974) and Brown et al. (1976) use two functional forms for the waterfowl production function – a double-logarithmic form (or Cobb-Douglas) and a Beverton-Holt production function. As the number of breeding ducks grows to infinity, the number of offspring grows indefinitely large in the case of the Cobb-Douglas production function, but is bounded by the available habitat (the ecosystem carrying capacity) in the case of the Beverton-Holt model. Because our estimated double-logarithmic production function exhibited increasing returns to scale, we find that increases in the costs of restoring wetlands are offset in the steady state by unbounded increases in optimal breeding populations, an unrealistic result. We also found that, with the Beverton-Holt production function, the dynamic model turns out to be highly unstable, which is not unusual in this case as noted by van Kooten and Bulte (2000, p.184). Indeed, the required properties of the waterfowl production function are better modeled using the following standard logistic growth function now commonly used in bioeconomic models:

$$g(D_t, W_t) = \gamma D_t \left(1 - \frac{D_t}{g W_t^{b}}\right) \tag{15}$$

where γ is the intrinsic growth rate and gW_t^b is the carrying capacity of the prairie pothole ecosystem (where g and *b* are parameters to be estimated). As indicated in the next subsection, this functional form also permits us to more easily introduce climate variables.

We have data on breeding ducks and immature offspring, and on wetlands (May pond counts), for the prairie pothole region of southern Alberta, Saskatchewan and Manitoba, namely, the U.S. Fish and Wildlife Service's (2010a) strata 26 through 40, over the period 1955 to 2009. We also have data on July ponds for the period 1955-2003, U.S. duck harvests for the Central flyway for the period 1961-2008, and Canadian harvests of ducks for the period 1969-2008. We use this data to estimate equation (15) using nonlinear least squares regression:[9]

$$g(D_t, W_t) = \underset{(8.73)}{2.89}D\left(1 - \frac{D}{\underset{(4.20)}{12.29}W^{\underset{(4.25)}{0.91}}}\right), \quad R^2 = 0.50 \qquad (16)$$

Finally, we employ H&B's (1974, p.50) values for intra-year survival rates for the period between breeding in May and the start of hunting season in September (s_1) and the period after hunting season until breeding begins (s_2). Brown et al. (1976) assume 5% of duck kills are not reported, and we use this factor to account for underreporting of bird kills by hunters. Loomis and White (1996) report non-use values for several endangered bird species, which are quite large for some species such as Whooping Crane. Ducks and geese tend to be plentiful, so their value to bird watchers and other viewers tends to be smaller. Therefore, we use a very low value for the amenity value of ducks. This value is lower than the values of endangered bird species reported by Loomis and White.

2.3 Socially Desirable versus Historical Wetlands Area and Waterfowl Populations

We determine the steady-state solutions by solving the system of equations (12), (13) and (14) for the case where non-use values are not taken into account (only hunter values are considered), and the steady-state solutions when non-use values of wetlands and ducks are included. A summary of the results in provided in Table 1, which gives the optimal steady-state values of ducks, harvests and wetlands.

When non-market amenity values are not taken into account, we have the situation examined by B&H (1973), H&B (1974) and Brown et al. (1974). When using a cost of wetlands of $45 per pond or lower, we confirm their findings, despite using different functional forms and updated information on duck populations and wetlands: for the most part, wetlands and duck harvests

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[9] The t-statistics are in parenthesis below the expression in which the estimated coefficient is found and are based on Newey-West HAC standard errors.

(and thus duck populations) are below socially desirable levels.

Table 1: Historic and Steady State Values of Ponds, Ducks and Harvests, Various Net Costs of Wetlands Restoration (millions)

Item	Ponds (*W*)	Ducks (*D*)	Harvests (*h*)
Historic values[a]	3.5	13.5	12.3
	Base Case		
No amenity value	2.6	12.8	12.6
Amenity value	4.1	20.3	19.6
	Cost=$45; B′(W)=$10[b]		
No Amenity value	3.5	17.0	16.8
Amenity value	6.3	30.6	29.0
	Cost=$35; B′(W)=$10[b]		
No amenity value	5.2	24.4	24.1
Amenity value	11.6	54.3	50.0
	Cost=$65; B′(W)=$10[b]		
No amenity value	1.96	9.9	10.0
Amenity value	2.9	14.8	14.3

Notes:
[a] Ponds and ducks are for Canada's prairie region and based on the average of 1955-2008 data from the U.S. Fish and Wildlife Service (2010a), while harvest is the average of 2007-2008 U.S. harvest for the Pacific, Mississippi and Central flyways (average total U.S. duck harvest was 14.1 million). There exists a mismatch in terms of the regions used for reporting of ponds versus waterfowl population data and harvest data.
[b] Cost refers to net annualized costs of restoring a pond plus the annual opportunity cost, while $B'(W)$ is the nonmarket (ecosystem service plus other amenity) benefit of an additional pond.
Source: van Kooten et al. (2011)

The matter is only made worse when the ecosystem amenity values of wetlands and the viewing value of waterfowl are taken into account. In that case, the socially optimal level of wetlands increases – increasing the marginal benefit of a pond should increase the number of ponds, which in turns leads to an increase in ducks and harvests as a result of increased breeding habitat. Then, increasing the value of waterfowl to viewers (parameter α) will decrease the shadow value of the marginal duck to hunters, indicating that the planner needs to raise the population of waterfowl over that in the model where ducks only had value to hunters. The base case results in Table 1 indicate that wetlands should be about 17 percent higher, which is consistent with H&B, while the duck population and harvests should be about 50% and 60% higher than historic levels, respectively (Table 1).

In addition to the actual values obtained in Table 1, ratios of ducks per pond and harvests per pond can easily be calculated. For May pond data, the historical levels are 3.85 ducks and 3.54 harvests per pond. In the current model under the base case 'amenity value' scenario, the optimal levels of ducks and harvests to ponds are 4.98 and 4.79, respectively. Thus, given the number of wetlands, historic levels of both waterfowl and harvests are too low from a social planner's perspective. This result could be an artifact of the logistics growth model, but it could also be that more should be done to provide dense nesting cover for breeding waterfowl, thereby increasing wetlands productivity.

Our estimate of $55/pond as the net annual cost of restoring and retaining wetlands might be considered conservative, and, from our review of the literature, it is quite possible that the net costs of conserving ponds could be lower. However, using lower values only reinforces the result that current wetlands protection levels do not appear to be adequate. Indeed, if the annual cost of restoring and retaining wetlands is $35/pond rather than $55 per pond, the number of ponds to protect rises from an historic level of 3.5 million to over 10 million.

2.4 Climate Impacts on Wetlands and Waterfowl Populations

Using temperature, precipitation and drought data for various locations across Western Canada's grain belt, Withey and van Kooten (2011a) estimated the following relationships using ordinary least squares:

$$W_t = \underset{(26.28)}{2.90} + \underset{(4.84)}{3.33}\, SPI_{t-1},\ R^2=0.30,\ \text{S.E}=0.95 \tag{17}$$

$$W_t = \underset{(1.83)}{3.138} + \underset{(4.07)}{0.085}\, P_{t-1} - \underset{(-2.83)}{0.310}\, T_{t-1},\ R^2=0.36,\ \text{S.E}=0.91, \tag{18}$$

where t-statistics are provided in parentheses, *W* is measured in millions of May ponds, *SPI* is the standardized precipitation index (a common drought measure), *P* is precipitation (in millimeters), and *T* is temperature (in degrees Celsius).

The authors then considered the following climate scenarios:

(i) an increase in temperature of 3°C, no change in precipitation;

(ii) no increase in temperature, a decrease in precipitation of 20%;

(iii) an increase in temperature of 3°C, a decrease in precipitation of 20%; and

(iv) an increase in temperature of 3°C, an increase in precipitation of 20%.

For specification (17), the corresponding global warming induced changes in SPI due to the four alternative changes in temperature and precipitation were first estimated, and then the effects of SPI on wetlands were found using the estimated regression coefficient on SPI_{t-1}. For specification (18), the effect of climate change on wetlands was found using the estimated coefficients on P_{t-1} (precipitation) and T_{t-1} (temperature) for the four precipitation-temperature scenarios identified above. The projected values of W under climate change are provided in Table 2, and inserted into the waterfowl population dynamics equation (16).

Table 2: Effect of Climate Change on Wetlands in the Absence of Wetlands Protection Policies: Percent Decrease in Wetlands Area

	Scenarios			
Regression Model	+3°C Temperature	−20% Precipitation	+3°C & −20% Precipitation	+3°C & +20% Precipitation
(17)	20	13	34	7
(18)	27	19	47	10

Source: Withey and van Kooten (2011a)

Subsequently, the associated bioeconomic model was solved for each of the four climate scenarios and two regression models. The results are provided in Table 3. With climate change, there are significant decreases in the optimal amounts of wetlands that society should retain. The reduction in wetlands ranges from 5% to 38% compared to the base case, no climate change scenario. Further, the proportional decline in ducks and harvests is significantly greater than the fall in wetlands. Because there are fewer wetlands, the model also projects a decrease in the ratio of ducks and harvests to wetlands. Clearly, with substantially fewer wetlands, the landscape cannot support the large duck populations that it currently does because, with climate change, the socially optimal levels of ducks and harvests are much smaller. These results illustrate the potentially severe effects of climate change on wetlands and migratory waterfowl in North America's duck factory.

Table 3: Optimal Values of May Ponds, Duck Populations and Duck Harvests (millions): Historic and Model Base Case and Climate Change Scenarios

Regression		Base	*Scenario i*		*Scenario ii*		*Scenario iii*		*Scenario iv*	
Model →	Historic	case	(17)	(18)	(17)	(18)	(17)	(18)	(17)	(18)
Ponds	3.5	4.1	3.4	3.2	3.7	3.5	3.0	2.6	3.9	3.8
Ducks	13.5	20.3	13.8	11.8	15.9	14.1	9.9	6.9	17.9	16.9
Harvests	12.4	19.6	13.4	11.5	15.4	13.7	9.7	6.8	17.3	16.4

Source: Adapted from Withey and van Kooten (2011a).

3. Regional Impacts

Wetlands are not evenly distributed across western Canada's southern Prairie Provinces. The eastern and northern regions receive more precipitation, while southern regions are warmer earlier. These factors determine the abundance of wetlands and their productivity. Given that the climate varies across the prairies, climate change will also have varying impacts. In this section, therefore, we consider how climate change affects various regions and impacts wetlands and their management. We do this by first solving the preceding bioeconomic model at the level of individual strata. We then examine how, at the margin, restoration or degradation of wetlands has a direct and an indirect effect on waterfowl populations. The direct effect is due to the gain (loss) of waterfowl resulting from the restoration (degradation) of the particular wetland. The indirect effect takes into account what happens in other regions. A panel data set that takes into account spatial aspects is employed to investigate this particular aspect. Finally, rather than a bioeconomic model as in the earlier research, we develop a region-specific land use model, calibrated using positive mathematical programming, to examine the impact of climate change on land use, including land in wetlands. Importantly, the model is also used to investigate the impact that biofuel policies designed to mitigate global warming will have on land use in the PPR.

3.1 Bioeconomic Modeling of Land Use at the Regional Level: The Impact of Climate Change

The bioeconomic model described in section 2 can be modified so that the social planner, or the authority, makes decisions regarding land use as well as decisions regarding levels of duck harvests and wetlands retention/restoration. In this case, the objective function (2) is rewritten as follows:

$$\sum_{t=1}^{T}\left[v(h_t)+\alpha D_t + B(W_t) - C(W_t) + N(a_t)\right]\rho^t \,, \tag{19}$$

where $N(a_t)$ is the net return to cropland a_t (\$/acre), and the other variables in the above function are as defined previously. Cropland excludes waterfowl habitat but takes into account land in summerfallow, crops or pasture. By including cropland in this model, we are able to estimate the effect of land use changes due to policies designed to mitigate climate change.

Withey and van Kooten (2011b) add the following state equation and land constraint to the bioeconomic model described above:

$$W_{t+1} = \beta_0 + \beta_1 W_t \, e^{SPI_t} \tag{20}$$

$$\bar{A} = W_t + a_t \tag{21}$$

Because we lack data, we let $C'(W_t) = c$, which is a constant equal to the annual cost of providing an additional pond, and $dN/da_t = N'(a_t)$ is the marginal net revenue from cropping the next acre taken out of wetlands. The bioeconomic model is solved in the same fashion as before, with the addition of constraints (20) and (21). That is, objective (19) is maximized subject to constraints (3), (4), (20) and (21), and solved as an augmented Lagrangian function.[10] In this case, however, there are two control variables – duck harvests (*h*) and area cropped (*a*) – rather than only harvests. Parameter values for this model are similar to those used above; only net revenues from cropping and the state equation (20) have been added. Further details are available by Withey and van Kooten (2011b).

Historic and model-determined steady-state values of wetlands area, duck populations and harvests, and area cropped are provided in Table 4. The socially optimal steady-state values of the four outcome variables in the model are for the case where no climate change is postulated to take place. Based on model derived shadow prices, Withey and van Kooten (2011b) find that an additional duck is worth about $9 (not shown in Table 4), while an additional acre of wetlands is worth about $50, with the value of marginal wetlands 28% higher in Saskatchewan than the regional average but worth 42% less in Manitoba (Table 4). Strata level details are available in Withey and van Kooten (2011b).

Table 4: Historic and No Climate Change Steady-State Values of Wetlands Area, Duck Populations, Duck Harvests and Cropped Area, by Province and Prairie Pothole Region Total (millions)

	Province			
Item	Alberta	Saskatchewan	Manitoba	TOTAL
Historic Values				
Wetlands (acres)	0.64	1.72	0.59	2.95
Duck populations	4.30	7.50	1.30	13.1
Duck harvests	—	—	—	12.30
Cropped area (acres)	21.4	48.10	11.1	80.60
Wetland shadow value	—	—	—	—
Base Case Optimal Values				
Wetlands (acres)	0.62	1.62	0.56	2.8
Duck populations	4.48	12.1	2.26	18.84
Duck harvests	4.48	10.43	2.24	17.15
Cropped area (acres)	21.42	48.2	11.13	80.75
Wetland shadow value ($/ac)	56.8	63.6	28.8	49.7

How do climate change and, importantly, biofuel policies to mitigate climate change affect the above results? To answer this question, Withey and van Kooten (2011b) first assumed that climate change would increase temperatures throughout the PPR by 3°C, and decrease

[10] The augmented Lagrangian function constitutes the Hamiltonian plus the static constraint (21) that must hold in every period (see Léonard and van Long 1992, pp.192-194).

precipitation by 10%. They then assumed that the renewable fuel standard for diesel that increases energy crop production (a policy for mitigating climate change) would increase the price of canola by 15%. They estimated that this would increase land in crops by 1.25 million; this increase in cropland was assumed to come from wetlands. The renewable fuel standard is combined with the climate change scenario. The model was then used to estimate the impacts of the no-climate change, climate change, and climate change plus renewable fuel standard scenarios at the regional, provincial and strata levels. Summary results are provided in Table 5 with greater detail found in Withey and van Kooten (2011b).

Table 5: The Effect of Climate Change and Climate Change Policies on the Socially Optimal Levels of Wetlands, Duck Populations and Harvests, and Cropped Area for Different Levels of Regional Analysis

Item	Wetlands ($\times 10^6$ acres)	Duck population ($\times 10^6$)	Duck harvests ($\times 10^6$)	Cropped area ($\times 10^6$ acres)
Historic[a]	2.95	13.1	12.3	88.5
Base-case Optimization[b]				
Entire pothole region	2.79	16.79	15.23	80.75
Province level	2.81	18.84	17.22	80.74
Stratum level	2.78	27.43	22.34	80.77
Climate change impacts[c]				
Entire pothole region	2.47	14.99	13.65	81.07
Province level	2.51	16.81	15.48	81.04
Stratum level	2.54	25.02	20.55	81.01
Climate change plus renewable fuel standard[d]				
Entire pothole region	1.23	7.78	7.22	82.31
Province level	1.26	8.43	7.99	82.29
Stratum level	1.29	13.52	11.23	82.26

[a] Ponds and ducks are for Canada's prairie region, based on US Fish and Wildlife Service (http://mbdcapps.fws.gov/) average of 1955-2008 data; harvests are average 2007-2008 US harvest (www.fws.gov/migratorybirds/NewReportsPublications/HIP/hip.htm).
[b] Based on solution to bioeconomic model accounting for the amenity values of wetlands and ducks.
[c] Optimization based on an increase in temperature of 3°C and a decrease in precipitation of 20%.
[d] Optimization based on climate change and increase in acreage planted to energy crops.
Source: Withey and van Kooten (2011b)

Under assumed climate change, optimal wetlands retention declines from 2.79 million to 2.47 million acres, which represents a decline of 12%. The optimal duck population falls by nearly 11% and harvests by 10%. Yet, even under climate change that negatively impacts wetlands, socially desirable duck populations and duck harvests are above historic (and current) levels. However, the impacts reported here are smaller than those found in the previous section, mainly as a result of modeling differences (especially the use of a nonlinear relation between wetlands and climate).

The optimal level of aggregate wetlands to retain when both climate change and the implementation of a renewable fuel standard are assumed is 1.23 million acres, a reduction of 56% from baseline. This greatly exceeds the decline in wetlands attributable to project climate change alone. It appears that climate mitigation policies that increase the value of agricultural land in crop production, in this case canola for production of bio-diesel, have a greater adverse environmental impact on wetlands and waterfowl than the threat of global warming.

The results of the analysis are similar, whether the analysis is conducted at the supra-regional (PPR) level, provincial levels and aggregated, or strata levels and aggregated (Table 5). Although not reported here, the climate change impacts on wetlands in the PPR are driven primarily by large reductions in Saskatchewan, although proportional declines in wetlands area are projected to be greatest for Alberta and least for Manitoba (in both level and proportional terms). At the strata level, the reduction in optimal wetlands retention is highest in strata 30-34 located in Saskatchewan, and stratum 26 in northern Alberta. In Alberta it is optimal to drain all wetlands in stratum 29 (see Figures 3 and 7), while wetlands reductions are projected to be smallest in eastern parts of Saskatchewan (strata 35) and Manitoba. These results are similar to those reported in section 3.3 below, where an entirely different model is employed.

3.2 Panel Data Model

It is clear that agricultural land use changes have an impact on waterfowl abundance in the Canadian Prairie Pothole Region. What is not clear is the nature of this impact? For example, in extremely arid years, migratory waterfowl will continue their flight north, into the boreal zone if necessary, to find adequate breeding habitat. When wetlands are drained, migratory waterfowl will seek breeding habitat in other areas of the pothole region. It is necessary to consider spatial aspects if one really wants to know the extent to which degradation of waterfowl habitat reduces waterfowl population levels over the entire grain belt. This requires the examination of wetlands, waterfowl and agricultural data across the region. It requires a model that takes into account what happens in various sub-regions simultaneously. It requires a model that takes into account spatial autocorrelation.

In order to examine the impacts of wetlands degradation across the study region, Wong et al. (2011) treated information from each of the strata in Figure 7 over the period 1955-2008 as a panel. Agricultural Census data for the Census subdivisions in Figure 7 were aggregated to the strata level. Then, using a standard static panel model, Wong et al. (2011) found that a one percent increase in the proportion of land in a region that is cropped led to a predicted 6% reduction in the density of duck populations. For similar proportional reductions in summerfallow and pasture acreage, the respective declines in duck density were found to be

7% and 6%. Estimates from models that used a dynamic rather than a static specification were more conservative, however. For the lagged dependent variable model, a one percentage point increase in cropland was predicted to decrease duck density by 4.6%. For summerfallow and pasture, the predicted decreases were 4.7% and 4.6%, respectively.

Spatial autoregressive models allow the derivation of measures for assessing direct and indirect impacts. The researchers found that the estimated direct impacts projected by a model that took into account spatial autocorrelation fell between the estimates obtained from the standard and dynamic models. However, when spillover effects were also included, the estimated impacts exceed those predicted by the standard (static) model.

The Wong et al. results suggest that, when wetlands are lost at one location, ducks do not compensate by breeding in other locations, or, if they do, that there is an overall reduction in fecundity. This makes programs to retain or create wetlands all the more worthwhile as additional wetlands in one location will result in enhanced productivity of ducks in another. It would appear that there are economies of scale for ducks in wetlands provision.

Because geographically referenced data are available, it is logical to use a spatial model. In this particular case, the bias resulting from not explicitly modeling spatial dependencies may not be practically significant, but neglecting possible indirect impacts only gives researchers a partial picture of how agricultural land use changes affect waterfowl populations. For example, one spatial model reported by Wong et al. estimated that the direct impact of a one percent increase in cropland would result in a 5% decline in duck density for a typical stratum, although the total impact is much larger (9%) because land use changes in one region not only affect the waterfowl population for that stratum, but also impact populations in surrounding regions. Thus, both standard and dynamic panel models yield downward biased estimators.

Wong et al. (2011) used the statistical results to provide an assessment of the efficacy of wetlands conservation programs. The North American Waterfowl Management Plan spent some \$1.2 billion during 1986-2008 to secure 25,500 km^2 of land in the Canadian PPR. This implied that an average of 1,100 km^2 of farmland was secured annually at a cost of \$52 million. In 2006, 1,100 km^2 constituted 0.25% of farm area and waterfowl density was roughly 30 ducks per square km. The conservation dollars spent securing habitat to increase the waterfowl population by a single duck can be estimated using these figures and the results from the regression models. These calculations are presented in Table 6. Assuming that the 1,100 km^2 of secured land came entirely from cropland, it costs somewhere between \$107 and \$262 to protect a marginal duck. However, these estimates are on the high side because it is less costly to secure land for wetlands if it is taken from summerfallow or pasture.

Table 6: Estimates of Conservation Dollars Spent Per Duck in 2006

Item	Standard panel specification	Dynamic model with lagged dependent variable	Spatial lag model with de-meaned data	Spatial lag model with alternative data transformation
Δ Duck Density	+0.44	+0.35	+0.67	+0.85
Δ Ducks in PPR	254,438	198,375	385,538	486,881
Expenditure per Duck	$204	$262	$135	$107

Notes:
Source: Wong et al. (2011)
The Canadian Prairie Pothole Region is roughly 575,000 km^2.

In summary, the analysis by Wong et al. (2011) indicates that, when determining the benefits of conserving wetlands, biologists need to look beyond the impact of wetlands restoration (or degradation) on local duck numbers only. They need to measure population increases in neighboring strata as well. By considering these indirect or spillover impacts of wetlands protection, the costs of preventing declines in waterfowl numbers or enhancing populations are also lower.

3.3 Regional Effects of Climate Change on Land Use: An Application of Positive Mathematical Programming

Withey and van Kooten (2011c) employ a multi-regional land use model that facilitates the explicit examination of tradeoffs between agricultural production and wetlands management. Positive mathematical programming (PMP) (Howitt 1995) is used to calibrate a land-use model to observed land uses in the study region. The calibrated model is then used to examine the impact of various climate change policies, which is done by varying the relevant model parameters. Observed data on average yields and land uses, along with the shadow values from the PMP calibration constraints, are used to estimate nonlinear yield functions for different agricultural land uses. Separate models for each of strata 26-40 employed by the U.S. Fish and Wildlife Service Population Survey (Figure 3) are calibrated to land use in 2006. In addition to wetlands, eight land-related activities were identified: spring wheat, winter wheat, barley, oats, peas, canola, tame pasture and hay land. For wetlands, data are lacking on net returns (yields, prices and production costs), so the model relies on private returns (wetlands represent a cost) plus public returns (positive social benefits). Given base case results, the impact of climate change is estimated by incorporating the climate-induced expected change in crop yields. In addition, the impact of one climate change mitigation policy affecting agricultural land use is examined, namely, policies to increase energy crops for biofuel. This is modeled by increasing the net returns to canola production.

Positive Mathematical Programming Model of Land Use

The PMP method is implemented in three stages. The first involves maximizing net returns to land uses subject to resource and calibration constraints. The linear program (LP) is as follows:

$$\text{Max} \sum (p_i y_i - c_i) x_i \tag{22}$$

$$\text{s.t.} \quad \sum_i a_{ij} x_i \le \bar{R}_j,\ \forall j \tag{23}$$

$$x_i \le x_i^0 + \varepsilon_i \tag{24}$$

where p_i, y_i and c_i are the prices, yields and average costs for each of land uses i, the allocation of land to activity i is denoted x_i; a_{ij} are the technical coefficients of production (the amount of resource j required per unit of x_i); and $\bar{R}_j$ is the total amount of resource j that is is total land available. Much like the Canadian Regional Agriculture Model (CRAM), we consider only the land resource so that $a_{i,\text{land}} = 1$ for all i.[11] Constraints (24) constitute the calibration constraints needed to implement PMP, with x_i^0 the observed acreage in each land use and ε a perturbation term that is chosen to be a very small positive number. The model is solved for each of the 15 strata and the nine land uses.

Dual values from the LP described by (22), (23) and (24) are then used in the second stage of the PMP calibration to estimate the parameters of a nonlinear yield function. Assuming a quadratic yield function, $y_i = (\beta_i - \gamma_i x_i) x_i$, Howitt (1995) shows that the dual value on the calibration constraints, λ_2 in equation (23), are equal to the difference between the value of the average and marginal products of land. Thus, γ_i and β_i are derived as follows:

$$\lambda_2 = \text{VAP} - \text{VMP} = p_i(\beta_i - \gamma_i x_i) - p_i(\beta_i - 2\gamma_i x_i) = p_i \gamma_i x_i \tag{25}$$

[11] Unlike the current application, the CRAM model considers a water resource constraint in addition to land constraints.

$$\gamma_i = \frac{\lambda_2}{p_i x_i} \tag{26}$$

$$\beta_i = y_i - \gamma_i x_i \tag{27}$$

Given the dual values for each calibrated land use (λ_2), as well as data on p, y and x, we can calibrate nonlinear yield functions that represent the decisions of landowners in a given region.

The perturbation coefficient on the right hand side of equation (24) forces the LP to produce dual values that are then used to parameterize the yield function. However, since the number of constraints exceeds the number of activities, one of the calibration dual values will be zero. This least profitable activity is considered a marginal crop, where the calibration constraint does not bind and the activity is constrained only by the land use dual value from equation (23). In such a case, one cannot tell the difference between average and marginal product of land, and additional information is required to calibrate the yield function for this crop. In particular, the dual value on the resource constraint (23) is adjusted with expected yield variation from the mean to estimate the dual value on the calibration constraint for this land use ($\overline{\lambda}_2$). All λ_2 values must be adjusted by $\overline{\lambda}_2$.

Finally, in the third step, the PMP problem becomes

$$\text{Max} \sum (p_i(\beta_i - \gamma_i x_i) - c_i) x_i \tag{28}$$

$$\text{s.t} \quad \sum_i a_{ij} x_i \le \overline{R}_j, \ \forall j \tag{29}$$

This model uses the calibrated yield function from the second stage to represent the landowners' decisions. Using only the resource constraint (29), the solution replicates the observed allocation for a base year. For different scenarios, only the parameters in (28) need to be adjusted.

Three scenarios are examined. First, the direct climate change impacts on land use in the study region are modeled via the impact of climate on crop yields. By changing yields, one changes the value of crops relative to wetlands and thereby the amount of land optimally allocated to wetlands. A regression model used to estimate the impact of annual precipitation and average maximum temperature on average crop yields for each crop in each stratum is as follows:

$$y_{ir} = \theta_0 + \theta_1 P_r + \theta_2 T_r + \varepsilon_{ir}, \tag{30}$$

where y_{ir} is observed average yield for crop *i* in region *r*; P_r and T_r are the precipitation and temperature, respectively, affecting region *r*; θs are parameters to be estimated; and ε is the error term. Given the estimated θs and an expected future climate scenario, one can estimate the change in yields from historical averages brought about by the changed climate. For scenario #1 estimates of the impact on yields are based on an increase in temperature of 3^oC and a decrease in precipitation of 10% (see section 2.4 above).

Second, although climate change affects crop yields and thereby wetlands, a warmer and drier climate also leads to a loss of wetlands. A loss of wetlands changes the returns of cropping activities relative to wetland values; in areas where wetlands are lost, the opportunity cost of cropping is reduced. Thus, looking only at changes in crop yields will underestimate the effect of climate on wetlands, and it is important to consider the direct effect of climate on wetlands. This is done by estimating equation (30) for wetlands as well, with the left-hand-side variable now measured in terms of area and not as a yield. Therefore, scenario #2 examines the impact of climate change on wetlands acreage in addition to estimating the effect of climate on crop yields. This is done for each region of the PPR as climate change affects wetlands and crop yields differently in each region via equation (30).

Finally, scenario #3 examines the impact of policies to mitigate climate change, namely, the Canadian government's Renewable Fuel Standard (RFS) that was implemented in May 2008. This policy requires two percent renewable content in diesel fuel by 2010 and 5 percent by 2015, which will increase the demand for canola oil and increase the net returns to planting canola in the Prairie Provinces. Mussell (2006) estimates that the price of canola will increase by $19 dollars per metric ton for the 2-percent blend and by $200 per ton for the 5-percent blend. For the PMP model, the RFS policy thus represents a 7% increase in the price of canola for the 2-percent blend and a 75% increase for the 5-percent blend. Since the latter result seems quite high, we consider the impact of increasing the price of canola by 10%. Scenario #3 considers the direct climate effects on crops and wetlands, as well as the increased price of canola.

Predicted Impact of Climate Change on Crop Yields and Wetlands Area

The regression model (30) is estimated for each of the land use activities and wetlands using ordinary least squares with results provided in a table in the Appendix. For the most part, temperature and precipitation have a positive marginal impact on yields, with such effects significant at the 5% or 10% level. If a coefficient had a sign that was unexpected, was insignificant and reduced the adjusted R^2, it was not included in the specification (as indicted by an entry of na in the table). Based on the statistical significance of the coefficients, the regression model provided a better fit to the data in Alberta and Saskatchewan than in

Manitoba.[12] The same specification was employed for all strata for consistency. Based on the magnitudes of the coefficients, temperature has a bigger impact on crop yields in Alberta than in Saskatchewan or Manitoba, and precipitation has a similar effect across provinces.

Climate change affects crop yields and wetlands areas. Assuming that landowners make no adjustments to input use (such as fertilizer) as a result of climate change, the projected changes in crop yields and wetlands area relative to historic values are provided in Table 7. For hay land and peas, for which there were no data, estimated effects are conservatively assumed based on the results for other crops. For wetlands, the values in Table 7 represent a decrease from historic levels in acres. For most crops in Table 7, the climate change scenario described earlier and employed here leads to an increase in crop yields, primarily because of warmer temperatures, with the impact highest for canola and lowest for wheat.

Table 7: Change in Crop Yields and Wetlands Area due to 3°C Higher Temperatures and 10% Lower Precipitation (10%), % Change by Stratum[a]

	Wheat	Barley	Oats	Canola	Dry Field Peas	Hay land	Wetlands
26	14.00	19.00	13.00	39.8		10.00	-25.0
27	6.22	8.80	7.55	20.23			-29.35
28	17.40	16.58	13.46	30.24		15.79	-31.09
29	16.56	14.92	9.22	32.2		16.22	-20.88
30	-2.08	2.74	-1.05	5.42		-19.02	-54.03
31	3.85	10.31	7.16	16.26	0.88		-43.24
32	-3.56	-2.92	-9.85	3.71	0.15		-50.8
33	11.84	12.83	16.40	15.05	34.76		-28.85
34	6.69	12.02	6.06	25.18	5.10		-51.34
35	-2.06	2.35	-2.26	5.54			-43.80
36	-5.60	0.61	-1.37	7.24			-7.32
37	13.42	21.98	14.98	3.48			-38.92
38	9.49	16.64	17.88	26.68			-18.89
39	-2.67	-4.54	-4.46	1.26			-35.00
40	-1.36	5.28	3.27	15.64			-33.93

[a] Projections based on the estimated coefficients in Appendix Table.

Not surprisingly, impacts vary substantially by region, and in a few cases the decline in precipitation outweighs the temperature effect, leading to lower crop yields. In Alberta (strata 26-29), climate change is projected to have a high positive impact on all crop yields in all strata. For several strata in Saskatchewan (strata 30-35) and Manitoba (strata 36-40), the increase in crop yields will be minimal or there may even be a decline.

[12] The reader will need to match strata and provinces using maps in Figure 3 or 7.

Climate change is projected, in our model, to reduce dramatically the area in wetlands as a result of warmer, drier conditions; the average reduction across regions is 29.3%. The reduction in Alberta is about average, the reduction in Saskatchewan is above average, and the reduction in Manitoba is below average.

PMP Modeling Results

The modeling results are provided in Tables 8 through 10. In Table 8, we provide the areas in each of the eight possible agricultural activities (various crops) and wetlands use for the PMP base-case replication of the observed land uses and each of the three climate scenarios that we identified above. Note that in the first five columns of Table 8, the social benefits of wetlands are added to the private costs of wetlands. In the last column, we consider total climate change results if only the private returns to wetlands are considered (i.e. wetlands represent a cost). This allows us to compare how climate change will impact wetlands management if they are privately managed versus management by a social planner. In Table 9, the percentage changes in land allocation are provided for each of the fifteen strata, but only for scenario #3 using the social value of wetlands, while a summary of the reduction in wetlands under this same scenario is provided in Table 10.

Table 8: Land Uses under Observed (2006), PMP Model Base Case and Climate Change Scenarios ('000s acres)

Scenarios[a]	Spring wheat	Barley	Oats	Winter wheat	Canola	Dry field peas	Wetland area	Hay land	Pasture
Observed	14626.1	7799.6	4020.4	406.7	11257.8	2992.9	3782.1	10551.4	9059.0
PMP Base	14621.1	7806.8	4019.1	409.2	11269.6	2975.3	3785.8	10562.6	9032.9
#1	13988.9	8429.0	4087.8	430.5	17591.9	3207.8	3285.7	9036.5	4433.9
#2	14563.1	8544.9	4111.5	433.4	17680.0	3311.2	1952.0	9132.4	4735.9
#3 (social)	13823.2	7967.0	4058.2	427.3	20231.6	3139.0	1877.3	8646.5	4321.9
#3 (private)	13959.4	8093.6	4083.4	430.8	20275.3	3298.8	831.5	8788.9	4730.2

Source: Adapted from Withey and van Kooten (2011c)
[a] Scenario #1 refers to change in crop yields due to increasing temperature by 3°C and decreasing precipitation by 10%; scenario #2 is the same as #1 but adds the projected change in wetlands under the same climate scenario; and scenario #3 adds to #2 an increase in the price of canola of 10%. Under scenario #3, two scenarios are considered depending on whether wetlands are valued at their social or only private net benefit.

Several trends are discernable from the tables. First, in terms of cropland, the changes modeled under scenario #1 suggest that climate change has the most pronounced positive effect on canola and barley plantings. This is not surprising given the yield changes expected as a result of climate change as indicted in Table 7. Compared to canola and barley, optimal plantings of most other field crops increase marginally, while those of spring wheat decline by between 0.5 and

5.5 percent, depending on the scenario. However, plantings of winter wheat are projected to increase (thus benefitting waterfowl that nest in winter wheat), although overall acreage in winter wheat remains small. As noted, canola planting increases by more than 50% as a result of climate change, but plantings are boosted by another 15% or so when biofuel policies increase the price of canola.

Table 9: Change in Land Use from Base Case by Stratum, Scenario #3 using Social Benefits of Wetlands (%)

Stratum	Spring wheat	Barley	Oats	Winter wheat	Canola	Dry field peas	Wetlands	Hay land	Pasture
26	-21.1	-36.1	-6.5	-20.5	298.1	-100.0	-67.6	-84.7	-100.0
27	-11.1	-23.4	-0.4	-13.0	197.2	-100.0	-45.4	-11.3	-54.4
28	15.7	29.5	14.9	16.9	50.5	32.2	-47.4	2.7	-100.0
29	20.9	34.0	12.4	22.6	56.8	40.2	-31.5	12.8	-88.2
30	-6.2	10.9	-1.1	-4.0	19.0	8.4	-53.1	-26.7	11.1
31	-0.2	17.9	8.5	-2.2	38.8	-50.8	-51.0	-4.1	-81.0
32	-10.4	3.6	-11.6	-2.2	34.2	14.1	-45.9	0.9	16.2
33	7.9	20.0	12.7	23.4	26.1	43.8	-35.0	-11.5	-18.3
34	1.1	16.4	3.7	3.4	56.8	-30.4	-59.2	-3.3	-37.8
35	-7.3	-0.6	-6.4	-10.4	75.4	-76.3	-46.0	-5.0	-7.2
36	-12.4	-0.2	-2.1	-36.1	17.9	18.2	-6.9	-9.1	-1.5
37	27.9	52.2	13.4	23.1	12.3	36.6	-47.2	10.5	-70.9
38	0.1	10.4	9.3	0.1	34.1	-9.9	-66.4	-23.4	-100.0
39	-32.9	-50.7	-4.6	-14.1	27.4	714.5	-33.7	-2.1	3.2
40	-10.1	3.1	0.8	-8.5	29.8	195.9	-41.5	-9.7	-28.1
Total	-5.5	2.1	1.0	4.4	79.5	5.5	-50.4	-18.1	-52.2

Source: Withey and van Kooten (2011c)

Table 10: Reduction in Wetlands by Stratum, Scenario #3 using Social Benefits of Wetlands ('000s ac)

	Stratum														
Scenario[a]	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	Total
Base	459	140	145	103	388	532	542	74	557	221	65	223	50	158	128	3786
#3 (social)	149	76	76	71	182	261	293	48	227	119	61	118	17	105	75	1877

Source: Withey and van Kooten (2011c)

[a] See note on Table 8.

Wetlands area is projected to decrease by about 13% due to the increased value of crops relative to wetlands (scenario #1), but, when the direct effect of climate change on wetlands is factored in (scenario #2), wetlands are reduced by an additional 35%, or by some one-half of observed area. Finally, consider what happens when the price of canola rises (scenario #3). If the social value of wetlands is used as the basis for scenario #3, wetlands area changes little from that in scenario #2, but, if social values are ignored by a private landowner, wetlands area falls by about 80% from that observed today. Meanwhile, the amount of land in pasture is projected to fall by about one-half in all three scenarios, because its value falls significantly compared to that of other land uses.

Notice that the above results are consistent with those presented in the earlier sections of this paper. The magnitudes are similar to those found using an optimal control model that estimates the effect of climate and biofuel policies on wetlands (section 3.1).

Tables 9 and 10 summarize what happens at the strata level, at least for scenario #3 when the private landowner is provided incentives to take into account the social values of wetlands. The change in wetlands across regions in the PPR is not constant, ranging from a loss of between seven and nearly 70 percent (Table 9), or four to 330 acres (Table 10). Unsurprisingly, the effect of climate change and climate change policies on wetlands is not homogenous across regions, because climate and soil characteristics (which impact crop yields and crop revenue) differ dramatically across the study region. In Table 9, the largest proportional declines in wetlands are in strata 26, 38, 34, 30 and 31, while the largest decreases in wetlands area are in strata 34, 26, 31, 32 and 30. Thus, wetlands loss is greatest in northern Alberta (stratum 26) and Saskatchewan (strata 30, 31, 32 and 34).

Recall that, in the land-use model, changes in wetlands in each stratum are driven primarily by the actual climate effect on wetlands area as determined from the relation in the Appendix table. However, the social benefits of wetlands and the opportunity cost of retaining them are given by the net returns to other land uses in the region; this also affects wetlands loss. Further, the net returns to other crops are impacted by climate-induced changes in crop yields and via the increased price of canola caused by biofuel policies to address climate change. Overall, therefore, there is a direct climate impact on wetlands and an indirect impact resulting from increases in net returns to cropping. Based on these factors, we can identify the potential drivers of the provincial patterns of wetlands loss as indicated in Tables 9 and 10. In doing so, it is helpful to consult Figure 7.

The largest actual reduction in wetlands area is projected to occur in Saskatchewan (strata 30-35). This is due in part to the fact that the largest areas of wetlands are found in Saskatchewan, while some of the largest proportional declines are also projected to occur in Saskatchewan, particularly in strata 30, 31 and 34. The declines in wetlands in these strata are driven by severe climate impacts (see Table 7), while increased crop yields in strata 31 and 34 also reduce the relative value of wetlands. Overall, wetland loss in Saskatchewan is only slight greater than the PPR average of 50%.

Wetlands loss in Alberta (strata 26-39) is projected to total 56%, which is the largest proportional loss of wetlands in the three provinces. The reason relates primarily to strata 26, because of large plantings of canola, which is the dominant crop in this area. Canola plantings in strata 26 are projected to increase significantly under climate change, and especially if governments aggressively pursue biofuel policies (see Table 10). Two of the other three strata in Alberta are also projected to lose wetlands. Climate effects on wetlands are below average in these strata, but crop yields are significantly increased due to a warmer climate, implying that cropping becomes a more valuable activity compared to retaining land in wetlands. The significant loss of wetlands in Alberta is consistent with our earlier projections using an optimal-control, bioeconomic model (see section 3.1 above).

Finally, the overall projected reduction in wetlands in Manitoba is smaller than the other provinces. While the proportional loss of wetlands in stratum 38 could be large, the associated actual loss in area is quite small. Because average climate change impacts on both wetlands and crop yields are smaller than for the other provinces, the overall wetlands loss in Manitoba is also well below the PPR average, but still significant at 40 percent.

Conclusions

The various analyses of wetland conservation and, by implication, the prospects for migratory waterfowl contain several common threads. First, based on the external or spillover benefits that wetlands provide, whether ecosystem service functions, viewscape value and/or value to hunters as breeding habitat, it is clear that current wetlands area is likely below the socially desirable level. Just how far below depends on what values are assigned to the various off-site benefits and to whom such benefits accrue. And, as demonstrated for the case of biofuel (bio-diesel) policies, one can conclude that government agricultural programs, such as direct subsidies, assignment of quota under the Canadian Wheat Board quota system, tax breaks for land development, et cetera, will also impact wetlands and migratory waterfowl populations (see van Kooten 1993a, 1993b; van Kooten and Bulte 2000).

It turns out that projected climate change is likely to have an adverse effect on wetlands and migratory waterfowl. All of the models considered in this study bear this out. Further, and somewhat disconcerting, there is some evidence to suggest that policies to encourage production of energy crops might pose a greater threat to wetlands and waterfowl than climate change itself. The models presented in this study indicate that large decreases in wetlands area can be expected in Alberta and Saskatchewan, with much smaller impacts in Manitoba. Given that climate change will have the greatest impact on wetlands in Saskatchewan, decision makers may wish to devote more effort to protecting wetlands in that province rather than in Alberta or Manitoba.

Even if the account is taken of the adverse impacts of climate, it will still be socially desirable to have more wetlands than the amounts projected by land use models that ignore the external spillover benefits of wetlands. Should the climate become warmer and drier, there will be a shift in optimal wetlands conservation from west to east, a result consistent with Johnson et al. (2005). It will be optimal to have more wetlands in Manitoba than Alberta, which has not been the case historically. Relative to current conditions, with climate change Manitoba is projected to have the most productive waterfowl habitat. This suggests that Manitoba is a second province where policy should target wetlands protection, although it remains an open question as to whether Manitoba can make up for the loss of wetlands in Saskatchewan.

Appendix Table: Estimated Parameters of the Climate Regression Model (28)

Stratum	Parameter	Wheat	Barley	Oats	Canola	Hay	Peas	Wetlands
26	β_0	-1.7	-10.9	0.31	-9.62			
	β_1	2.22**	3.88**	3.59**	2.98**			
	β_2	0.042**	0.059**	0.067**	0.012			
27	β_0	-3.23	-2.58	-0.32	-8.71			0.19**
	β_1	1.27	2.1*	2.31*	1.87**			-0.009
	β_2	0.049**	0.063**	0.073**	0.029**			3.43E-0.5
28	β_0	-9.06	-10.08	-11.05	-20.5*	-0.25		0.267**
	β_1	2.12**	3.19**	3.18**	2.77**	0.118*		-0.001**
	β_2	0.04**	0.055**	0.07**	0.03**	0.002*		-0.0002**
29	β_0	-18.8	-19.3	-17.1	-30.5**	-0.88		0.157**
	β_1	2.29**	3.21**	2.78**	3.06**	0.13**		-0.006*
	β_2	0.037*	0.05**	0.06**	0.03**	0.001**		na
30	β_0	2.57	-0.49	-1.76	5.87	1.08		0.23**
	β_1	0.51	1.42	1.27	0.75**	na		-0.033
	β_2	0.057**	0.08**	0.12**	0.028	0.0019		0.0007
31	β_0	11.25	5.42	4.8	4.46		7.97	0.52**
	β_1	0.76	2.12**	2.33**	1.43**		0.63	-0.052**
	β_2	0.029**	0.05*	0.078*	0.018**		0.042**	0.00055**
32	β_0	13.66	22.4	29.29	6.63		19.43	1.16
	β_1	na	0.01	na	0.48		0.64	-0.077**
	β_2	0.028**	0.04**	0.054**	0.02**		0.005	na
33	β_0	-8.77	-16.03	-33.3*	-2		-32.4	0.18
	β_1	1.47**	2.41**	3.8**	1.21**		3.67**	-0.009*
	β_2	0.05**	0.08**	0.12**	0.02**		0.086**	na
34	β_0	10.83*	8.07	12.33	7.41		13.58	0.92*
	β_1	0.92	2.25*	1.92	1.74**		0.75	-0.07*
	β_2	0.02**	0.04**	0.055**	0.001		0.02	Na
35	β_0	12.7	12.59	18.84	4.34			0.65**
	β_1	0.14	0.81	0.36	0.62			-0.04**
	β_2	0.02**	0.03**	0.05**	0.02**			na
36	β_0	14.89*	23.5	25.45**	11.95			0.05
	β_1	na	0.06	0.27	0.36*			-0.0008
	β_2	0.034**	0.005	0.02	na			2.86E-0.5
37	β_0	18.59**	18.77	33.88*	6.7			0.39**
	β_1	1.4*	3.26**	2.79*	0.18			-0.02**
	β_2	0.002	na	na	0.004			0.0001
38	β_0	10.36	8.24	-9.15**	-7.94			0.07**
	β_1	1.32	3.15*	4.36**	2.47**			-0.0029
	β_2	0.02*	0.027	0.057**	0.021*			na
39	β_0	22.36	21.82*	28.17**	5.96			0.28
	β_1	Na	na	na	0.35			-0.017**
	β_2	0.019**	0.039**	0.05**	0.019**			na
40	β_0	26.57	22.63*	22.84	2.81			0.32**
	β_1	0.01	1.27	1.37	1.38*			-0.02**
	β_2	0.01	0.03*	0.05**	0.017**			na

*indicates significance at 10%; ** indicates significance at 5%

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