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A bioeconomic supply model for Louisiana nutria and impacts on wetlands conservation associated with economic incentives

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**A BIOECONOMIC SUPPLY MODEL FOR LOUISIANA NUTRIA AND IMPACTS
ON WETLANDS CONSERVATION ASSOCIATED WITH ECONOMIC
INCENTIVES**

A Thesis
Submitted to the Graduate Faculty of the
Louisiana State University and
Agriculture and Mechanical College
in partial fulfillment of the
requirements for the degree of
Master of Science

in

The Department of Environmental Studies

by
Cheikhna Ould Dedah
B.S., Nouakchott University, 2000

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DEDICATION

I dedicate this humble work to the soul of my Father “Dedah Abderrahmane.”

May God bless him with his mercy.

ACKNOWLEDGMENTS

I wish to express my deepest gratitude and appreciation to my major adviser Dr. Walter Keithly, Jr. for his guidance, availability and encouragement throughout the conduct of this research. I am indebted to him for his kindness and generosity during my stay in the U.S. Also, I wish to express my sincere appreciation to Dr. Rich Kazmierczak for his wise advice and valuable input in the outcome of this thesis. I would like to thank my other committee members, Drs. Ralph Portier, Hamady Diop, and Jing Wang for their invaluable efforts, suggestions and feedback. Additional thanks go to Louisiana Sea Grant for its financial support.

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ABSTRACT

Nutria (*Mayocastor*) were first introduced to Louisiana in 1938. With few natural predators and high prolific productivity, they became well established in the surrounding coastal marsh within a few years. Prior to 1980's, as a result of high demand for nutria products from European countries, harvest pressure was sufficient to keep the population in 'check' with their wetlands capacity. By the mid-1980's, however, prices had fallen sharply, culminating in declining annual harvests and an increasing population. Because of their feeding habits, the increased nutria population has resulted in a substantial amount of wetland degradation. In this thesis, a long-run bioeconomic supply model for nutria is developed and the expected harvest associated with different bounties is incorporated into a wetland-loss model to investigate the extent to which alternative bounties lessen wetland degradation. With respect to the bioeconomic supply model, harvest per hectare is specified as a function of the harvested price per pelt, opportunity costs of the trapper, and the variables that impact the carrying capacity (a weather severity index and the alligator population density). Results suggest that MSY is achieved at a real price (based on 2000 Implicit Price Deflator) of approximately \$17 and that MSY is equal to 1.5 million pelts when all explanatory variables, other than price, are held at their respective means. The signs of the coefficients of the explanatory variables are consistent with *a priori* expectations. As the alligator population density increases, long-run nutria harvest is expected to decline. Similarly, lower opportunity costs associated with the trappers' time (measured via an increase in the unemployment rate) was found to result in an increase in long-run harvest.

Based on incorporation of the predicted harvests associated with various bounties into the simulation model (i.e., a wetland-loss model), results suggest that wetland degradation is

lessened in response to an increasing bounty. However, the results are highly sensitive to changes in the level of some parameters in the wetland-loss model such as the biomass destroyed-to-consumed ratio, the critical density, and time-to-maturity. Finally, a benefit cost analysis implies that the benefits associated with the various bounties outweigh the costs.

CHAPTER 1: INTRODUCTION

1.1 Background

Nutria (*Myocastor coypus*), a large semi-aquatic rodent native to South America was first introduced to Louisiana in 1938 (Lowery, 1974; Nowak *et al.*, 1991). Shortly thereafter, a small number of nutria were intentionally released into the wild (Coastal Louisiana) while others escaped their holding facilities during the succeeding years. With few natural predators, the population of nutria rapidly expanded. The increasing population, in conjunction with a market for nutria pelts, culminated in the establishment of a viable commercial trapping industry by the mid-to-late 1940's (Lowery, 1974).

Historically, harvest pressure is thought to have kept the Louisiana nutria population at a level commensurate with the underlying carrying capacity, primarily wetland vegetation which constitutes the majority of the nutria diet. From the 1960's through the late 1970's, nutria harvests ranged from about one million to two million pelts annually with Europe, especially Germany, constituting the primary market for the product (Figure 1-1) (Marx *et al.*, 2003).

Beginning in the early 1980's, the demand for nutria pelts, and the associated price, began to decline (Figure 1-1). This decline is generally attributed to a number of factors including, but not limited to, success associated with a strong anti-fur campaign, the increasing acceptance of synthetic fur products, and several "mild" winters throughout Europe (Louisiana Department of Wildlife and Fisheries, 2003). From a base harvest averaging 1.5 million animals per year during the 1970's, Louisiana's reported harvest fell to an average of about 790 thousand animals annually during the 1980's and declined again to an average of

190 thousand per year during the 1990's. By the turn of the decade, nutria harvests had fallen to less than 30 thousand annually (Figure1-1).

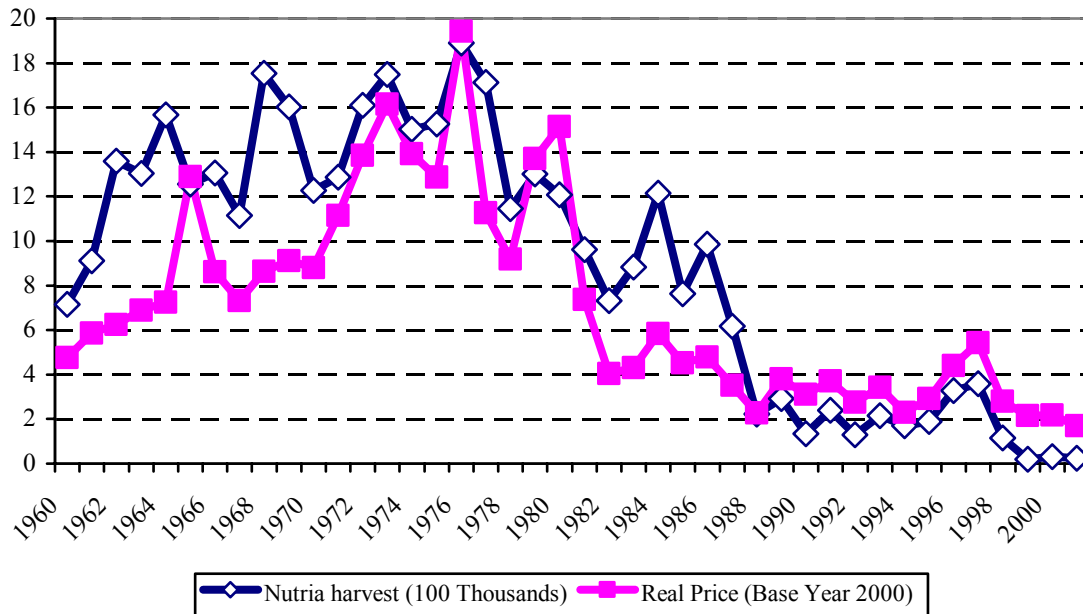


Figure 1-1. Louisiana Nutria Harvest and Price: 1960 - 2001

With diminishing harvest pressure, the nutria population expanded rapidly. Given the non-indigenous nature of the species, it is now believed to have expanded beyond a level commensurate with the surrounding environment (U.S. Geological Survey, 2000). Nutria feed primary on the roots and rhizomes of the marsh plants that can result in death of the plants. This feeding behavior very often results in a process known as ‘eat out’ which leaves the marsh fragmented and vulnerable to natural erosion in subsequent periods (Carter *et al.*, 1999, Linscombe *et al.*, 1981; Harris and Webert, 1962). Given that wetland vegetation is the primary diet of this non-indigenous species, there are signs that the population is now contributing to wetland degradation throughout the coast. In a 2003 aerial survey, for

example, more than 80 thousand acres of Louisiana coastal marshes were found to be affected by nutria feeding activities; primarily in the form of herbivore damage. This value is considered to be conservative because only the worst areas can be detected from aerial survey techniques (Marx *et al.*, 2003).

Wetlands provide a number of economic services to the citizens of Louisiana and the United States. These include, but are not limited to, hurricane protection, a nursery area for important commercial and recreational fish species, and the ability of wetlands to assimilate wastes. As wetlands are lost or degraded by a nutria population in excess of that level that can adequately be supported by the surrounding environment, the economic services derived from these wetlands will diminish and the society's welfare, measured by the economic value of these wetlands, will diminish.

Recognizing this fact, the Coastwide Nutria Control Program, funded by the Coastal Wetlands Planning and Protection Act¹, was initiated in January 2002. One of the major provisions of this program is an economic incentive payment to encourage increased nutria harvest (i.e., a "bounty"). By offering four dollars per delivered tail among registered participants, the goal of the program is to "encourage the harvest of up to 400 thousand nutria annually from coastal Louisiana (Louisiana Department of Wildlife and Fisheries, 2003)

1.2 Goals and Objectives

The primary goal of this research project is to develop a bio-economic supply model for Louisiana nutria and assess the impacts of various population levels on the surrounding environment (i.e., coastal wetlands). To accomplish this goal, the following objectives are specified:

¹ Funding for this program comes from the Louisiana Department of Natural Resources and the Natural Resources Conservation Service.

(1) Develop a bioeconomic model of the Louisiana nutria industry: The development and estimation of this model given will allow the investigation of changes in long-run nutria harvest associated with a change in any exogenous (independent) variable. Using this model as the basis for analysis provides the information needed to estimate the “expected” change in long-run harvest associated with introducing an extra-market incentive (i.e., bounty) given specified values for the exogenous variables.

(2) Integrate the “expected” change in long-run harvest associated with different bounty levels with changes in wetlands loss: Nutria herbivory activities are destructive to wetlands habitats due to their engagement in a process called “eat out”. This activity is exacerbated during the winter months when the natural mortality of plants is higher and growth among remaining plants is retarded. Feeding patterns during the winter months are, hence, particularly destructive and can significantly reduce the marsh’s aboveground biomass. If the nutria population is abundant as a result of low harvest pressure, then their herbivory activities can cause the marsh ecosystem to break up. The model developed by Carter *et al.* (1999) is used to investigate the marsh loss associated with different expected nutria harvest levels related to alternative bounties.

(3) Assess the benefits and costs associated with alternative harvest incentive programs: Wetlands provide a multitude of economic functions including hurricane and flood protection, their ability to assimilate wastes, and their provision of nursery grounds for fish and shellfish. Wetland loss due to nutria levels in excess of that which can be maintained by the surrounding environment will reduce the economic functions provided by wetlands. The diminution in these economic functions translates to a reduction in societal welfare, *ceteris paribus*. Based on available information pertaining to the economic value associated with

Louisiana's wetlands, one is able to establish a lower bound approximation of the loss in benefits to society (i.e., value) associated with alternative nutria population levels in excess of what can be supported by the surrounding environment. These estimations are, by their very nature, crude given the "state of the art" associated with accurately estimating values of non-market goods (see, for example, Pearce and Turner (1990) for details associated with non-market estimation techniques). Only through the comparison of the marginal benefit (reduced wetland damages) and the marginal cost of nutria control program (e.g., subsidies to nutria fur industry), can the question of whether complete or partial eradication of nutria population be answered.

1.3 Thesis Format

To accomplish the aforementioned objectives, the thesis proceeds as follows. A short introduction to the biology of nutria, and historical wetland losses in Louisiana associated with nutria, is presented in the next chapter (Chapter 2). Following this, a theoretical bioeconomic model for Louisiana nutria is developed and presented. In Chapter 4, the results associated with the estimated bioeconomic model are presented and discussed. In addition, wetland losses associated with different bounty programs are presented as well as the benefits and costs associated with each of these programs. The final chapter presents a summary of some of the key findings and presents management and policy implications associated with these findings.

CHAPTER 2: NUTRIA BIOLOGY AND WETLANDS

The first section in this chapter provides a brief discussion regarding nutria distribution and its introduction into Louisiana. Then, some basic biological characteristics of nutria are provided along with a discussion related to those factors which limit nutria distribution, such as human-induced mortality and weather severity are discussed. The last section discusses nutria impacts on Louisiana coastal wetlands.

2.1 History of Nutria and Its Distribution

Nutria is a large semi-aquatic rodent indigenous to South America. Their original range includes Brazil, Bolivia, Paraguay, Uruguay, Argentina and Chile (Nowak *et al.*, 1991). The establishment of a nutria population in Louisiana dates back to 1938 when E.A. McIlhenny imported fourteen nutria from Argentina and placed them in a 35-acre pen at Avery Island, Iberia Parish. Because of the rapid growth rate of the nutria within this confined environment, the population level quickly exceeded the ability of the artificial environment (i.e., pen) to hold them in an adequate manner. As a result, a number of animals escaped during the succeeding years, especially during the hurricane of 1940 (Lowery, 1974). The escaped nutria grew at an exponential rate and became established in the surrounding marsh areas within a few years (Evan, 1970; Lowery, 1974). Adding to this escaped population, sportsmen and trappers transported nutria from Texas to Louisiana in 1941 and released them into the adjacent marshes (Lowery, 1974). By 1943, the species was widespread throughout much of coastal Louisiana (Lowery, 1974).

In the late 1940's, nutria were promoted as biological controllers of weed vegetation, primarily water hyacinth and alligator weed, that was clogging bayous and lakes. Also, with the expectation of high pelt prices, many landowners ordered breeding stocks and released

them into their marshes. In 1957, Hurricane Audrey was responsible for pushing thousands of nutria out of the marshes into the adjacent sugar cane and rice fields. Shortly thereafter, sugarcane and rice farmers began to complain about nutria herbivory damage. As a result, nutria was taken off the list of protected wildlife species in 1958² (Lowery, 1974; Louisiana Department of Wildlife and Fisheries, 2003).

When taken off this list, the state began promoting nutria fur as a natural resource and nutria harvests increased rapidly. By 1962, nutria was the leading revenue generator to the Louisiana fur industry. Given concerns that harvest rates were “excessive,” nutria was returned to the protected wildlife list in 1965. From 1962 to 1982, harvest pressure (roughly 1.3 million nutria harvested annually) lowered the nutria population and complaints were relatively few during this period.

Demand for nutria fur began to decline during the early-to-mid 1980’s which, given the worldwide supply of fur, resulted in declining prices being received by the Louisiana trappers. While the reasons for this decline have not been clearly established, a number of hypotheses have been advanced over the years. First and foremost, an anti-fur movement, which had its “grass roots” beginning as early as the 1970’s became an ever-increasing force and was well entrenched by the early-to-mid 1980’s (Myers, 2001; Emberley, 1997). This movement, in essence, changed preferences away from natural fur. Second, and in conjunction with the first hypothesis, substitute products, primarily synthetic furs, were becoming increasingly available and priced at a level that could easily compete with natural product. Third a combination of fur market overproduction, economic recession and a series of “mild” winters weakened demand during the 1980’s (Anonym, 1993; Aulerich, 1998).

² Nutria were originally placed on the protective species list due to concerns that they would be “overharvested” given the originally limited population.

Finally, the fur market demand is subject to fashion fluctuation. During the 1970's, high demand was for long hair fur product and tastes are believed to have changed during the 1980's from a desire for long-haired fur products to short-hair products (Erickson and Sampson, 1978).

The decline in demand (and related price) for Louisiana nutria translated into a commensurable decline in trapping activities. In general, total nutria mortality can be decomposed into a natural mortality component and a trapping component. As mortality associated with trapping declined, nutria population rapidly increased; particularly in light of the few predators associated with this non-native species. As the population increased, damages to Louisiana coastal marshes, as well as to the sugar cane and rice fields, expanded at a rate commensurate with the expansion in the nutria biomass (Louisiana Department of Wildlife and Fisheries, 2003).

2.2 Biological Characteristics

Nutria look like beaver or muskrat but with long, rounded tail, and webbed hind feet (Evan, 1983). The pelage consists of a dense, stale-colored underfur covered with long-dark brown or yellowish brown hairs. The density of the underfur is thicker during winter. The belly is the most valuable portion of the pelt because it contains a lighter gray underfur part.

Nutria are mainly herbivory opportunistic feeders, consuming different types of plants that are available in their surrounding habitats (Evan, 1983; Willner *et al.*, 1979). Nutria like any other rodents are prolific, reach sexual maturity at early ages (4-6 months depending on environmental conditions), and breed continuously during the year (Atwood, 1950; Newson, 1966; Willner *et al.*, 1979). Females usually come in estrus every 24 to 26 days and stay in heat for one to four days. Estrus begins within a day or two after giving birth or after

miscarriage (Evan, 1970). In general, nutria gestation period is between 127 days and 138 days (Evan, 1970).

Nutria live in territorial groups typically composed of one alpha male and one alpha female, several adult and sub-adult females, and a variable number of juveniles. The dominance of the alpha male and female is expressed through their chasing of the other subordinate animals. Males tend to monopolize a large number of females. As males tend to have a larger range, their probability of encountering traps or predators is more likely than that for females (Gosling and Baker, 1989).

The habitat ranges of nutria in their native countries are marshes, swamps, lagoons, and along rivers and lakes margins (Atwood, 1950). In Louisiana, Atwood (1950) found that the range for nutria was primary confined to the coastal marshes. Nutria prefer marshes with fresh water plants even though they can be found in salt and intermediate marshes, as well as in forest (Genesis Laboratories, Inc. 2002.). Nutria usually stay close to the water where they get shelter in the hole burrowed underneath the water bank and in the nearby vegetation. When nutria are frightened, they swim very quickly and leave only the head and the back above the water surface. However, if the threat is greater, nutria will dive under the water slapping the water with its hind feet making a noise that will alert other nearby individuals (Warkentin, 1968).

2.3 Threats to Nutria

Human predation is one of the primary factors that can impact the Louisiana nutria populations. From the mid-1960 until 1981, nutria was the “backbone” of the Louisiana fur industry with harvests fluctuating from about one to two million animals annually. After the 1980-81 season, annual harvest declined dramatically as a result of the decline in price with

production in 2000 (approximately 20 thousand pelts) being but a small fraction of what it was in previous decades.

Cold weather is also considered to be one of the major factors limiting the abundance and distribution of nutria population in their temperate regions (Gosling *et al.*, 1983). Several studies reported mass mortality among nutria during extreme cold conditions. For example, a harsh winter in 1962-1963 was responsible for a significant increase in nutria mortality (approximately 80 to 90%) in England (Ellis, 1963; Gosling and Baker, 1989; Newson, 1966). In Maryland, the abnormally cold winter of 1976-1977 was credited with killing 90% of the local population level (Willner *et al.*, 1979).

Other abnormal weather conditions can also result in high mortality levels. In Louisiana, for example, the floodwaters associated with Hurricane Audrey were responsible for a significant increase in mortality³ (Harris and Chabreck, 1958). While impacts of other hurricanes on nutria mortality are less well documented, one would hypothesize that any major disturbance of the type associated with large hurricanes would result in a short-term increase in mortality.

While weather and man are the major threats for nutria throughout the world, nutria also face some threats from different predators. In Louisiana, for example, alligator (*alligator mississippiensis*) is a major predator, especially in areas where nutria densities are high. In Sabine National Wildlife Refuge, Louisiana, Valentine *et al.*(1972) reported that nutria remains constituted about 46% of the food content in those alligators found to have had nutria in stomach content (56% of the alligators sampled had nutria in the stomach content). In a

³ Harris and Chabreck (1958) report that Hurricane Audrey either killed or drove away 70% of the nutria in specific area under study (south central part of Marsh Island which lies in Vermillion Bay). The researchers were unable to separate mortality from animals leaving the area.

more recent study by Wolfe *et al.* (1987), based on 100 alligators killed during the 1984 alligator season (September) between the Mississippi state line and eastern New Orleans, Wolfe *et al.* (1987) found muskrats and nutria accounting for 83% of the alligators diet, based on weight. While muskrats had a higher frequency of occurrence, nutria accounted for a higher proportion of total stomach content, by weight. Specifically, nutria accounted for 60% of the total weight content among sampled alligators while muskrat accounted for about 24% of the total.⁴ Most of the remaining stomach content consisted of gar (11%) and catfish (5.7%).

While a number of studies indicate high levels of nutria consumption by alligators. Due to the high reproduction rate of nutria, some researchers question whether the natural mortality rate of nutria is “significantly” impacted by the alligator population (Wolfe *et al.*, 1987). Certainly, at low densities of either alligators or nutria, one would expect little impact. However, as populations of both alligators and nutria have expanded in recent decades, one might hypothesize an increasing impact.⁵

2.4 Nutria Impacts on Coastal Wetlands

Around 41% of the coastal wetlands in the United States are Louisiana-based (Bergstrom *et al.*, 1990). These wetlands provide society with a broad variety of values such as hurricane protection, waste assimilation, aquifer recharge, nursery ground for fish and shellfish, and unique recreational values. Currently, the loss rate of Louisiana’ wetlands is estimated to be between 25 to 28 square miles a year (NOAA. Fisheries, 2004). Among the

⁴ In terms of frequency of occurrence, Wolfe *et al.* (1987) report that 37% of the sampled alligators had nutria in the stomach content.

⁵ As discussed in a subsequent section, the impact of an increasing alligator population on nutria harvest is examined in greater detail.

causes for these losses are subsidence, erosion, canal dredging, industrial and commercial development, and sea level rise (Bergstrom *et al.*, 1990; Farber, 1996).

Already in a weakened state from the factors cited above, herbivory activities by nutria and other animals further contribute to wetland deterioration. For example, a survey of nutria herbivory damages indicated that more than 80 thousand acres of Louisiana coastal marshes were severely affected by nutria feeding activities in 2003 (Marx *et al.*, 2003).

Nutria herbivory damages are most profound in the low salinity marshes of the upper estuaries, as well as in the developing delta of the Atchafalaya River. Fuller *et al.* (1985), in a study of nutria herbivory activities in the Atchafalaya Delta, found significant effects of grazing by nutria on the establishment of vegetation on newly created mudflats. In a recently completed survey conducted for the Barataria-Terrebonne National Estuary Program, Linscombe and Kinler (1996) estimated that over 12.6 thousand acres (5,099 ha) of marsh were damaged along transect lines flown in May 1993. This estimate increased to over 15.4 thousand acres (6,232 ha) by December 1993 with areas shown to have been impacted in the May study showing little recovery. Extrapolation on a Basin-wide scale indicated that approximately 60 thousand acres (24,282 ha) were damaged in December 1993 in the Barataria-Terrebonne Basin. Damage was not limited by marsh type; swamps and bottomland hardwoods, as well as fresh, intermediate, and brackish marshes were identified as being damaged by nutria. In the spring 1996 flight, the damage had increased to over 20.6 thousand acres (8,337 ha) along transects corresponding to 80 thousand acres (32,376 ha) Basin-wide. Only 9% of the impacted sites showed some recovery.

In 1998, the first coast wide aerial survey of nutria herbivory was conducted. The survey results indicate that approximately 24,000 acres (9,717 ha) located in 170 sites along

the survey transects are impacted by nutria herbivory. In 1999, the impacted acreages increased to reach 27,000 (approximately 10,931 ha) located in 150 sites along the survey transects. The number of impacted acres along the survey transects as well as the number of damage sites decreased in 2002 to approximately 21,185 acres and 94 sites, respectively. Extrapolating this observed damage to coast wide basis, suggests that approximately 79,444 acres coast-wide were impacted by nutria by 2002 (Marx *et al.*, 2003). In 2003 the number of damaged sites decreased (84 sites) but the impacted acreages slightly increase to 21,888 acres (82,080 acres coast wide). Finally, the recent nutria herbivory survey in 2004 showed a decrease in the number of impacted sites and total acres. Compared to 2003, the impacted acres fell to 19,906 along the transect line (approximately 63,000 acres coast wide) and the number of damaged sites fell to 69 sites. Marx *et al.*, (2004) suggests that the 2004 reduction in damaged sites and impacted acreage reflect the effects associated with the 2003 implementation of the four-dollar bounty program.

2.5 Economic Values and Losses Associated with Wetland Deterioration

Though it is difficult to quantify the non-market values provided by Louisiana coastal wetlands, limited research suggests that the value may be “large”. Bergstrom *et al.* (1990), for instance, estimated the on site recreation-based value of Louisiana’s 3.25 million acres of coastal wetlands and found an aggregated gross economic value of approximately \$145 million. Dividing this value by the total area acreages yields an average gross estimate of the on site-based recreational value of \$44.69 per acre annually.

Using historical wind frequencies throughout coastal Louisiana, Farber (1985) estimated a storm wind damage function for the coastal region. Specifically, based on the hypothesis that loss of intervening wetlands would result in an expected increase in wind

damage to property, he found that the loss of a one mile strip of wetlands along the coast would result in a discounted increase in property damages over the next 100 years ranging from \$1.1 million to \$3.7 million (expressed in 1980 dollars), depending on the discount rate (based on 8% and 3%, respectively).⁶ This translates to an increased cost of property damage equal to between \$7 and \$23 per acre, again depending on the discount rate.

Farber and Costanza (1987) estimated the value of wetlands system in the Terrebonne parish, Louisiana, for commercial fishing and trapping, recreation, and storm protection. All the following estimates were based on 1983 dollar value, and using 8% discount rate. They estimated the marginal value of wetlands to be \$468.25 per acre per year for commercial and trapping activities. For recreation-based activities, the marginal value per acre per year is \$111 using 2.6 % population growth rate. For storm protection, the marginal value per acre per year is \$ 7.48, assuming a 1.7% population growth rate for the effected parishes.

Finally, Farber (1996) estimated the loss in the economic welfare to society if 80% of Louisiana's coastal wetlands disappeared by the year 2083 at a constant rate ranging between 25,500 acres and 27,500 acres a year. He estimated the lost benefits based on wetlands contribution to commercial fisheries, recreational fishing activities, residential and commercial properties losses, wastewater treatment, and aquifer recharge. Using 1990 as a base year and a discount rate equal to three percent, the value per acre ranged from \$9.1 thousand to \$10.3 thousand based on a constant rate of loss equal to 25,500 acres per year and \$8.4 thousand to \$9.6 thousand based on an assumed loss rate of 27,500 acres per year.

⁶ These figures were based on a constant population growth rate of 1.72% annually in the coastal parishes during the 100-year period of analysis.

CHAPTER 3: MATERIALS AND METHODS

This chapter discusses some theoretical concepts associated with the development of the bioeconomic model for Louisiana nutria. To this end, the chapter is divided into two sections. The first section presents a general framework related to population dynamics, the long-term surplus yield function, and the bioeconomic supply model for a renewable resource. It also outlines the bioeconomic model, in particular the supply curve for nutria population. The second section presents data sources that were utilized in the current analysis, layouts the conceptual nutria bioeconomic supply model, and addresses the nutria-biomass-area model.

3.1 Theoretical Bioeconomic Model of Nutria

In order to develop a bioeconomic model for nutria, general elements of bioeconomic model for a renewable resource are first discussed. Then, a theoretical bioeconomic model for nutria is presented.

3.1.1 Population Dynamic Models for Renewable Resources

There are several population dynamic models with varying degree of complexity that are given in the literature to specify the relationship between effort and related harvest of a renewable resource. These models are generally divided into two categories: dynamic pool models and surplus-yield (or surplus production) models. It is the latter category that is the focus of this study as this group of models combines the effects of growth, recruitment and natural mortality into a common function of population size and natural growth (Fox, 1970).

The most commonly used surplus models are the Schaefer model and the Fox model (Fox, 1970; Schaefer, 1954). In the Schaefer model, the growth of the stock, measured in weight, is assumed to be a function of its size in weight. An underlying Logistic growth

function associated with stock size is assumed. The Fox model, on the other hand, assumes a Gompertz growth function of the underlying stock size. In describing the various relationships, emphasis will be given to the Schaefer model. The Fox model is discussed in less detail but is considered when the supply equation is derived.

Given the underlying logistic growth function specified by the Schaefer model, the instantaneous growth rate of a population can be expressed as:

$$F(X_t) = \frac{dX}{dt} = rX_t \left(1 - \frac{X_t}{K}\right) \quad (1)$$

where X_t is the size of the stock at time t (measured in weight), r represents the intrinsic growth rate of the stock (biomass), and K is the carrying capacity. The intrinsic growth rate of the stock (r) and the carrying capacity (K) are assumed invariant with respect to time.⁷

Based on this relationship, growth rate is a parabola function of the stock (biomass) at time t (Figure 3-1). With an abundance of food and space, at small stock levels the stock will grow rapidly (i.e., dX_t/dt will be large).⁸ As the stock grows over time, it will become increasingly subject to those factors in limited supply relative to population size, such as food. As such, the growth in the stock begins to fall (i.e., dX_t/dt will be declining). The population is a maximum when it reaches its carrying capacity, i.e., $X=K$. At this point, the rate of growth is equal to the rate of natural mortality and, hence, the change in population size will be zero (i.e., $dX_t/dt=0$).

⁷ With this specification, stock size (X) is a function of time (t) but carrying capacity (K) and the intrinsic growth rate (r) are not considered to be a function of time (t). However, this does not imply that the carrying capacity and/or the intrinsic growth rate cannot change over time. In general, factors that affect a given ecosystem (e.g., pollution, wetland loss) can impact carrying capacity.

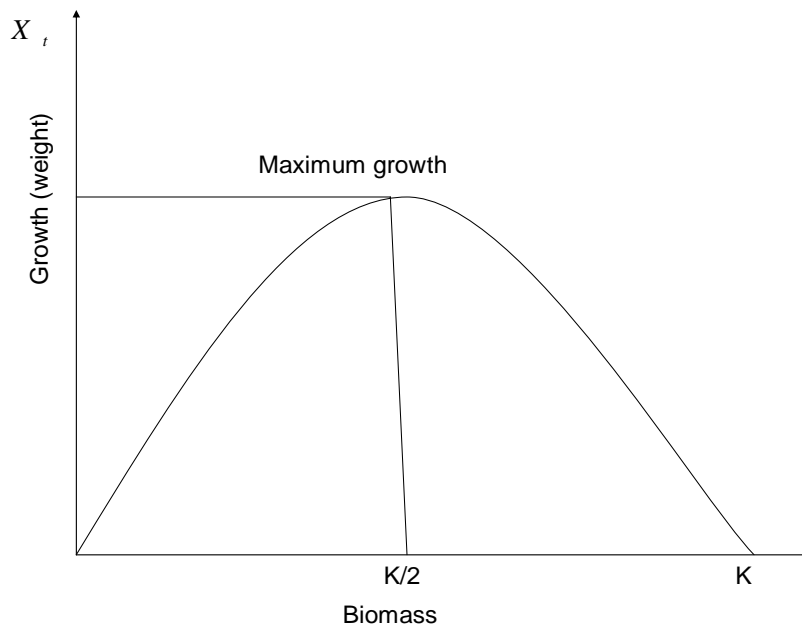


Figure 3-1. The Biological Growth Curve Associated with Schaefer Model.

To mathematically derive this relationship, equation (1) can be set equal to zero (i.e., implying that the change in population size is equal to zero) and solved for X_t . The solutions are $X_t=0$ or $X_t=K$, implying the growth rate is equal zero when the stock size is zero or the stock is at its maximum carrying capacity K (Bell, 1978; Hartwik and Olewiler, 1986). The natural growth rate is a maximum when the stock size is $K/2$. This can be illustrated mathematically by taking the derivative of the instantaneous growth rate function (i.e., equation 1), setting it equal to zero, and solving for X_t :

$$dF(X_t)/dx = r\left(\frac{1-2X_t}{K}\right)=0$$

Solving for X_t yields: $X_t= K/2$

⁸ In addition, natural predators may be less successful in feeding on a small stock because of

3.1.2 The Long Term-Surplus Yield Function for Renewable Resources

The long run surplus yield curve for a renewable resource represents the relationship between effort (say, the number of traps or trapping days), and catch (or harvest) at point in time t . This production function, which is used to determine the long-term equilibrium catch (harvest) associated with any level of effort, depends on the reproduction rate of the stock as well as the carrying capacity.

In equilibrium, the amount harvested by weight will be equal to the growth rate of the stock (also expressed in weight), implying a steady-state equilibrium. Within the confines of this scenario, the long-run surplus growth curve for stock is the “sustainable yield” curve because the population size will not be affected by fishing effort since catch is replaced by the natural growth of the stock. The maximum surplus growth represents the maximum sustainable yield (MSY) that can be derived from the stock on a continuing basis (Anderson, 1986; Bell, 1978).

Given the underlying assumptions associated with the Schaefer model, the relationship between harvest (H) and effort (E) is given by:

$$H = \alpha * E - \beta * E^2 \quad (2)$$

where α and β are theoretical parameters relating long-run yield (H) to effort given the underlying carrying capacity (K) and intrinsic growth rate (r) of the renewable resource being considered.⁹

The corresponding equation relating catch (H) to effort (E) based on the Gompertz/Fox surplus production model is given by

its dispersion over a wide area.

⁹ As discussed by Bell (1978), the positive parameter α , and β are functions of the catchability coefficient and the population carrying capacity (K).

$$H = E * e^{(\alpha - \beta E)} \quad (2')$$

Dividing equation (2) (or equation 2') by effort yields a linear and exponential relationship between catch per unit of effort (CPUE) and effort in the Schaefer and Fox models, respectively:

$$CPUE = \frac{H}{E} = \alpha - \beta * E \quad (3)$$

$$CPUE = \frac{H}{E} = e^{(\alpha - \beta * E)} \quad (3')$$

As specified in equation (2), harvest is a quadratic function of the effort. The theoretical parameters α and β are positive and can be estimated via standard linear regression techniques given appropriate data on harvest and effort.¹⁰ Initially, harvest increases with an increase in the effort and reaches a maximum at that point where the growth rate is a maximum. Any expansion of effort beyond MSY results in a declining long-run harvest because the rate of harvest exceeds the rate at which the stock can be replenished (Figure 3-2). Setting the derivative of the harvest equation (equation 2) with respect to effort – the slope of the production function – equal to zero, yields the amount of effort that will give MSY; i.e.,

$$\frac{dH}{dE} = \alpha - 2\beta * E = 0$$

Solving for effort (E) yields:

$$E_{MSY} = \alpha / 2\beta$$

¹⁰ Without going into detail, one should recognize that a unit of effort can vary through time as a result of technological or other changes. Hence, effort is generally standardized to some base period for the purpose of analysis.

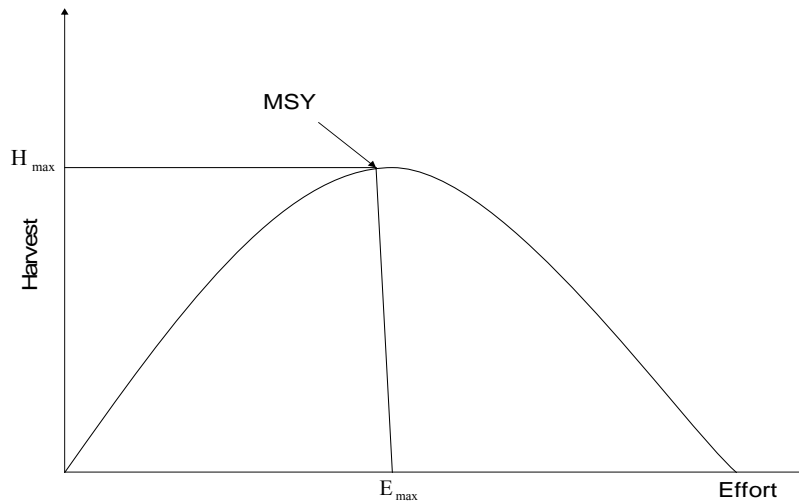


Figure. 3-2. The Long Run Sustainable Yield Curve Associated with Schaefer Model.

Finally, substituting this value back into equation (2) provides the solution to maximum sustainable yield (MSY), or:

$$MSY = \alpha^2 / 4\beta.$$

Applying the same procedure to the Fox model yields the following:

$$E_{MSY} = -1 / \beta; \text{ and}$$

$$MSY = -\frac{1}{\beta} e^{(\alpha-1)}$$

3.1.3 Bioeconomic Supply Curve for Renewable Resources

3.1.3.1 Bioeconomic Supply Curve Relating Long-Run Harvest to Effort

Generally, the supply curve of interest in economic analyses is the long run bioeconomic supply curve wherein all factors of production are embodied in one variable “effort”. The name bioeconomic is composed of two elements: (1) the biological relationship

between harvest and effort and (2) the economic relationship between the total cost and the effort expended.¹¹

Industry profit (π) generated by the renewable resource combined with the use of capital and labor is the difference between total industry revenues (TR) and total industry costs (TC) and can be expressed as:

$$\pi(E) = TR - TC$$

Since profit is given by the difference between the value of a good produced from using a natural resource and the costs accrued during the production process, rent can be considered as an economic “surplus” (Hartwick and Olewiler, 1986).

Total revenue (TR) is the product of output price (p) and harvest (H) of the renewable resource, or:

$$TR = p * H \quad (4)$$

The total revenue curve can be produced by multiplying each point on the sustainable yield curve by the output price (under the assumption of constant price). If the output price is a constant (for any level of sustained harvest), the total revenue curve will have the same shape as the sustainable yield curve because total revenues will vary proportionately with harvest.¹²

Total costs represent the value of scarce resources used in harvesting endeavors and, as such, do not merely represent “out of pocket” expenditures. Rather, total costs these expenditures but also a “normal” return on capital and labor. In other words, there is an

¹¹ To facilitate the analysis, all firms are assumed to be homogeneous. While this assumption can be relaxed, doing so complicates the analysis. As considered in a later section, nutria harvesters are assumed to be homogeneous. Given this assumption, there is no need to delve into more complex theoretical scenarios.

¹² The assumption of a constant output price (i.e., output price is invariant to the level of harvest) can be easily relaxed (see Anderson, 1986). Given the fact that the Louisiana nutria harvest has always been a minor component of the fur market, it seems realistic to assume that

opportunity cost to the use of capital and labor. For example, consider a fisherman who has a long-term investment in a vessel of, say, \$500 thousand. Instead of investment in the vessel, he could have invested in the bond market and would receive a “normal” return from this alternative investment. Similarly, there is an opportunity cost to the fisherman’s time which is directly tied to income that could be received from other employment opportunities. Total costs, when considered in an economic framework, include the “normal” returns that one would receive from the next best use of capital and labor.

Assuming that cost per unit of effort (c) is constant, total industry costs can be expressed as:

$$TC=c \cdot E \quad (5)$$

As expressed, total industry costs increase linearly with effort. This implies that the cost of adding an additional unit of effort (i.e., the marginal cost of effort) is the same as the cost of the previous unit. The long-run industry revenue (TR) and the total cost (TC) curves associated with the hypothetical harvest of a renewable resource are illustrated in Figure 3-3 (a). As indicated, the TR curve takes the general shape of the long-run yield curve. Total costs (TC) increase linearly with respect to the amount of effort employed.

The average cost, marginal cost, average revenue, and marginal revenue curves corresponding to the total revenue (TR) and total cost (TC) curves are presented in Figure 3-3 (b). The average revenue (AR), which is a measurement of the revenue per unit of effort ($AR=TR/E$), is downward sloping throughout the entire range because as effort increases, the return per unit of effort decreases. It is equal to zero when TR is equal to zero. The marginal revenue curve ($MR=dTR/dE$) is downward sloping for the same reason. However, it turns negative beyond that point where TR is a maximum because additional units of effort result in

the price flexibility with respect to output is close to, if not equal to, zero. Hence, changes in output price with respect to changes in harvest are not considered.

a decline in long-run yield and, hence, total revenue (TR). The marginal cost curve, which shows the changes in total cost associated with the changes in effort, is equal to the average cost curve because of the assumption of constant cost per unit of effort (Anderson, 1986).

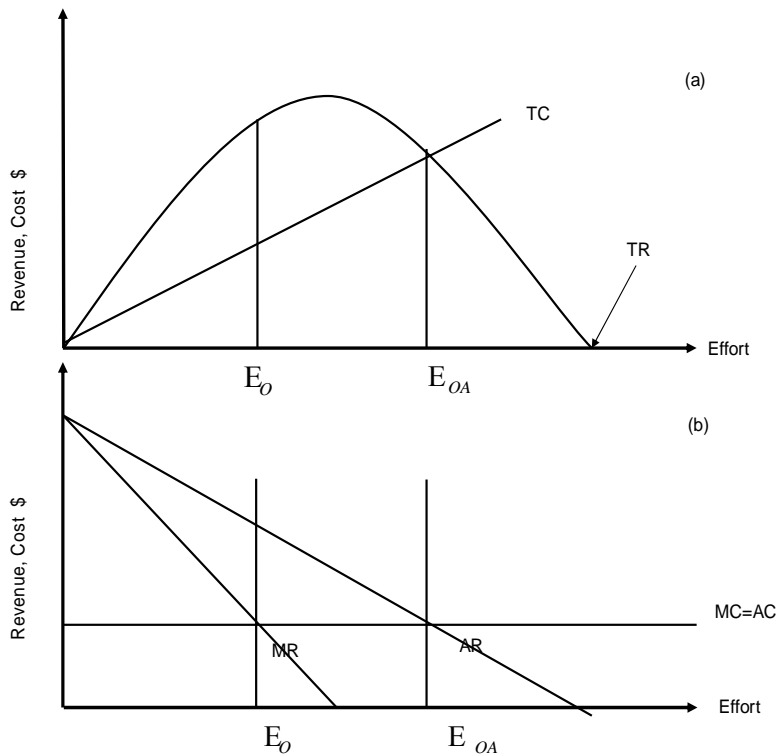


Figure 3.3: Open Access Equilibrium

Based on the sustainable yield curve derived above, in conjunction with a constant output price (p) and cost per unit of effort (c), the equilibrium level and harvest associated with different scenarios can be depicted (Figure 3-3). For the sake of demonstration purposes, a numeraire of one (e.g., output price is equal to \$1.00) is assumed. With no entry restrictions (i.e., under an open access scenario), the level of effort will increase until the total industry revenue (TR) is equal to total industry cost (TC), or where industry profits are equal to zero (Figure 3.3 (a)). Expressed in another manner, at the open-access equilibrium, average cost

per unit of effort is equal to the average revenue per unit of effort (Figure 3.3 (b)). This is represented by a level of effort equal to E_{OA} . At this point, the rent derived from the use of the scarce resource is equal to zero.

To examine why this is the case, assume any level of effort in excess of that associated with E_{OA} . Given such a scenario, total costs (TC) exceed total industry revenues (TR), indicating negative economic profits. Under such conditions, industry effort will be reduced until E_{OA} , is attained at which point economic profits (rents) are equal to zero. Conversely, at any level of effort less than E_{OA} , total industry revenues (TR) exceed total industry costs (TC), indicating positive economic profits (i.e., total industry revenues in excess of opportunity costs). Assuming no entry restrictions, these positive economic profits will attract additional effort until such time that the level of effort is that associated with the open-access equilibrium (i.e., E_{OA}). At this level of effort, all economic profits will be dissipated.

The open access equilibrium level of effort (E_{OA}) is not economically efficient because at this level the marginal cost of producing an additional unit of fish (i.e., marginal cost of effort) exceeds the marginal revenues associated with that additional effort (i.e., the value accruing to society associated with the additional effort). In addition, the same long-run harvest that is produced under E_{OA} can be produced with a lower level of effort, E_o . A level of effort in excess of that level which is economically efficient suggests that scarce resources can be employed elsewhere which would, in turn, enhance net benefits to society.

3.1.3.2 The Bioeconomic Supply Curve Relating Long-Run Harvest to Output Price

In general, most of the literature associated with modeling the long-run yield curve for a renewable resource (i.e., the long-run supply curve) examines the equilibrium relationship

between long-run output (harvest) and effort. This differs from traditional economic supply analysis whereby quantity supplied (output) is evaluated in terms of changes in the output price, holding other relevant factors (e.g., input prices) constant.

Copes (1970) is generally credited with developing the theory which relates the long-run harvest of a renewable resource to its output price (i.e., the relationship between quantity supplied and price) while simultaneously considering those factors which would shift the supply curve¹³. The analysis proceeds from the established relationships between fishing effort, yield, and total cost. The long term surplus or yield curve represents the relationship between the fishing effort and the sustainable harvest. This curve reaches its apex when at the level of effort sufficient to achieve maximum sustainable yield (MSY). Based on the assumption of a positive linear relationship between effort and total cost, one can examine total costs as a function of long-term harvest. Doing so shows that the total cost curve, which represents the relationship between costs and long-run harvest (output), has the same shape as the sustainable yield curve; where costs are plotted on the vertical axis while output is plotted on the horizontal axis.

The primary characteristic of the total cost curve is that as long-run harvest initially increases, total costs also increase. Even after long-run harvest reaches a maximum and begins to decline, however, total costs continue to increase. Hence, beyond MSY, output (represented by the horizontal axis) falls yet total costs continue to increase.

Finally, this characteristic of the total cost curve is transferred to the average cost curve (the supply curve) which has a backward bending shape at price higher than the level that brings the maximum sustainable yield (output). As the output price increases, harvest

increases until it reaches MSY and thereafter decreases, eventually approaching zero asymptotically. The supply curve for a renewable resource as derived by Copes (1970) is a long run supply curve expressing equilibrium levels of harvest or output as a function of output price, holding other factors constant. Graphically, output is represented on the horizontal axis while the output price is represented on the vertical axis.

In conjunction with the above theoretical discussion of the long-run supply curve (the average cost curve) under the assumption of a complete open access situation, it should be noted that the long run supply curve is represented by the marginal cost curve when the resources are privately owned or when the level of the effort can be limited through licensing or other restriction methods. In this case, the long run supply curve (the marginal cost curve) has zero elasticity at any output price greater than that necessary to achieve MSY. Copes (1970) argued that the marginal cost curve might be derived from the average cost curve (the long run supply curve discussed previously) under the absence of any divergence of private and social cost.

For illustration purposes, the procedure used by Hartwik and Olewiler (1986) to generate a long-run supply curve for a renewable resource is considered here. Assume that the price per unit of output (for example the price per pound of fish) increases from $P_0 = \$0.5$ per pound to $P_1 = \$1.00$ per pound, and increases once again to $P_2 = \$2.00$ per pound. The total revenue curve can be produced by multiplying each point on the sustainable yield curve by the corresponding output price. Three different total revenue curves corresponding to each price level are given in Figure 3-4. Adding the total cost curve to the graph, we can sketch three open access equilibrium points between long-run harvest and output price. Then for the

¹³ While Copes (1970) is generally credited with developing the theory that relates long-run harvest to output price, Cunningham et al. (1985) suggest that the backward bending supply

resource, the sustainable yield curve can be transferred to a total revenue curve. The long run supply curve is graphed by projecting the open access equilibrium points on Figure 3-4 (Anderson, 1986; Hartwik and Olewiler, 1986).

When the output price (P) is low, say $P=\$0.5$, the long-run equilibrium harvest is H_0 . When the output price increases to $P=\$1$, the long-run equilibrium harvest increases to H_1 . However, at an output price equal to $\$2.00$, the long-run equilibrium harvest falls to a level below H_1 because the level of effort associated with the higher price is beyond that level needed to harvest MSY. At the beginning, the output rises with the increase in price but after the maximum sustainable yield is reached, the output declines causing the curve to backward (Copes, 1970; Hartwik and Olewiler, 1986).

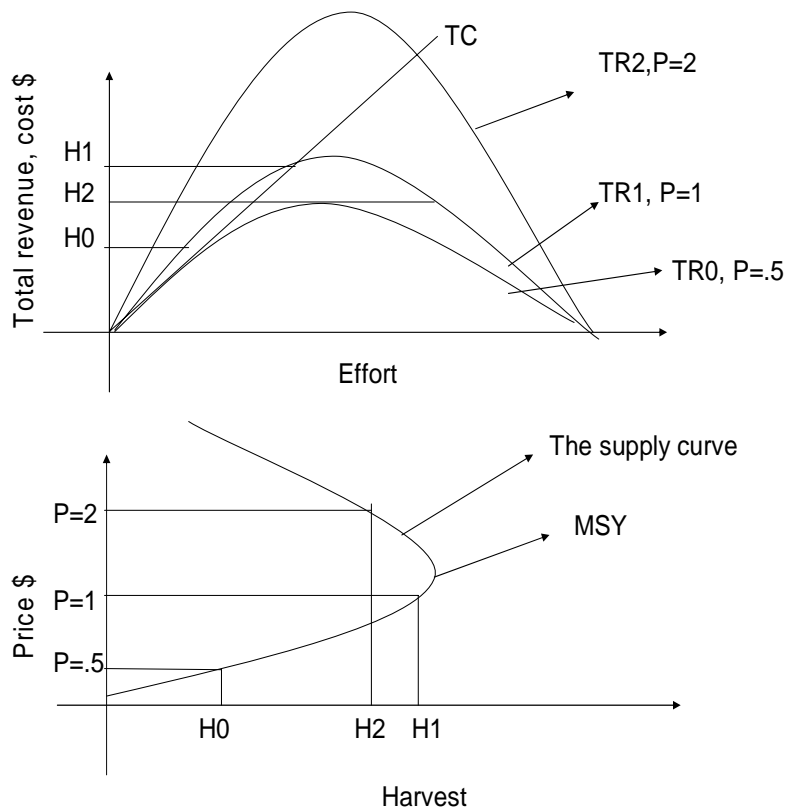


Figure. 3-4. Total Revenue and Supply Curves under Open Access Equilibrium Conditions.

model appears to have first been employed by Turvey (1957).

3.1.4 The Bioeconomic Supply Curve for Nutria

Since the supply curve is directly derived from the sustainable yield curve and the total cost curve, any shift in the sustainable yield curve translates into a similar shift in the long run supply curve. Given the sustainable yield curve, the carrying capacity (K) and intrinsic rate are assumed to be constant over time. Fluctuations in carrying capacity and intrinsic rate levels due to random events are ignored in most surplus production models. For instance, in fisheries, these parameters can be subject to random environmental factors such as seawater temperature, salinity, epidemics, and oil spills (Hartwik and Olewiler, 1986; Agbesi, 2002). Bell (1978) included seawater temperature in his supply model for American Lobster. Kahn and Kemp (1985) investigated the effect of the reduction of the level of submerged aquatic vegetation (SAV) on fish populations in the Chesapeake Bay. Agbesi (2002) incorporated temperature, and salinity in his bioeconomic model for marine pelagic fish population. In the nutria supply curve, special consideration is given the following environmental events that can affect the long- run sustainable yield curve.

- (1) Wetlands: Nutria are generally herbivorous, and eat 2 ½ to 3 ½ pounds of food daily (Evan, 1970). Hence, wetlands are a critical habitat for nutria population. By the end of the last century, it was estimated that about 30% of Louisiana wetlands had been lost. This estimate is equivalent to an average loss of 35 square mile per year. Some natural causes of this loss are subsidence, erosion, canal dredging, industrial and commercial development, urban sprawl, and sea level rise (Farber, 1996). Herbivory by nutria and other animals add another source of pressure on the already weaken ecosystem of these wetlands and can induce further deterioration. A recent survey of

wetlands damages estimates that more than 80,000 acres are directly damaged by nutria grazing activity (Marx *et al.*, 2003).

Due to a reduction in coastal Louisiana wetlands, the carrying capacity (K) in support of any nutria population has declined. Referring to Equation 1, a change in K impacts the instantaneous growth rate and the overall yield curve. This effect can be illustrated graphically through the downward shift of the long run sustainable curve (Figure 3-5(a)). Similarly, the nutria backward-bending supply curve (i.e., the supply curve whereby long-run yield is specified in relation to output price) moves to the left as wetland acreages decrease (Figure 3-5(b)). From both graphs, the maximum sustainable yield decreases from MSY_1 to MSY_2 as a result of the wetland loss.

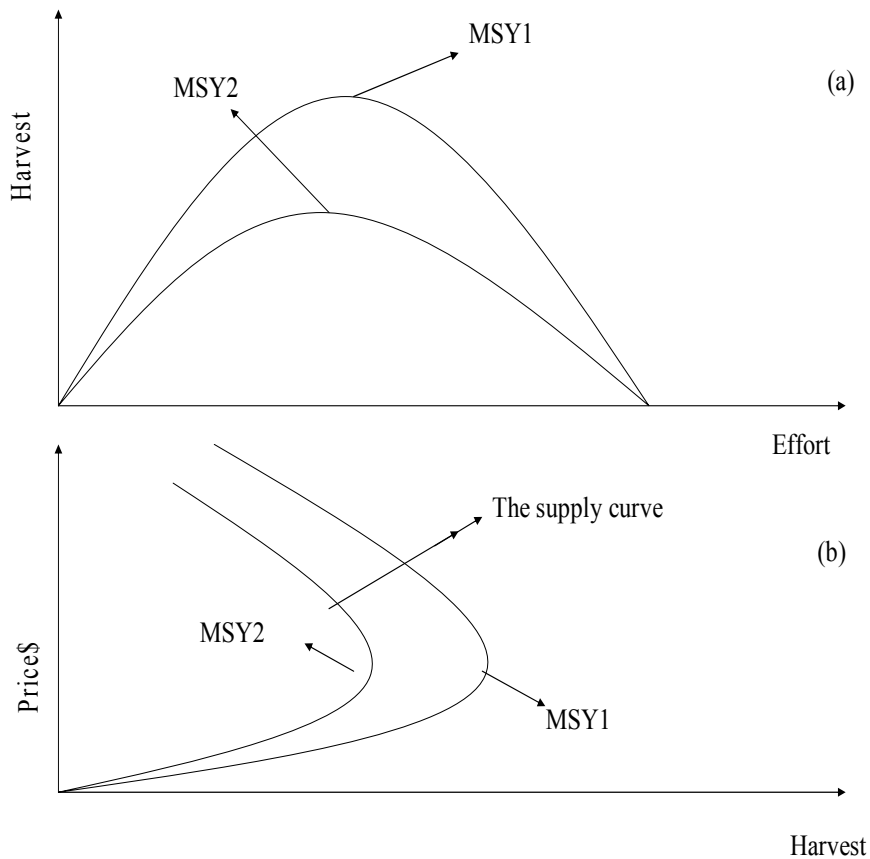


Figure. 3-5. Hypothetical Shift in Long-Run Yield Curve and Corresponding Supply Curve Resulting from Wetland Loss.

- (2) Extreme weather events: Cold weather is considered to be one of the major factors limiting the abundance and distribution of nutria population in their temperate regions (Gosling *et al.*, 1983). For example, cold weather is associated with female abortion and litter frequency in the following spring (Gosling, 1974; Newson, 1966). Besides, the reproduction failure among females during the winter, mass mortality among adult might occur if the winter is severe enough. The harsh winter 1962-1963 winter in England was responsible for mortality of between 80% and 90% of the existing nutria population (Gosling and Baker, 1989; Newson, 1966). In Maryland, a similar pattern was observed (Willner *et al.*, 1979). Lowery (1974) reported that the nutria population in Louisiana was severely impacted by a harsh winter in February 1962. He claims that millions of nutria were likely killed in that winter and prolonged effects of the 1962 cold winter were documented through missing tails and feet of the trapped survivors for several years thereafter. Graphically, with one important distinction, the effect of extreme cold-weather events has similar patterns as that shown for wetland acreages. The distinction is that these extreme events result in only a temporary, rather than permanent, shift in the long-run yield curve and the backward-bending supply curve.
- (3) Alligator population: Alligators are the major predator of Louisiana nutria. In Sabine National wildlife refuge, Louisiana, Valentine (1972) reported that nutria remains constituted about 56% of 413 alligator stomachs he examined in 1961. In the same study, the author found that this prey-predation relationship is highly density dependent, implying that the alligator predation rate increases in relation to nutria density. Wolfe *et al.* (1987) found that approximately 60% of the weights of alligator diets consist of nutria

and the frequency of nutria remains is 37%. As its major predator, therefore, one can anticipate that as the Louisiana alligator population increases (decreases), the nutria population will decrease (increase) resulting in downward (upward) shift in the nutria sustainable yield and supply curves.

3.2 Data Sources and Estimation Methods

3.2.1 Data Sources

The bioeconomic model for Louisiana nutria was estimated based on annual data covering the 1960 through 2001 period.¹⁴ In order to estimate the bio-economic model of nutria, data were collected the following variables: harvest (number of pelts), price per pelt, wetland loss, weather, unemployment rate in the coastal parishes, and alligator population.

3.2.1.1. Harvest and Price Data

Annual data on Louisiana's nutria production for the period 1960-2001 were used for the analysis. Price data reflect the price received by trappers on a per pelt basis. In order to adjust for inflation, the nominal price was deflated by Implicit Price Deflator (base year = 2000). The source of harvest and price data is the Louisiana Department of Wildlife and Fisheries. The implicit price deflator was derived from the Bureau of Economic Analysis Statistics.

3.2.1.2. Coastal Wetland Availability

There is no single source that provides Louisiana's coastal wetland loss (or remaining acreage) on an annual basis. Data on annual wetland loss in Louisiana from 1960 forward is used to compute annual remaining wetland acreage. The annual values of wetland loss used

¹⁴ The Louisiana nutria trapping season runs from November through February of the following year. Reported harvest and price data for, say, the November 1960 through February 1961 season are recorded on the basis of 1960-61 harvests and price. For purposes of this study, the 1960-61 records are referred to as 1960 data.

for the current analysis are based on estimates derived by Turner (1997). Using 1968 wetlands acreage as the base year¹⁵, the annual wetland acreages variable is derived by adding cumulative losses up to that year if it is less than 1968 and subtracting if year is greater than 1968.

3.2.1.2. Extreme Temperature Events

The source of meteorological data is the New Orleans Audubon Weather Center of the National Oceanographic and Atmospheric Administration. The winter severity index (freeze) is computed with slight modification of Gosling formula (Gosling *et al.*, 1983). A similar modification is used by Raggiani *et al.* (1995) to investigate the effect of cold weather on nutria in Italy. The original version of the formula is:

$$CRS = \sum_{i=0}^{i=n} x_i^2$$

Where i is a run, the number of succeeding freezing days during the winter; x is the length of the run and n is the number of runs in the winter season. A freezing day is a 24h period where the maximum temperature is less than or equal 5°C and minimum temperature doesn't go above 0 °C (Gosling *et al.*, 1983). This formula is based on ice formation conditions and takes into consideration the fact that the effect of the number of runs will be cumulative through the winter. The longer the run, therefore, the more severe effect the freezing winter will be expected to have on the nutria population (Gosling *et al.*, 1983).

No study has systematically examined the effect of weather on the nutria population in Louisiana. To investigate the effect of weather on harvest, the Gosling formula was employed

¹⁵ In 1968, Louisiana's total Coastal wetland acreages was estimated to be 3,858,082 acres (Louisiana Wildlife and Fisheries Commission, 1970).

but with no restriction on the maximum day temperature to calculate the number of runs each winter. In order to calculate the number of freezing days in each winter, each year began in

December of the previous year instead of the normal year that started in January.

Using December as the start month of each year avoids any overlapping between winters in the model if the year started at January instead.

3.2.1.3. Unemployment Rate

The opportunity cost of trappers is measured by the unemployment rate in the six Louisiana coastal parishes where the majority of nutria pelts have historically been harvested. These parishes are Plaquemines, St. Bernard, Terrebonne, Vermilion, Calcasieu, and Cameron. The yearly average unemployment rate for the 1970 through 2001 period is calculated by adding the number of unemployed people for the six parishes and dividing the sum by the number of civil labor force. Data on unemployment by parish from 1970 to present is provided by Louisiana Department of Labor. Data by parish are not available prior to 1970. The average state unemployment rate was used as a proxy for the six-parish unemployment rate prior to 1970.

3.2.1.4. Alligator Population

An estimate of annual Louisiana alligator population is not available. However, the estimated number of nests, based on annual aerial nest counts conducted by the Louisiana Department of Wildlife and Fisheries Fur and Refuge Division, is available from 1971 to present. Data on alligator nests prior to 1971 is not available since this program took place only early 1970's to monitor the recovery of the population level After they became listed on the federal endangered species list in 1967 (Newsom *et. al* 1987). Kelly (2004) estimated the alligator population recovery rate to be between 13-14% in 1971-1972. So for the purpose of

this study, estimates for the annual number of nests prior to 1971 were determined based upon a 13% survival rate as reported by (Kelly, 2004). Using this estimate of survival, specifically, back-calculations were made to 1960.

3.2.2 The Bioeconomic Supply Model

The nutria supply model is developed by an indirect simulation of the exponential surplus model (Fox, 1970). It is assumed that nutria population follows a Gompertz growth function, which results in an exponential relationship between effort and the population size or biomass (harvest per unit of effort). Therefore, under the exponential surplus-yield model, harvest approaches zero asymptotically when the level of effort increases. The resulting nutria supply curve has a backward bending shape as established in literature (Copes, 1970; Bell, 1978; Hartwik and Olewiler, 1986).

There are some compelling reasons for using the Fox model as the biological basis for the nutria population. Some of these reasons are as follows. First, nutria trapping is controlled by the season length which runs from the end of November to February. This season length limitation and the fact that nutria are very prolific animals make it highly unlikely that harvest will approach zero even at very high trapping levels. Second, the fact that trappers target mainly adult nutria lends further credence to the hypothesis that very high levels of effort (say, the result of high prices) will not result in long-run (sustained) harvests approaching zero. This is one of the characteristics that differs the Fox model from other biological models such as the Schaefer. Third, using the Fox model as the biological model for nutria population allows the derived supply curve to have internal interactions between the price and other

parameters in the model. Finally, the Fox model provides a flexible functional form for purposes of analysis.¹⁶

The hypothetical supply equation is estimated using standard regression that relates the endogenous variable (harvest per hectare)¹⁷ to a set of exogenous variables which include the deflated price¹⁸, unemployment rate, winter severity index (freeze), and number of alligator nests per hectare. The functional form associated with the bioeconomic nutria supply model is directly related to the functional form associated with the Fox model.

$$HARVEST_HE_t = EXP(\beta_0 + \beta_1 * PRICE_t + \beta_2 * Log(PRICE_t) + \beta_3 * UNEMPLOYED_t + \beta_4 * ALLIGATOR_t + \beta_5 * FREEZE_t) + Error$$

where:

$HARVEST_HE_t$ is the nutria harvest per hectare in year t (i.e., the total harvest divided by estimated coastal wetland hectares);

$PRICE_t$ represents the deflated pelt price received by the trappers in year t (i.e., the current price deflated by the implicit price deflator, base year = 2000);

¹⁶ The harvest of nutria reflects a combination of open access (on state-owned properties) and private access (privately owned wetlands) and the relative contribution of the total take from public property versus private property is unknown. As previously discussed, assuming an open-access situation, the equilibrium harvest will occur at that point where average costs intersect average revenues. Under a private property regime, the equilibrium harvest will occur at that point where marginal revenues equal marginal costs. The equilibrium long-run supply curves differ under these two scenarios. The Fox model is flexible and can, to some extent, “capture” this combination.

¹⁷ Harvest per hectare was used as the endogenous variable, rather than harvest because there is significant multicollinearity between available wetlands and the estimated number of alligator nests.

¹⁸ One might question whether price is exogenous. Specifically, changes in price are likely to influence long-term harvest but, in certain situations, changes in long-term harvest may also influence price (suggesting the need to estimate harvest and price in a simultaneous framework). This is not likely to be of concern in the current study since Louisiana nutria supply constitutes but a small share of the world nutria supply and an even smaller component of the world long-hair fur market supply. As such, large changes in harvest are likely to have little or no influence on price.

UNEMPLOYED_t, represents the unemployment rate for six coastal parishes in Louisiana in year t (the value for a given year represents the difference between that year's unemployment and the mean);

ALLIGATOR_t, is the estimated number of alligator nests per hectare in year t;

FREEZE_t, is the winter severity index measured using the modified version of Gosling formula.

In general, the rationale for many of the exogenous variables to be used in estimating the supply equation has already been presented. However, some additional explanation is in order. Changes in the number of alligator nests results in changes in carrying capacity. Hence, increases (decreases) in the estimated number of alligator nests (*ALLIGATOR*) are anticipated to result in a reduction (increase) in long-term nutria harvest, *ceteris paribus*.

The variable *FREEZE*, like the variable *ALLIGATOR*, is expected to result in shifts in the supply curve. However, whereas the number of alligator nests has been trending upwards over time (suggesting a long –term change in the carrying capacity), *FREEZE* represents a “more” random influence on the supply curve. Finally, while the output price (*PRICE*) determines the slope of the long-run supply curve throughout its range, input prices (i.e., costs) determine its position. There are relatively few costs involved in trapping nutria with the value of the trapper's time (i.e., his opportunity cost) likely constituting the primary one. The variable *UNEMPLOYED* is a proxy for the trapper's value of time.

Based on the theoretical analysis provided by Copes (1970), increased (decreased) costs would result in an upward (downward) shift in the long-run supply curve with the slope of the supply curve (throughout its range) remaining the same at any level of costs. As such, maximum sustainable yield (*MSY*) will remain constant for any given level of costs. Given

harvest as the endogenous variable, however, regression does not allow for and upward (downward) shift in the supply curve with changes in input costs (i.e., the unemployment rate). Using the standardized unemployment rate suggests that increases (decreases) in unemployment merely represent transitory movement off the long-run curve (i.e., essentially a disequilibrium condition). At any output price (PRICE), therefore, unemployment rates in excess of the mean (i.e., low opportunity costs of time) are represented by expected harvests in excess of those that would be expected at the mean unemployment rate. This is represented by an expected level of harvest to the right of the long-run yield curve at any output price. Conversely, low unemployment rates relative to the mean (i.e., high opportunity costs) are represented by an expected harvest level to the left of the long-run yield curve at any output price. Given the relatively low costs, this assumption appears plausible.

3.2.3 Nutria-Biomass-Area Model

Carter *et al.* (1999) developed a model that links the nutria feeding behavior with wetland loss. The model is composed of three linked components: 1) the nutria population dynamic model; 2) the marsh biomass model for plant species *Spartina patern* and, *Scripus americanus*; and 3) the marsh area model. The model main framework can be summarized as follows (see Figure 3-6):

- 1- As the number of nutria increases, the individual biomass needs increase so the total biomass density decreases;
- 2-When the biomass density decreases below the critical density level, a part of the marsh area is lost permanently; the lower the density, the greater the loss rate (Part B of Figure 3-6);
- 3- As the area of the marsh decreases, the total biomass that the marsh can generate decreases, and the fewer the number of nutria that the marsh can support (Parts C, and D of Figure 3-6);

The model code is created with Stella software and the simulation is conducted on 20 hectare marsh area and with initial number of nutria equal to 40 (Carter *et al.*, 1999).

Previously, a harvest sector was not activated in the model. For the purposes of this study, this sector will be developed and linked to the model. The predicted harvest associated with different bounty programs is linked to the Stella model after adjusting it for 20 hectare plots and a 13 week season length.

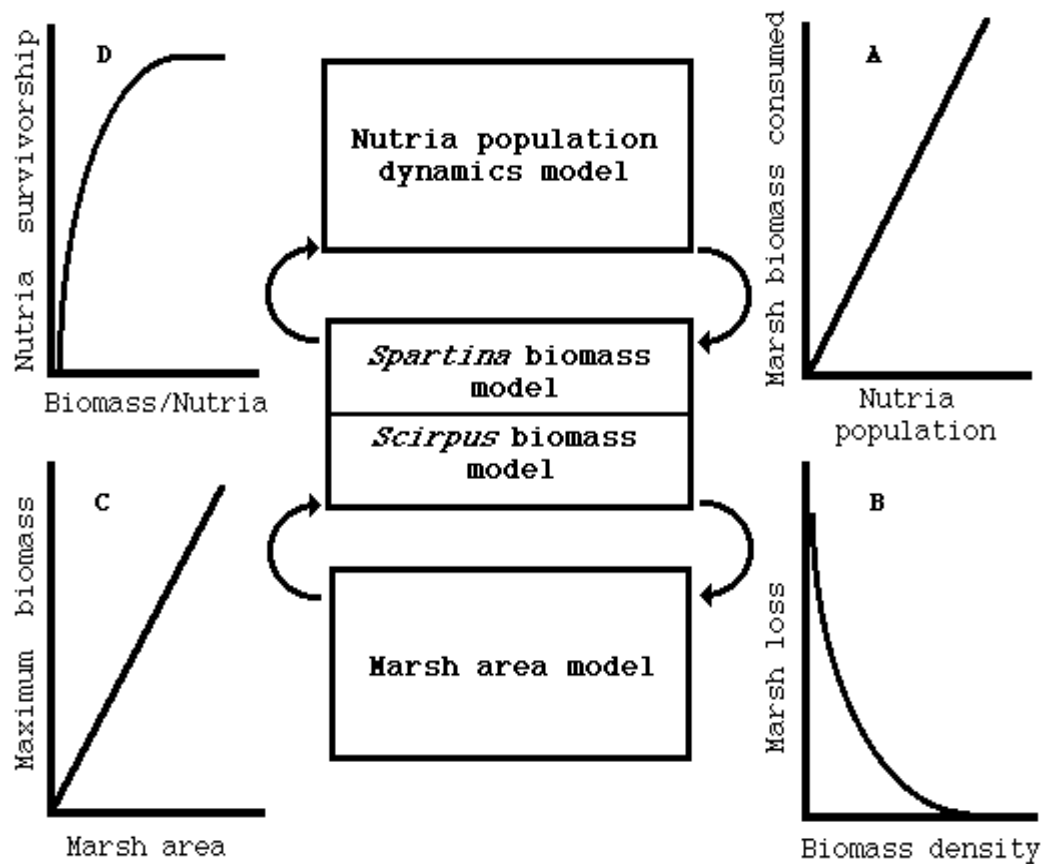


Figure. 3-6. Conceptual Model (Source, Carter *et al.*, 1999)

CHAPTER 4: RESULTS AND DISCUSSIONS

This chapter presents the results of the estimated bioeconomic supply model of nutria population in Louisiana. The supply model is derived through an indirect simulation of the Fox model (Fox, 1970). The chapter’s outline is as follows. The next section presents the results of the supply model. The second section discusses changes in wetlands damages associated with different bounty levels. In the final section, a brief cost/benefit analysis associated with alternative bounties is considered.

4.1 The Supply Model

4.1.1 Model Results

The nutria bioeconomic model¹⁹ was estimated based on data from 1960 to 2001.

Results are presented in Table 4-1.

Table 4-1: Selected Long-Run Nutria Supply Model Results

Harvest per Hectare= $\exp\{\beta_0 + \beta_1*Price + \beta_2*\log(Price) + \beta_3*(Unemployed) + \beta_4*Alligator + \beta_5*Freeze\} + Error$ ²⁰			
Model Df =6	Error Df = 36	SSE = 0.5253	MSE = 0.0146
	R ² = 0.9038	Adj. R ² = 0.9018	DW_test=1.56
Parameter	Estimate	Std. Error	t-Value
Intercept	-2.66	0.399	-6.67
Price	-0.090	0.032	-2.18
Log(Price)	1.559	0.309	5.04
Unemployed	0.059	0.014	4.27
Alligator	-21.844	6.099	-3.58
Freeze	0.006	0.002	3.36

¹⁹ Also nutria supply equation is evaluated using quadratic function of the price based on the Schaefer model. The result was similar. All the parameters are significant at 1% level of significance.

²⁰ The supply equation based on the Schaefer model is given by the following equation:
Harvest per Hectare = $\beta_0 + \beta_1*Price + \beta_2*Price_square + \beta_3*Unemployed + \beta_4*Alligator + \beta_5*Freeze + Error$.

Based on several criteria, the estimated model appears to be satisfactory. As discussed in more detail below, the signs associated with the estimated parameters generally conformed to *a priori* expectations based on theoretical considerations. Second, the model appears to be statistically sound. For example, all variables in the model are significant at 1% level of significance. Furthermore, there is no evidence of serial correlation. Finally, a large proportion of the variation in the dependent variable (harvest per hectare) is explained by the estimated model ($R^2 = 0.904$). A more detailed analysis of some relevant statistical considerations can be found in the appendix to this chapter.

The negative sign associated with the Price coefficient and the positive sign associated with the Log(Price) coefficient²¹, when considered jointly, allow the supply curve to have the theoretical backward bending shape at prices above those needed to achieve MSY. This implies that harvest will initially increase as price level increases, but at a decreasing rate. Beyond MSY, higher prices will result in lower long-run yields.

The positive sign on UNEMPLOYED is consistent with the hypothesis that the long-run harvest varies inversely with opportunity costs. In other words, increases in the unemployment rate in coastal parishes (i.e., a decline in opportunity costs) imply a reduction in costs associated with trapping activities stimulating increased trapping.²² As a result, nutria harvests would increase, *ceteris paribus*.

²¹ The supply elasticity with respect to the price is given by $(\beta_1 + \beta_2 / Price)$. Since β_1 is negative and β_2 is positive, harvest will increase at a decreasing rate as the price increases; then it decreases when the price exceeds that needed to achieve MSY.

²² In theory, decreased (increased) costs should shift the supply curve upwards (downwards) while not changing the slope of the supply curve throughout its range. Hence, MSY would not change. However, this theoretical consideration could not be applied to the current study due to the model specification. The “disconnect” between theory and application suggests that additional analysis may be warranted.

The negative sign associated with the estimated ALLIGATOR coefficient is consistent with the hypothesis that an increase in alligator nest density (measured by the estimated number of nests per hectare) increases the predation rate on nutria. It therefore reduces nutria populations and, consequently, the long-run nutria harvest. The results of this model provide evidence that alligator is one of the major predators of nutria in Louisiana. This result is consistent with findings from Valentine *et al.* (1972) and Wolfe *et al.*, (1987). Both studies confirmed that large alligators tend to feed heavily on nutria whenever they coexist in one area; the higher nutria density, the higher the predation rate.

The positive sign on the winter severity index (FREEZE) is not consistent with what has been established in the literature on the vulnerability of nutria to cold weather. Severe winter is known to be one of the profound factors limiting nutria in their temperate regions (Ellis, 1963; Gosling and Baker, 1989; Newson, 1966), including Louisiana (Lowery, 1974). Based on the modified version of Gosling formula used in the current analysis, increasing the number of freezing days was found to have a positive (and statistically significant), rather than negative, influence on harvest. While the reason for this unexpected finding cannot be ascertained, one can speculate that the colder temperatures culminate in increased movement of nutria (particularly if there is vegetation “dieback”), hence, making them more susceptible to capture.

Extreme cold weather conditions such as those reported by Lowery (1974) are rare events in South Louisiana. One might hypothesize that finer “tuning” of the Gosling formula might show a negative relationship between temperature and harvest in those rare years where temperature remains low for a duration long enough to result in significant mortality. In other words, temperatures below freezing yet above some absolute temperature (say, ten degrees

Fahrenheit) result in increased harvests. Conversely, extremely cold and sustained temperatures (say, less than 10 degrees Fahrenheit) result in increased mortality and, hence, a reduction in harvest.²³

The price at which the supply curve bends backwards can be derived by taking the first derivative of the supply equation with respect to the price and equating it to zero, or:

$$\frac{d(\text{harvest}_{he})}{d(\text{Price})} = 0$$

Taking this derivative results in the following equation:

$$(\beta_1 + \beta_2/\text{Price}) * \exp(\beta_0 + \beta_1 * \text{Price} + \beta_2 * \log(\text{Price}) + \beta_3 * (\text{Unemployed}) + \beta_4 * \text{Alligator} + \beta_5 * \text{Freeze}) = 0$$

Given that the right-hand term (i.e., $\exp(\beta_0 + \beta_1 * \text{Price} + \beta_2 * \log(\text{Price}) + \beta_3 * (\text{Unemployed}) + \beta_4 * \text{Alligator} + \beta_5 * \text{Freeze})$) does not equal zero, the other term (i.e., $(\beta_1 + \beta_2/\text{Price})$) must equal zero. Hence, one is left with:

$$\text{Price} = -\beta_2 / \beta_1 = (1.559 / 0.0903) = \$17.27$$

Hence, the maximum long-term harvest is reached at a deflated price of \$17.27 per pelt.

Based on this price and the mean level for all other exogenous variables in the model, maximum long-term harvest is found to equal approximately 1.5 million animals per year, *ceteris paribus*.

²³ Personnel in the Fur Division at the Louisiana Department of Wildlife and Fisheries have suggested that cold temperatures, by themselves, likely do not contribute to increased nutria mortality because nutria can flee the water and wait on land for temperatures to warm. Rather, it is extremely cold temperatures in conjunction with strong northern winds (that push the water into the marshes and prevents nutria from escaping the cold waters) that cause high mortalities.

The nutria supply curve is graphically presented in Figure 4-1 by varying pelt price while setting alligator population (i.e., number of nests), wetland acreage, deviation from unemployment rate, and winter severity index at their mean levels.

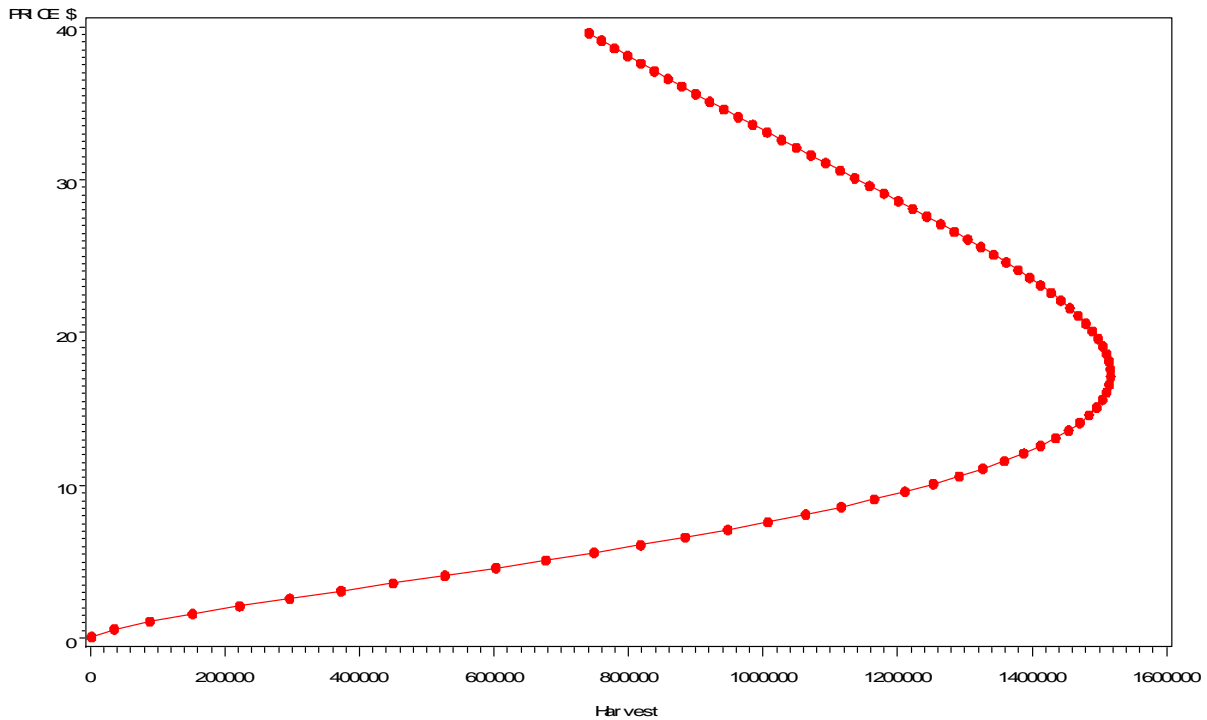


Figure 4-1: The Estimated Long-Run Nutria Supply Curve when all Exogenous Variables, other than Price, are Held at Their Mean Levels.

The estimated nutria supply curve behaves in a manner consistent with that provided in the literature for renewable resources (Bell, 1978; Clark, 1976; Copes, 1970; Hartwik and Olewiler, 1986). Specifically, harvest initially increases at a decreasing rate with increases in price. After reaching a maximum, long term harvest declines with additional price increases and eventually approaches zero asymptotically. Holding all environmental shifters and

unemployment rate at their mean levels, the maximum sustainable level²⁴ occurs at a harvest level equal to approximately at 1.5 million nutria, or a harvest per hectare equal to 1.03 animals.

To simulate the effect of change in alligator population on long-run nutria harvest, the bioeconomic nutria supply curve was plotted using alligator per hectare density in the years 1970 and 2000, holding independent variables other than price at their mean levels(Graph 4-2).

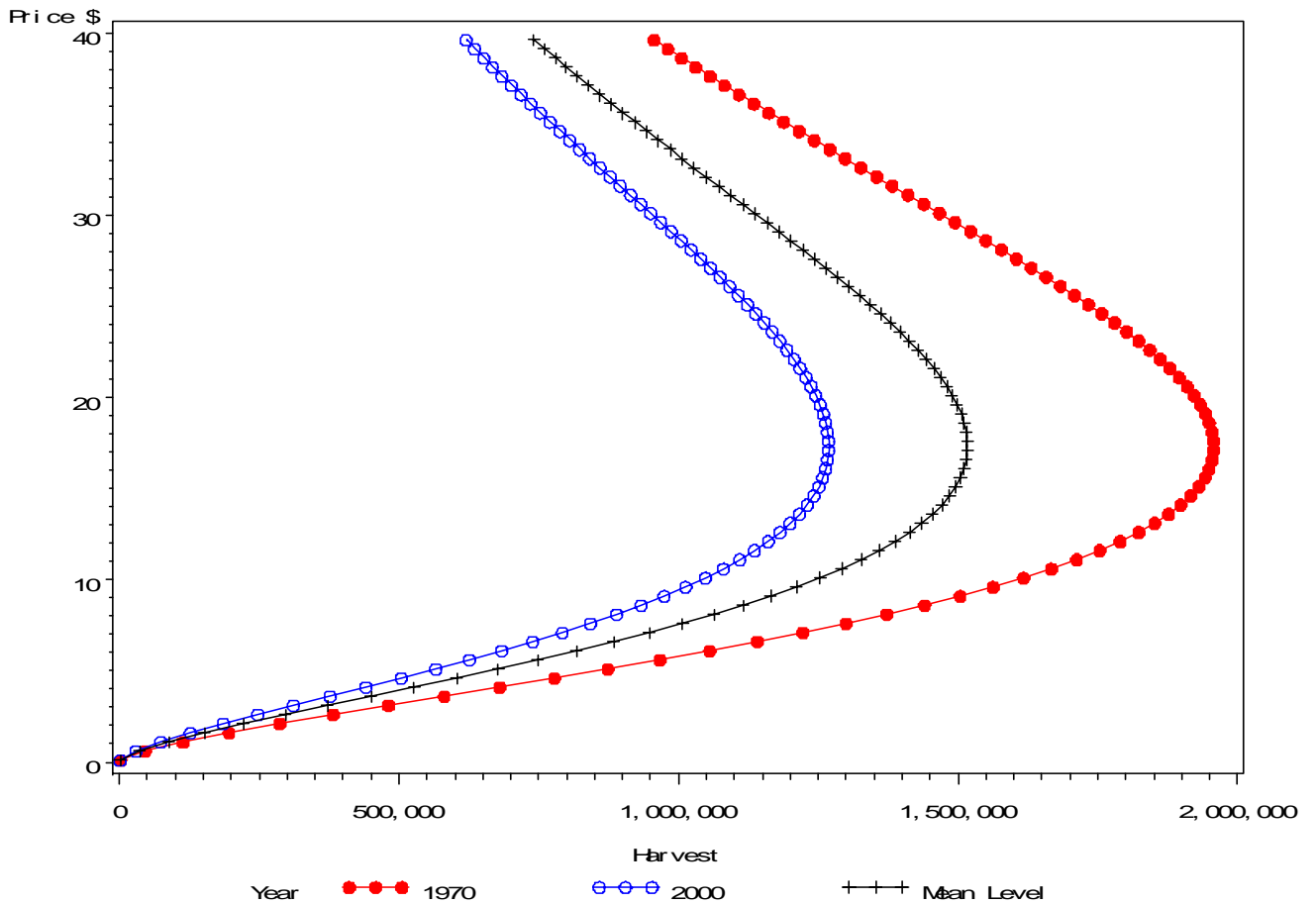


Figure 4-2: Estimated Impact of a Change in Alligator Population on Long-Run Nutria Supply Curve.

²⁴ Using the Schaefer model the MSY occurs at 1.6 million nutria pelt and the price which generates MSY is \$18.81.

The graph shows that the long-term harvest is reduced over time as the alligator population per (available) hectare increases. In 1970, the MSY was approximately 1.9 million. By 2000, it decreased to 1.3 million. This indicates that MSY decreased by approximately 600 thousand nutria pelts as a result of increasing alligator nest per hectare increasing by more than 0.014 (from 0.0038 nests per hectare in 1970 to 0.018 nests per hectare in 2000).

4.1.2 Predicted Harvests with a Bounty

In 2002, the Fur and Refuge Division of the Louisiana Department of Wildlife and Fisheries requested Federal funds for a nutria control program under Public Law 646, the Coastal Wetland Planning Protection and Restoration Act (CWPPRA). The nutria control program is targeting 400 thousand nutria pelts per year through a bounty price of \$4.00 received directly by the trappers (Genesis Laboratories, 2002). Since 2002-2003 and 2003-2004 harvest data were not used in the estimating the bioeconomic model, one can predict harvest quantity based on different price levels in these years.

To predict harvest under the \$4.00 incentive program, assumptions regarding possible reactions of the trappers to the incentive must first be considered. The first assumption is that trappers receive the \$4.00 per pelt via the program but do not process the pelt.²⁵ Under this scenario, the trappers receive \$4.00 per pelt for their effort. Based on this assumption, the model predicts 2002 and 2003 harvests of 292 thousand and 299 thousand nutria, respectively, given current wetland acreage. The observed harvests under the \$4.00 per tail bounty program

²⁵ In general, one would expect that an increasing proportion of the nutria pelts would be processed and sold as the price of the pelt increased; given the \$4.00 bounty. Conversely, however, one might anticipate that the number of pelts processed and sold is, itself, a function of the bounty. Specifically, as the ratio of bounty to pelt price increases, one might expect a decline in the proportion of the pelts being sold. In 2002, a total of 47 thousand pelts were sold or approximately 15% of the total 308 thousand for which a bounty was collected.

in 2002 and 2003 were 308 thousand and 333 thousand nutria, respectively. Hence, based on the \$4.00 bounty in conjunction with the assumption that all trappers will take the bounty but not process and sell the pelts, the predicted harvests are approximately 15-30 thousand below the observed harvests for the two years.

The assumption that none of the pelts are processed and sold by the trappers is likely to be somewhat unrealistic. Hence, an alternative assumption is that trappers receive the \$4.00 bounty but also process and sell all pelts at \$1.75 per pelt (i.e., the prevailing price in 2001). Under this scenario, the predicted 2001 and 2002 average annual harvest is 448 thousand nutria. Given the somewhat unrealistic assumption that all pelts are processed and sold, as one might expect, these numbers are considerably higher than the observed values. Overall, only 15% of the 308 thousand animals taken for the bounty were subsequently sold for the additional revenues associated with the pelt.

Finally, one can assume that a given percentage of the harvested product will be processed and sold while the \$4.00 bounty will be received for the harvested product. For the purposes of discussion, it is assumed that one-half of the harvested product will be processed and sold, suggesting revenues received per animal by trappers of \$4.88 (i.e., an average price of \$5.75 for one-half of the harvested product and \$4.00 for the remaining one-half). Under this assumption, the predicted average harvests for the years 2002 and 2003 equaled 374 thousand.

As noted, only about 15% of the 308 thousand animals harvested in 2002 were subsequently sold for the additional revenues associated with the pelts. Furthermore, one would anticipate that this percentage would fall as the bounty is increased. Hence, one could

realistically assume that there would be almost no sale of pelts at bounties in the \$6.00-and-over range and this assumption is made in estimation of harvests at higher bounties.

With an assumed \$6.00 bounty, the predicted harvest per hectare is 0.34091 or 462 thousand nutria in total for 2002 and 0.34996 nutria pelt per hectare (474708 nutria pelts) in 2003. Under an assumed \$8.00 bounty, the predicted harvests averaged 618 thousand per year for the two-year period. Finally, with an assumed bounty of \$10.00 dollars bounty the predicted harvest in 2002 is 725 thousand and 749 thousand in 2003. Average two-year predicted Long-run harvests associated with bounties ranging from \$4.00 to \$18.00(the MSY level) are presented in Table 4.2. As indicated, at \$18.00, the expected harvest is approximately 922 thousand. This number, which is lower than the 1.5 million MSY estimate, reflects the use of 2002-03 figures of exogenous variables in making the prediction.

Table 4-2: Predicted 2002-2003 Average Long-term Nutria Harvest

Bounty	\$4.00	\$6.00	\$8.00	\$10.00	\$12.00	\$14.00	\$16.00	\$18.00
Predicted Harvest ^a (thousands)	296	469	618	737	814	882	909	922

^a Harvest is predicted using 2002-03 values for exogenous variables in the model.

In 2002-03, a \$4.00 bounty program was implemented with a goal of increasing harvest to 400 thousand animals. The goal of this bounty program (400 thousand pelts) is tested using the fitted nutria supply model. Two cases, which vary depending on how the trapper will react to this program, are considered in this analysis.

The first assumption is that the majority of trappers will process the pelts in addition to the price of the bounty. The effective price in this case is approximately \$5.75 (the bounty level, \$4.00, plus approximately \$1.75 per pelt received the previous year). Using the effective price and the values of other explanatory variables based on 2002 year, then the null

hypothesis that harvest is greater than or equal to 400 thousand nutria pelts against the alternative that harvest is strictly less than 400 thousand nutria pelt could not be rejected at 5% level of significance. If the effective price is approximately \$4.00 (the bounty value) which implies that high percentages of the trappers didn't process the pelts, then the null hypothesis is rejected at 5% level of significance. Since empirical evidence suggests that only about 15% of the trappers have sold the pelts under this program, one is left to conclude that the program will most likely not achieve the desired goals.

Based on the results of these tests, it seems that the goal of the bounty (400 thousand pelts) will be achieved only at a bounty in excess of \$4.00. The results associated with these tests are presented in Table 4-3.

Table 4-3: Four-Dollars Bounty Test

H0: 400,000 harvest level is the goal of the bounty	P -Value	Df_Error
Price= \$4.00	0.0152	36
Price= \$5.75	0.8912	36

4.2. Wetlands Loss Simulation Model

In general, nutria are herbivore animals that feed primarily on the basal portion of the plants leaving behind mass destruction of the plants during the feeding process. This destructive behavior turns the marsh to open area and disturbs the marsh ecosystem. During winter, nutria dig underneath plants, sometimes turning them upside down looking for roots and rhizomes. This digging activity overturns the upper peat layer of the marsh, and disturbs the soil-root matrix system (Harris and Webert, 1962; Johnson and Foot, 1997; Linscobe *et al.*, 1981). Currently, a nutria population in excess of that which can be maintained by the

surrounding environment is one of the major factors contributing to the destruction of approximately 80 thousand acres of Louisiana wetlands (Marx *et al.*, 2003).

The Louisiana Fur and Refuge Division staff estimates that the equivalent of 400 thousand nutria need to be removed from the coastal environment to alleviate or eliminate the ongoing wetland loss due to the nutria herbivory (Genesis laboratories, 2002). Carter *et al.* (1999) developed a model that integrates nutria herbivory activities with the marsh-area losses. In conjunction with the result of the bioeconomic nutria supply model, the model by Carter *et al.* (1999) will serve as the basis for calculating the changes in wetland deterioration associated with different market incentive programs.

4.2.1. The Nutria-Biomass-Area Model (NBA) Description

This model comprises three components: the nutria population component, the vegetation biomass component, and the area loss component. The Nutria-Biomass-Area Model (NBA) model simulation starts with 20-hectare plot and an initial nutria population size of 40 individuals, half males and half females.²⁶ The biomass component is divided into two sub models: one for *Spartina patens* and the other for *Scripus americanus*. Data on the aboveground biomass of the two species in the protected plot in brackish marsh were used to fit the model. The loss of marsh area starts when the vegetation density falls below some pre-assigned critical density (1,800 kg/ha). Marsh losses associated with nutria herbivory activities are assumed to be permanent (Carter *et al.*, 1999).

²⁶ One of the primary limitations of the simulation model used in the current analysis (i.e., Carter *et al.*, 1999) reflects the 20-hectare plot constraint. Specifically, one would hypothesize that as vegetation falls below some critical level, nutria would move out of the plot into adjoining plots. Movement of nutria to contiguous plots is not a function of the model and, hence, is not considered here. The reader, however, should be aware of this

4.2.2 The Marsh Losses and Bounty Programs

The original version of the NBA model did not account for mortality due to a direct removal of nutria individuals through trapping. The harvest sector, while present in the model, was not active. For purposes of the current analysis, the harvest sector was activated and the three month-trapping season was converted to a thirteen week span with one-week intervals. The standard values of some of key parameters in the model along with their respective ranges are presented in Table 4-4.

Table 4-4: Standard Values of Selected Parameters used in the Simulation and Their Possible Ranges (the Standard Value is the Default Value used in the Simulation).

Parameters	Standard Value	Range
Young per Female	6	3-14
Gestation Period	19 weeks	15-25 weeks
Time to Maturity	20 weeks	5-50 weeks
Initial Juvenile	0	0-10
Initial Available Females	10	0-40
Initial gestation females	10	0-50
Individual Biomass Need ^a	96.25kg	0-204kg
Impregnation Rate	Density Dependent	12.5-100%
Critical Vegetation Density	1800kg per hectare	0-1800kg per Hectare
Adapted from Carter <i>et al.</i> (1999)		

^a This value is calculated under the assumption that the biomass-destroyed-to-consume ratio is 10 to 1.

The time of the year where the harvest sector is active is chosen to represent the period when phonology biomass growth of both species on the site is a minimum. Harvest season starts at week 35 and is completed after week 48 every year. The first week of harvest starts when the nutria population number reaches 72 per 20 hectare, which is equivalent to nutria density of 3.6 per hectare (Carter *et al.*, 1999). In order to obtain the expected harvest on a 20-hectare plot, the predicted harvest at each price level in 2002 (as discussed in Section 4.1.2) is

limitation when considering expected wetland impacts associated with different bounties and the related benefit/cost analysis.

multiplied by 20 and divided by 13 to obtain the equivalent harvest on a weekly basis. The harvest is assumed to be constant during the five-year simulation period.

Consistent with Carter *et al.* (1999), the model is considered to be sensitive to a parameter if a change in this parameter changes the timing of the marsh loss by more than 10 weeks. The model is then used for simulation purposes assuming no bounty and various bounties ranging from \$4.00 to \$18.00 per animal (the \$18.00 bounty is approximately that which yields MSY). Of primary interest to the current analysis is the remaining marsh area at the end of each year and the time it takes for the marsh to collapse (i.e., the marsh area falls below ten percent of the original 20-hectare area).

In 2002, under a “no bounty” program, the real price received per pelt is \$1.38 and the predicted harvest per hectare is 0.05145 (69,790 nutria pelts), which is equivalent to harvesting 0.07915 nutria per week per 20-hectare area. Carter *et al.* (1999) define that the marsh collapses when the plot area falls below 10% of its original level. Using the same definition, the marsh collapses at week 46 of the third year under the assumption of no bounty in 2002²⁷. With the \$4.00 bounty, the predicted harvest is 0.21547 and the weekly take is 0.3315 per 20-hectare area. Though the \$4.00 bounty is found to retard marsh loss, it does not prevent the marsh collapse that occurs in the last week of the third year (Figure 4-3). The \$4.00 bounty postpones the collapse by approximately six weeks.

When the bounty is increased to \$6.00 (and the predicted harvest per hectare is 0.32601) the crash is avoided in the third year but is merely postponed to week 23 of the fourth year. With a bounty of \$8.00 per animal, the marsh crash is postponed by an additional one-half year (week 52 of the fourth year) when compared to a bounty of \$6.00.

²⁷ Given that the season extends from December to February, the 2002-2003 season is simply referred to as the 2002 year in the current analysis.

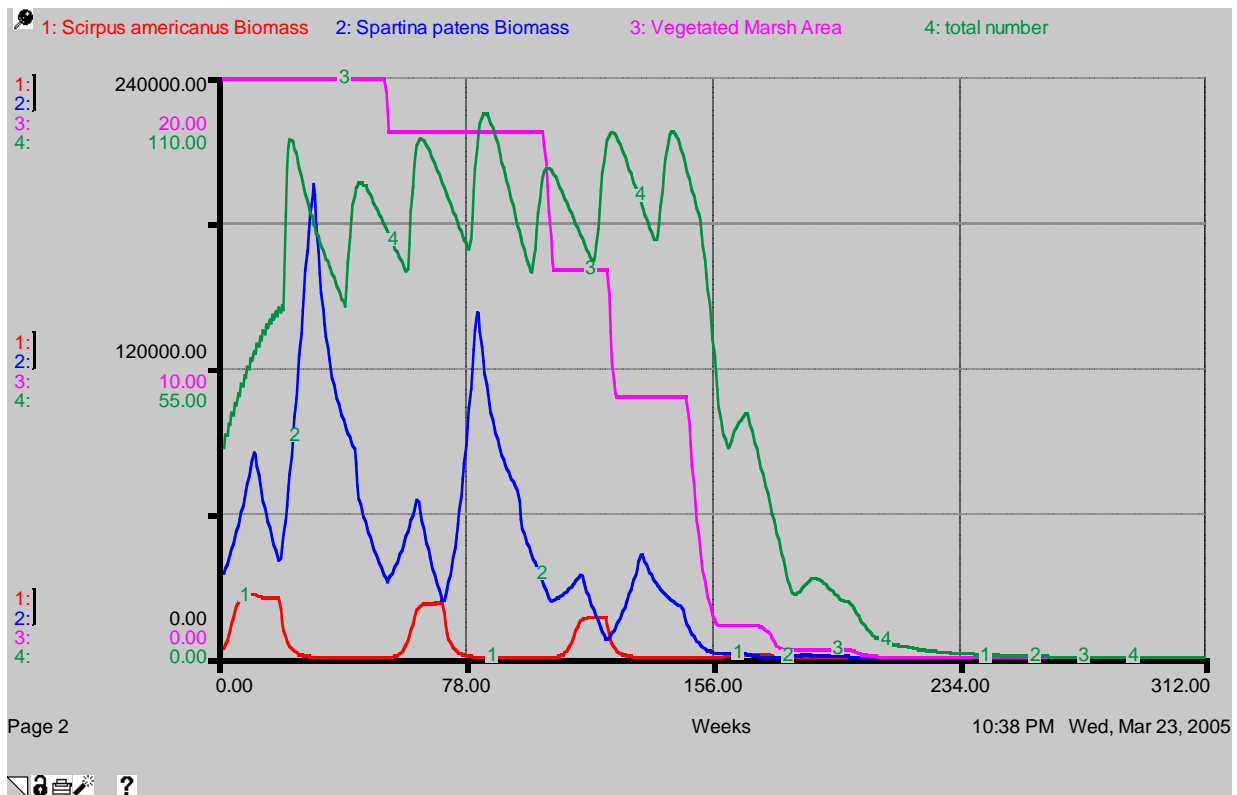


Figure 4-3. Example of Graph Simulation Illustrating Changes in Plant Biomass, Nutria Numbers and Vegetated Marsh Area under Four-Dollar Bounty.

Finally, with a \$10.00 bounty, the marsh crash occurs at the end of year five. The marsh area collapse is totally avoided at any bounty in excess of \$10.00. These findings, and others associated with higher bounties, are summarized in figure 4-4, where the vertical-axis represents the number of remaining hectares each year, and the horizontal axis represents the time horizon.

Based on Figure 4-4, one observes a decreasing trend in the marsh loss (an increasing trend in the remaining wetland acreage) in association with an increase in bounty. Using the standard basic values of all biological parameters in the NBA model, it appears that increasing the bounty postpones marsh collapse. The crash occurs within three years under no bounty and \$4.00 bounty, within four years for \$6.00 and \$8.00 bounties, and within five years associated with a \$10.00 bounty. When the bounty level exceeds the \$10.00 threshold,

an eventual collapse of the marsh area is completely avoided. Over the 5-years simulation period, the marsh area remains at approximately 10 hectares for \$12.00 bounty and above 15 hectares for higher bounties.

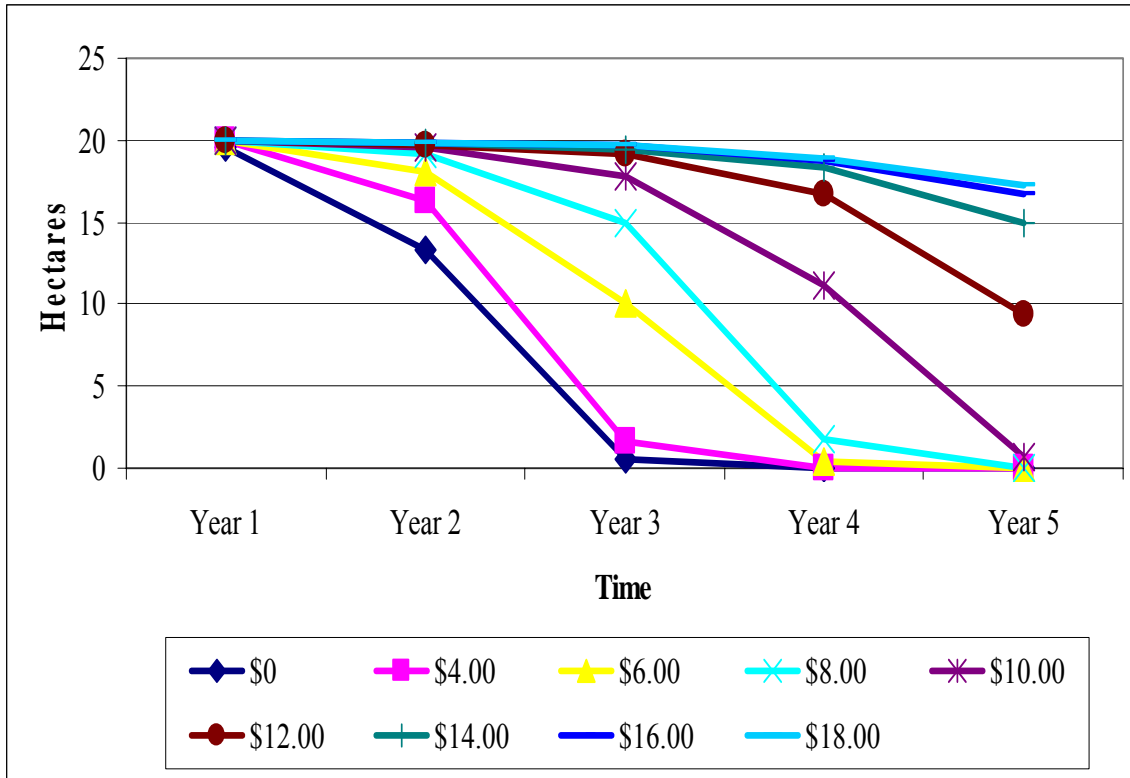


Figure 4-4: Estimated Wetland Losses in Relation to Various Bounties and a Biomass Destroyed-to-Consumed Ratio of 10:1 (BDCR=10/1)

4.2.3 Sensitivity Analysis

Carter *et al.* (1999) found that nutria-biomass-area model is sensitive to the nutria weekly biomass requirement and week-to-maturity. They also found the NBA model to be sensitive to critical density (the density at which the marsh loss starts) under high and low ranges of the weekly nutria biomass requirements. Standard values for these parameters were employed in the previous simulations. In this section, the NBA model responses to different bounty programs are examined when the standard values associated with these key parameters (and others) are varied.

1-Varying the Biomass Destroyed-to-Consumed Ratio: Nutria feeding behavior tends to be wasteful. It is estimated that nutria waste more than 90% of the plant materials while they are feeding on the bases of plants (Taylor *et al.*, 1997). To account for this waste, Carter *et al.* (1999) used 10 to 1 ratio as the standard value for the biomass destroyed –to-consumed ratio (i.e., ten kilograms of the plants are destroyed for every kilogram consumed). The researchers also assume, as a matter of convenience, that adult nutria destroy twice as much vegetation as is destroyed by young nutria. In this sensitivity analysis, the biomass destroyed –to-consumed ratio is varied from a 10:1 to an 8:1 ratio in order to analyze changes in marsh loss associated with changes in the assumed biomass destroyed-to-consumed ratio.

Assuming that the biomass destroyed –to-consumed ratio(BDCR) is 9:1 postpones the marsh area crash by more than a year under the scenario of no bounty. No crashes of the marsh area were observed during the 5-year simulation period associated with bounties of \$4.00 or more. The marsh area remains intact when the bounty level is greater or equal to \$10.00 (see Figure 4-5).

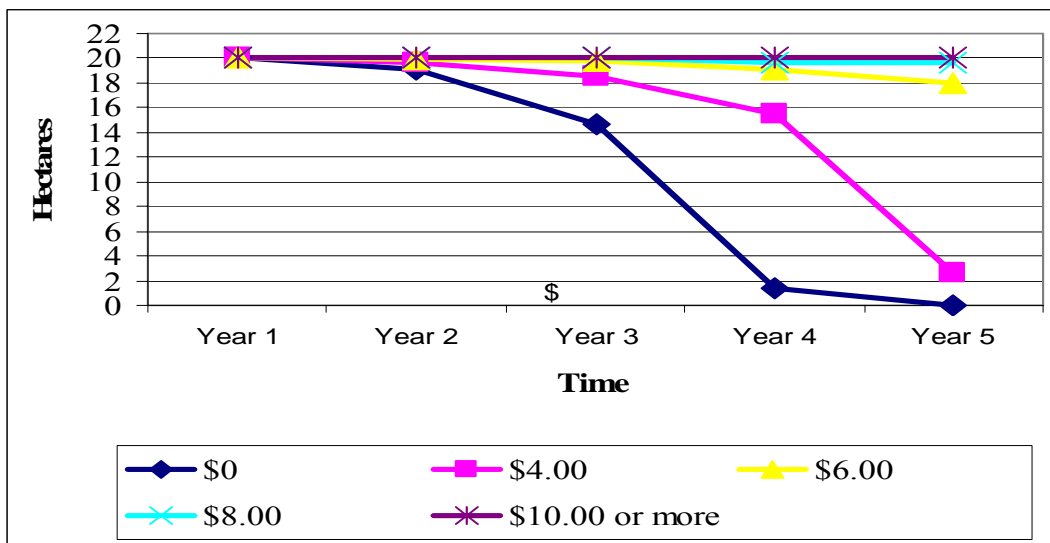


Figure 4-5: Estimated Wetland Losses in Relation to Various Bounties and a Biomass Destroyed-to-Consumed Ratio of 9:1 (BDCR=9/1)

If nutria destroy eight or less times what they eat, then the marsh area is approximately stabilized at 20-hectare under bounty or no bounty scenario. In general, one can conclude that the model is very sensitive to the weekly amount of biomass requirement, and if it happens that nutria destroy only nine times of what they eat, then an \$8.00 bounty is satisfactory for maintaining marsh stability.

2-Time-to -Maturity: Nutria reach sexual maturity at an early age; generally before they reach full growth. The average age when nutria reach sexual maturity, however, varies from season to season and depends, in part, on food availability (Atwood, 1950; Evan, 1970; Newson, 1966). In this model, the standard value for time-to-maturity variable is 5 months (20 weeks) and this variable can vary from between three to nine months. For this sensitivity analysis, different ranges of time-to-maturity variable are used to replicate its effect. The model results associated with a \$4.00 bounty are presented in Table 4-5.

Table 4-5: Time-to-Maturity Sensitivity Analysis: The Remaining Marsh Area at the end of each Year Given a Four-Dollar Bounty.

Year	Time-To-Maturity			
	3 Months	5 Months	6 Months	9 Months
Year 1	20	20	20	20
Year 2	4.3	16.28	18.96	19.41
Year 3	Crash at Week 20	Crash at Week 52	14.78	19.39
Year 4	Crash	Crash	Crash at Week 51	19.19
Year 5	Crash	crash		18.39

As indicated, the model appears to be sensitive to the variations in the time-to-maturity variable. When the time to maturity is five months, the marsh area crashes at the last week of the third year and the marsh area crashes earlier (week 20 of the third year) when a three months to maturity age is assumed. However, the marsh area remained above 18

hectares during the simulation period when the time-to-maturity is assumed to equal nine months. Carter *et al.* (1999) found that the marsh losses are highly influenced by the changes in time-to-maturity because intra-annual variation of the population size can put pressure on the marsh biomass at critical time.

3- Varying the Critical Density: The standard value used for the critical density in the model is 1800kg. In other words, permanent marsh loss starts only if the vegetation density drops below this value. Changing the critical density to 1600 kg postpones the marsh crash by 20 weeks under the \$4.00 bounty program. The marsh area stabilized at 20 hectare during the five years simulation if the critical density is assumed to be 1400 kg.

4- Changing the Pregnancy Rate: In the standard model, the pregnancy rate is a function of nutria density. For purposes of sensitivity analysis, the pregnancy rate was permitted to vary from 40 percent to 80 percent. There was little impact associated with pregnancy rate on remaining marsh area at the end of each year as well as the time it takes for the marsh area to collapse. The marsh area collapses at the same time (week 51 of the third year) when the pregnancy rates varied from 40% to 80% and when the pregnancy rate was density dependent, the marsh area crashes at week 52 of the third year (Table 4-6).

Table 4-6: Pregnancy Rate Sensitivity Analysis: The Remaining Marsh Area at the end of each Year of the Simulation at Four-Dollar Bounty.

Year	Pregnancy Rate			
	Density-Dependent	40%	60%	80%
Year 1	20	19.95	18.81	20
Year 2	16.28	14.64	15.72	16.18
Year 3	Crash at Week 52	Crash at Week 51	Crash at Week 51	Crash at Week 51
Year 4	Crash	Crash	Crash	Crash
Year 5	Crash	Crash	Crash	Crash

5-Varying the Number of Young per Female: Changing the number of young per female from six to twelve advances the time the marsh collapse by approximately a half year suggesting that the model results are not “highly” sensitive to the number of young per female.

The positive impacts of various market incentive programs in the form of bounties can be observed by examining the amount of remaining wetlands over the period of simulation. As the bounty increases, the preserved hectares increases and time to collapse is postponed (see Figures 4-4 and 4-5).

It appears that prevention of a complete collapse of the marsh during the five-year simulation period is unlikely for any bounty less than \$10.00 when the standard value of the biological parameters in nutria-biomass-area model are utilized in the analysis,. This conclusion, however, is sensitive to changes in the values used for certain parameters in the model such as the biomass destroyed to consumed ratio, critical density, and the week-to-maturity. It is not sensitive to changes in the number of young per female and the pregnancy rate. Model sensitivity was not conducted for other parameters such as gestation period and the adult and juvenile survival rates since previous simulations did not indicate the area loss to be sensitive to these parameters (Carter *et al.*, 1999).

These simulations also suggest that implementing \$4.00 bounty, while retarding the rate of wetland loss, will most likely not prevent the crash of the marsh area. If the biomass destroyed-to-consumed ratio (BDCR) is 10 to 1, the collapse occurs at the end of the third year. However, when the BDCR is 9 to 1 then the crash is merely avoided during the five years simulation and the remaining marsh area at the end of year five is 2.58 hectares. If the critical density is less than 1,600 kg/ha or the week-to-maturity variable is adjusted

significantly up to nine months then the crash of the marsh area is avoided under the \$4.00 bounty for the five-year simulation and the total marsh area is reduced by a small amount at the end of the last year of the simulation.

4.2.4 Cost/Benefit Analysis

The purpose of benefit/cost analysis is to ascertain the change in benefits associated with any given project and to compare these additional benefits to the project costs. If the benefits exceed costs, there are positive net benefits which imply that the value society gains from the project exceed the costs to society in furtherance of the project (i.e., resources being given up). Conversely, if costs exceed benefits, the resources being given up by society in furtherance of the project exceed (i.e., costs) are greater than the value (benefits) of the project to society.²⁸

Given that wetlands provide benefits to society, retarding or eliminating the loss in wetlands associated with nutria “eat-outs” reflect benefits. For purposes of this study, the marginal benefit associated with each bounty level is defined as the present value of the number of hectares which are preserved due to this bounty each year during the five-year simulation period.²⁹

Based on an analysis by Farber (1996), the implied wetland value of wetlands to commercial fishing activities is equal to \$156 per hectare (based on 2000 dollars), at the margin. In other words, the marginal value of commercial seafood production can be expected to decline by \$156 for each hectare lost due to nutria “eat outs” (or other reasons). This per hectare basis value is used to compute the marginal (or more precisely given the

²⁸ A detailed discussion of benefit/cost analysis can be found in any advanced environmental economic and/or welfare text, such as Kolstad (2000) or Just *et al.*(1982).

discrete change, incremental) benefits associated with each bounty level.³⁰ The present value of the marginal benefits is estimated as follows:

$$PVMB=156* \sum_{i=1}^{i=5} (X_{bi} - X_{nbi})/(1+r)^i \quad (1)$$

where:

PVMB is the present value of the marginal benefit of the corresponding bounty;

X_{bi} is the remaining hectares at the end of year i if there is bounty;

X_{nbi} is the remaining hectares at the end of year i if there is no bounty;

r is the discount rate, assumed to be 3% for the current study.

To calculate the marginal benefits associated with each bounty, the yearly number of hectares remaining under the “no bounty” scenario is subtracted from the remaining hectares associated with each bounty, the results for which are presented in Tables 4-7 (assuming a BDCR of 10:1) and 4-8 (assuming a BDCR of 9:1). Values of other parameters used in the simulation model reflect those used in the ‘standard’ model.

Tables 4-7 and 4-8 show an increase in the total number of hectares protected over the 5-years simulation period in association with an increasing bounty. When the BDCR is 9:1 then the area stabilizes at 20 hectares when the bounty is \$10.00 or more. So the protected number of hectares due to these bounties remains the same. Given the fact that the cost will increase as

²⁹ In theory, benefits (or costs) should be extended indefinitely if they continue to accrue. Such a procedure could not be conducted, however, given built-in constraints associated with the simulation model used in the current analysis..

³⁰ Benefits considered for this study are limited to those related to commercial fishing activities. Furthermore, estimates provided by Farber (1996) reflect the marginal value product of additional (reduced) wetland acreage, not increases (decreases) in producer and consumer surplus. While changes in producer and consumer surplus represent the true change in benefits, these estimates are unavailable. Almost certainly, however, producer and consumer surplus is less than marginal value product; perhaps by a significant amount.

the bounty level increases then implementing a bounty level higher than \$10.00 is not economically optimal if the BDCR=9:1. This point is considered below in more detail.

Table 4-7: Yearly Preserved Hectares per Bounty with an Assumed Biomass-Destroyed-to-Consumed Ratio (BDCR) equal to 10:1.

Year	Bounty							
	\$4.00	\$6.00	\$8.00	\$10.00	\$12.00	\$14.00	\$16.00	\$18.00
Year1	0.38	0.38	0.38	0.38	0.38	0.38	0.38	0.38
Year2	3	4.79	5.91	6.25	6.44	6.55	6.61	6.62
Year3	1.19	9.54	14.51	17.27	18.61	19.01	19.16	19.21
Year4	0.04	0.33	1.71	11.14	16.68	18.28	18.73	18.85
Year5	0	0.01	0.04	0.73	9.38	14.91	16.71	17.22

Table 4-8: Yearly Preserved Hectares per Bounty with an Assumed Biomass-Destroyed-to-Consumed Ratio (BDCR) equal to 9:1.

Year	Bounty			
	\$4.00	\$6.00	\$8.00	\$10.00 or more
Year1	0	0	0	0
Year2	0.59	0.91	0.94	0.94
Year3	3.95	5.06	5.34	5.34
Year4	14.03	17.71	18.26	18.6
Year5	2.54	18	19.62	19.96

Assuming that there is relatively well defined property rights associated with the harvest of nutria, the area under the long-run supply curve will equal the costs of production (Figure 4-6).³¹ The bounty represents merely a transfer payment from the government to the

³¹ The majority of Louisiana wetlands are privately owned and the landowner can allow or deny entry on the property as he sees fit. Hence, there is a certain amount of control over trapping activities. As control over these activities increase, one would expect the area under the supply curve to accurately reflect the true costs of production.

trapper and does not represent a “true” cost in benefit/cost analysis since it does not incur use of scarce resources.

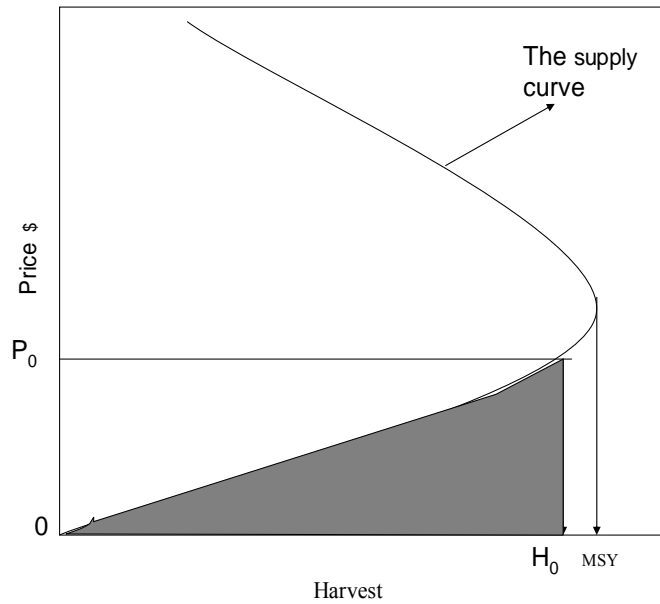


Figure 4-6: A Graphical Illustration of the Marginal Cost Associated with Implementing a Bounty.

The annual marginal costs (MC) are defined as:

$$MC = 20 * (TR - \int_{p=0}^{p=p_0} \text{Harvest_per_hectare} dp)$$

where:

TR is total revenue (TR = p * Harvest_Per_hectare).

$\int_{p=0}^{p=p_0} \text{Harvest_per_hectare} dp$ is the area between the supply curve and the bounty

price level (p = p₀).

The aggregate present value of annual marginal costs (PVMC) over the five-year simulation is expressed as:

$$PVMC = MC * \frac{1}{p^5} \times \frac{(1 - p^5)}{(1 - p)} \quad (2)$$

MC is the annual marginal cost.

$p = r + 1$ where r is the discount rate, assumed to equal 3% for the current analysis.

At a \$4.00 bounty, total annual marginal costs on the 20-hectare plot (i.e., the area under the long-run supply curve) were estimated to equal \$19.25 or \$88.00 over a five-year time horizon (using a discount rate of three percent). Based on equation (1), the marginal benefit to society associated with the \$4.00 bounty is estimated to equal \$675 when a BDCR ratio of 10:1 is assumed and \$2,868 when a BDCR of 9:1 is assumed.

The marginal benefits and costs for alternative bounties are presented in table 4-9. The marginal benefits are provided under two scenarios; the first being an assumed biomass destroyed-to-consumed ratio is 10:1 and second being an assumed biomass destroyed-to-consumed ratio is 9:1.

Table 4-9. Benefit/Cost Analysis Based on the Reduction in Marginal Value Product of Commercial Fishing Associated with Wetland Loss due to Nutria Damage.

Bounty	Costs	Benefits	
		BDCR= 10/1	BDCR= 9/1
\$4.00	\$88	\$675	\$2,868
\$6.00	\$99	\$2,173	\$5,649
\$8.00	\$162	\$3,236	\$5,985
\$10.00	\$232	\$5,034	\$6,076
\$12.00	\$288	\$7,148	\$6,076
\$14.00	\$344	\$8,179	\$6,076
\$16.00	\$369	\$8,511	\$6,076
\$18.00	\$382	\$8,604	\$6,076

As the information presented in Table 4.9 indicates, the benefits to commercial fishing activities associated with alternative bounties appear to be larger than the costs associated the different bounty levels.³² Given that wetlands provide many other economic services in addition to the commercial fishing value, the total benefits associated with implementing a certain bounty level would certainly be much larger.³³

Table 4-10 presents incremental changes in marginal costs and benefits due to a movement from one bounty to another. When the bounty increases from \$4.00 to \$6.00, the change in marginal cost is \$11 and the change in marginal benefits varies from \$1,498 to \$2,781, based on the assumed BDCR. Therefore, increasing the bounty from \$4.00 to \$6.00 is economically beneficial. When the bounty changes from \$8.00 to \$10.00, the change in marginal benefits (\$91) slightly outweighs the change in marginal costs (\$70) using 9 to 1 BDCR. If the level of the bounty exceeds \$10.00, there is no change in the marginal benefits while the costs continue to increase assuming that the BDCR is 9 to 1. Based on a 9 to 1 BDCR, establishment of a bounty in excess of \$10.00 does not appear to be beneficial. Using both biomass ratios, the highest net benefit-cost ratio is achieved when the bounty level increases from \$4.00 to \$6.00.

³² Technically, one should subtract out the “status quo” condition (i.e., conditions that would occur under the “no bounty” scenario) to obtain marginal benefits and marginal costs. Since harvest is extremely limited under the status quo condition (approximately 20-thousand nutria), this calculation was not performed.

³³ This statement should be qualified in the sense that, as previously noted, the value of wetlands to commercial fishing reflects the marginal value product of additional (less) acreage, rather than the gain (loss) in producer and consumer surplus associated with the change in acreage.

Table 4-10. The Incremental Changes in the Benefits and Costs Based on the Lost Values of Commercial Fishing

The Changes in the Bounty level	The marginal Changes in the Cost	The Marginal Changes in the Benefit	
		BDCR= 10/1	BDCR= 9/1
\$4 to \$6	\$11	\$1,498	\$2,781
\$6 to \$8	\$63	\$1,063	\$336
\$8 to \$10	\$70	\$1,798	\$91
\$10 to \$12	\$56	2,114	\$0
\$12 to \$14	\$56	1,031	\$0
\$14 to \$16	\$25	332	\$0
\$16 to \$18	\$13	93	\$0

CHAPTER 5: CONCLUSIONS AND RECOMENDATIONS

Nutria were introduced to Louisiana in 1938. Within a few decades, nutria took a prominent place in the Louisiana fur industry. In 1962, nutria passed muskrat for the first time in Louisiana's fur history in term of quantity and revenues received by the trappers (Lowery, 1974). Nutria continued to play a vital role as a source of income to the Louisiana fur industry for the following two decades with an average of 1.5 million pelts being harvested annually during the 1970-82 period. This harvest pressure was sufficient to keep the population at a level commensurate with the surrounding wetlands environment. For reasons not fully understood, the demand for nutria pelts, and the associated price received for the harvested product, fell sharply during the early-to-mid 1980's and has yet to recover. The decline in price quickly translated to a decline in harvesting activities, a sharp reduction in the quantity being harvested, and an increasing nutria population. Empirical evidence suggests that the nutria population is "excessive" in relation to what can be supported by the surrounding wetlands environment. As such, nutria herbivory activities are increasingly impacting Louisiana's coastal wetlands (approximately 80 thousand acres are reportedly being degraded as a result of nutria feeding activities. (Marx *et al.*, 2003)).

Understanding the factors that influence the long-run harvest of nutria, assessing the use of economic incentives to influence harvest levels, and examining the benefits and costs associated with using these economic incentives provides the primary focus of this thesis. Given this focus, a nonlinear regression technique is first used to model long-run industry harvest as a function of the harvest price, alligator population density, weather conditions, and unemployment rate. Model results associated with the analysis appear to closely replicate

historical patterns and the signs associated with the estimated parameters tend to conform with economic theory and are statistically significant. The long-run industry supply increases with an increasing price until MSY is reached at which point further price increases result in a decline in long-run harvest. Specifically, at relatively low prices, harvest increases at a decreasing rate with respect to price, reaches a maximum at a price approximating \$18 per pelt, and declines with respect to prices in excess of that in excess of that needed to produce MSY. Harvest approaches zero asymptotically when the price level increases indefinitely. The maximum sustainable yield was found to be approximately 2.1 million pelts in the early-1970's but has subsequently declined due to a combination of declining wetland acreage and an increasing alligator population. When all exogenous variables with the exception of price are held at their mean levels, MSY is found to equal approximately 1.5 million pelts.

Harvests for 2002 and 2003 are predicted at alternative economic incentives (bounties) ranging from \$4.00 to \$18.00. The average predicted harvest for 2002-2003 under a \$4.00 bounty program is approximately 295 thousand animals while a \$18.00 bounty results in an estimated harvest of 922 thousand animals. The average value for the actual harvest for the two years under the \$4.00 bounty program was 218,000 animals which closely approximates the predicted harvest.

To examine the impacts that alternative bounties would have on retarding wetland loss, a simulation model developed by Carter *et al.* (1999) was employed in the analysis. Results from this exercise suggest that an increasing bounty yields an higher remaining hectares each year and a postponement in the time it takes for the marsh area to collapse . A \$4.00 bounty is found to retard marsh loss, but it does not prevent an eventual crash of the marsh area which occurs at the last week of the third year. The marsh crashes in the middle of

year four for \$6.00 bounty and at the end of years four and five for \$8.00 and \$10.00 bounties, respectively. Eventual crash of the marsh area is completely avoided only at bounties exceeding \$10.00.

Investigating the sensitivity of the results by changing standard values of one or more key model parameters reveals that the results are highly sensitive to changes in the biomass-destroyed-to-consumed ratio (BDCR), the critical density, and the time-to-maturity variable. Conversely, results do not appear to be sensitive to changes in pregnancy rate and young per female.

Changing the BDCR to 9/1 postpones the crash timing of the marsh area by more than a year under the “no bounty” scenario and the collapse of the marsh area is avoided with even the lowest considered bounty (i.e., \$4.00 per pelt). The marsh area remains at approximately 18 hectares at the end of the simulation period for \$6.00 bounty while the area remains almost stable at 20 hectares for a bounty of \$8.00.

Implementing the traditional cost-benefit analysis with respect the different bounties suggests that the benefits to commercial fishing activities associated with alternative bounties appear to be significantly larger than the costs.³⁴ However, the magnitude of the benefit-cost ratio varies considerably with changes in the standard values of key parameters introduced into the Nutria-Biomass-Area model. In this thesis, the benefit-cost analysis is investigated using 10:1 and 9:1 biomass destroyed-to-consumed ratios. When the BDCR is 10:1, the incremental benefits associated with the \$4.00 bounty over the 5-year simulation period equal \$675 while the incremental costs equal \$88. The incremental benefits increase bounty increases to reach

³⁴ A *caveat* associated with this statement is in order. Specifically, benefits of wetlands to commercial fishing were measured via the marginal value product of wetlands to output rather than the more justifiable changes in consumer and producer surpluses. Estimates of consumer and producer surplus, however, are unavailable.

\$8,604 at \$18.00 bounty. If the BDCR is 9:1, the incremental benefits are \$2,868 at the \$4.00 bounty and remain constant at \$6,076 after a \$10.00 bounty is reached. This is due to the fact that the marsh area will stabilize over the 5-years simulation period at a bounty of \$10.00 or more when the BDCR is 9:1.

Some policy implications can be drawn from the results of this analysis. While relatively high prices received for the harvested pelts prior to mid 1980's kept nutria in check with their environmental capacity, the subsequent decline in price culminated in an increased nutria population and a concomitant increase in wetland degradation (harvest level dropped to reach as low as 20 thousand in 1999-2000 season). In an attempt to reduce the standing nutria population via increased harvests, the State, with assistance from the Federal government, instituted a \$4.00 bounty program in 2003 with the goal of increasing harvest to 400 thousand animals annually. The results of this study suggest that a \$4.00 bounty is insufficient to encourage the level of trapping effort which would be required to maintain a 400 thousand animal annual take. With less certainty, the results also suggest that a \$4.00 bounty is insufficient if one of the goals of the bounty program is to significantly curtail wetland degradation caused by nutria herbivory activities. If the goal of the bounty program is to retard all wetlands damages due to nutria feeding, then a bounty level of \$16.00 or above might be warranted when the BDCR is 10:1. On the other hand, sensitivity analysis shows that to reach the same goal a bounty level of \$8.00 or more is enough if the BDCR is equal to 9:1.

Though the overall outcome of this research appears encouraging, it needs to be emphasized that these results should be used with a certain amount of caution due to the limitations of the Carter *et al.* (1999) biological model. Some of these concerns and limitations include:

- 1- The lack of real data on the biomass destroyed-to-consumed ratio and the density at which the marsh area starts to break down.
- 2- The 20-hectare plots used in the simulation are closed systems with no migration of nutria into or out of the area as the condition of the wetlands deteriorate (improve). If nutria migrate from an area before the complete elimination of vegetation, the impact across a broader range of wetlands may differ from that estimated in the simulation experiment.
- 3- The simulation model was constructed for only one type of ecosystem where nutria are found, i.e., brackish marsh. The biomass measurement for both species is based on an enclosed brackish marsh plot. This may differ from the biomass in fresh or intermediate marshes.
- 4- The density at the beginning of the first year harvest season is assumed to equal 3.6 per hectare. The results of this simulation may change if the nutria density is higher or lower.

Some of these limitations are lessened by investigating the sensitivity analysis of the results which shows how the results are expected to change when the value of one or more key variables is changed. Currently, an enhanced version of the nutria-biomass-area model is being constructed which (a) considers a variety of marsh types and (b) allows for increased flexibility of nutria migration in association with marsh degradation (Carter, 2004; Delozier, 2004). As this model is put in place, some key obstacles of this research will be overcome and more precise and better results will be achievable.

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APPENDIX

MODEL DIAGNOSIS

The supply model estimated in this thesis is nonlinear model. The model functional form is estimated using OLS procedures. For Ordinary Least Squares procedure to be consistent, the following key assumptions have to be met.

1- The error term are normally distributed with mean zero and a constant variance σ^2 .

$$\varepsilon_i \rightarrow N(0, \sigma^2).$$

2- The random errors ε are statistically independent. So, $\text{Cov}(\varepsilon_i, \varepsilon_j) = 0$, $i \neq j$ (Freund and Wilson, 1997).

To investigate these assumptions, the error term of the model is exposed to series of diagnostic tests and the results of the analysis are presented in the next section.

1. Normality

One of the most powerful tests for assessing the normality assumption is the Shapiro-Wilk W test (Shapiro and Wilk, 1965). This test assumes that under the null hypothesis, the error terms ε are normally distributed. Using the p-value of this test (0.1080), normality assumption is satisfied in this analysis.

Exhibit 1: Normality Diagnosis

Test	Statistics	Pvalue
Shapiro-Wilk	0.95215	0.2130

2. Heteroscedasticity

White (1980) developed a test of error's heteroskedacity. The test assumes that the error terms are normally distributed and evaluates whether the variance is constant across observations.

The null hypothesis is:

$H_0 : \sigma^2_i = \sigma^2$ for all i , against the alternative that they are not equal. Based on the p-value of White test (0.2130), we conclude that the null hypothesis of constant variance can not be ruled out.

Exhibit 2: Heteroscedasticity Diagnosis

Test	Statistics	DF	Pr>Chi_sq
White test	30.31	25	0.2130

3. Autocorelation

One of the underlying assumptions of OLS is that the error term corresponding to different observations are uncorrelated ($Cov(\varepsilon_i, \varepsilon_j) = 0$). The variance covariance matrix is a diagonal matrix with σ^2 on the diagonal ($cov(\varepsilon) = \sigma^2 I_t$, where I_t is the unitary or identity matrix). In a model that uses time series data, it is very common to find that the error terms are not independent due to the nature of the data collection process. This phenomenon is known as autocorrelation or serial correlation (Griffiths et.al 1993). To check whether there is evidence of serial correlation in the nutria supply model, a Durbin-Watson test (DW) values for the first, second, third orders are computed and reported in the output. Using 5% level of significance, all DW-test values are within the inconclusive range of rejecting the null hypothesis that the error terms are over time correlated. Hence, one can conclude that there is no strong evidence of the existence of serial correlation in the model based on the statistical values of DW test.

Exhibit 3: Serial Correlation Diagnosis

Order	Durbin-Watson Statistics
First	1.56
Second	2.03
Third	2.55

4. Multicollinearity

Multicollinearity occurs when one or more of the independent variables in multiple regression are highly correlated (Freund and Wilson, 1997). Multicollinearity does not influence the bias of the OLS estimators, but it inflates the coefficient and the variance and making the estimators inefficient (McGuirk *et al.*, 1993). There are several statistical sets for detecting the presence of multicollinearity among the explanatory variables, and the most common used ones are the condition index and the variation inflation factor. The condition index (some time referred to as the condition number) is based on principal component analysis and calculated by dividing the largest eigenvalue of the $(X'X)$ matrix with the eigenvalue of the corresponding independent variable. The rule of the thumb is that a condition index value greater than 30 indicates a presence of multicollinearity (Belsley, at el.1980). In this analysis, the highest condition index is 69.3195 which indicates that the model may have a multicollinearity problem but that the multicollinearity is not “extreme”. Investigating the correlation matrix of the explanatory variables reveals that the potential source of this collinearity is a high correlation between the price and the natural log of the price variable (-0.97). However, both price and log(price) were found to be statistically significant in the estimated bioeconomic model, suggesting the multicollinearity between these two variables did not ‘significantly’ influence the results.

Exhibit 4: Collinearity Diagnosis (Correlations of Parameter Estimates Matrix)

	β_0	β_1	β_2	β_3	β_4	β_5
β_0	1	-0.9946	0.9637	-0.4350	0.0680	-0.1981
β_1	-0.9946	1	-0.9764	0.3775	-0.1199	0.2282
β_2	0.9637	-0.9764	1	-0.3954	0.1425	0.2282
β_3	-0.4350	0.3775	-0.3954	1	-0.1201	-0.1511
β_4	0.0680	-0.1199	0.1425	-0.1201	1	-0.3918
β_5	-0.1981	0.2282	0.2282	-0.1511	-0.3918	1

Exhibit 5: Collinearity Diagnosis(Eigenvalue(E), Condition Number(CN), and Proportion of Variation Matrix)

Harvest per Hectare= $\exp\{\beta_0 + \beta_1 \cdot \log(\text{Price}) + \beta_2 \cdot \text{Price} + \beta_3 \cdot \text{Alligator} + \beta_4 \cdot \text{Freeze} + \beta_5 \cdot (\text{Unemployed})\} + \text{Error}$								
	E	CN	β_0	β_1	β_2	β_3	β_4	β_5
β_0	4.2690	1.0000	0.0002	0.0001	0.0003	0.0085	0.0150	0.0009
β_1	1.1256	1.9452	0.0000	0.0000	0.0001	0.0256	0.0012	0.4447
β_2	0.3766	3.3628	0.0001	0.0001	0.0012	0.0277	0.8606	0.0011
β_3	0.1840	4.8105	0.0008	0.0006	0.0028	0.7548	0.0001	0.4896
β_4	0.0539	8.8919	0.0444	0.0001	0.0427	0.0252	0.1119	0.0174
β_5	0.0009	69.3195	0.9544	0.9991	0.9530	0.1582	0.0113	0.0463

5-Misspecification

The RESET test proposed by Ramsey (1969) is a general misspecification test. This test is designed to detect a variety of model misspecifications such as omitted variables and/or an incorrect functional form (Griffiths et.al 1993). In this analysis, the Ramsy test of power 1,2 and 3 is (RESET) is conducted by fitting the square, cubic and fourth term of harvest per hectare predicted values ((Φ_t^2) (Φ_t^3) (Φ_t^4)) into the model as an additional explanatory variable and then re-estimating the model. Then the coefficients of these prediction variables are singly and jointly tested against zero. The results of this test are reported in Exhibit 5.

Exhibit 5: Misspecification Diagnosis (Ramsey’s Reset Test)

Test	P-Value
Reset1	0.0005
Reset2	0.0022
Reset3	0.0041

The P-values associated with the Ramsey's reset tests indicate a possible model misspecification. However, the properties of this test with respect to nonlinear models are not well established and, hence, the validity of these findings with respect to the current analysis are uncertain.

As a conclusion, it seems that there is no evidence of violation of OLS key assumptions such as normality, homogeneous of variance and independency of the error cross observations, However, the set of tests considered in this analysis are just a few of many diagnostic tests which could be considered in a more comprehensive diagnostic analysis.

VITA

Cheikhna Dedah graduated from Lycée d'Aioun (high School) in Mauritania in 1995. In 1996, he joined the Nouakchott University of Economics and graduated in 2000 with Bachelor of Science in economics with concentration on business administration and management .In fall 2002, he enrolled at Louisiana State University, where he is pursuing a degree of Master of Science in the Department of Environmental Studies.