The Effect of Climate Change on Optimal Wetlands and Waterfowl Management in Western Canada

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The effect of climate change on optimal wetlands and waterfowl management in Western Canada

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CONTENT

1.INTRODUCTION（1）

1. Warmer temperatures and a decrease in precipitation in the 21st century could severely deplete wetlands.
2. Drier conditions will have a major impact on the prairie pothole region (PPR)—North America's duck factory.
3. Study Area: southern parts of the Canadian prairie provinces of Alberta, Saskatchewan and Manitoba.

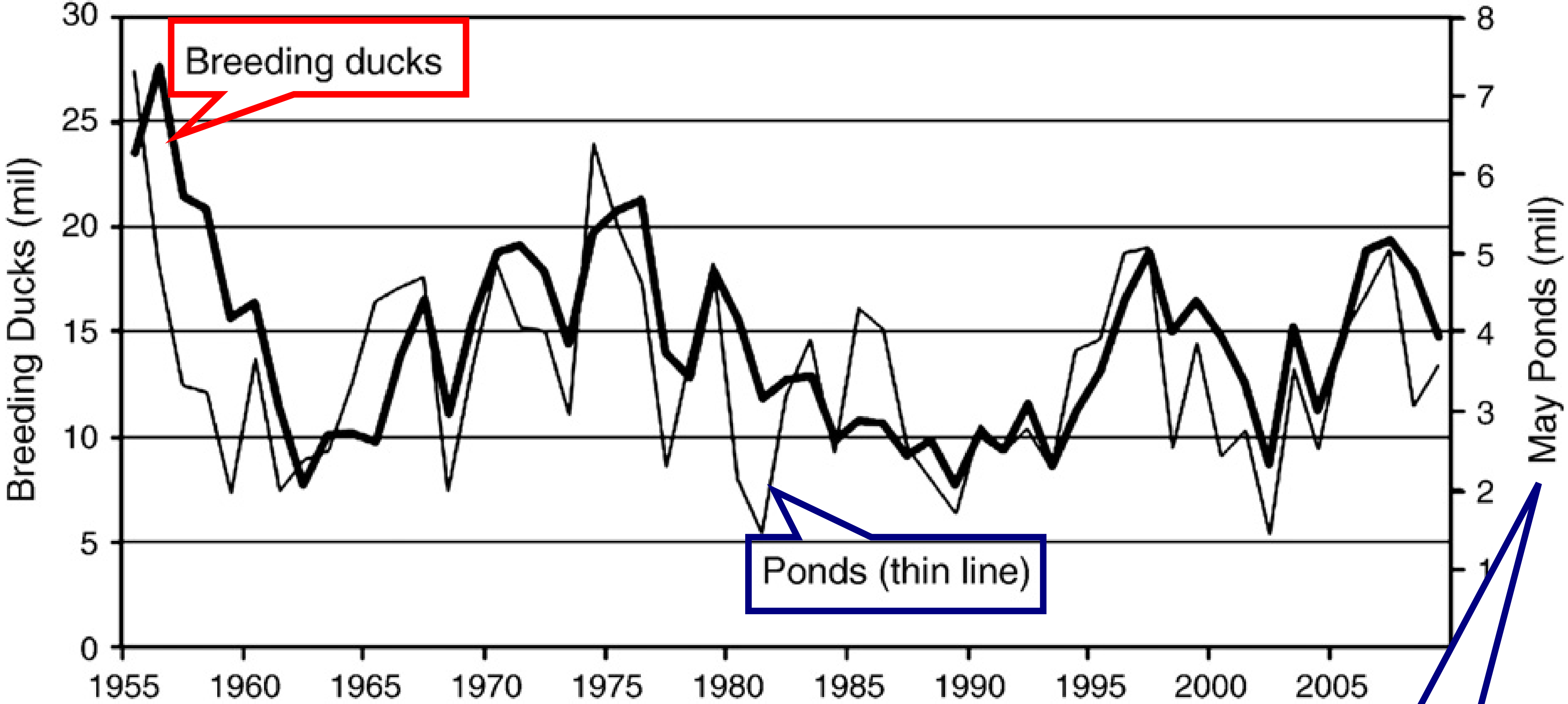

Fig. 1. Relationship between wetlands and waterfowl in Canada's Grain Belt, 19 2009.

May – Sep.
breeding season

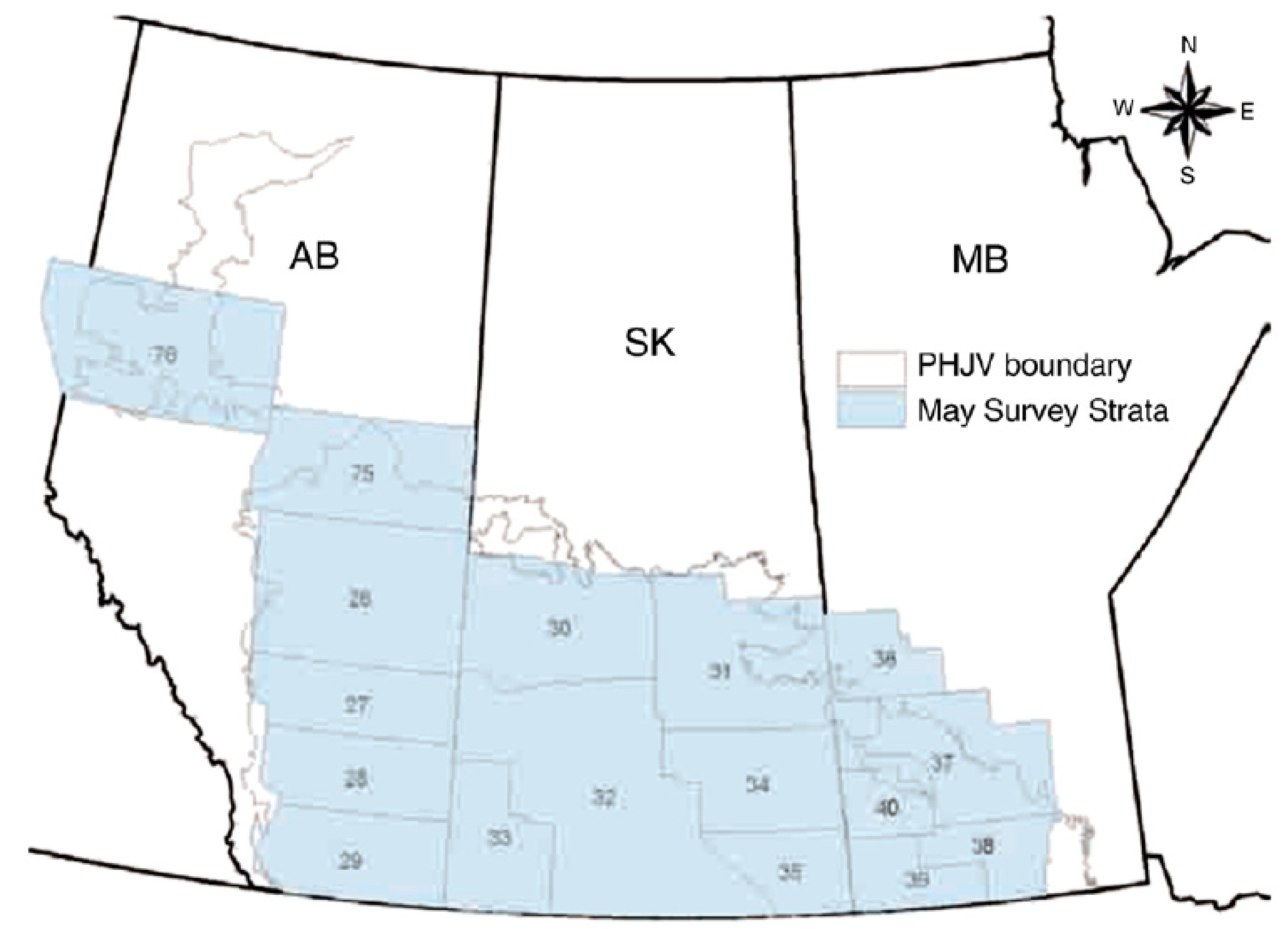

Fig. 2. The prairie pothole region of Canada.

1.INTRODUCTION（2）

4. The Intergovernmental Panel on Climate Change (IPCC) predicts that surface temperatures around the globe could rise by between 1.1 and 6.4 °C by 2100.
5. Johnson et al. (2010), The regional climate models predict that temperatures could rise by 1.8 °C to 4 °C in the prairie pothole region.

1.INTRODUCTION（3）

6. Study purpose: Use a waterfowl–wetlands bioeconomic model to solve for socially optimal levels

（1） breading ducks (D_t).

（2） duck harvests (h_t).

（3） wetlands retention under current climate conditions (W_t) .

（4） various climate change scenarios.

2.LITERATURE（1）

1. Larson (1995) estimates the effect of temperature and precipitation on wetlands using linear multiple regression analysis.
2. She finds that the percentage of basins filled with water is a function of this year precipitation , last year fall precipitation, fall maximum average temperature, and the difference between April minimum and maximum average temperatures.

frost seal

snowmelt

2.LITERATURE（2）

3. For a 3 °C increase in temperature, wetlands are projected to decline by 15%.
4. Coupled with an increase (decrease) in precipitation of 10%, wetlands are projected to increase (decrease) by 2% (31%).
5. Sorenson et al. (1998) regressed May ponds on average May Palmer Drought Index (PDI); they find $R^2=0.72$, indicating that the PDI explains a great deal of the variation in wetlands.

decrease > increase

W α 1/T , W α P

2.LITERATURE（3）

6. Their results show that severe drought (PDI=–3.4) will decrease wetlands by 54%, whereas mild drought (–1.2) will decrease wetlands by 23%.
7. For an increase in temperature of 1.5 °C (2.5 °C) coupled with an increase in precipitation of 7% (15%), wetlands decrease by 15% (15%).
8. Larson and Sorenson's studies find the changes in wetlands are more sensitive to temperature changes than precipitation.

2.LITERATURE（4）

9. Johnson et al. (2005) use the WETSIM simulation model to estimate the spatial impact of wetlands in the following scenarios:

(1) An increase in temperature of a 3 °C and no precipitation change;

(2) A 3 °C increase in temperature and a decrease 20% precipitation ;

(3) A 3 °C increase in temperature and increase 20% precipitation

±20% in 100 years

result: 2

2.LITERATURE（5）

(A) If precipitation is constant or decreasing, wetlands will decrease and waterfowl habitat will be pushed to the north and east.

(B) At 3rd scenario, precipitation increase of 20%, offset the effect of temperature.

10. Johnson et al. (2010) suggest that all prairie wetlands will suffer due to temperature of warming; the order in which wetlands are susceptible increases from temporary wetlands to semi permanent wetlands to seasonal ones.
11. Johnson's spatial analysis sheds light on where the retention of wetlands might occur.

3.MULTIPLE REGRESSION MODEL（1）

3.1 Regression Model

1. We employ two linear regression equation to estimate the impact of climate change on wetlands. Simple regression
2. The first specification relies solely on the direct impact of drought on wetlands, similar to Sorenson et al. (1998), with the standardized precipitation index (SPI) index used as the drought measure rather than the PDI.

3.MULTIPLE REGRESSION MODEL（2）

3. The second specification is similar to Larson (1995), with wetlands (pond numbers) regressed on the climate variables temperature and precipitation.
4. Lagged values are considered for both SPI and precipitation, given that precipitation in previous years impacts wetland numbers. (Fig. 3)

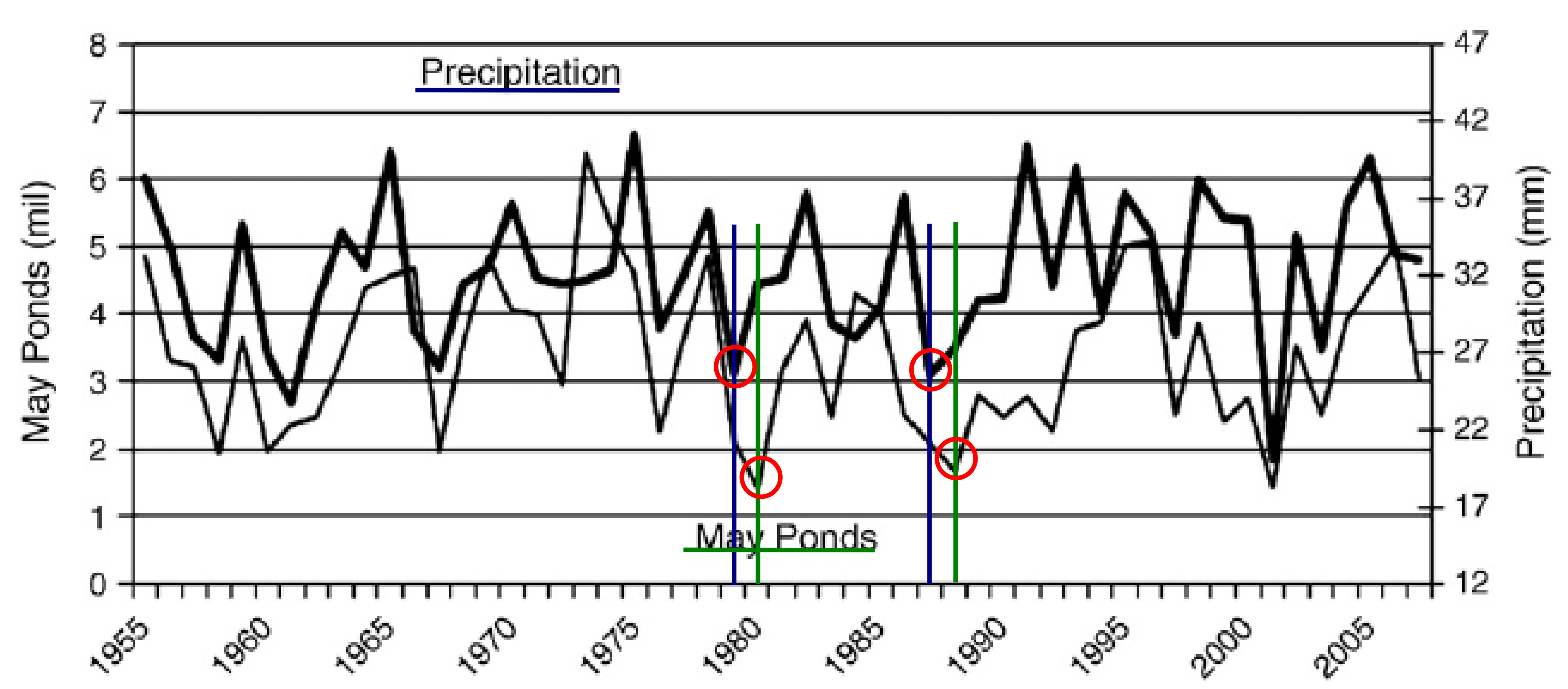

Fig. 3. May ponds and lagged precipitation in the Canadian PPR.

3.MULTIPLE REGRESSION MODEL（3）

5. In each case, the final regression model is chosen on the basis of adjusted R^2 and statistical significance.

3.MULTIPLE REGRESSION MODEL（4）

6. The final specifications of the alternative regression equations are as follows:

$$W_t = \beta_{\mathbf{0}} + \beta_{\mathbf{1}} SPI_{t\text{-}1} + \varepsilon_{\mathbf{t}} \qquad (1)$$

$$W_t = \gamma_0 + \gamma_1 P_{t\text{-}1} + \gamma_2 T_{t\text{-}1} + \xi_t \qquad (2)$$

Where

W_t：refers to wetlands (number of ponds) in period t,

SPI_{t-1}：lagged value of SPI;

P_{t-1}：lagged value of precipitation;

T_{t-1}：lagged average annual maximum temperature;

β_s, γ_s：model parameters to be estimated;

ε_t, ξ_t：assumed to be independent and identically distributed error terms that are normally distributed.

3.MULTIPLE REGRESSION MODEL（5）

3.2 Regression Results

1. The two regression equations were estimated using wetlands data from the annual May waterfowl breeding population and habitat surveys conducted by the United States Fish and Wildlife Service and the Canadian Wildlife Service.
2. We use May pond counts in the southern prairie provinces, corresponding to U.S. Fish and Wildlife Service's strata 26–40, for the period 1955–2007.

3.MULTIPLE REGRESSION MODEL（6）

3. Eqs. (1) and (2) are estimated by ordinary least squares:

$$W_t = 2.9 + 3.33SPI_{t-1,} \qquad R^2=0.3,\ S.E=0.95 \qquad (3)$$

$$W_t = 3.138 + 0.0085P_{t-1} - 0.31T_{t-1,} \qquad (4)$$

R^2=0.36, S.E=0.91

Where

W：measured in millions May ponds.

SPI：an index.

P：in millimeters.

T：in degrees Celsius.

COMMENT:

No statistical significance of the regressors

3.MULTIPLE REGRESSION MODEL（7）

4. Model (4) includes temperature and precipitation and leads to a higher R^2 value, although neither (3) nor (4) produce an R^2 as high as that found by Larson (1995) or Sorenson et al. (1998).

R^2=0.72(PDI)

R^2=0.63 (precipitation and temperature)

COMMENT:
The results were not as good as the literature.

4. BIOECONOMIC MODEL（1）

4.1 Analytical Model

1. Maximizes the following objective function:

$$\sum_{t=1}^{T}\left[\boxed{v(h_t, y_t, z_t)} + \boxed{\alpha D_t} + \boxed{B(W_t) - C(W_t)}\right]\rho^t \qquad (5)$$

Where

Benefit from hunting

Benefit from non-hunting

Benefit from wetland restoration

z_t ： demographic characteristics

α ： non-use value

Potential value of ducks which are not hunted

D_t ： mature ducks returning to the breeding

W_t ： wetland pond number

ρ =1/(1+r) ： discount factor with r the discount rate.

T ： length o… lanning horizon

Adjustment for the value

$V(h_t,y_t,$… erived from duck hunting;

$B(W_t)-$… etlands (measured in millions of ponds)

4. BIOECONOMIC MODEL（2）

2. The dynamics of duck numbers is given by:

$$D_{t+1} = s_2\left[s_1 D_t + g\left(D_t, W_t\right) - \pi h_t\right] \quad (6)$$

$$D_t \geqq 0,\ h_t \geqq 0,\ W_t \geqq 0, \text{ and } D_0 > 0,\ W_0 > 0 \quad (7)$$

Where

S_1 ：fraction of May breeders surviving to September

S_2 ：fraction of mature ducks that are not killed by hunters and survive to return to the breeding grounds in year t+1 (so $1-s_2$ is the natural mortality during this period)

$g(D_t,W_t)$ ：the number of offsprings

$\pi > 1$ ：accounts for the loss of ducks that are killed remained by hunters but not collected or reported

D_{t+1} ：number of mature ducks returning to the prairie pothole breeding grounds in year t+1

4. BIOECONOMIC MODEL（3）

3. The number of offsprings that are produced is given by the recruitment function $g(D_t, W_t)$, where

$$\partial g / \partial D_t > 0, \quad \partial^2 g / \partial D_t^2 \leq 0$$

$$\partial g / \partial W_t > 0, \quad \partial^2 g / \partial W_t^2 \leq 0$$

Growth curve : logistic model

Baby Duck function

4. BIOECONOMIC MODEL（4）

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

$$V_t(h_t, D_t, W_t, \lambda_{t+1}) = \underset{h_t, W_t}{Maximize}\{ [v(h_t, y_t, Z_t) + \alpha D_t + B(W_t) - C(W_t)] + \rho V_{t+1}(D_{t+1}) \} \tag{8}$$

Lagrange multiplier method

Maximum economic value

Where

V_t ：value function

$\lambda_t = \partial V_t / \partial D_t$ ：shadow price of an additional duck.

$\partial V_t / \partial h_t = 0$ and $\partial V_t / \partial W_t = 0$

4. BIOECONOMIC MODEL（5）

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

$$\partial V_t / \partial h_t = \partial v / \partial h_t - \rho \lambda_{t+1} s_2 \pi = 0 \qquad \text{(9a)}$$

$$\partial V_t / \partial W_t = B'(W_t) - c + \rho \lambda_{t+1} s_2 \, \partial g / \partial W_t = 0 \qquad \text{(9b)}$$

$$\partial V_t / \partial D_t = \lambda_t = \rho \lambda_{t+1} s_2 (s_1 + \partial g / \partial D_t) \qquad \text{(9c)}$$

Where

c=Dc / dW_t：annual cost of providing an additional pond in each period.2

4. BIOECONOMIC MODEL（6）

6. Letting $\lambda_{t+1} = \lambda_t$ and $D_{t+1} = D_t$, $\forall_t$, we can identify for three equations that characterize the steady-state conditions:

$$B'(W) + \frac{1}{\pi}\frac{\partial v}{\partial h}\frac{\partial g}{\partial W} = c \qquad (10a)$$

$$\left(s_1 s_2 + s_2 \frac{\partial g}{\partial D} - 1\right) + \frac{\pi s_2}{\partial v / \partial h}\alpha = r \qquad (10b)$$

$$(1 - s_1 s_2)D = s_2 g(D, W) - \pi h \qquad (10c)$$

Solve the parameters: W, D, h

4. BIOECONOMIC MODEL（7）

4.2. Calibrating the Bioeconomic Model

1. Lacking information on the value of ducks to hunters, we adapt the valuation equation estimated by Brown and Hammack (1973) and adjust all values by the U.S. CPI. The resulting function is $v(h)=1.62\ h^{0.409}$.
2. Using this function, we find that the value of harvesting an additional duck at current levels of harvest is quite small.
3. To address this problem, we adjust the function by weighting it by the number of hunters.

4. BIOECONOMIC MODEL（8）

4. There was an average of 808,500 U.S. duck hunters in the Mississippi, Central and Pacific flyways during 2007–2008, spending an average of 7.2 days in the field and harvesting 15.2 ducks (Table 1).

Flyway	Year	Harvest	Hunters	Harvest per hunter	Days afield	Days per hunter
Mississippi	2007	6,719,700	474,400	14.2	3,479,100	7.3
	2008	6,522,900	466,400	14.0	3,410,000	7.3
Central	2007	2,666,000	193,400	13.8	1,127,400	5.8
	2008	2,086,000	178,300	11.7	946,100	5.3
Pacific	2007	3,441,000	147,500	23.3	1,269,900	8.6
	2008	3,300,600	157,700	20.9	1,303,300	8.3
U.S. Totals	2007	14,578,900	995,700	14.6	6,978,400	7.0
	2008	13,723,200	980,500	14.0	6,686,400	6.8

4. BIOECONOMIC MODEL（9）

5. Little is known about non-U.S. (mainly Canadian) hunters, except for what data are available which indicates that they spend less time in the field and kill fewer birds.
6. Therefore, we assume that the average hunter spends 7 days in the field to harvest 14.5 birds. 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.

4. BIOECONOMIC MODEL（10）

7. Given these values, each bird is worth approximately \$26. Multiplying this value by the average 2007–2008 harvest yields a total benefit of \$319.8 million.
8. Assuming that the superscripted parameter on harvest in the above hunter valuation function is 0.4, He calculate $v(h)=114.58h^{0.4}$, with v(h) and h measured in millions.

$v(h)=1.62\ h^{0.409}$

4. BIOECONOMIC MODEL（11）

9. More relevant to the PPR study area, Belcher et al. (2001) estimated the benefits of wetlands retention in Saskatchewan. From this literature, we find that wetlands range in value between \$39.62 (based on Belcher et al.) and \$338 per hectare (based on Woodward and Wui).
10. Notice that benefits are measured in hectares, while the measure for wetlands used in this study is ponds. If we assume an exponential distribution of pond sizes, we can calculate the average pond to be 0.27 ha.

4. BIOECONOMIC MODEL（12）

11. Upon adjusting the above values for an average pond size in the PPR, we find that the marginal value of a pond ranges between \$11 and \$91. The lower value is from Belcher et al. (2001), which is used in this study as it is based on a similar region.

4. BIOECONOMIC MODEL（13）

12. The cost of retaining wetlands is a net opportunity cost. We obtain estimates of the annual private net opportunity cost of retaining wetlands from Cortus et al. (2010), who use a farm-level simulation model to determine the net private costs of retaining wetlands in the PPR. They measure the net annual opportunity cost to be between \$8 to \$11 per pond.

4. BIOECONOMIC MODEL（14）

13. One-time cost of restoring wetlands. Hansen (2009) estimates the costs of restoring wetlands in the prairie pothole area, and finds that r costs range between $360 and $1300 per pond. However, these costs are one-time costs, and need to be converted to an annual basis. Suppose that the authority purchases a 30-year easement on the larger property. In that case, the annualized restoration cost would be $12 to $44 per pond.

U.S experiences

14. We find that annual costs range broadly from $20 to $55 per pond. We conservatively assume a baseline cost of $55.

4. BIOECONOMIC MODEL（15）

15. A logistic production (growth) function of the following form is estimated for ducks:

$$g(D_t, W_t) = \eta D_t \left(1 - \frac{D_t}{gW_t^{\,b}}\right)$$

The rate at which a population increases in size if there are no density-dependent forces regulating the population

Where

$gW_t^{\,b}$: carrying capacity of the prairie pothole ecosystem

η ： intrinsic growth rate.

We have data on breeding ducks and immature offspring, and on wetlands (May pond counts), for the PPR(strata 26 through 40) over the period 1955 to 2007.

4. BIOECONOMIC MODEL（16）

16. We use the data to estimate Eq. (11) using non-linear least squares:

$$g(D_t, W_t) = 2.89D\left(1 - \frac{D}{12.29W^{0.91}}\right) \qquad R^2=0.50,\ S.E=7.79 \tag{12}$$

The predicted change in wetlands under different climate scenarios works through the carrying capacity of the logistics function.

COMMENT:
No statistical significance of the regressors

4. BIOECONOMIC MODEL（17）

author calculation

Hammack and Brown's(1976)

v(h)=114.58h^0.4

Table 3 Model ... ns and parameters u... the simula...

Item	...e case parame...r values
Marginal hunter benefit func...	... ∂ h=46.8 $h^{-0.6}$
Marginal product of wetlands in d... production	∂ g... ∂ W=0.214$D^2W^{-1.91}$
Marginal product of breeding ducks	∂ g/... D=2.89–0.470$DW^{-0.91}$
Intra-year duck survival rates	s_1=0.95, s_2=0.80
Marginal cost of protecting wetlands	c=C′(W)=$ 55
Marginal amenity value of wetlands	B′(W)=$11
Marginal non-hunting value of a duck	α =$1
Adjustment for underreporting of kills	π =1.05

Lommis and White(1996)

Brown(1976)

$$g\left(D_t, W_t\right) = 2.89D\left(1 - \frac{D}{12.29W^{0.91}}\right)$$

5. RESULTS FOR VARIOUS CLIMATE

Larson(1995), Sorenson et al.(1998), Johnson et al(2005),

5.1 Climate C… e and the Impact on Wetlands

1. The climate scenarios are listed as followed:

(1) an increase in temperature of $3\ ^{\circ}\mathrm{C}$, no change in precipitation;

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

(3) an increase in temperature of $3\ ^{\circ}\mathrm{C}$, a decrease in precipitation of 20%;

(4) an increase in temperature of $3\ ^{\circ}\mathrm{C}$, an increase in precipitation of 20%.

5. RESULTS FOR VARIOUS CLIMATE SCENARIOS（2）

+3 ˚C temperature ＞−20% precipitation

Precipitation −20% ＞ +20%

Table 2 Effect of climate scenar wetlands: percent de n wetlands.

Regression model	Scenarios			
	+3 ˚C temperature	−20% precipitation	+3 ˚C and −20% precipitation	+3 ˚C and +20% precipitation
$W = 2.9 + 3.33SPI_{t-1}$	-20%	-13%	-34%	-7%
$W = 3.138 + 0.0085P_{t-1} - 0.31T_{t-1}$	-27%	-19%	-47%	-10%

multiple regression ＞ simple regression

The same

+20% precipitation, wetland still decrease (-)

5. RESULTS FOR VARIOUS CLIMATE SCENARIOS（3）

5.2 Effect of Climate Change on Optimal Wetlands

)..

average of 1955–2008 data (U.S. Fish and Wildlife Service) http://mbdcapps.fws.gov/

	Ponds (W)	Ducks (D)	Harvests (h)
Historic	3.5	13.5	12.4
Base case	4.1	20.3	19.6

Bioeconomic model, no climate change

Base case > Historic
Wetland benefit consideration

5. RESULTS FOR VARIOUS CLIMATE SCENARIOS（4）

(4.1-3.2)/4.1=22%

regression Eqs. (3) or (4)

Ta... onds, du...
and climate change e... a

Regression model	Base case	Scenario i		Scenario ii		Scenario iii		Scenario iv	
		(3)	(4)	(3)	(4)	(3)	(4)	(3)	(4)
Ponds (W)	4.1	3.4	3.2	3.7	3.5	3.0	2.6	3.9	3.8
Ducks (D)	20.3	13.8	11.8	15.9	14.1	9.9	6.85	17.9	16.9
Harvest (h)	19.6	13.4	11.5	[illegible]	13.7	9.7	6.75	17.3	16.4

(19.6-11.5)/19.6=41%

(20.3-11.8)/20.3=42%

Climate change : Ducks (D) > Ponds (W)

6. CONCLUSIONS

+3 ˚C and −20% precipitation

1. Climate change regression : the worst case, wetland decreased as much as 47%.
2. Bioeconomic model: the worst case,

wetland decrease 38% → duck reduce 66%.

3. Policy suggestions:
   (1) Encourage landowner to conserve wetland rather than agriculture activity
   (2) Charge American hunters
   (3) Hunting regime management
   (4) Develop sustainable carbon sequestration tech

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Thank you
for your attentions!!

Standardized Precipitation Index (SPI)

1. SPI is an probability index which only consider the precipitation to estimate drought condition.
2. median : The probabilities are standardized so that an index of zero indicates the median precipitation amount.
3. The index is negative(-) for drought, and positive(+) for wet conditions.
4. SPI could be applied in both short-term (1 month) and long-term (2 years) drought.

Palmer Drought Index (PDI)

1. Developed by Palmer (1965).
2. Use temperature and rainfall information to determine dryness.
3. PDI has the best performance in long term drought (several months), not good in short term (weeks).
4. PDI is standardized to local climate to be comparable in different locations.

Palmer Drought Index (PDI)

- PDI classification

PDI	Class
≧4	Extremely wet
3.00 ~ 3.99	Very wet
2.00 ~ 2.99	Moderately wet
1.00 ~ 1.99	Slightly wet
0.50 ~ 0.99	Incipient wet spell
0.49 ~ -0.49	Near normal
-0.50 ~ -0.99	Incipient dry spell
-1.00 ~ -1.99	Mild drought
-2.00 ~ -2.99	Moderate drought
-3.00 ~ -3.99	Severe drought
≦-4	Extreme drought

PDI= - 1.2

PDI= - 3.4

Wetland Simulation Model (WETSIM)

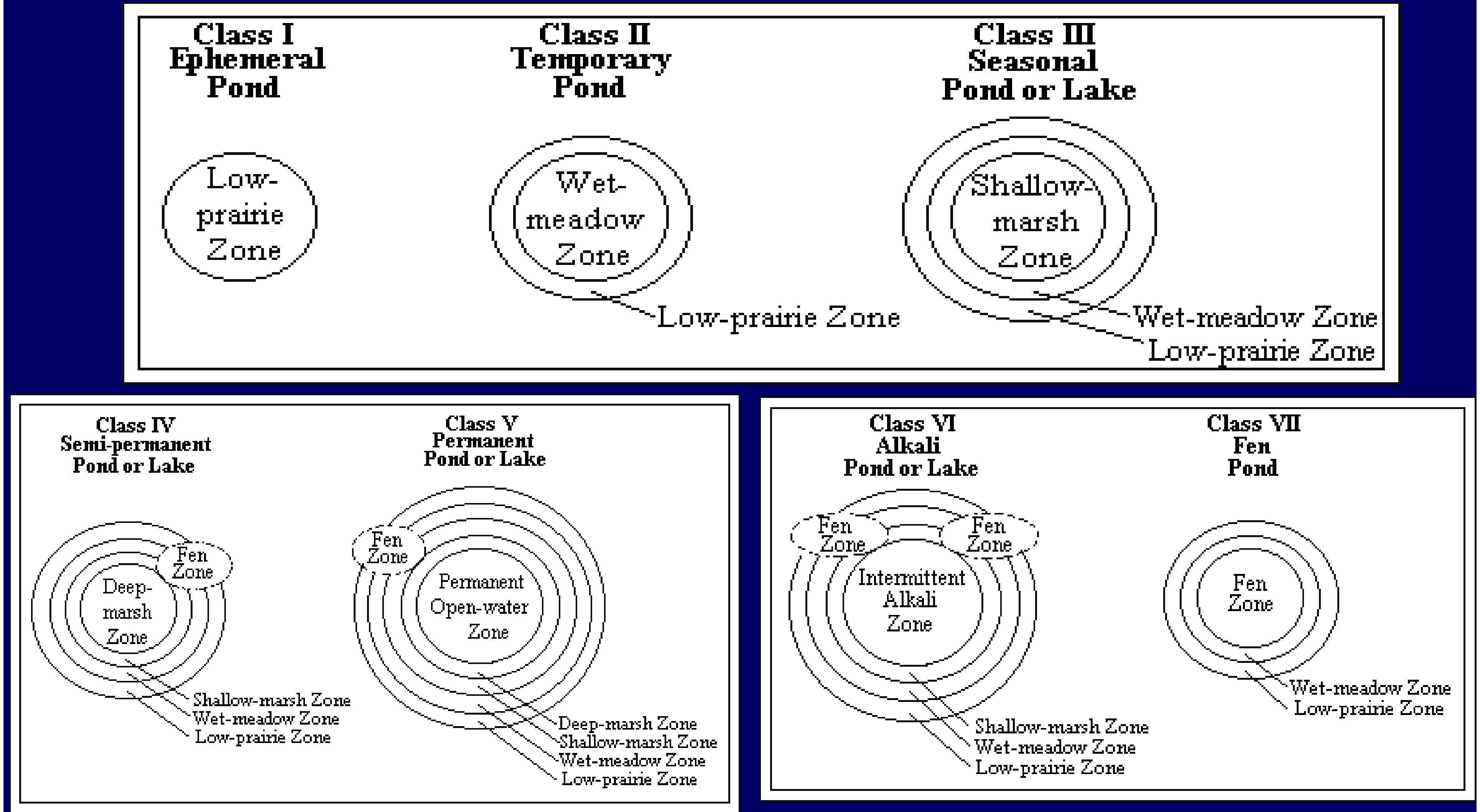
1. Developed by Poiani and Johnson (1991).
2. A deterministic model based on watershed and wetland hydrological processes.
3. Use daily precipitation and temperature to simulate wetland water balance and vegetation.
4. The cell size was $5m \times 5m$.
5. This model was calibrated and validated by the field data in PPR.

Wetland Classification in the Glaciated Prairie Region

- **Classification was based on the vegetation zone in the central or deeper part**

Class	description
ephemeral ponds	Central zone represented by low-prairie vegetation
temporary ponds	Central zone represented by wet-meadow vegetation
seasonal ponds	Central zone represented by shallow-marsh vegetation
semipermanent ponds	Central zone represented by deep-marsh vegetation
permanent ponds	Central area represented by permanent-open-water zone
alkali ponds	Central area represented by intermittent-alkali zone
fen ponds	Central zone represented by fen vegetation

Wetland Classification in the Glaciated Prairie Region



Bellman equation

- Dynamic programing: simplify a complicated problem to sub-problems. Then combine the solutions of the sub-problems to reach an overall solution.
- Bellman equation: When the problem is difficult to separate, we can use a time sequence “value function” V_t (y) to present the value at t in the state of y. That recursive relationship called the “Bellman equation”.
- Bellman principle of optimality: An optimal policy has the property that whatever the initial state and initial decision are, the remaining decisions must constitute an optimal policy with regard to the state resulting from the first decision.

Lagrange multiplier method

A strategy for finding

to constraints.

$$v\left(h_t, y_t, z_t\right) + \alpha D_t + B(W) - C(W)$$

maximize f(x, y)

subject to p(x, y) =

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

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

$$\wedge\left(x, y, \lambda\right) = f(x, y) + \lambda \cdot (p(x, y) - c)$$

To get the maximum, set the first derivative of the function =0

$$\frac{\partial \wedge}{\partial x} = 0, \quad \frac{\partial \wedge}{\partial y} = 0, \quad \frac{\partial \wedge}{\partial p} = \lambda$$

$$\Rightarrow \begin{cases} \dfrac{\partial r_t}{\partial h_t} = \dfrac{\partial V}{\partial h_t} - \rho\lambda_{t+1} S_2 \pi = 0 & \text{...............(9a)} \\ \lambda_{t+1} = \dfrac{1}{\rho S_2} \dfrac{1}{\pi} \dfrac{\partial V}{\partial h_t} & \text{................(9a')} \\ \dfrac{\partial V_t}{\partial W_t} = B'(W_t) - C + \rho\lambda_{t+1} S_2 \dfrac{\partial g}{\partial W_t} = 0 & \text{.........(9b)} \end{cases}$$

解聯立方程式

將 (9a')帶入(9b)

$$B'(W_t) - C + \frac{1}{\pi} \frac{\partial V}{\partial h_t} \frac{\partial g}{\partial W_t} = 0$$

$$B'(W_t) + \frac{1}{\pi} \frac{\partial V}{\partial h_t} \frac{\partial g}{\partial W_t} = C \quad \text{......(10a)}$$

$$\begin{cases} \lambda_{t+1} = \dfrac{1}{\rho S_2}\dfrac{1}{\pi}\dfrac{\partial V}{\partial h_t} & \text{.....................(9a')} \\ \dfrac{\partial V_t}{\partial D_t} = \lambda_t = \alpha + \rho\lambda_{t+1} S_2 (S_1 + \dfrac{\partial g}{\partial D_t}) & \text{....................(9c)} \end{cases}$$

將 $\lambda_{t+1} = \lambda_t$ 帶入(9a')及(9c)

$$\begin{cases} \lambda_t = \dfrac{1}{\rho S_2}\dfrac{1}{\pi}\dfrac{\partial V}{\partial h_t} \\ \lambda_t = \alpha + \rho\lambda_t \left[S_1 S_2 + S_2 \dfrac{\partial g}{\partial D_t}) \right] \end{cases} \Rightarrow 0 = \alpha + \frac{1}{\pi S_2}\frac{\partial V}{\partial h_t}\left[S_1 S_2 + S_2 \frac{\partial g}{\partial D_t} - \frac{1}{\rho} \right]$$

$$\because \rho = \frac{1}{1+r} \Rightarrow \frac{1}{\rho} = 1 + r$$

解聯立方程式

$$0 = \frac{\pi S_2 \partial h_t}{\partial V}\alpha + S_1 S_2 + S_2 \frac{\partial g}{\partial D_t} - 1 - r$$

$$S_1 S_2 + S_2 \frac{\partial g}{\partial D_t} - 1 + \frac{\pi S_2}{\partial V / \partial h_t}\alpha = r \quad \text{......(10b)}$$

$$D_{t+1} = s_2\left[s_1 D_t + g\left(D_t, W_t\right) - \pi h_t\right] \quad \text{.....................(6)}$$

$$D = S_2\left[S_1 D + g(D,W) - \pi h_t\right] = S_1 S_2 D + S_2 g(D,W) - S_2 \pi h_t$$

$$(1 - S_1 S_2)D = S_2 g(D,W) - S_2 \pi h_t = S_2\left[g(D,W) - \pi h_t\right]$$

$$\left(1 - s_1 s_2\right)D = s_2 g\left(D,W\right) - \pi h \quad \text{......(10c)}$$

COMMENT

$$\left(1 - s_1 s_2\right)D = s_2\left[g\left(D,W\right) - \pi h\right] \quad \text{......(10c-my)}$$

Critical Point Theorem