Optimal Waterfowl Hunting Management Strategies for Private Landowners: A Minnesota Case Study

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Abstract:

A bio-economic model based upon waterfowl population, habitat, and hunting data in the state of Minnesota is used to examine the optimal management strategy of a waterfowl hunting enterprise on privately owned land. Various state sponsored incentive programs are then analyzed for their effect on hunting and waterfowl equilibrium levels, as well as the economic viability of the hunting enterprise. A waterfowl habitat and maintenance cost reimbursement incentive program is found to be the most effective at inducing additional hunting opportunities in Minnesota, while providing economic incentives for private landowners to actively manage their land.

Key words: *hunting enterprise, sustainable harvest, waterfowl*

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Introduction

Waterfowl hunting and conservation efforts in Minnesota have traditionally been very successful. Minnesota ranked number three among duck harvesting states from 1961, when federal surveys began, until the early 1990's. Since then, however, Minnesota's rank has dropped to number five. Waterfowl breeding populations in North America expanded dramatically in the 1990's (22 million to 40 million), yet duck harvests and hunter participation in Minnesota declined. Since 1970, Minnesota has seen a decline in waterfowl harvests from 1.07 million to 680,000, a decline in registered hunters from 161,000 to 120,000, and a decrease in the hunter average daily duck bag by 20% (MDNR, 2001).

The decline in waterfowl hunting activities in Minnesota is naturally disturbing to hunters, conservationists, and government officials alike. Hunters contribute immensely to local economies, creating jobs and providing tax revenues. In 1996, hunters in the United States spent \$5.1 billion on travel expenses, \$1.4 billion on state taxes, \$923 million on hunt leases, \$565 million on hunting licenses, and \$155 million on excise taxes (Southwick, 2001). Not only do hunters benefit local economies, but they also contribute to conservation efforts. The majority of hunters feel that the time spent hunting provides a high level of personal satisfaction, or that there is an intrinsic value in hunting. Hence, hunters wish to protect future hunting opportunities and ensure that future generations receive the same hunting opportunities they did. In 1996, hunters contributed \$296 million in dues and donations to conservation organizations such as Ducks Unlimited and Nature Conservancy (Southwick, 2001).

Minnesota natural resource officials contribute declines in hunting activity to the degradation of much of Minnesota's wetlands and other waterfowl habitats. The Minnesota Department of Natural Resources reports that Minnesota has lost more than 52% of its original wetlands, with 45 counties reporting a loss of 90%. Natural waterfowl habitats in Minnesota are declining primarily due to reduced food sources and increased disturbance.

The 1990's in Minnesota was a period of record precipitation levels. Many regions of the state saw precipitation levels, which exceeded historical averages by as much as 40 inches. High water levels diminished the abundance of shallow lakes, where water depths are less than two meters. Shallow lakes provide waterfowl, especially in the fall, with an abundance of vegetation and other important foods, such as wild rice. Wild rice is very sensitive to water levels. Many of Minnesota's wild rice beds are actively managed, but many beds have declined over time. Increased water levels have also connected previously separated basins, leading to changes in fish populations and vegetation.

As smaller wetland basins decline, waterfowl are forced to concentrate into larger basins, which have increased pressure from hunters, shoreline development, and fall fishing activities. Lakes, which previously provided security for waterfowl during the hunting season, can now be accessed by hunters using off-road and four wheel vehicles, fall fishing has increased dramatically in recent years, and recreational shoreline development is also on the rise. These factors contribute to waterfowl disturbance, which can lead to high waterfowl movement into basins in other states, which may not provide as much pressure.

In an effort to mitigate the decline in hunter activity, the Minnesota Department of Natural Resources has proposed a two year project (2001-2003) under the heading "Restoring Minnesota's Wetland and Waterfowl Hunting Heritage", which has two objectives. The first is to achieve 1970-79 duck harvest levels and to maintain the harvest distribution of each waterfowl species. The second is to assess and improve Minnesota waterfowl hunter satisfaction measured though hunter surveys. To achieve these two objectives resource officials propose actions to increase recruitment of locally reared waterfowl to promote population stability and improve waterfowl hunting opportunities. Stategy 2 of the project states that officials should “Consider a program of tax or other incentives to encourage farmers/landowners to allow waterfowl hunting on private property”. Of the Minnesota waterfowl hunters surveyed in 2000, 42.5% hunted exclusively on private lands. Hence, private lands are an important source of hunting opportunities in Minnesota. Crossley and Peterson (2001) maintain that there are large gains in efficiency resulting form private wildlife management, as well as improved economic returns to private landowners and their local communities. However, the authors point out that overexploitation of the wildlife resource may also result.

If wildlife officials in Minnesota are going to achieve their objectives though private landowner programs, they are going to have to provide enough incentive to private landowners to maintain a habitat, which will recruit and sustain locally reared waterfowl and to regulate hunting activity, such that waterfowl populations on their land do not overcrowd or crash, both of which would lead to diminished breeders over time. Rich Staffon of the department of natural resources testifies that “Landowners with wetlands can protect or improve them, making them more attractive to wildlife”. However, as Crossley and Peterson (2001) point out, participation in these programs should be voluntary, where incentives, either financial or in quality of life, are high enough to encourage participation.

In this research we propose an optimal strategy for managing a private hunting enterprise, which maximizes the net-present value of the enterprise given three separate incentive programs.

The incentive provided to landowners will directly affect the amount of hunters they allow to use of their land, the improvements and maintenance of waterfowl habitats on their land, and hence the sustainability of the waterfowl population on their land. For the purposes of this study, we will consider the following incentive programs. The first is a per hunter lease fee, which provides a payment to the landowner for each hunter they allow use of their land for hunting purposes. The second is a seasonal lump sum payment, which will offset the opportunity cost involved in using the land for hunting purposes. The third is a direct reimbursement of all land management costs for projects which directly improve waterfowl habitats on the land. A separate evaluation of each incentive program will allow us to make policy recommendation for the incentive program, which provides the highest possibility of achieving Minnesota's goals concerning waterfowl population stability and increased waterfowl hunting opportunities.

Methodology

The optimal management of a hunting enterprise is a complicated bio-economic problem in which many issues must be considered. The first of which is how to model such a problem. Traditionally, wildlife has been managed under sustainable harvest practices, where wildlife can be used for human purposes, but must be regulated in a way such that the annual harvest does not exceed the wildlife's ability to sustain itself at a healthy population level (Southwick, 2001). Thus, sustainable harvest practices ensure that private landowners will benefit on a long-term basis. Hence, as with the majority of bio-economic problems, it makes sense to use an optimal control framework, in which a feedback rule adjusts harvest rates at each time interval in response to the present ecological situation. The problem confronting the private landowner is one of finding the maximum return from a given parcel of land. This problem is formulated as an infinite horizon optimal control problem where the landowner must adjust the harvest (number of hunters) each period in order to maximize the net present value of the resource (the waterfowl population). While the model focuses upon optimal management of a single unit of land it allows for the possibility of population influx from neighboring parcels. Hence, the essence of the landowner's problem is one of optimally managing the extraction of a renewable resource whose renewal rate is determined both by the natural birth and mortality rate of the current population as well as recruitment from outside populations.

As Johnson (2000) points out, there is still uncertainty regarding the impact of harvesting on waterfowl populations. Previous literature on waterfowl dynamics hypothesizes that waterfowl populations may be more affected by reproductive effectiveness than by waterfowl survivorship. However, a lack of data and incomplete biological info has been a main factor in inhibiting research gains in this area. Cohen (1986) attempted to measure the compensatory relationship between natural mortality and harvest mortality in Mallard ducks. Cohen found there to be a compensatory relationship for male Mallards, but the findings for female Mallards were inconclusive. If a compensatory relationship does indeed exist, a higher degree of waterfowl may be harvested without reducing population levels. Nichols (2000) attributes the issues in measuring harvest impact on waterfowl populations to partial observability and partial controllability. He states that state variables such as waterfowl population are not known, but must be estimated, and control variables such as harvesting or hunting cannot be imposed directly, but must be applied indirectly through hunting regulations. However, as may be evident, the private landowner can measure waterfowl populations on his/her land quite accurately, and additionally has the ability to control harvesting on a per hunter basis. As is described later in more detail, a direct statistical relationship between harvesting and waterfowl populations was found based on Minnesota data.

Model Formulation

The goal of this section is to explore the variations in long-run sustainable hunting and waterfowl population rates resulting from different biological and economic conditions. The general formulation of the landowner problem is as follows:

$$\underset{Ht}{\text{Max}} \int_0^\infty e^{-dt} [P_H H_t] \, dt \qquad (1)$$

subject to

$$\dot{D} = rD_t \left(1 - \frac{D_t}{K_H}\right) - H_t \qquad (2)$$

where

H_t = Hunters at time t per parsel of land

P_H = Hunting fee provided to the private landowner

$= a_1 P^b \left[\left(1 - \frac{H_t}{K_H}\right)\right]$ where :

a_1 = Parameter reflecting hunting experience value per parcel of land

P = Ponds per parsel of land

b = Parameter reflecting quality of habitat

K_H = Maximum hunters per land parsel

D_t = Waterfowl population at time t

r = Waterfowl population replenishm ent rate (natural birth, mortality, and recruitmen t)

$$\frac{(D_{Year\,2} - (D_{Year\,1} - Harvest_{Year\,1})}{D_{Year\,1}}$$

K_H = Carrying capacity per parsel of land

$= a_2 P^b$ where :

a_2 = 4.88 from Brown et. all

P = Ponds per parsel of land

d = Real annual discount rate

Essentially, the return to private landowners from allocating a parcel of land to waterfowl production is the hunting fee collected. Thus, the decision is one of maximizing the net present value of hunting fees via the choice of optimal hunting rates each period. In deciding upon an optimal strategy, the landowner must account for two important factors. The first is how hunting in one period will affect future waterfowl populations. The second is how the willingness of hunters to pay for access is affected by the number of hunters using the land.

The effect of hunting rates on the waterfowl population is represented by (2). The first part of this expression captures the relationship between population growth rate and the land's carrying capacity. Carrying capacity, a_2P^b, is expressed as a function of the number of available ponds. This functional form is adopted directly from the form first developed by Brown et. all (1976) and estimated by Beaverton and Holt. It reflects the absolute population limit on a parcel of land given a fixed number of ponds. This value is increasing in both the number of available ponds, P, as well as the suitability of those ponds for waterfowl.

It is assumed the waterfowl population will increase at a steady rate, r. This intrinsic growth rate incorporates both the natural birth and mortality rates of waterfowl as well as new recruitment to the parcel of land. New recruitment refers to waterfowl nesting on a parcel of land, whom were neither born on the land nor nested on the land in a previous season. For low population levels, the growth rate of the population from both reproduction and recruitment is low. Similarly, as the population approaches the land's carrying capacity, the population growth rate decreases until it reaches zero at carrying capacity. This natural population dynamic is directly affected by hunting, H. For simplicity, it is assumed that all hunters fill their bags so the harvest rate is equal to the number of hunters and the harvest rate is set to one.

The tradeoff between the number of hunters and the fee hunters are willing to pay is reflected in the function, $\mathbf{P_H} = a_1 P^b \left[\left(1 - \frac{H_t}{K_H}\right)\right]$. Similar to the way in which carrying capacity depends upon both the number of ponds as well as the suitability of those ponds for waterfowl habitat, the basic access fee a landowner is able to charge is dependant upon the quality of the waterfowl habitat, P^b, and the values placed upon that quality, a_1.

As stated in the report, "The 2000 Waterfowl Hunting Season in Minnesota: A Study of Hunters' Opinions and Activities," the value placed upon hunting has as much to do with the ability to commune with nature as it does harvesting ducks. This attitude is expressed by the function, $\left(1 - \frac{H_t}{K_H}\right)$. As the number of hunters on a given parcel of land increases, the quality of the hunting experience and, consequently, the hunters' willingness to pay for that experience decreases. It is assumed this value goes to zero as the number of hunters using the parcel of land approaches its capacity. It should be noted that little research exists on what is a parcel of land's "hunting capacity". However, the use of a dimensionless model alleviates this problem by focusing on the rate and not actual capacity.

The original objective function of the landowner is reduced to a dimensionless problem, which arrives at an optimal hunting and waterfowl population rates rather than actual hunter and population numbers. This simplification is done for two important reasons. The first is interpretability. Much of the data concerning waterfowl populations and hunting management exists on various scales of measure, thus reducing the problem to one of percentages of total capacity, rather than one of absolute value, leads to results with direct bio-economic interpretations. The second reason is tractability. As is discussed in the following section, the job of gathering and properly analyzing waterfowl populations and hunting data is extremely problematic. Where data does exist, it is often subject to wide variation and measurement error. The development of a dimensionless problem allows for comparisons between different incentive programs, as well as populations and habitats.

The number of total parameters in the system can be reduced to a smaller set of dimensionless parameters by the following dimensionless variables into (1).

$$\begin{aligned} d_t &= \frac{D_t}{a_1 P^b} = \frac{D_t}{K_D} \\ h_t &= \frac{H_t}{K_H} \\ t &= td \end{aligned} \tag{3}$$

Many of these new dimensionless variables have intuitive bio-economic interpretations. For instance, h_t is simply the percentage of total hunting capacity used at time t, and d_t is the percentage of the waterfowl carrying capacity.

Solving these new variables for existing variables and substituting into the objective function yields the following dimensionless objective function:

$$\underset{ht}{\text{Max}} = K_H \int_0^{\infty} e^{-t} \left[h_t \left[s_1 \left(1 - h_t \right) \right] \right] dt \tag{5}$$

Similarly, substituting the dimensionless variables into the equation of motion and solving for the change in the population rate with respect to the scaled rate of return, τ, arrives at

$$\dot{d} = ?_1 d_t \left(1 - d_t \right) - ?_2 h_t \tag{6}$$

where the dimensionless parameters of s_1, γ_1, and γ_2 represent the maximum hunting fee, the intrinsic growth rate of the waterfowl population and the ratio of the land's maximum waterfowl population to the parcel's maximum number of hunters. Each of these parameters is scaled by the real annual discount rate, which reflects the annual rate of return from the next best alternative use of the parcel of land.

Conditions for a Maximum

The problem of the private landowner now amounts to one of selecting hunting rates in a manner that maximizes the return from the parcel of land, or maximizing the dimensionless objective function, (5), subject to the dimensionless equation of motion, (6). Omitting hunting capacity, K_H, and forming the Hamiltonian leads to:

$$H^{CV} = \left[\mathbf{s}_1\left(h_t - h_t^2\right)\right] + l\left[g_1\left(d_t - d_t^2\right) - g_2 h_t\right] \tag{7}$$

The necessary conditions for maximizing returns are as follows:

$$¶H/¶h = 0 = s_1\left(1 - 2h_t\right) - ??_2 \tag{8a}$$

$$-(¶H/¶d) = \dot{?} - t? = -\left[??_1\left(1 - 2d_t\right)\right] \tag{8b}$$

Using the conditions of (8) along with (6) allows for the derivation of equations of motion for hunting rates, $\dot{h}$, waterfowl populations, $\dot{d}$, and the shadow value of future hunting revenues, $\dot{?}$. The specific forms of these equations are:

$$\dot{d} = ?_1 d_t\left(1 - d_t\right) - ?_2 h_t \qquad \text{or} \tag{9a}$$

$$= ?_1 d_t\left(1 - d_t\right) - ?_2\left(\frac{1}{2} - \frac{??_2}{2s1}\right) \tag{9b}$$

$$\dot{h} = \left(2h_t - 1\right)\left[t - ?_1\left(1 - 2d_t\right)\right] \tag{9c}$$

$$\dot{?} = ?\left[t - ?_1\left(1 - 2d_t\right)\right] \tag{9d}$$

The set of equations expressed in (9) allows for phase diagram analysis in either state-costate (d, λ) or state-control (h,d) space. Because the goal of this project is the analysis of optimal hunting strategies and their relation to sustainable waterfowl populations, focus will be paid to state-control space or the (h,d) phase plane. Solving (9a) and (9c) for the zero-change nullclines yields:

$$\dot{d} = 0 \Rightarrow h_t = \frac{?_1}{?_2} d_t\left(1 - d_t\right) \tag{10a}$$

$$\dot{h} = 0 \Rightarrow d_t = \frac{1}{2} - \frac{t}{2?_2} \quad (10b)$$

The dynamics of the system are expressed by:

$$\partial\dot{d} / \partial h_t = -?_2 < 0 \quad (11a)$$

$$\partial\dot{h} / \partial d_t = 2?_1(2h - 1) < 0 \quad (11b)$$

The nullclines (10) and dynamics (11) of the system imply a stable, saddle point equilibrium.

Model Calibration

Although the major interest of this study is the effect of the purposed incentive programs upon private management decisions in order to properly model these decisions, it is first necessary to gain an improved understanding of how mitigating factors such as habitat variation and behavioral characteristics affect breeding population levels.

To quantify these effects, a regression analysis was conducted. The results of that analysis are presented in the following section. However, prior to the presentation of the results, a brief discussion regarding the purpose and goals of this secondary analysis is required. The goals of the secondary analysis are twofold. First, the analysis seeks to empirically investigate what adjustments to the theoretical model are needed in order to account for differences in waterfowl species and/or habitat areas. Second, an estimate of the level of habitat disturbance caused by hunting activity is needed. Consequently, the following analysis attempts to estimate how the level of hunting activity within a given year affects breeding population levels the following year[2].

[2] The parameter is especially of interest given concerns regarding the decrease of breeding numbers within Minnesota.

Data Overview

Data for the years 1990- 2001 was gathered from three main sources. Waterfowl breeding population data are from the Wetland Wildlife Populations and Research Group[3]. Harvest data are from the annual hunter survey of the U.S. Fish and Wildlife Service and climate data were gathered from the Western Regional Climate Center. Summary statistics of the variables appearing in the final model are supplied in Table 1.

According to the 2001 Waterfowl Breeding Population Survey, waterfowl habitats within the state of Minnesota are assigned to one of three strata. Each stratum is defined by lake basin (=10 acres) density. Definitions of the three strata are as follows:

- Stratum I: High Density, 21 or more basins per township
- Stratum II: Moderate Density, 11-20 basins per township
- Stratum III: Low Density, 2 to 10 basins per township

In a similar way, the State of Minnesota assigns each waterfowl species a type according to the major behavior patterns of that species. For instance, the waterfowl type dabblers, refers to species whose eating habits are classified as dabbling on the water surface versus diving for food, or divers. Table 2 contains a list of waterfowl species in which breeding data is available along with the type classification of each species.

Harvest data were supplied by the U.S. Fish and Wildlife Service (USFWS) Harvest Surveys Section's annual mail questionnaire sent to registered hunters. Survey results are compiled on a county by county basis with the responses from any given county weighted in order to correspond to historical trends and known hunter activity within that county. In order to properly match waterfowl harvest numbers with the breeding population data supplied by the

[3] A section of the Minnesota Department of Natural Resources

Waterfowl Population Breeding Survey, hunter survey respondents were re-compiled by strata and waterfowl type.

Monthly climate data (precipitation and temperature) by county were collected for the years of interest as well as for several preceding years. Once collected, yearly averages, year-to-date amounts, and 10 year monthly moving averages were calculated for each county. These results were then used to compute a weighted average for each habitat strata. Each county's weight for a given strata was determined by the percentage of a strata's habitat existing within that county. Year-to-date and 10 year moving averages were not found significant predictors in preliminary analysis and were subsequently dropped from further model specifications.

Estimated Results

A variety of fixed effects model specifications were fit with dummy variables used to identify strata and waterfowl type. For all models considers, Prior Year Harvest (LaggedHa), Average Precipitation (Precip), and Temperature (Temp) were also included. Other possible predictors including interaction terms and polynomials were included or excluded according to their predictive power in order to arrive at a final model. For clarity, the general form of the regression equation used to arrive at the final model was as follows:

$$\begin{aligned} \text{Population} = {} & \alpha_o + \alpha_1(\text{Strata1}) + \alpha_2(\text{Strata2}) + \alpha_3(\text{Dabbler}) + \alpha_3(\text{Diver}) \\ & + \beta_1(\text{Prior Year Harvest}) + \beta_2(\text{Precip}) + \beta_3(\text{Temp}) \\ & + \beta(\text{Other Predictors and Interactions}) + \varepsilon \end{aligned} \tag{12}$$

where $\varepsilon_i \sim N(0, \sigma^2)$

The final model selected as a result of this process was the following:

$$\begin{aligned} \text{Population} = {} & 2242273 - 0.335\ \text{LaggedHarvest} - 2251\ \text{Precip} - 98937\ \text{Temp} \\ & - 44253\ \text{Strata1} - 16198\ \text{Strata2} + 69525\ \text{Dabbler} - 17484\ \text{Diver} \\ & + 1160\ \text{Temp2} \end{aligned} \tag{13}$$

Residual analysis of the OLS estimation of (12) indicated the assumptions of normality and constant variance appeared to hold. This was further supported by appropriate tests.

However, the possibility of an outlier was also found. Further investigation indicated this outlier was most likely the result of a data entry error and could be dropped. However, to protect against a selection bias, the final model, (12) was re-estimated two different ways. First, the suspect data point was dropped and the model estimated using OLS. Second, the model was re-estimated using Iteratively Re-weighted Least Squares (IRLS) where the weights were determined by squaring the residuals from the auxiliary regression:

$$\hat{\mathbf{e}} = \mathbf{X}\boldsymbol{\beta} + \mathbf{v} \tag{14}$$

Results from both the IRLS estimation as well as the OLS estimation excluding outliers are presented in Table 3. As can be seen, parameter estimates from IRLS are comparable to OLS estimation.

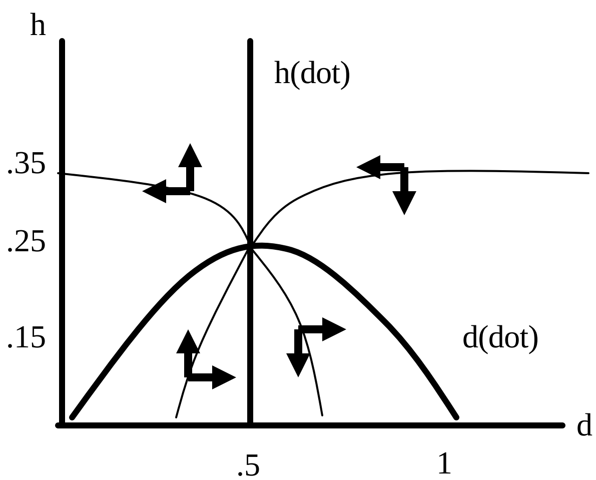
Empirical Application

A base set of dimensional parameter values was used to determine the dimensionless parameter values, which were then inserted into the theoretical model to determine equilibrium levels of hunting, waterfowl population, and the current shadow value of future hunting revenues for the private landowner (Table 4).

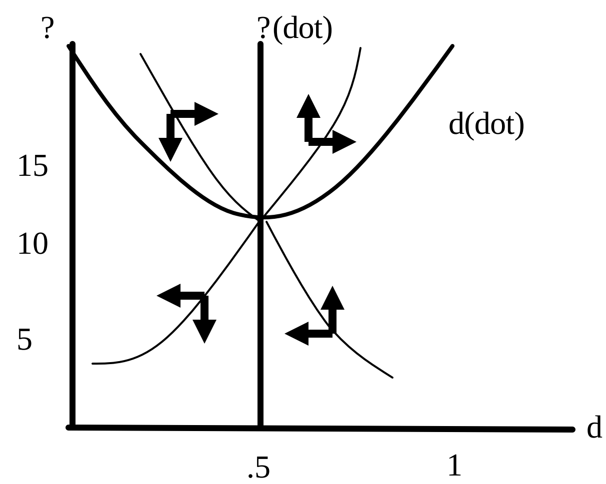
The values for a_2 and b were provided by previous mallard studies (Brown et. all, 1976), the discount rate, delta, was determined based on current market returns, and the waterfowl growth rate, r, was estimated based on Minnesota waterfowl breeding and population data for both dabbler and diver waterfowl types. It should be pointed out that waterfowl growth rates for each type vary widely across years, and the diver type tends to have a much stronger growth rate than the dabbler type. Hence, it is important for the landowner to investigate the type of waterfowl breeders on the land parcel and use a growth rate, which is appropriate to its specific waterfowl population. The breeding habitats or ponds per parcel of land, was estimated based on the Minnesota stratum data previously described. A basic a_1 value was assigned equal to that of a_2, as an initial lease value based on the waterfowl carrying capacity of the land parcel.

The base problem identified an equilibrium hunting rate of 22.9% of the total hunting capacity, in which a maximum of 50% of the current waterfowl population could be harvested. Additionally, the current shadow value of future hunting revenues was 11 (Table 4). As seen in Figure 1, the private landowner may adjust the hunting rate per the present state of the waterfowl population. For example, should the current waterfowl population be at 75% of capacity, the private landowner should allow hunting at approximately 35% of the hunting capacity to put the system on a stable manifold, which will guide the system towards equilibrium levels. If the current waterfowl population was at 40%, the private landowner should allow hunting at approximately 10% of total hunting capacity.

Figure1: Phase Diagram Analysis



(h,d) Phase Plane



(?,d) Phase Plane

The next step of our analysis is to perturb the base parameter values to mimic our three state sponsored incentive programs.

Per-hunter Lease Fee

The first incentive program is the per-hunter lease fee, which may take the form of a tax credit or other payment to the private landowner for each hunter allowed use of the land. This program directly impacts the revenue function of the landowner. In order to measure the impact of this type of incentive program, we must increase the a_1 parameter value in the model. For this purpose we have chosen to increase a_1 from its base value of 4.88 to 19.88, by increasing the value of the land quality by 15. Essentially, this incentive programs provides the private land owner with an additional fee above what the hunter may be willing to pay. It also provides an incentive for the landowner to allow hunting or additional hunting, which increases hunting opportunities without incurring added expenses.

The adjustment to the a_1 parameter did not change the equilibrium level of hunting or the annual harvest rate, but it substantially increased the shadow value of future hunting revenues from 11 to 48 (Table 5).

Seasonal Lump Sum Payment

The second incentive program is the seasonal lump sum payment, which could take the form of a property tax or other tax rebate paid to the private landowner each hunting season, with a requirement that the landowner allow hunters to use the land. The lump sum payment essentially lowers the discount rate, or the opportunity cost involved in using the land for hunting purposes. In order to measure the impact of this type of incentive program, we decrease the discount rate from its base level of 8% to 2%. The adjustment to the discount parameter did not change the equilibrium level of hunting or the annual harvest rate, but it substantially decreased the shadow value of future hunting revenues from 11 to 2.9 (Table 6).

Cost Reimbursement

The third and final incentive program is the cost reimbursement program, which effectively reimburses the private landowner for expenses incurred in improving and maintaining the waterfowl habitats on the land. In order to measure the impact of this type of incentive program, we must increase the b parameter in our model to show an increase in the effectiveness of the waterfowl habitats at attracting and maintaining breeding pairs. We have elected to increase this parameter by 10%, which effectively changes b from .791 to .891. The benefits of the program would, in fact, only be realized should the private landowner incur land management costs relating to waterfowl habitats.

The adjustment to the b parameter increased both the equilibrium value of the percentage of hunting capacity used from 22.9% to 30.9%, and the current shadow value of future hunting revenues from 11 to 15. The equilibrium value for total allowable harvest of 50%, however, did not change (Table 7). Thus, this incentive program will induce a higher level of hunting across time as well as increase the value of the hunting enterprise for the private landowner.

Conclusion

In this study we have provided a baseline bio-economic model, which can be used by private landowners to maximize the net present value of their fee-hunting enterprise, while actively managing their waterfowl populations so as not to induce crashes or overcrowding. Each of the three incentive programs provided a different picture of the overall hunting activity, waterfowl population levels, and present value hunting revenues. The cost reimbursement incentive program, however, was the most successful at promoting the goals of Minnesota's waterfowl hunting heritage restoration project. The cost reimbursement plan encourages landowners to improve and maintain their waterfowl habits, which leads to increased recruitment of locally reared waterfowl and eventually to waterfowl population stability. Additionally, this incentive program increased hunting opportunities from 22.9% of total hunting capacity to 30% of total hunting capacity, while maintaining a stable population harvest at 50%. The second best incentive program was found to be the per-hunter lease fee, which improved the present value of future revenues for the private landowner, but did not increase hunting activities or encourage waterfowl habitat maintenance.

Of course the specifics of the cost reimbursement incentive program need additional refinement. The program must induce private landowners to participate in the program and provide enough incentive for them to effectively manage their fee hunting enterprise. In other words, the program must align the incentives of both the private landowner and Minnesota Wildlife programs. This refinement is an agency theory type of problem and is the focus of our ongoing research.

In closing, it is important to note one of the most curious finding of this research, is the insensitivity of equilibrium waterfowl population levels to the incentive programs that were explored. This is likely due to the ease at which the private landowner is able to maintain his/her waterfowl population via recruitment. As a result, the landowner is not overly concerned with the sustainability of his/her initial population as long as any harvesting of that population can easily be replaced by recruitment from other populations.

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Appendix

Table 1: Summary Statistics of Variables

Variable	N	Mean	Med	SD	Min	Max	Q1	Q3
Breeding Population	81	50293	33493	46543	7714	217490	16852	65485
Prior Year Harvest	81	61851	50780	43795	4876	190639	31722	82938
Average Monthly Precipitation	81	28.702	28.444	2.45	24.044	34.356	27.045	30.879
Average Temp	81	42.2	42.569	2.355	37.054	46.67	40.563	43.4

Table 2: Species and Type Classification

Species	Waterfowl Type	Species	Waterfowl Type
Mallard	Dabbler	Redhead	Diver
Black Duck	Dabbler	Canvasback	Diver
Gadwall	Dabbler	Scaup	Diver
American Wigeon	Dabbler	Ring-necked Duck	Diver
Green-winged Teal	Dabbler	Goldeneye	Diver
Blue-winged Teal	Dabbler	Bufflehead	Diver
Northern Shoveler	Dabbler	Ruddy Duck	Diver
Northern Pintail	Dabbler	Hooded Merganser	Diver
Wood Duck	Dabbler	Large Merganser	Diver
Coot	Other		
Canada Goose	Other		

Table 3: Results from Corrected Models

Predictor	Coef	*SE*	T	*P*	
OLS Estimation Excluding Outlying Data Point					
Constant	921806	*1473654*	0.63	*0.5359*	
LaggedHa	-0.30741	*0.11277*	-2.73	*0.0102*	
Precip	-1.34432	*1380.692*	0	*0.9992*	
Temp	-39850	*68455*	-0.58	*0.5644*	
Strata1	-51082	*10351*	-4.93	*<.0001*	
Strata2	-29983	*8223.856*	-3.65	*0.0009*	
Dabbler	83249	*10401*	8	*<.0001*	
Diver	-17126	*7725.614*	-2.22	*0.0336*	
Temp2	466.19944	*796.3027*	0.59	*0.5622*	
S	***0.0000129***	***R-Sq***	***85.49%***	***R-Sq***	***81.97%***

Iteratively Re-weighted Least Squares Estimates					
Constant	778719	*587334*	1.33	*0.189*	
LaggedHa	-0.3265	*0.08313*	-3.93	*<.0001*	
Precip	-1916	*861.1*	-2.22	*0.029*	
Temp	-32099	*27679*	-1.16	*0.25*	
Strata1	-41779	*5752*	-7.26	*<.0001*	
Strata2	-14390	*7437*	-1.93	*0.057*	
Dabbler	77385	*6410*	12.07	*<.0001*	
Diver	-9134	*4999*	-1.83	*0.072*	
Temp2	388.8	*325.7*	1.19	*0.237*	
S	***17852***	***R-Sq***	***83.90%***	***R-Sq(adj)***	***82.10%***

Table 4: Initial Parameter Conditions

Dimensional Parameters			
	Base	**Incentive**	**Total**
a1	4.88	0	**4.88**
a2	4.88	0	**4.88**
B	0.791	0	**0.791**
Ponds	20	0	**20**
Delta (discount rate)	0.08	0	**0.08**
Waterfowl Growth Rate{r}	0.3516	0	**0.3516**
Hunter Capacity {Kh}			**20**
T			**1**
a1*p^b (Price Parameter)			**52.18366152**
a2*p^b (Waterfowl Capacity)			**52.18366152**
ht (Hunting rate-used for Revenue Function example)			**0.229347192**
Dimensionless Parameters			
S1			**104.367323**
G1			**4.395**
G2			**4.790771531**
Tau			**0.08**
Equilibrium d			**0.5**
Equilibrium h			**0.229347192**
Equilibrium ?			**11.7923841**

Table 5: Per-hunter Lease Fee Conditions

Dimensional Parameters			
	Base	Incentive	Total
a1	4.88	15	19.88
a2	4.88	0	4.88
B	0.791	0	0.791
Ponds	20	0	20
Delta (discount rate)	0.08	0	0.08
Waterfowl Growth Rate{r}	0.3516	0	0.3516
Hunter Capacity {Kh}			20
T			1
a1*p^b (Price Parameter)			212.5842605
a2*p^b (Waterfowl Capacity)			52.18366152
ht (Hunting rate-used for Revenue Function example)			0.229347192
Dimensionless Parameters			
S1			425.1685209
G1			4.395
G2			4.790771531
Tau			0.08
Equilibrium d			0.5
Equilibrium h			0.229347192
Equilibrium Lambda			48.03946636

Table 6: Seasonal Lump Sum Payment Conditions

Dimensional Parameters			
	Base	Incentive	Total
a1	4.88	0	4.88
a2	4.88	0	4.88
B	0.791	0	0.791
Ponds	20	0	20
Delta (discount rate)	0.08	-0.06	0.02
Waterfowl Growth Rate{r}	0.3516	0	0.3516
Hunter Capacity {Kh}			20
T			1
a1*p^b (Price Parameter)			52.18366152
a2*p^b (Waterfowl Capacity)			52.18366152
ht (Hunting rate-used for Revenue Function example)			0.229347192
Dimensionless Parameters			
S1			104.367323
G1			17.58
G2			19.16308612
Tau			0.02
Equilibrium d			0.5
Equilibrium h			0.229347192
Equilibrium Lambda			2.948096024

Table 7: Cost Reimbursement Conditions

Dimensional Parameters			
	Base	Incentive	Total
a1	4.88	0	4.88
a2	4.88	0	4.88
b	0.791	0.1	0.891
Ponds	20	0	20
Delta (discount rate)	0.08	0	0.08
Waterfowl Growth Rate{r}	0.3516	0	0.3516
Hunter Capacity {Kh}			20
t			1
a1*p^b (Price Parameter)			70.41051942
a2*p^b (Waterfowl Capacity)			70.41051942
ht (Hunting rate-used for Revenue Function example)			0.309454233
Dimensionless Parameters			
S1			140.8210388
G1			4.395
G2			3.550605819
tau			0.08
Equilibrium d			0.5
Equilibrium h			0.309454233
Equilibrium Lambda			15.11452087