Improving the Efficiency of Wildlife Management: An Application to Waterfowl Production in the Prairie Pothole Region

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Abstract: Wildlife management agencies increasingly use economic analyses to improve the efficiency of their management policies. Few economic studies consider supply-side analyses for wildlife management, due, in part, to a lack of biological response data that capture the full range of management strategies and the influence of landscape characteristics. This paper uses a simulation model to generate biological response functions, which are then embedded within an economic model to determine least cost management strategies. The procedure is applied to waterfowl management in the Prairie Pothole Region of the northern Great Plains. Results highlight management inefficiencies that result from oversimplified response functions that do not account for non-linear relationships or spatial heterogeneity. Results also indicate that intensive management activities, which are generally compatible with agricultural land use, are a cost effective means of achieving waterfowl population objectives. This has important implications for the tradeoff between agricultural and waterfowl production in the Prairie Pothole Region.

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Wildlife management prior to the 1960's consisted primarily of enacting and enforcing laws to regulate the exploitation of harvestable species (Pearse and Bowden 1968). However, increasing concern about the natural supply of wildlife, combined with growing demand for wildlife resources expanded the role of management to include the augmentation of wildlife populations. As the role of wildlife management shifted from protection to production, the need to efficiently allocate limited management funds also increased. As a result, economic analyses are increasingly brought to bear on wildlife management decisions. Nobe (1971) recognized this trend, stating: "It appears that economic input is moving rapidly from the role of "window dressing" to that of an integral part of policy formulation and administration of game and fish resources…"

Economic analyses of wildlife management have, to date, emphasized non-market valuation issues (Matulich and Hanson 1986). Equally important to wildlife managers and policy makers are the supply-side production relationships that determine minimum cost approaches for achieving management objectives. In the absence of supply-side analyses, balance cannot be struck between the benefits and costs of wildlife management projects, and limited management resources will be allocated inefficiently. The purpose of this paper is to illustrate the value of detailed supply-side analyses, and demonstrate how results can be used to more effectively guide wildlife management decisions. We use a biological simulation model to generate wildlife production relationships, which can then be integrated into economic models to determine optimal least cost management strategies. We apply the procedure to waterfowl management in the Prairie Pothole Region of the northern Great Plains, deriving insights into the design of efficient management strategies, which have important implications for waterfowl conservation and land use in the region. In the following sections we discuss an underlying data problem which has hindered supply-side analyses of wildlife management issues, and the problems these data limitations have posed in past research. This is followed by a brief background on waterfowl, before continuing to the methodology and results.

Background

Supply-side Analyses of Wildlife

Identifying management strategies that achieve wildlife population objectives at minimum cost requires detailed production information that relates biological response to incremental changes in management effort. The lack of detailed supply-side analyses has largely been attributed to inadequate biological response data (Matulich and Adams 1987). Biological data often isolates specific components of highly complex interdependent biophysical systems, abstracting away from interactions between system components. Those interested in the technical input-output relationships, however, information on these interactions to derive biological response surfaces. With currently available data, response surfaces must often be pieced together using information from numerous uncoordinated biological studies, which typically only consider a few management strategies and intensities. Furthermore, when biological data from multiple studies are pooled, spatial and temporal variation across studies makes it difficult to isolate the marginal effects of management from those of exogenous factors, such as weather.

In lieu of detailed and consistent response data, supply-side analyses often use highly aggregated measures of biological response, such as species richness, thereby limiting policy implications to broad, macro-level questions (Wenum, Wossink and Renkema 2004;Wossink, et al. 1999). Attempts at more micro-level analyses tend to use largely restricted or indirect measures of inputs. Management activities, inputs, are often limited to a single management activity, such as harvest in fisheries models (Conrad 1999;Hannesson 1993). Hammack and Brown (1974) aggregated all waterfowl production activities into a single input, the number of spring ponds, disregarding all other management activities that can influence waterfowl production. Studies that have attempted to analyze multiple management activities are generally restricted by data limitations to the assumption of linear response and costs (e.g. Lokemoen 1984;United States Fish and Wildlife Service 1996). This assumption implies that derived average and marginal costs are constant for all levels of production, are independent of other management activities and are invariant to location specific environmental conditions.

Other economic studies that consider multiple management activities tend to treat wildlife production as a by-product of market production activities and thus the opportunity cost of wildlife production is necessarily a decrease in market output. Examples include studies of forest bird species or farmland wildlife, where “management activities” are alternative harvest rotations or crop regimes (Hyde 1989;Montgomery, Brown and Adams 1994;Rohweder, McKetta and Riggs 2000;Wenum, Wossink and Renkema 2004;Wossink, et al. 1999). In many instances wildlife management activities are available that do not inhibit market production; in such cases, the cost of wildlife production may be grossly overstated if wildlife production is treated as incompatible with market production activities.

Supply-side analyses that consider only a subset of available management activities, or that piece together response from uncoordinated biological studies are unlikely to generate cost surfaces that accurately represent the full range of substitution possibilities available to wildlife managers and conservationists. As such, policy prescriptions may not represent minimum cost production alternatives and the supply curve for wildlife will remain elusive. Much of the additional work needed is in the territory of biologists and requires cooperation across the disciplines of biology, ecology and economics in increasing. However, while improvements in biological data are in the future, critical wildlife management decisions are being made in the present.

Waterfowl Management in the Prairie Pothole Region

Waterfowl are one of the most economically important wildlife resources in North America, generating an estimated $3 billion annually from hunting and bird watching activities (U. S. Fish and Wildlife Service 2004). Waterfowl are therefore the focus of much research and management. Waterfowl management in the U. S. began in the early 1900's with the implementation of harvest restrictions (Nichols, Johnson and Williams 1995). Growing concerns about habitat loss and population fluctuations gradually shifted management emphasis from harvest regulation to habitat protection and restoration. In 1986, the United States and Canada signed the North American Waterfowl Management Plan (NAWMP) with the primary objective of returning waterfowl populations to their 1970's levels. Mexico signed NAWMP in 1994, making it a truly continental effort and one of the most comprehensive wildlife initiatives to date. As of 2003, NAWMP partners have invested $3.2 billion to protect and enhance waterfowl habitats (U. S. Fish and Wildlife Service 2004). There are also many other programs that benefit waterfowl, such as the Conservation reserve Program and Wetlands Reserve Programs. Despite billion-dollar investments in waterfowl management, populations continue to fluctuate, with some species showing signs of long term decline (Garrettson, Moser and Wilkins 2003).

One of the most critical areas in North America for waterfowl management is the Prairie Pothole Region (PPR), which encompasses 715,000 km^2 of north central United States and south central Canada. The PPR represents only ten percent of the continents' waterfowl breeding area, yet it produces fifty percent of North America's game ducks in an average year (Smith, Stoudt and Gallop 1964). Waterfowl in the PPR are subject to both environmental and anthropogenic influences that affect their population level. The regions' persistent wet/dry cycles are largely responsible for the fluctuation in waterfowl populations. Waterfowl have, however, evolved to withstand these weather cycles, even prolonged drought (Cowardin 1983).

Of greater concern to waterfowl managers are anthropogenic factors affecting waterfowl populations (see Dahlgren and Korschgen 1992), particularly the effects of landscape alterations associated with intensive agriculture. Agriculture is the primary land use in the PPR and the economic incentives that agricultural producers face are often inconsistent with waterfowl production. Increases in farm mechanization has led to the perception of small prairie wetlands as "problem areas" that impede efficient machine use (Higgins, Naugle and Forman 2002). As a result, incentives to drain small wetlands have eliminated a large portion of PPR wetlands that historically supported waterfowl (Austin 1995;Cowardin 1983;Krapu 1996;Tiner 1984).

In addition to draining wetlands, agricultural activities have adversely impacted upland areas that provide critical nesting habitat for many waterfowl species (Cowardin 1983;Euliss and Mushet 1999;Lynch, Evans and Conover 1963;Tiner 1984). For example, the development of genetically modified crops (e.g. drought resistant soybeans) has prompted a shift towards monoculture tillage, resulting in a decline in suitable upland wildlife habitat (Higgins, Naugle and Forman 2002). Additionally, farm support programs that emphasize commodity production provide further incentives for producers to convert marginal farmland, which can support waterfowl production, to crop production (Connor, et al. 2001).

Agriculture has also had numerous indirect effects on waterfowl in the PPR, including the distortion of natural predator/prey relationships. By reducing available wetland and upland habitat, agricultural activities have concentrated breeding waterfowl into smaller areas making them more vulnerable to predation (Austin 1995;Greenwood and Sovada 1996). Populations of generalists species like skunk, raccoon, American crow and red fox, which flourish in disturbed areas and have a high propensity to prey on waterfowl eggs, have increased, while populations of more waterfowl "friendly" species, such as grizzly bears, wolf and kit fox, have all but disappeared (Sargeant and Raveling 1992).

Agriculture will undoubtedly continue to dominate the PPR landscape. The challenge to waterfowl managers is, therefore, to increase duck production in spite of the challenges this fragmented agricultural environment present. The opportunity cost of using land in the PPR for waterfowl production instead of agriculture is high. This implies a need to select efficient waterfowl management strategies. The first step in maximizing management efficiency is to derive biological response functions that expose the tradeoffs between a range of management alternatives across heterogeneous agricultural landscapes.

Approximating Biological Response

Approximating waterfowl response to management activities requires two steps. First, waterfowl response data is generated using the Mallard Productivity Model (MM). A continuous response surface is then estimated from the data using regression analysis. Each step is described below in more detail.

Simulating Response Data

The MM is a stochastic computer model that simulates recruitment[1] of mallard ducks (*Anas platyrhyncos*) as a function of habitat conditions and management effort (Cowardin, et al. 1988). We use the MM to generate data on the number of recruits produced under a range of management activities and intensities. Waterfowl production is simulated on three landscapes

[1] Recruitment is a measure of the number of incremental ducks added to the population during the breeding season.

(bad, average, good) to account for location specific differences in biological response and input costs. Landscapes were selected to represent the spectrum of land use currently observed in the PPR and are differentiated according to their relative waterfowl and agricultural productivity in the absence of management activities. Each landscape consists of 8 km^2 (2000 acres), roughly the average farm size in the PPR, but differ significantly in initial habitat characteristics. Table 1 presents the initial habitat configuration of each landscape. The bad and average landscapes are both dominated by agricultural activities but differ in wetland abundance. The bad landscape represents an intensive agricultural operation, with high quality agricultural land and significant wetland drainage. The average landscape has average quality agricultural land, but relatively less wetland drainage. Although much of the PPR is dominated by active farmland, significant conservation and restoration has taken place through programs such as the Cropland Reserve Program and Wetland Reserve Program. The good landscape represents the conserved and restored acreage in the PPR, with intact wetlands and CRP enrolled acreage each accounting for nearly a third of the landscape.

Biological response to management activities is simulated on each of the three landscapes. The following eight management activities are considered, each of which are used in the PPR to increase waterfowl production: 1) cropland retirement (CR), 2) conservation tillage (NT), 3) delayed haying (DH), 4) planted cover (PC), 5) planted cover fenced (PCF), 6) nest structures (NB), 7) predator control (PRED), and 8) wetland restoration (WR). Management activities are simulated by transferring acreage between the MM's 26 habitat categories, such as transferring cropland to the CRP habitat to simulate cropland retirement, or by adjusting model parameters, such as reducing the predation index parameter to simulate predator control.

Simulations are performed for each management activity in isolation, as well as for combinations of management activities. This allows us to identify the effects of individual activities on waterfowl production, as well as interaction effects between management activities. Additionally, each management activity is considered at multiple levels (e.g. 10, 20,…,100 acres) to identify the marginal effect of changes in management effort on mallard recruitment.

Since the MM is stochastic, the result of each simulation represents only one observation on a random process and is therefore an unsatisfactory measure of response. To more accurately capture response we generate 300 realizations of each management scenario and calculate mean response. Following Ross (2002, p. 116), the number of simulations is chosen such that the 95% confidence interval around the estimated mean was +/- 3.5 recruits. The resulting data set consists of mean recruits and activity levels for 352, 376, and 427 scenarios on the bad, average and good landscapes, respectively.

Estimating Continuous Response Surfaces

Simulations discussed above generate data that reflect how waterfowl respond to various levels and combinations of management activities on three alternative landscapes. To embed this information within the manager's decision model we approximate a continuous supply response surface using the simulated data. An alternative to approximating a single function would be to directly embed the simulation model within the optimization routine. The complexity of the MM and programming language differences between the MM and common optimization packages made this alternative impractical.

Little guidance exists on the appropriate specification of the waterfowl response surface, however, some underlying principles from production theory are likely applicable. The principle of diminishing marginal physical product, for example, is expected to apply to many management activities. That is, as one management activity is incrementally increased, ceteris paribus, production is expected increase at a decreasing rate. We expect that diminishing returns exists for management activities that directly increase nesting habitat: CR, DH, NT, PC, PCF and NB. This is because the number of breeding waterfowl pairs is largely determined by the number of ponds (Cowardin, et al. 1983). As the amount of available nesting habitat increases for a fixed number of ponds, and therefore a fixed number of pairs, recruits are expected to increase at a decreasing rate as the quantity of available nesting habitats exceeds the number of breeding waterfowl pairs available to utilize that habitat. The spatial scale necessary to observe diminishing marginal returns, however, is not known a priori. Management activities that create nesting habitat that is not highly attractive to breeding waterfowl or has low nest densities relative to other available habitats, such as CR, DH, and NT, may need to be applied at very high levels for diminishing returns to be observed. On the contrary, highly attractive habitats or habitats that permit high nest densities, such as PC, PCF, and NB, may exhibit diminishing returns at relatively low levels.

A second principle guiding the specification of the response function is that of complementary versus substitute inputs. Habitats within the same landscape that are very similar in their attractiveness to breeding waterfowl are likely to compete for the limited number of breeding pairs, implying that management activities that create similar habitats may be technically competitive. Competition between management activities implies that increasing one management activity decreases the marginal productivity of other competitive activities. For example cropland retirement, planted cover, and planted cover fenced all create similar grassland type nesting cover and therefore may be technically competitive. Waterfowl managers in the

PPR, recognizing the potential for competing habitats, recommend that management activities, such as PC and PCF, be located in areas with little adjacent nesting cover (USFWS, 1996).

Biological literature suggests another group of interdependent management activities. Research on waterfowl nest depredation suggests that large block of intact grassland cover reduce nest densities, decreasing the probability of nest predators locating and depredating nests (Reynolds, R. E. et al. 2001, Kantrud, H. A. 1993). Functionally, PRED is therefore likely competes with high levels of habitat management actions, such as CR, NT, DH, and PC, which create extensive nesting cover. A quadratic approximation has the functional form necessary to capture diminishing marginal products and interdependence as well as the attraction of being simple to estimate. The response function taker the following general form:

$$(1) \qquad y = \alpha + \sum_{i}^{k} (\beta_{1i} x_i + \beta_{2i} x_i^2) + \sum_{i}^{k} \sum_{j}^{k} \delta_{ij} x_i x_j + \varepsilon \ ,$$

where, y is waterfowl production measured as the number of recruits, x_i is the level of management action i, ε is random disturbance terms and α, β_1, β_2, and δ are parameters to be estimated.

We estimate the parameters by ordinary least squares using the Limdep NLOGIT 3.0 software package (Greene, W. H. 2003). Theory and intuition discussed above suggests second-order terms for CR, DH, NT, PC, PCF and NB. The estimated coefficients on second-order terms for CR, DH, and NT are not significant on any landscape, suggesting that these management practices do not exhibit diminishing returns at the levels applied in this study. An F-test for the joint significance of the coefficients on CR^2, DH^2, and NT^2 fails to reject the hypothesis that these coefficients are all equal to zero. These variables are therefore excluded from the specification. Summary statistics for the variables included in the approximate response are provided in Table 2.

Using the variables listed in Table 2, we estimate four models, one for each landscape, and a pooled model that assumes the coefficients, excluding the intercept term, are constant across landscapes. The pooled model assumes that waterfowl response to management is independent of initial landscape characteristics. As a specific example, the pooled model assumes that the marginal productivity of cropland retirement on a landscape containing abundant wetlands is equal to that on a landscape with few or no wetlands. To test whether response depends on initial landscape characteristics we perform a Chow test of the individual versus the pooled models. The calculated F-statistic is 587.23, with a 99% critical value of ≅ 1.70; therefore we reject the null hypothesis that the estimated coefficients are the same across landscapes, and adopt separate waterfowl response function for each landscape.

Estimation Results

Parameter estimates for each landscape are provided in Table 3. Signs and significance are, in general, as expected. Coefficients on individual management activities are positive and significant on all landscapes. Coefficients on NB^2, PC^2 and PCF^2 are negative and significant, confirming the presence of diminishing returns with respect to these management activities. Interaction variable coefficients are negative and significant, with a few exceptions, confirming the hypothesis that these management actions are technically competitive.

Examining individual coefficients reveals that the intensive management activities NB and PCF are the most productive per unit, while the extensive CR and NT management practices generate the fewest recruits per unit treated. Comparison across landscapes reveals that, in general, management actions are most productive on the average landscape. The average landscape has relatively abundant wetlands which attract many breeding pairs, but in the absence of management it provides insufficient nesting habitat. When management activities that increase nesting habitat are implemented, many breeding pairs benefit. Marginal productivities of management activities that increase nesting habitat on the average landscape are further enhanced by the lack of competing nesting habitat on the starting landscape. Relatively low productivity on the bad landscape is the result of too few breeding pairs available to take advantage of management activities. Intermediate levels of productivity for management activities on the good landscape results from competition among abundant amounts of alternative habitat. Prior to management, the good landscape has abundant wetlands and nesting habitat, which compete with management activities thereby reducing the marginal productivity relative to the average landscape which has fewer nesting habitat to compete with management activities. With the response surface estimated for each landscape we can integrate the response functions into the optimization model, which is discussed next.

Management Decision Model

Managers are assumed to choose from the set of available management activities and landscapes the cost minimizing combination(s) of management activities for achieving a pre-specified population objective. Let

w_{il} denote the per unit cost of management activity i on landscape l;

x_{lj} denote the level of management i on landscape l;

$f_l(x_{1l}\ldots x_{Il})$ denote the response function for landscape l as given by (1);

Y^* denote the production objective, measured as the change in recruits (i.e. $Y - \alpha$ in (1));

k_l denote technical constraint levels on landscape l;

a_{il} denote technical constraint parameters.

The basic management decision model can be written as:

(2) $$\min_{\{x\}} \sum_{i=1}^{I} \sum_{l=1}^{L} w_{il} x_{il} \ ,$$

subject to

$$(3) \qquad Y^* \le \sum_{l=1}^{L} f_l\left(x_{1l}, \ldots, x_{Il}\right).$$

$$(4) \qquad k_l \ge \sum_{i=1}^{I} \sum_{l=1}^{L} a_{il} x_{il} \ .$$

Equation (4) represents a set of biological and land use constraints the manager faces. An example of these constraints is that the total acres of cropland retired at location *l* via the CR management activity cannot exceed the total number of cropland acres available at landscape *l*.

Cost estimates for each of the management activities considered are required to solve the manager's problem. Cost estimates are obtained from the management literature and correspondence with waterfowl management agencies in the PPR. Table 4 provides the per unit cost estimate for each management activity on each landscape. Costs include land use, management, and construction costs, where applicable. Land use costs are based on farmland rental rates for North Dakota cropland, pasture and hayland in 2004 (Knopf 2004). To account for location specific cost differences, we assume that differences in initial cropland acreage between the three landscapes reflect differences in cropland quality. Therefore we assume that the rental rate of cropland on the average landscape is equal to the average observed rental rate. We assume that the rental rate of cropland on the good and bad landscapes is equal to the maximum and minimum observed rental rates, respectively. Finally, for management activities that have a useful life of more than one year, relevant costs are annualized using a four-percent discount rate.

We use the Matlab 6.5 software package to solve the non-linear programming problem representing the manager's decision model. The manager's problem is solved iteratively for production objectives ranging from zero to Y^{max}, where Y^{max} is the maximum number of recruits that can be produced subject to (4). This producest the total cost function for producing waterfowl recruits. Average and marginal cost functions are then derived from the total cost function using point estimates. Again four models are solved, one for each landscape and a pooled model that optimizes over all landscapes simultaneously, hereafter denoted the full model.

Results and Discussion

The results and discussion are presented in two parts. First, general results and insights gained from solving the manager's problem across a heterogeneous landscape are presented. We then expand the model to the regional level to identify minimum cost management strategies for meeting NAWMP goals for mallards in the U.S. portion of the PPR.

General Results

Previous studies of the efficiency of waterfowl management activities assume linear biological response and cost functions (Lokemoen 1984;United States Fish and Wildlife Service 1996). This results in constant and hence equivalent marginal and average costs for individual management activities. If cost or response are, in fact, non-linear, policy suggestions derived from linear functions could be largely misguided.

To demonstrate the potential error generated by assuming linearity, we derive cost functions for the full model assuming a linear response function (i.e. setting the coefficients on all second-order and interaction terms to zero) and compare it to the cost function generated assuming a quadratic response function. Figure 1 compares total and marginal cost for the full model assuming a linear versus quadratic response function. Incorrectly assuming a linear response function leads to an overestimation of production per unit of effort, and hence an underestimation of the total and marginal cost of achieving management objectives. For example, if the production objective was to produce 400 additional recruits across the three landscapes, the linear model underestimates the marginal cost of the last recruit by $17 and underestimates the total cost by over $2,350. When costs are underestimated, management effort is over-expended on a given landscape taking resources away from more efficient application. This result illustrates the potential consequence of over-simplifying the biological response function. If there is evidence that response functions are non-linear, supply-side analysis should reflect this knowledge.

Accounting for cost and response differences across landscape types provides important insights regarding the efficient spatial targeting of management efforts. Figure 2 compares the marginal cost curves across landscapes for a production objective ranging from 0 to 75 recruits. Over this range of production, marginal costs range from $7 for the first recruit to almost $70 for the 75th recruit, indicating significant differences in the marginal cost across the three landscapes. Failing to recognize differences in marginal cost across landscape types can result in the prescription of management activities that are efficient for one landscape type yet inefficient for another. Additionally, when multiple landscape types are available, differences in marginal costs can be exploited to improve management efficiency. Efficient management strategies in this case will not simply be the most cost effective combination of management activities, they will be the most cost effective combination of activities and landscapes.

The solution to the full model derives such a multi-landscape marginal cost curve (see figure 2). The marginal cost of the 75th recruit in the full model is $16, roughly $3 less than marginal cost of the 75th recruit on the average landscape (the least expensive of the three single landscapes). The total cost of producing 75 recruits in the full model is $300 less than the least expensive single landscape. Efficiency gains can be achieved by optimizing over multiple landscapes simultaneously because each additional landscape relaxes resource constraints and creates additional low marginal cost activities for the manager to exploit. This result is comparable to the familiar example of efficiency gains that can be achieved with tradable pollution permits when marginal abatement costs differ across firms. Similarly, when wildlife response or cost functions differ across landscapes managers can more efficiently reach population objectives by reallocating management activities to landscapes with the lowest marginal cost.

Meeting NAWMP Goals on the U.S. Prairies

The results and discussion thus far have taken place on up to three 2,000 acre landscapes managed simultaneously. We now expand the model to consider the production objectives of the NAWMP in the U.S. portion of the PPR. This region encompasses 58 million acres (235,000 km^2), including areas of Iowa, Minnesota, North Dakota, South Dakota, and Montana. NAWMP activities for this region are administered by the Prairie Pothole Joint Venture (PPJV). In 1995 the PPJV established an overall waterfowl population objective of 6.8 million ducks, including a mallard population objective of 1.2 million ducks (U. S. Prairie Pothole Joint Venture 1995). To estimate the minimum cost of achieving the PPJV's mallard objective we assume that 2400 units of each landscape type (each unit is one 2,000 acre landscape) is available for management. This corresponds to 14.8 million acres, less than 25% of the U.S. portion of the PPR. With 2400 units we can safely assume that the landscapes are sufficiently spatially separated, such that interdependence of management activities between landscapes can be disregarded (i.e. there are no source-sink dynamics occurring between landscapes).

According to the waterfowl response function estimated for each landscape type, 2400 units of each landscape type can produce 211,000 mallard recruits with no management activities applied. This leaves 988,800 additional recruits needed to meet the PPJV's mallard population objective. The minimum cost management strategy to meet this objective is determined by solving the manager's problem across the 7200 available landscapes. The total cost of meeting the mallard objective is $19 million, or cost of $19 per recruit. The optimal management strategy includes only two activities, nest structures and predator control (see table 5). These management activities are relatively cost effective because they place no restrictions on agricultural land use. Landowners are only required to provide access their property by professional predator trappers and to allow nest structures to be erected within the boundaries of existing wetlands. The total number of acres that must be removed from agricultural production is therefore minimal.

Predator control may not be a viable management activity due to political objections to lethal trapping and an insufficient supply of professional trappers.   The manager's problem is therefore re-solved assuming that predator control is not allowed. Results for this model are provided in table 6. Without predator control, the cost of achieving the mallard objective increases from $19 to $214 million, with cost per recruit increasing from $19 to $216. The large increase in total cost occurs because the management activities substituted for predator control require land to be removed from agricultural production, which has a high opportunity cost. Wetland restoration, planted cover and planted cover fenced are applied in the absence of predator control. Altogether, 2.9 million acres are removed from agricultural production when predator control is not allowed. Although this is a significant reduction, 34% is located on the good landscape, which represents land of marginal agricultural value. If additional landscapes were made available, significantly less agricultural land would be lost because intensive management activities would be applied at a larger scale.

The tradeoff between the number of available landscapes and the number of acres removed from agriculture can be demonstrated by solving the manager's problem of producing 988,800 recruits without predator control, for a range of numbers of available landscapes. Figure 3 depicts how the cost per recruit and number of acres removed from agriculture change as the total number of management landscapes increases from 6,300 to 21,000. Given 6,300 landscapes (12.6 million acres), the PPJV's mallard objective can be achieved only with the removal of three million acres from agricultural production, at a cost of $311 per recruit. Given 21,000 landscapes (42 million acres), the PPJV's objective is achieved without removing any acreage from agricultural production, at a cost of $16 per recruit. The number of acres removed from agricultural production and the cost of achieving the population objective decrease sharply as the number of landscapes is increased. This is because intensive management activities, such as nest structures, substitute for land extensive activities, such as planted cover.

Results from the NAWMP application suggest important insights for achieving mallard population objectives in the PPR. Intensive management activities, which are generally compatible with agricultural production, are more cost effective than extensive management activities, which generally compete with agriculture for land resources. A related finding is that increasing the number of landscapes available for applying intensive management activities actually reduces the need to remove land from agricultural production. This suggests that common ground can be found between rural communities concerned with farmland loss and those concerned with waterfowl conservation. This result should be particularly encouraging to the waterfowl community given growing restrictions on the conversion of farmland to conservation, particularly in the Canadian portion of the PPR (e.g. The Saskatchewan Farm Security Act(2004)).

Predator control, though controversial and potentially difficult to apply on a large scale, is a cost effective way to increase mallard recruits. The cost of completely omitting predator control from our analysis is nearly $200 million; allowing for even limited levels of predator control in our analysis significantly reduces total cost. This tradeoff should be considered in the ongoing debate over the appropriateness of predator control as a waterfowl management tool.

Results from the general modeling exercise highlight two important aspects of supply-side analysis for wildlife management. First, cost function estimates can be improved by incorporating diminishing marginal returns and the interdependence of management activities into supply-side analyses for wildlife. Second, biological response and costs vary with landscape characteristics. Therefore, spatial heterogeneity should be accounted for in the estimation of cost functions to ensure that efficient management strategies are prescribed. An additional benefit of developing landscape-dependent cost functions is the opportunity to increase management efficiency by equating the marginal costs of activity-landscape pairs.

Conclusion

Few economic studies have considered supply-side analyses for wildlife management, due, in part, to a lack of biological response data that capture the full range of management strategies and the influence of landscape characteristics. Simulation models provide a means for estimating complete response surfaces in the absence of adequate biological data, which can then be embedded within an economic model to derive least-cost wildlife management strategies. This study conducts a supply-side analysis for waterfowl management, deriving insights into the design of efficient management strategies, with important implications for waterfowl conservation and land use in the Prairie Pothole Region.

Simulation models provide an opportunity to conduct thorough supply-side analyses in the absence of complete biological response data; however, they are not without limitations. The simulation model used in this study, for instance, applies only to one waterfowl specie. Many of the management strategies considered, however, are likely to provide production benefits to multiple waterfowl species, particularly extensive management activities. If the benefits accruing to other species were considered, the relative efficiency of some activities in our analysis of mallards would increase and the results highlighted in this paper would be dampened. Future modeling efforts should incorporate multi-species response functions. Additionally, our model does not account for potential source-sink population dynamics that are likely present at a large spatial scale. To address regional efficiency questions more accurately, potential landscape interdependencies should be explored. Ideally, increased communication between biologists and economists will lead to the development of more complete biological data sets that address these limitations. Economists, in turn, should regularly solicit from biologists' the unresolved management issues that are most relevant to wildlife policy.

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Table 1. Initial Habitat Configuration of Simulated Landscapes

	Bad Landscape		Average Landscape		Good Landscape	
	Acres	***%***	***Acres***	***%***	***Acres***	***%***
Fall-plowed Grain	862	43.1	784	39.2	0	0
Stubble Grain	366	18.3	400	20	0	0
Summer Fallow	184	9.2	201	10.1	0	0
Grassland	317	15.9	191	9.5	357	17.9
Hayland	122	6.1	134	6.7	371	18.5
CRP	0	0	0	0	706	35.3
Seasonal Wetland	74	3.7	147	7.4	230	11.5
Semi-Permanent Wetland	36	1.8	99	4.9	200	10
Temporary Wetland	3	0.15	10	0.5	100	5
Permanent Wetland	1	0.05	3	0.1	5	0.25
Other	35	1.7	31	1.6	31	1.55

Table 2. Summary Statistics for Variables used in the Approximation

	Mean			Std. Deviation		
Variable	Bad	Average	Good	Bad	Average	Good
Recruits(y)	36.2	75.2	140.6	19.6	41	67.7
CR	212.5	213.3	74.1	365.9	354.3	146.5
DH	19	20.1	27.4	38	40.1	63.2
NT	127.1	130.2	--	281.2	269.3	--
NB	3.5	4.3	9.6	8.5	10.2	17.7
PC	56.9	57.1	54	133.4	133.6	118.8
PCF	41.7	37.9	44.4	103.67	88.1	104
PRED	536.9	545.2	500	669.9	659.8	665.2
WR	26.1	27.8	25.8	41.7	41.2	41.7
NB^2	83.8	121.4	404	257.6	348.2	915.8
PC^2	20,989.8	21,055.1	16,982.8	88,421.1	86,775.8	54,371.3
PCF^2	12,458.8	9,179.5	12,758	61,065.6	29,396.2	44,103.6
PRED*CR	162,602.3	167,425.5	55,891.7	349,529.7	341,672.4	142,701
PRED*DH	15,502.8	16,526.6	20,796.2	38,318.9	40,557.6	59,896.1
PRED*NT	85,045.5	94,819.1	--	266,841.8	264,760.5	--
PRED*PC	30,738.6	32,579.8	33,357.8	92,748.6	96,349.3	100,459.4
CR*PC	10,460.2	12,047.9	3,474.5	38,735.9	47,348.6	13,814.4
CR*PCF	7,278.4	8,026.6	2,514.3	26,776.1	29,719.6	10,847
n	352	376	314			

Note: all variables are measured in acres, except for recruits and NB which are simple unit measures.

Table 3. Parameter Estimates for the Waterfowl Response Function

	Landscape		
Variable	Bad	Average	Good
Constant	7.98***	17.82***	62.32***
	(0.843)	(1.56)	(1.78)
CR	0.008***	0.017***	0.022***
	(0.001)	(0.003)	(0.006)
DH	0.065***	0.127***	0.064***
	(0.015)	(0.025)	(0.016)
NT	0.004***	0.01***	--
	(0.002)	(0.003)	
NB	1.92***	3.69***	1.31***
	(0.132)	(0.227)	(0.155)
PC	0.043***	0.082***	0.05***
	(0.007)	(0.013)	(0.018)
PCF	0.158***	0.446***	0.278***
	(0.006)	(0.024)	(0.017)
PRED	0.029***	0.064***	0.11***
	(0.0007)	(0.001)	(0.001)
WR	0.114***	0.138***	0.17***
	(0.009)	(0.016)	(0.017)
NB^2	-0.023***	-0.046***	-0.006**
	(0.004)	(0.006)	(0.003)

PC^2	-0.00003***	-0.00006***	-0.00003
	(0.00001)	(0.00002)	(0.00003)
PCF^2	-0.0001***	-0.0007***	-0.0002***
	(0.00001)	(0.00007)	(0.00004)
PRED*CR	-0.000008***	-0.00002***	0.00003***
	(0.000001)	(0.000003)	(0.000006)
PRED*DH	-0.00009***	-0.0002***	-0.00008***
	(0.00001)	(0.00003)	(0.00002)
PRED*NT	-0.00001***	-0.00003***	--
	(0.000002)	(0.000003)	
PRED*PC	-0.00002***	-0.00006***	-0.00004***
	(0.000005)	(0.00001)	(0.00001)
CR*PC	-0.000009	-0.000005	-0.000001
	(0.00001)	(0.00002)	(0.00006)
CR*PCF	-0.00007***	-0.0002***	-0.00003
	(0.00001)	(0.00003)	(0.00007)
F[n,k]	223.49	304.77	840.63
R^2	0.919	0.935	0.977
Adj. R^2	0.915	0.932	0.976

Note: **, *** indicate significance at the 5% and 1% levels, respectively. Standard errors are in parentheses.

Table 4. Per Unit Management Costs by Landscape

	Landscape		
Management Activity	Bad	Average	Good
Cropland Retirement	$70.00	$33.00	$25.00
No-till	$15.00	$15.00	$15.00
Delayed Hay	$25.00	$25.00	$25.00
Nesting Structures	$22.90	$22.90	$22.90
Planted Cover	$17.50	$17.50	$17.50
Planted Cover Fenced	$110.20	$110.20	$110.20
Wetland Restoration	$75.00	$38.00	$30.00
Predator Control	$2.00	$2.00	$2.00

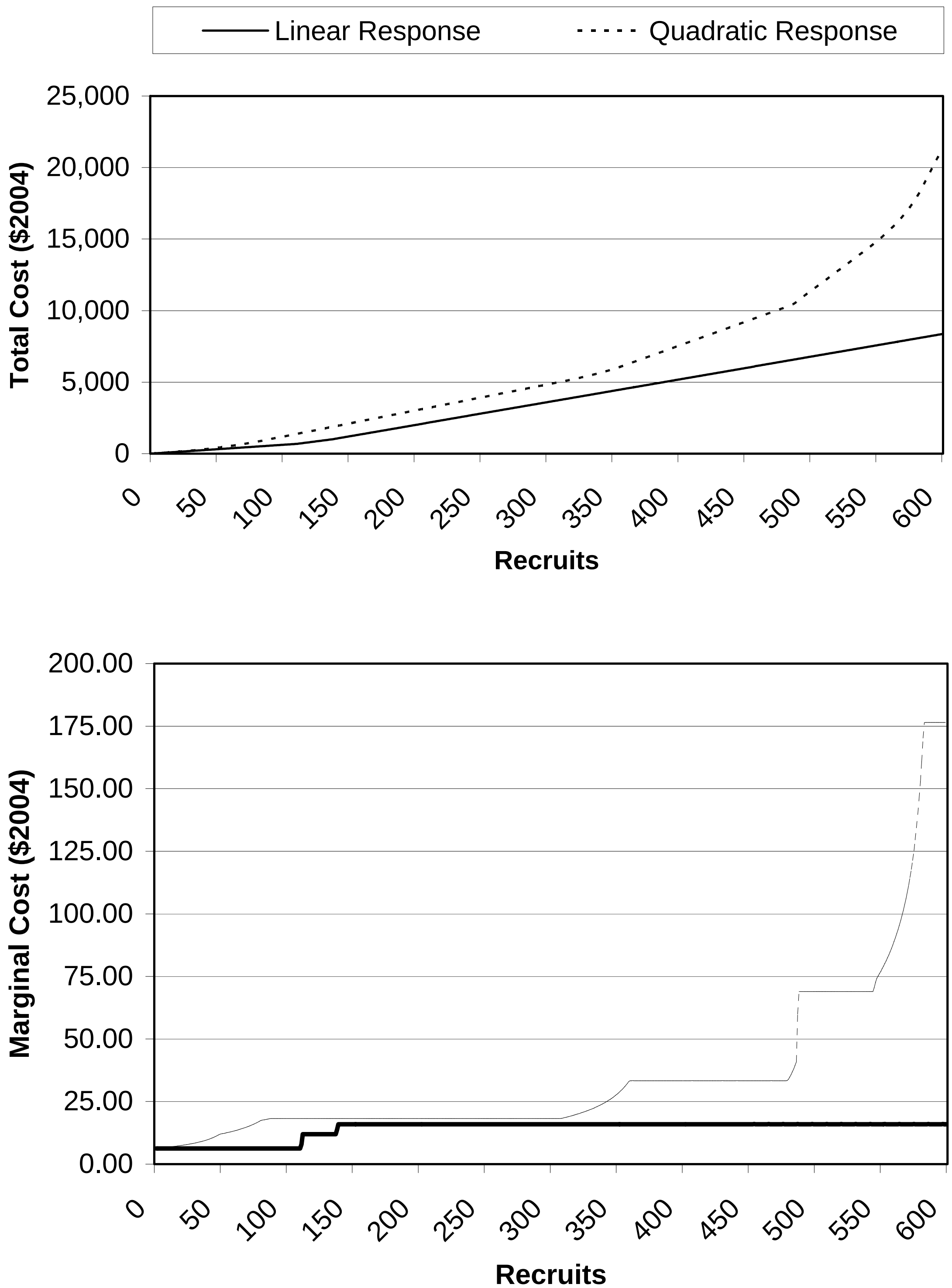

Figure 1. Total cost and marginal cost functions for linear and quadratic response functions

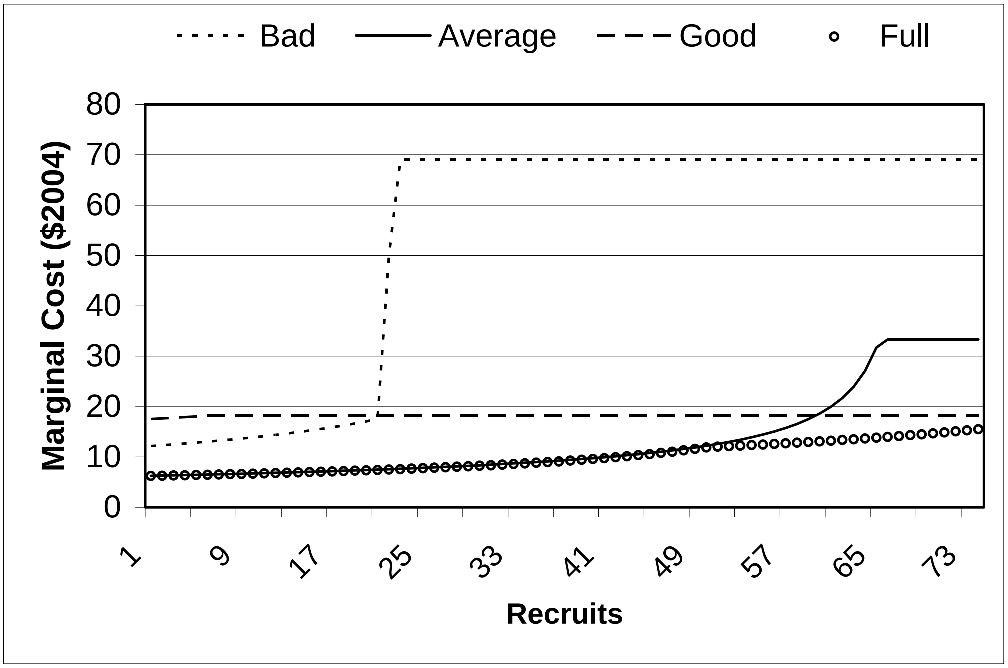

Figure 2. Comparison of marginal cost curves across the bad, average and good landscapes

Table 5. Minimum Cost Activity Levels for Meeting PPJV Population Objectives

	Bad	Average	Good
Management Activity	Per Landscape / Total	Per Landscape / Total	Per Landscape / Total
Nest Structures (units)	14 / 33,600	30 / 72,000	52 / 124,800
Predator Control (acres)	-	868 / 2,083,200	2000 / 4,800,000
Total Cost	$19,039,000.00		
Average Cost	$19.25		

Table 6. Minimum Cost Activity Levels for Meeting PPJV Population Objectives without Predator Control

	Bad	Average	Good
Management Activity	Per Landscape / Total	Per Landscape / Total	Per Landscape / Total
Delayed Hay (acres)	122 / 292,800	134 / 321,600	305 / 732,000
Nest Structures (units)	41 / 98,400	37 / 88,800	106 / 254,400
Planted Cover (acres)	-	26 / 62,400	-
Planted Cover Fenced (acres)	289 / 693,600	165 / 396,000	222 / 532,800
Wetland Restoration (acres)	159 / 381,600	130 / 312,000	200 / 480,000
Total Cost	$21,436,000.00		
Average Cost	$21.67		

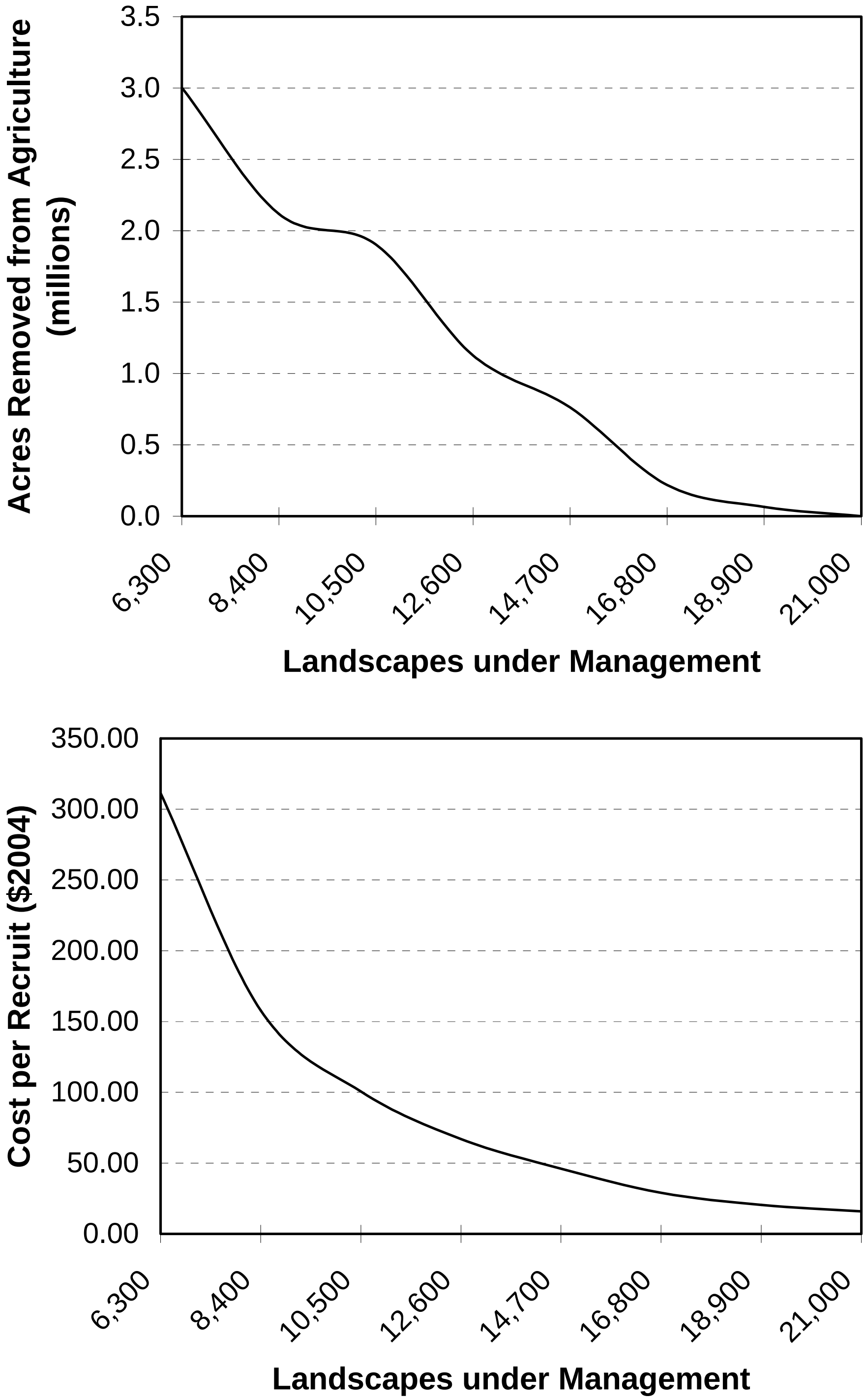

Figure 3. Total cost and acres removed from agriculture as a function of the number of managed landscapes for efficient management plans meeting the PPJV mallard population objective