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Temporal and spatial harvest patterns of river otter in Louisiana and its potential use as a bioindicator species of water quality

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TEMPORAL AND SPATIAL HARVEST PATTERNS OF RIVER OTTER IN LOUISIANA AND ITS POTENTIAL USE AS A BIOINDICATOR SPECIES OF WATER QUALITY

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ABSTRACT

Louisiana is the leading state in number of river otters used in reintroduction programs in other states and in the production of pelts. However, habitat loss and degradation have prompted concern about the status of otter populations. This dissertation undertakes a spatial and temporal analysis of river otter harvest activity and examines environmental factors related to monitoring mercury levels in streams in Louisiana. Harvest data for 1957-2004 were analyzed to identify spatial and temporal trends in otter harvest activity. Changes have occurred in the last 20 years in the spatial dynamics of otter harvest in Louisiana, these include an increasing proportion of harvested otters coming from upland parishes in more recent years, and an increase in the proportion of trappers catching otters in that region. Spatial analysis indicated that this shift in harvesting activity has been gradual rather than abrupt. An explanation for this shift could be a greater interest of upland trappers in catching otters because of increasing otter pelt price and a decline in pelt price for other furbearer species. Analyses indicated that a management plan based on spatial control of harvest could be an option in Louisiana, with rice fields and protected areas playing an important role in the management/conservation plan. Temporal analysis suggested that the number of otters harvested 1 and 5 years ago has an impact on number of otters harvested at present time. An autoregressive model was developed to describe this association and to forecast number of otter pelts to be harvested 1 year in the future. The structure identified in the harvest data was used to develop a model to describe the dynamics of the otter populations. The simulation using 4-year and 8-year periods offered a reasonable approximation to the estimated cyclic dynamics of otter population in Louisiana. Mercury levels in otters were compared to levels in fish collected in different streams in Louisiana. Mercury levels in otters were higher than in fish. Otter samples also identified streams where mercury

level in water may require further analysis. These results suggested that a mercury monitoring program based on river otters could be feasible in Louisiana.

CHAPTER 1

RIVER OTTER AS A NATURAL RESOURCE IN LOUISIANA

Uncertainty in resource status and the lack of knowledge of processes governing dynamics of populations are probably the main problems facing managers when trying to define strategies for sustainable use of renewable natural resources (Rosenberg *et al*. 1993). It has been this uncertainty that has generated opposite points of view regarding the real possibilities of achieving a sustainable use of natural resources (Ludwig *et al*. 1993, Rosenberg *et al*. 1993).

Uncertainty, defined as 'the state of knowledge about the relationship between the world, and a statement about the world' (Hunsaker 2001), could have multiple sources when it refers to the status of natural resources. Some sources of uncertainty could be intrinsic, such as poor understanding of the ecology, natural history, or behavior of the species; whereas extrinsic sources also are possible, such as ones originating from environmental stochasticity. For instance, poor knowledge of the reproductive biology of the species being exploited could lead to local or regional extirpation of its populations. Conversely, even if vast information on population dynamics is available, the fact that a harvest rate sustainable under certain environmental conditions could be not sustainable after a shift in those conditions also could drive a population to extinction. It has been noted that, in the face of substantial uncertainty, managers of fisheries resources have been under pressure to maintain high harvest levels despite scientific advice suggesting a decrease in that level (Sissenwine and Rosenberg 1993), resulting in overexploitation of the resource (Rosenberg *et al*. 1993)

Knowledge of population dynamics of secretive animals is usually scarce, which increases the uncertainty about effects of harvest on the population. That is the case for river otter (*Lontra canadensis*), a furbearer species with a long history in the fur trade market.

River otters inhabited much of the North American continent by the time European settlers arrived (Melquist *et al.*2003), and because of the characteristics of its fur, the species became a valuable resource to the settlers, as shown by early records from New England indicating that the species has been traded in the fur market since the 16^{th} century (Melquist and Dronkert 1987). Its economic value resulted in overharvest of otter populations in North America, contributing to extirpation of the species from some areas of its range by the mid 1800s (Armstrong 1972).

River otter also is very sensitive to habitat changes, and otter populations have been affected indirectly by human activities like agriculture, forestry, and industry (Kruuk 1995). Water pollution and habitat modification and loss also are among the most important threats to river otter populations. Drainage of wetlands for conversion into agricultural lands has been an important source of habitat loss for otters (Lowery 1974), but toxic chemicals such as PCBs and mercury have also been blamed for the decline of otter populations (Mason and Wren 2001).

During the 1970s and early 1980s, concern about river otter declines in North America (ESSA, 1978) led many wildlife management agencies to conduct surveys to determine the conservation status of river otter populations. In the United States in the 1970s, the species had been extirpated in 11 states and experienced severe decline in 9 others (Nilsson 1980), which stimulated national and international efforts to expand existing populations and re-introduce extinct populations (Halbrook *et al*. 1996). More than 4,000 otters have been released in 21 states in the United States and 1 Canadian province (Alberta) since the late 1970s through re-introduction projects (Hubbard and Serfass, *in press*), successfully restoring most of the extirpated populations (Raesly 2001).

Louisiana leads the United States as a source for otters to be used in re-introduction projects (Raelsy 2001) and in the production of river otter pelts (Shirley *et al*. 1988). Raesly

(2001) reported that 64% of reintroduction projects released at least some animals from Louisiana, and Linscombe and Kinler (1985) determined that from 1970 to 1982, an average of 7,470 otters were harvested annually in Louisiana. The exploitation of Louisiana otters for restoration projects and pelts mandates reliable and effective management and conservation strategies, particularly addressing the impact of human activities on otter populations (e.g., harvesting and release of environmental contaminants). Understanding these issues is a necessity for management and monitoring programs that are not only concerned with welfare of otter populations, but also with the aquatic ecosystems that support them.

In Louisiana, otter populations have been described as more abundant in coastal areas (Shirley *et al.* 1988, Chabreck *et al*. 1985, Ensminger and Linscombe 1980), although upland parishes also may support large populations (Chabreck *et al.* 1985). Upland parishes differ from the coast geologically, geographically, vegetationally, and in the level and kind of human activities, which could generate different dynamics for otter populations in upland areas. Despite its statewide distribution, the large number of otters harvested every year, and the lack of knowledge of population dynamics, no studies have been conducted on river otters in Louisiana for more than 20 years. General information about its ecology was reported by Lowery (1974), and some detailed information about habitat use, abundance and distribution, and diet have been published (Chabreck *et al*. 1982; 1985, Edwards 1983, Holcombe 1980).

As mentioned above, river otter is among the most important furbearer species in Louisiana, and harvest records per trapping season have been kept almost without interruption since 1914 by the Louisiana Department of Wildlife and Fisheries (LDWF). Starting in 1977, LDWF also began requiring fur buyers and dealers to record directly from trappers the species, approximate date, and parishes for all furbearer species trapped.

Harvesting data are a valuable source of information, particularly when no other sources are available for a particular species. This study presents the analysis of the database kept by the LDWF for the period 1957-2004, focusing on the following variables: number of otters harvested, number of licensed trappers, and number of trappers that caught those otters (otter trappers) each trapping season. Harvesting ratio (otters/otter trappers) per trapping season and parish was estimated and also included in the analysis. Each trapping season was named by the year in which it ended, i.e., if a particular trapping season started December 1 1983, and ended March 31 1984, that trapping season was named ‘1984'. Data were analyzed and summarized at different scales. Pooled data across seasons and parishes were used to summarize data at the state level or for the whole period analyzed, whereas data by parish in each trapping season was used to analyze data at a finer scale. Data analysis also was performed at a regional scale, dividing the state into coastal and upland regions following Linscombe and Kinler (1985).

The following chapters offer an overview of river otter harvest in Louisiana during 1957-2004 describing spatial and temporal trends, and how these harvesting patterns could be incorporated into the development of a management plan for otters in Louisiana. Some insights into otter population dynamics also are presented. Chapter 2 presents a spatial approach in the analysis of the data for 1984-2003. Spatial trends in harvest activity are identified and described. Chapter 2 also evaluates the possibility of developing a management plan for river otters in Louisiana based on the concept of Marine Protected Areas (MPA), which is currently used in the fisheries industry. Chapter 3 focuses on the identification of temporal patterns in harvesting using time series analysis. A simple model is presented to forecast number of river otters harvested one trapping season in the future. Chapter 4 describes the analyses of the same time series for number of otters harvested and relates the structure of this time series to the possible

structure of the actual otter population. A model that describes the possible dynamics of otter populations in coastal Louisiana is discussed.

Chapter 5 describes the analysis of mercury levels in otter tissue in Louisiana and discusses the feasibility of using otters as an indicator species. Regarding water contamination, the fact that otters are fish-eating mammals that can bioaccumulate persistent, waterborne contaminants to levels significantly above environmental concentration (Roos *et al*. 2001, Sjöåsen *et al.* 1997, Halbrook *et al.* 1996, Mason 1989, Mason and Wren 2001, Mason and Mac Donald 1993) creates the potential that otters could be used as a bioindicator species in environmental monitoring programs. The large sample size of carcasses that may be available from harvesting activities across Louisiana provides an excellent opportunity to obtain samples necessary to use otters as a bioindicator species at the state or regional level. Finally, Chapter 6 presents an overview on how the findings of this study could be used as a starting point for the development of a sound management plan for river otters in Louisiana. All the information and results generated by this study could contribute to the development of a spatially explicit model that could be used to predict specific locations in the landscape where otter management or conservation planning efforts, and water quality monitoring programs should be concentrated.

CHAPTER 2

SPATIAL DYNAMICS OF RIVER OTTER HARVEST IN LOUISIANA DURING 1984-2003

The fur trade has played an important role in the economic development of North America since European settlement. In some regions fur trading was only a secondary activity against other economic activities like mining, forestry, or agriculture (Ray 1987); however, in other places like Louisiana, trapping and fur trading continues to be an important activity for the local economy and also has become part of the cultural heritage (Tarver *et al*. 1987).

Louisiana has been for many decades at the top of the list of areas in North American in fur production (St. Amant 1959, Linscombe and Kinler 1985), particularly in the production of river otter pelts, where the state leads the United States in number of pelts produced (St. Amant 1959, Ensminger and Linscombe 1980, Linscombe and Kinler 1985, Shirley *et al.* 1988). Louisiana also has been the main source of live individuals to be released in re-introduction projects across the nation (Raelsy 2001).

Decline of river otter populations was severe during the 19th century (Armstrong 1972), with overharvest as one of the main reasons for that decline. Overharvest is a common issue in natural resource management (Caughley 1977, Getz and Haight 1989, Clark 1990,), sometimes a consequence of lack or inappropriate management plans, but lack of knowledge of the target species is probably the main problem facing conservation and managing agencies. Considering that riparian habitat is key for river otter survival and reproduction (Kruuk 1995, Melquist *et al*. 2003), information on habitat use and availability becomes crucial for the development of conservation and management plans. In this regard, when habitat loss and degradation are ongoing processes, actions should be taken to understand the impact of habitat modifications on river otter populations (Melquist and Dronkert 1987).

Production of otter pelts in Louisiana is high, and it has been associated with the abundance of suitable habitat (St. Amant 1959, Chabreck *et al.* 1985, Linscombe and Kinler 1985). Some concerns about river otter population status in Louisiana as a consequence of habitat loss and degradation were expressed in the 1970s, when large areas covered by forested wetlands in northeastern parishes began to be drained, cleared, or converted to croplands (Lowery 1974, National Research Council 1982). In coastal areas the loss of wetlands and marshes due to coastal erosion (Boesch *et al.* 1994) also could be seen as a potential source of habitat loss. Pesticides and heavy metals have been identified as potentially important agents in river otter habitat degradation in Louisiana (Beck 1977, Fleming *et al.* 1985), but despite these concerns, no studies have been conducted on otters in Louisiana for almost 20 years and, consequently, the status of populations remains unknown.

Declines in habitats, and wildlife and marine harvests have prompted calls in the international community to take actions. Fisheries have taken the lead by developing an Ecosystem Approach to Fisheries (EAF) and encouraging the use of Marine Protected Areas (MPAs) as an integral part of an optimal management system (Balmford *et al.* 2004). Advocates of the implementation of MPAs offer two main arguments for their use, i) MPAs will provide an insurance policy against management failures resulting from lack of knowledge or insufficient understanding of the system being managed, and ii) MPAs and other spatial controls on fishing activities can increase the net sustainable value derived from the resource being managed beyond the value derived if the spatial controls are not adopted (Bonhsack 1993, Holland 2002, Sumaila 1998). Some developments on the idea of spatially structured harvesting strategies for wildlife have been explored by McCullough (1996), but the concept remains unexplored in wildlife management.

There are many reasons that prompt the implementation of a management of plan for river otters in Louisiana: *i*) river otter is an elusive and secretive species, making the knowledge of the species and its populations status limited (Melquist *et al*. 2003), and *ii*) it is a top predator in freshwater systems in Louisiana, representing a potential umbrella species for our conservation efforts of many other species in these ecosystems. Considering the poor knowledge of biological and ecological aspects of this species in Louisiana, developing a management plan based on spatially structured harvesting strategies seems a suitable approach. The urgent need for a management plan for the species is also supported by the fact that the species seems to be heavily harvested in the state and by the uncertainty related to the species response to changes in habitat availability and quality. As a first step in the development of such a plan, in this chapter I analyze spatially referenced harvesting records maintained by the Louisiana Department of Wildlife and Fisheries (LDWF) during 1984-2003 to describe spatial patterns in otter harvesting. The identification and description of these patterns will be a valuable tool in setting the basis for a sustainable use of this charismatic species in Louisiana. There is particular interest in identifying areas of high/low otter production, in knowing if those areas change over time, and in the association of those changes to changes in habitat availability. These findings also could be used as a starting point for future research, particularly in developing hypotheses and research questions, and identifying potential study areas.

Methods

I analyzed river otter harvest data collected by the Louisiana Department of Wildlife and Fisheries during 1984-2003. I used exploratory spatial data analysis (ESDA) techniques (Haining 2003) to summarize data, and to detect patterns and generate hypotheses (Tukey 1977, Good 1983). ESDA techniques could be considered an extension of exploratory data analysis (EDA), and since spatial associations are considered in the analysis, theses techniques will allow

answers to questions such as: Where do the extreme values for a particular variable in a boxplot fall on a map? Where do the areas with highest/lowest variability fall on a map? or, which areas consistently show high/low values for a particular variable? Maps for each trapping season and boxplots for each variable were generated with ArcView (ESRI v3.3 2002) and SigmaPlot 8.02a (Systat Software, Inc. 2002). Because differences in habitats exist between coastal and upland areas (Chabreck *et al.* 1985, 2001), separate boxplots for each region also were generated. To monitor changes in the proportion of otter trappers/licensed trappers each season between coastal and upland areas, significant differences (" = 0.05) were tested using 2-proportion tests (Ott and Longnecker 2001).

Changes in the location of the weighted mean center (Shaw and Wheeler 1988, Levine 2002) were used to identify spatial changes in total number of otter harvested, trappers, and harvest ratio (number of otters/ number trappers who caught those otters) in different parishes during the period analyzed. This is given by

$$\overline{X} = \sum_{i=1}^{n} \frac{W_i X_i}{n} \quad ; \quad \overline{Y} = \sum_{i=1}^{n} \frac{W_i Y_i}{n}$$

where $\overline{X}$ and $\overline{Y}$ represent the mean of all point coordinates X_i and Y_i, respectively, W_i represents the weight variable, and n is the sample size.

From a geographical standpoint, data available for this study represented aggregated data; in other words values of different variables were associated to a polygon (i.e. parish, instead of a point). Thus, to estimate the weighted mean center, aggregated data were transformed into point data by assigning values of each variable associated to a particular parish (polygon) to the centroid (point) of that parish. I defined centroid as the central location within a specified geographic area (e.g., parish). Then, all the parish centroids were used as the set of points from

which to estimate the weighted mean center for each trapping season. In this particular case, each point involved in the mean center estimation was weighted by the focus variable (i.e., number of otters, licensed trappers, harvest rate) in each parish.

The weighted mean center produced a different mean center than the unweighted mean. For instance, by using number of otters trapped in each parish each season as the weighting variable, the mean center was displaced toward areas with greater number of otters harvested. Mapping this mean center for each trapping season allowed me to describe the spatial differentiation in the central tendency of each variable through time. CrimeStat 2.0 (Levine 2002) was used to estimate the weighted mean center, and ArcView 3.3 (ESRI 2002, Spatial Analyst Extension) for centroid identification and graphical display of mappable results.

I used Moran's scatterplot and Moran's *I* (Anselin 1996, Fotheringham *et al.* 2000) to identify global spatial trends across Louisiana in mean number of otters and mean harvest ratio, where global associations could be defined as associations that apply equally across the study area assuming that the relationship being examined does not vary across the study area. Moran's *I* estimates the degree of linear association between a vector of observed values *y* and a weighted average of the neighboring values, or spatial lag, *Wy*. Neighboring values were estimated with the rook's definition of contiguity between parishes (Upton and Fingleton 1985). For details and interpretation of Moran's *I* and scatterplot see Anselin (1996).

To identify areas where total otter harvest and harvesting rate were consistently high over the years, I used the standardized Local Moran's statistic $Z(I_i)$ (Anselin 1995, Fotheringham *et al.* 2000) which focuses on the presence of differences across space rather than assuming that such variations do not exist (Fotheringham *et al.* 2000). This local analysis is applied to each individual point/zone, and the index *I* indicates clustering or dispersion relative to the local neighborhood. Zones with high *I* values have an intensity value that is higher than their neighbors whereas points with low *I* values have intensity values lower than their neighbors.

The equation that describes Local Moran's statistic is given by

$$I_i = \frac{(Z_i - \overline{Z})}{S_z^2} \sum_{j=1}^{n} \left[W_{ij} (Z_j - \overline{Z}) \right]$$

where $\overline{Z}$ is the mean intensity over all observations (n), Z_i is the intensity of observation i, Z_j is the intensity for all other observations, j (where $j \neq i$), S_z^2 is the variance over all observations, and W_{ij} is a distance weight for the interaction between observations i and j. The distance weights between parishes were defined as

$$W_{ij} = \frac{1}{d_{ij}}$$

were d_{ij} is the distance between the centroid of observation zone i (parish i), and another observation j (parish j).

Local Moran's I is a suitable tool for the identification of 'hot spots' and 'cold spots'. Hot spots were defined as zones which are similar to the neighboring zones in terms of the values for the variable being analyzed. Thus, a hot spot could be a region where neighboring parishes have either high or low harvesting rate. Cold spots were defined as areas which were different from their neighborhood in terms of number of otters harvested or harvest rate. Moran's scatterplots and global Moran's I were generated with the software GoeDA v 0.9.5-i5 (Anselin 2004), and Local Moran's I using Crime Stat v 2.0

Results

Twenty one parishes were categorized as coastal parishes following Linscombe and Kinler (1985) (Figure 2.1). A total of 58,019 otters were harvested in Louisiana by 7,341 trappers during the 15 trapping seasons analyzed (see Table 2.1). Boxplots for upland and coastal areas indicated a left skewed distribution of the number of otters harvested each season (Figure 2.2), with the median always being below 200 otters in coastal parishes and below 50 otters in upland parishes. The number of otters harvested per trapper in coastal and upland areas showed a

symmetric distribution in coastal areas and a left skewed distribution in upland parishes (Figure 2.3).

Results from 2-proportion tests indicated that the proportion of otter trappers/licensed trappers in coastal and upland parishes changed throughout time (Table 2.2). Number of otters harvested varied across space and time (Appendix). These maps show number of otters harvested and otter per trapper in each of the 64 parishes for the 15 trapping seasons, and their comparison suggested changes in harvest activity for the period analyzed. A formal estimate of that variation is shown by mapping the spatial distribution of the coefficient of variation for number of otters harvested and number of otters per trapper (Figure 2.4). In addition to variations at the parish level (Figure 2.4), spatial changes in the number of otters harvested at the state level were indicated by the gradual southeast-northwest shift from 1984 to 2003 in the location of the weighted mean center (Figure 2.5).

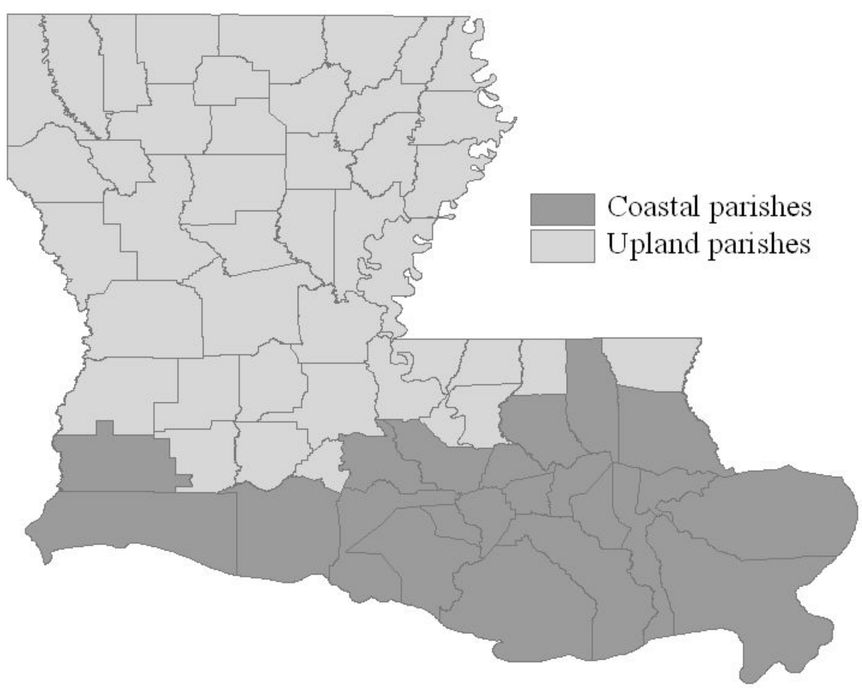


Figure 2.1. Map showing location of coastal and upland areas in Louisiana.

Table 2.1. Number of otters, otter trappers, and licensed trappers for upland and coastal Louisiana for 15 trapping seasons during 1984-2003.

trapping season	otters		otter trappers		total licensed trappers	
	coast (%)	upland (%)	coast (%)	upland (%)	coast (%)	upland (%)
1984	3122 (84)	587 (16)	547(73)	199(27)	3752(45)	4621(55)
1985	3363(84)	646(16)	438(70)	194(30)	5425(57)	4180(43)
1986	2601(72)	1015(28)	464(58)	342(42)	4054(44)	5110(56)
1987	3507(71)	1429(29)	698(54)	590(46)	2571(47)	2967(53)
1988	2702(77)	833(23)	545(60)	358(40)	2651(47)	2969(53)
1993	1056(58)	778(42)	58(29)	145(71)	384(46)	461(54)
1994	2435(72)	948(28)	150(45)	186(55)	515(49)	536(51)
1995	4828(75)	1620(25)	266(50)	272(50)	797(48)	864(52)
1996	5363(78)	1546(22)	173(47)	194(53)	651(49)	692(51)
1998	1532(44)	1951(56)	138(30)	329(70)	889(43)	1169(57)
1999	1392(60)	922(40)	118(47)	135(53)	713(55)	593(45)
2000	1326(50)	1331(50)	106(37)	179(63)	257(43)	347(57)
2001	2828(63)	1695(37)	92(36)	167(64)	342(42)	477(58)
2002	999(39)	1581(61)	59(30)	141(70)	282(40)	429(60)
2003	2107(52)	1976(48)	124(35)	234(65)	605(51)	589(49)
total	39161(68)	18858(32)	3976(52)	3665(48)	23888(48)	25994(52)
0	2611	1257	265	244	1593	1733
s	1303	466	213	120	1668	1727

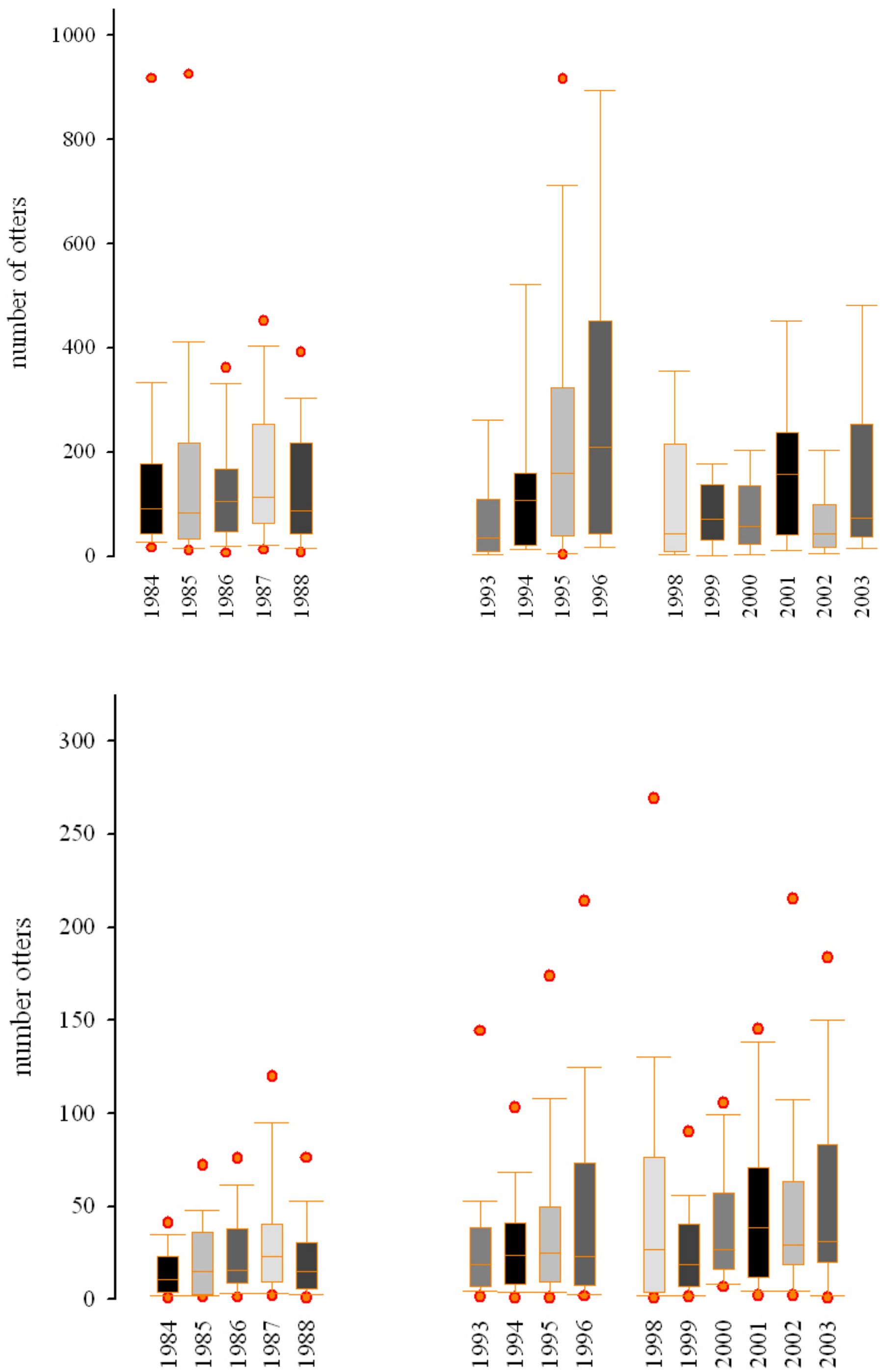


Figure 2.2. 5th/95th percentile boxplots of number otters harvested per parish in coastal (top) and upland (bottom) areas in Louisiana during 1984-2003.

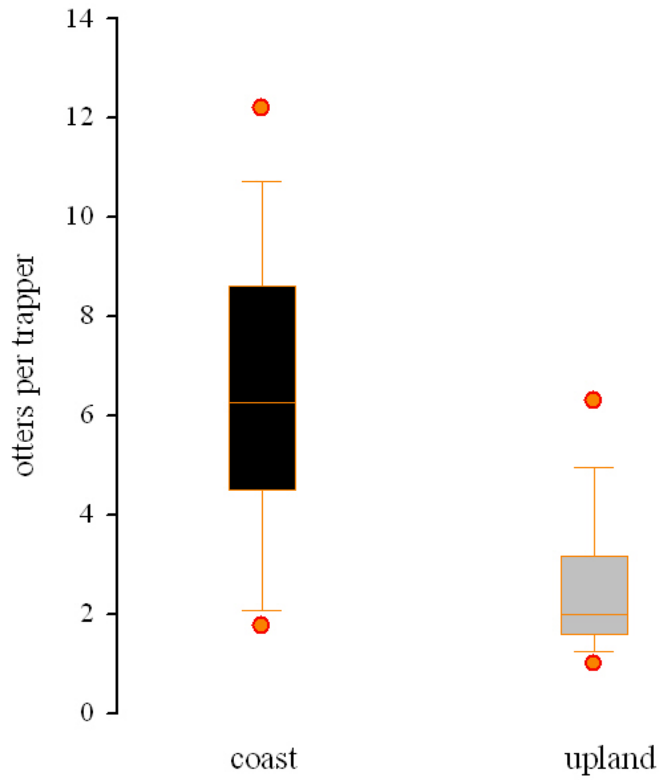


Figure 2.3. 5th/95th percentile boxplot for mean number of otters per trapper harvested in coastal and upland parishes in Louisiana during 1984-2003.

No strong spatial autocorrelation was indicated by the scatterplot or Moran's *I* coefficient (Moran's $I = 0.2313$), however, it is worth noting that most of the points in the upper right corner and the lower left corner corresponded to coastal and upland parishes, respectively (Figure 2.6). This indicates the presence of a certain degree of positive spatial autocorrelation, with coastal parishes having, in general, higher mean number of otters harvested than the mean for the state, and upland parishes having lower mean number of otters harvested. The scatterplot and Moran's *I* for number of otters per trapper which indicate the lack of spatial autocorrelation in this variable (Moran's $I = 0.08$); however, 2 points corresponding to St Bernard and Plaquemine parishes were above the mean in terms of number of otters harvested per trapper (Figure 2.7).

Local Moran's *I* statistic indicates the presence of hot and cold spots in terms of the 2 variables analyzed, mean number of otters and mean number of otters per trapper in each parish. Two cold spots were identified based on number of otters harvested per parish, corresponding to

Claiborne and Winn parishes, which had relatively fewer otters harvested than the neighboring parishes. These 2 parishes are separated by a set of parishes forming a hot spot extending east-west and formed by Madison, Richland, Ouachita, Jackson, Lincoln, Bienville, and Bossier parish. Two other areas were identified as hot spots; one extending diagonally between the city of Alexandria and the city of Lake Charles, and a second one corresponding to Assumption, St. James, Ascension, and Livingston parish. Based on mean number of otters per trapper, one hot spot was identified, corresponding to Jefferson Davis parish in southwestern Louisiana, and a cold spot in the northeast part of the state (Madison parish; Figure 2.8).

Discussion

Changes have occurred in the last 20 years in the spatial dynamics of river otter harvest in Louisiana, such as an increasing proportion of harvested otters coming from upland parishes in more recent years, and an increase in the proportion of trappers catching otters in that region. The migration of the weighted mean center is an indication of those changes. However, considering the complexity of the system being studied, where ecological, social, political, and economic issues play a role, determining which forces are responsible for those changes is not possible with the data available at this time. As mentioned before, one goal in this study was to identify patterns in the spatial dynamics of otter harvest in Louisiana, and generate working hypotheses that could be used as starting points in a more integrated study of the dynamics of the fur industry in Louisiana.

Percentages of otters harvested in coastal and upland areas have changed during 1984-2003 when compared to the period analyzed by Linscombe and Kinler (1985). Linscombe and Kinler (1985) estimated that during 1977-1982, 85.6% and 14.4% of otters harvested were in coastal and upland areas, respectively, whereas estimates for 1984-2004 indicate that 68% and 32% of the total number of otters were harvested in coastal and upland habitat, respectively. Spatial analysis indicates that this shift in harvesting activity has been gradual rather than abrupt.

Analysis supports the suggestion that a gradual shift in otter harvest distribution has occurred over time, as shown by the increasing number of otters harvested in upland parishes in

Table 2.2. Results from 2-proportion test comparing proportion between number of trappers that caught at least one river otter and total number of licensed trappers in coastal and upland areas in Louisiana during 1984-2003. P_{coast}: proportion in coastal areas, P_{upland}: proportion in upland areas.

Trapping season	P_{coast}	P_{upland}	$P_{coas}t - P_{upland}$	P-value
1984	0.14	0.04	0.1	<0.0001
1985	0.08	0.05	0.03	<0.0001
1986	0.11	0.07	0.04	<0.0001
1987	0.27	0.19	0.08	<0.0001
1988	0.20	0.12	0.08	<0.0001
1993	0.15	0.31	- 0.16	<0.0001
1994	0.29	0.35	- 0.06	0.052
1995	0.33	0.31	0.02	0.41
1996	0.26	0.28	- 0.02	0.55
1998	0.15	0.28	- 0.13	<0.0001
1999	0.16	0.23	- 0.07	0.005
2000	0.41	0.51	- 0.1	0.011
2001	0.27	0.35	- 0.08	0.012
2002	0.21	0.33	- 0.12	<0.0001
2003	0.20	0.40	- 0.2	<0.0001

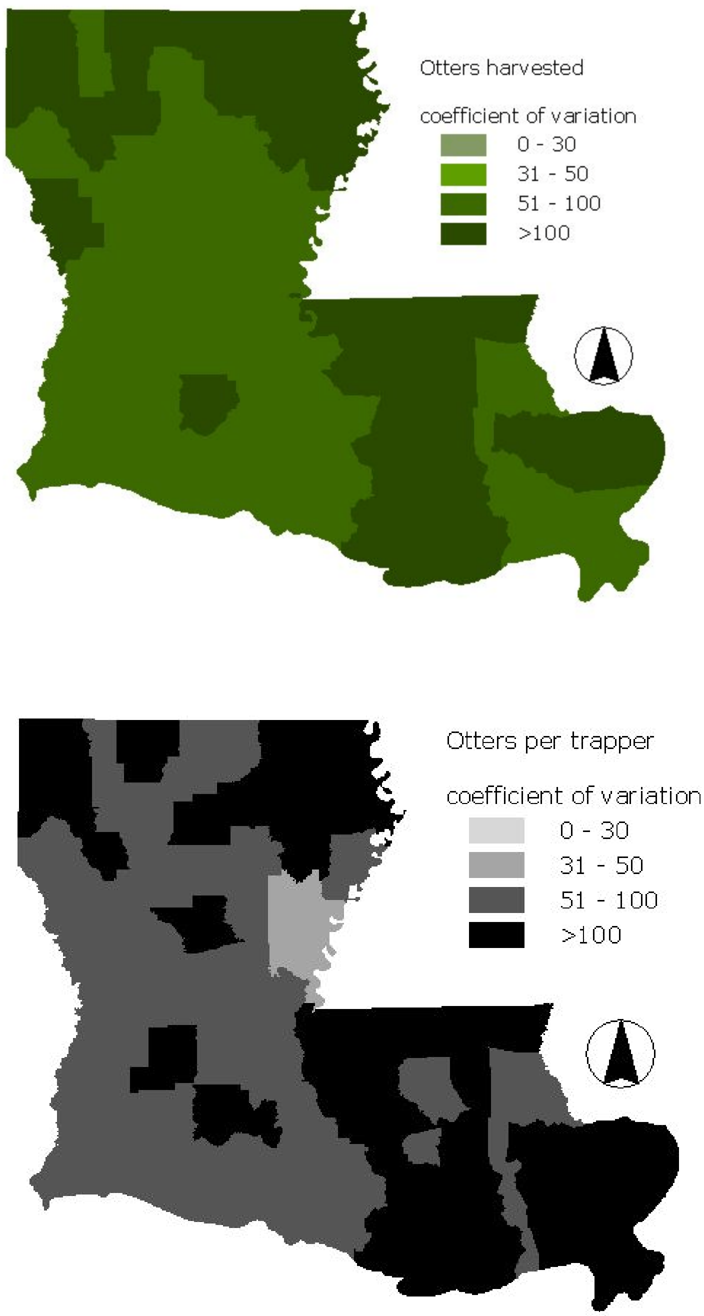


Figure 2.4. Coefficient of variation for number of otters (top) and harvesting ratio (bottom). Louisiana trapping seasons 1984-2003.

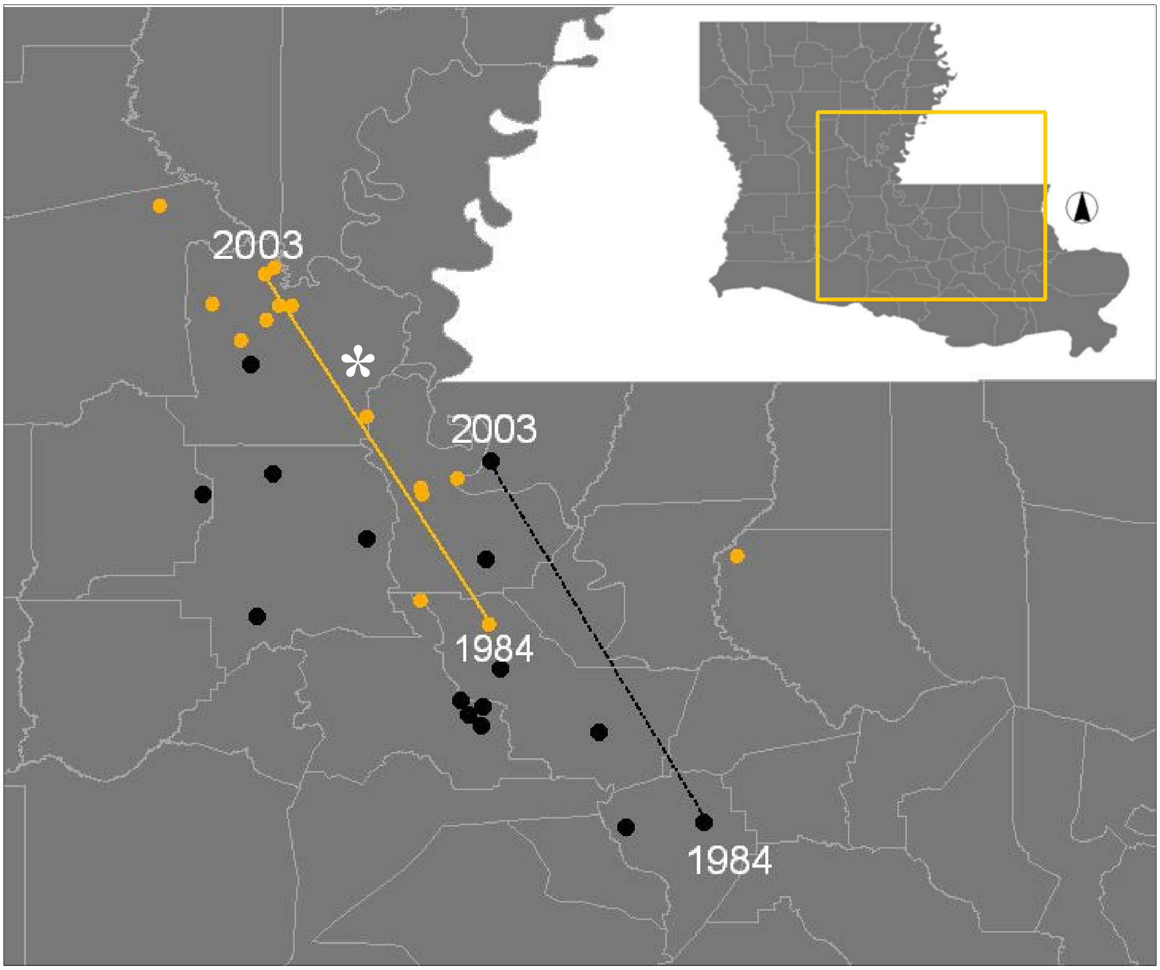


Figure 2.5. Displacement of mean center weighted by number of otters harvested (light circles) and harvesting rate (dark circles) in Louisiana during trapping seasons 1984-2003,
(*) Unweighted mean center.

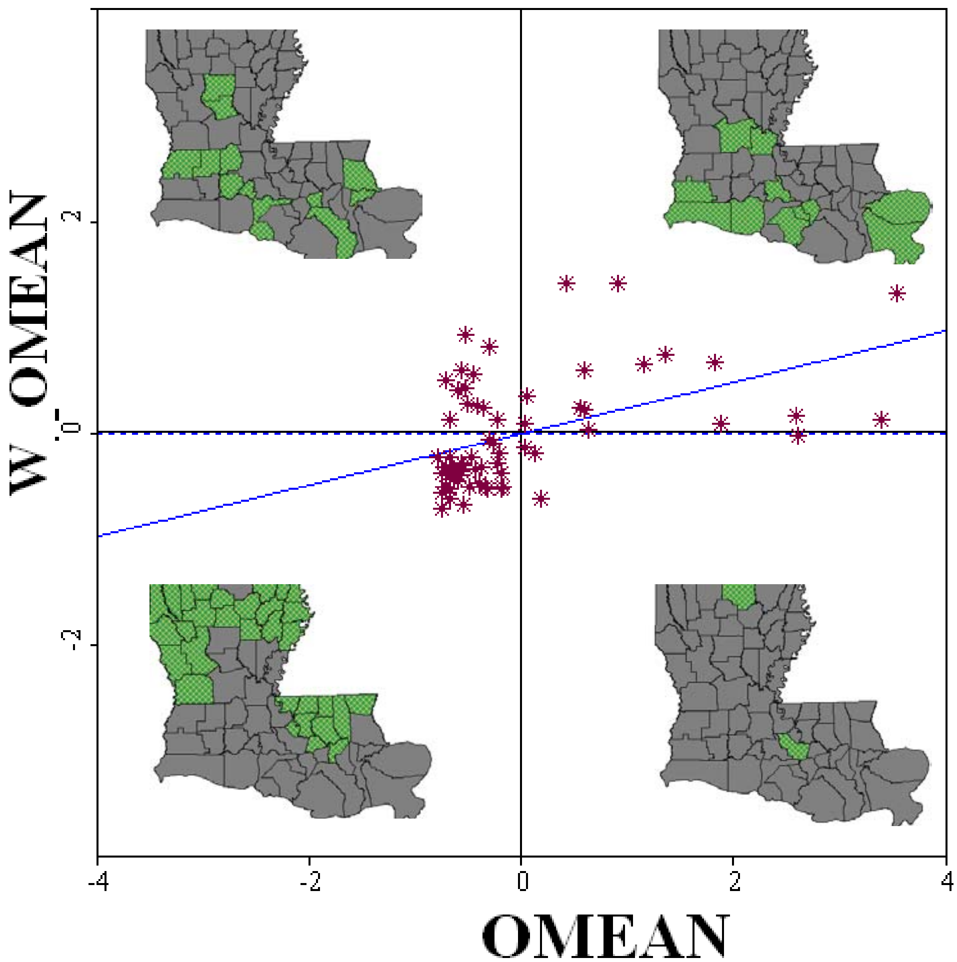


Figure 2.6. Moran's scatterplot for mean number of otters harvested in Louisiana parishes between 1984-2003. OMEAN stands for mean number of otters and W_OMEAN for weighted mean number of otters. Moran's $I = 0.23$

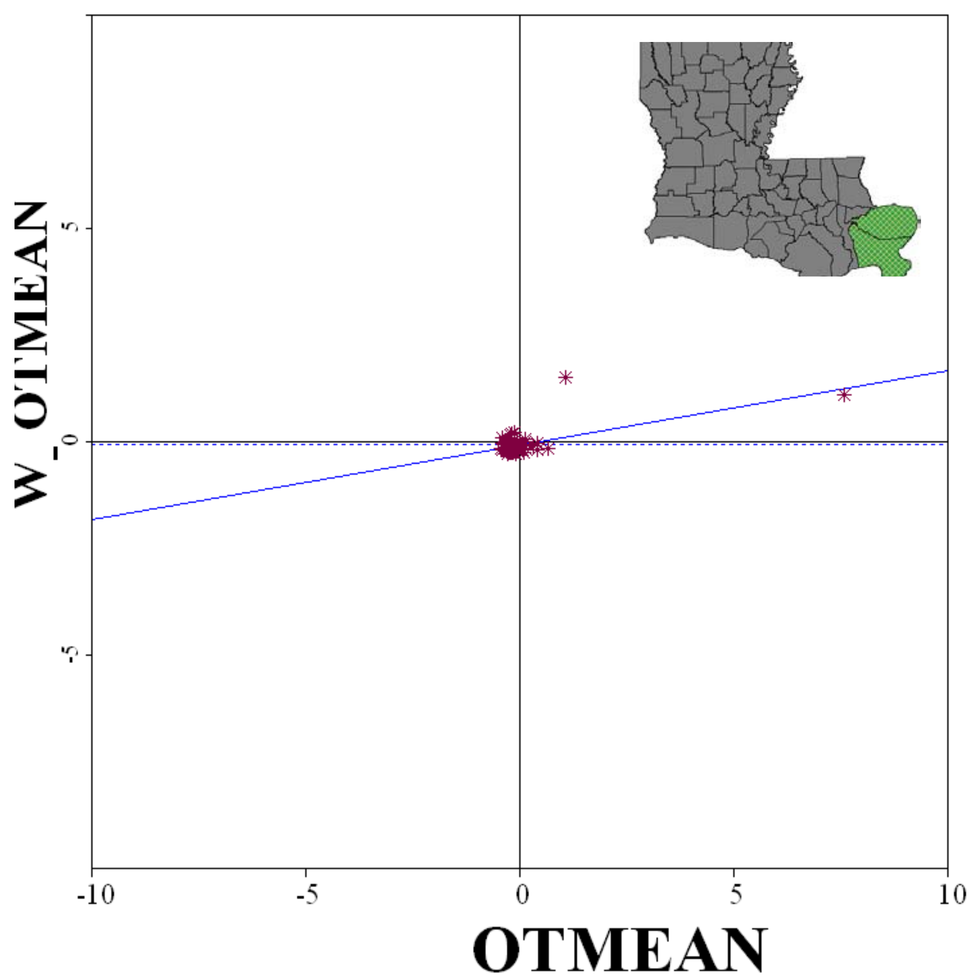
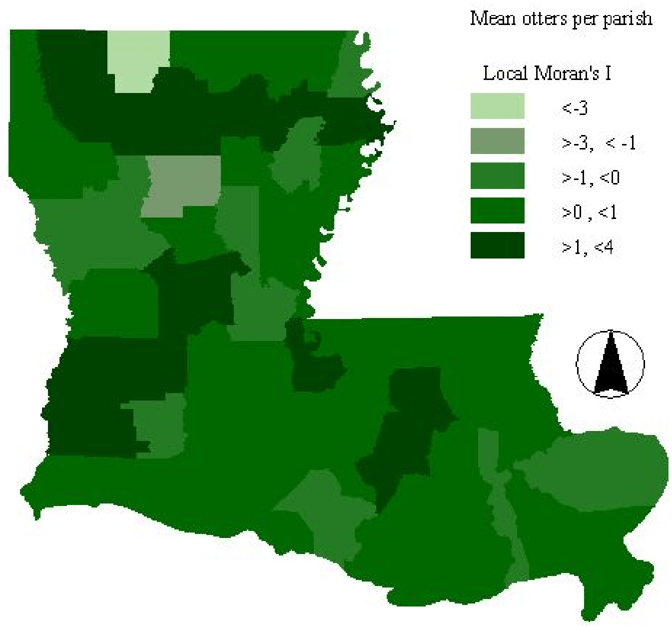


Figure 2.7. Scatterplot for number of otters harvested per trapper in Louisiana parishes during 1984-2003. OTMEAN stands for mean number of otters per trappers and W_OTMEAN correspond to the weighted values. Moran's $I = 0.08$



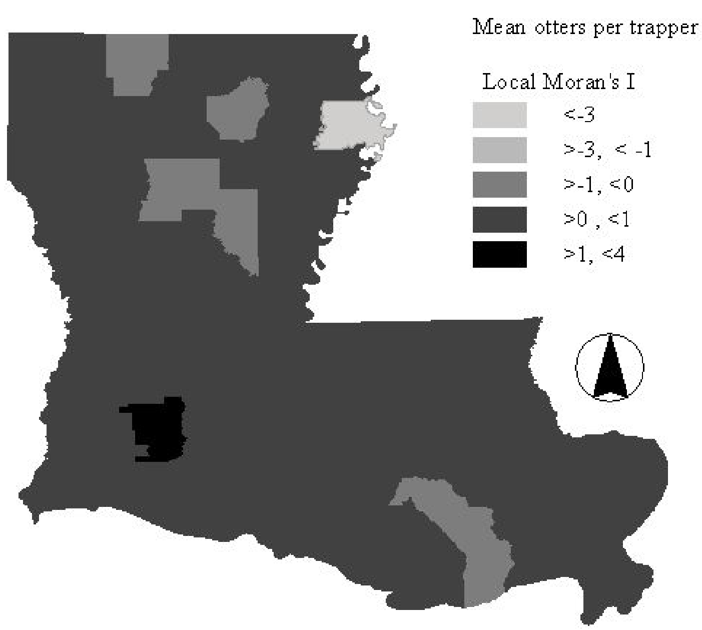


Figure 2.8. Local Moran’s *I* for mean number of otters per parish (top) and mean number of otters per trapper (bottom)

more recent years and the displacement of the weighted mean center. Multiple, and likely synergistic, mechanisms are potentially causal in the spatial changes observed in otter harvest. A parsimonious explanation for this shift could be a greater interest of upland trappers in catching otters because of increasing otter pelt price and a decline in pelt price for other furbearer species. However, otter pelt price increases may fail to explain the gradual shift in otter harvest distribution, because it is reasonable to assume that upland trappers would exhibit a generalized interest in river otter pelts given its higher price and not a gradual, from south to north, regional change in attitude toward harvesting otters.

A second explanation for the gradual shift in otter harvesting distribution may be the generalized coastal erosion process observed in Louisiana. Louisiana is experiencing the greatest coastal erosion rates in the United States (Duke and Kruczynski 1992, Boesch *et al.* 1994), which is characterized by the gradual conversion of coastal wetlands into open water habitat. This gradual erosion could be causing a gradual and continuous reduction in otter habitat in coastal areas, which may result in the migration and redistribution of otters in upland habitats.

Assuming that harvesting rate is trapper-dependent, and that pelt price of different species has an impact on the attitude of the trapper toward a particular species, it is reasonable to hypothesize that less skilled trappers would quit trapping activities, given the low price of pelts in general, leaving the best trappers targeting otters. This decline in number of licensed trappers has a twofold effect on the ratio of otter trappers/licensed trappers. The reduction of the denominators will make the ratio larger, but it also would make the numerator larger considering that a reduction in number of trappers has been attributed to increasing furbearer populations through reductions in harvest (Lovell *et al.* 1998), which would contribute to increased catchability given the higher abundance. This set of conditions would result in an upward trend in the proportion of otter trappers/licensed trappers in upland areas in Louisiana.

I acknowledge that the processes causing these changes in otter harvest activity remain to be identified, and that I offer speculative explanations. However, these speculations provide a baseline from which future otter research in Louisiana could develop questions and hypotheses

that need to be addressed if reliable management plans for river otter are to be developed in Louisiana. Among those questions to be addressed are: Is there any change in trapper attitude that may have led them to target river otters more now than in the past? Is there any trend in river otter abundance in Louisiana? What is the status of coastal and upland populations? What is the effect of coastal erosion on otter populations?

Given the importance of taking actions for the management of the species in the near future, spatial associations in otter harvesting in Louisiana indicate that some preliminary steps could be implemented until a more formal management plan for the species is developed. Besides the lack of a strong spatial autocorrelation, coastal parishes tend to produce more otter pelts than the mean, whereas upland parishes tend to produce fewer pelts than the mean for the state. Among the 4 marsh or lowland types defined in coastal areas (Linscombe and Kinler 1985) the Inactive Delta of the Mississippi River appears to be the richest area in terms of otters harvested per trapper. This area also is one of the regions presenting the highest percentage of variation in both total number of otters harvested and otters per trapper (Figure 2.4), which illustrates the magnitude of the dynamics in the area. The Southeast Swamp and the Atchafalaya Basin also appear as highly dynamic regions in terms of variability .

Despite the relative lack of global spatial autocorrelation, Local Moran's *I* identified Jefferson Davis parish, in southwest Louisiana, and surrounding areas as a region with relatively high harvesting rate. In northeast Louisiana, Madison parish was identified as an area with a relatively lower value for otter per trapper than neighboring parishes. This result is largely the consequence of Tensas parish having a higher harvesting rate (more than four times the ratio for Madison parish). Considering that the harvesting rates used for the estimation of Local Moran's *I* were averages for 15 years, it could be assumed that differences between parishes in number of otters per trapper is not the consequence of variability among trapper's skills, and that other variables are responsible for those differences. One factor that could be contributing to this trend is the percentage of each type of land cover in the region. Three major protected areas are present: Tensas National Wildlife Refuge and Big Lake Wildlife Management Area in Tensas

and Madison parish, and Buckhorn Wildlife Management Area in Tensas parish. Considering that the dominant landcover for these parishes is agricultural land (Hartley *et al.* 2000), these protected areas, which are forested wetlands, could provide primary habitat for otters in the region (Chabreck *et al*. 1985). If there is a direct association between habitat availability and river otter abundance, differences in harvesting rate could be explained by differences in habitat availability between Tensas and Madison parish since the largest fraction of Tensas National Wildlife Refuge and Big Lake Wildlife Management Area are in Tensas parish.

Conversely, Jefferson Davis and surrounding parishes were identified as a hot spot based on high harvesting rate. Again, habitat characteristics probably offer the most reasonable explanation, particularly considering the value of marshes and wetlands in coastal parishes like Cameron and Vermillion, which has been recognized in other studies (Chabreck *et al.* 1985, Linscombe and Kinler 1985). North of these coastal habitats are lands identified as agricultural lands in the Gap analysis for Louisiana (Hartley *et al*. 2000), which mostly correspond to rice fields (Anonymous 1997). Rice fields have been recognized as important surrogate habitat for wildlife (Elphick 2000, 2004, Elphick and Oring 2003, Tourenq *et al.* 2001). River otters are frequently found in these fields (Nair and Agoramoorthy 2002), where one important item in their diet, the crawfish, is often grown as a companion crop with rice in Louisiana (Schueneman 2002).

Spatial analysis and results of otter harvesting data presented in this chapter indicates that changes have occurred in this activity in the last 20 years in Louisiana. Conducting a survey among trappers is important for the identification and understanding of the sources of those changes. Coastal areas continue to be an important source for otter pelts, particularly the Inactive Delta of the Mississippi River (Linscombe and Kinler 1985). However, the Chenier Plain in western Louisiana also is an important habitat for otters, where the role of field rice as alternative habitat for river otters remains to be studied. Results from this study also could be indicative of the importance of protected areas for otters in upland parishes. Harvesting pressure

in these areas should be evaluated since Wildlife Management Areas are most likely the only reservoir of otters and source for dispersal in upland parishes.

CHAPTER 3

TEMPORAL DYNAMICS OF RIVER OTTER HARVEST IN LOUISIANA DURING 1957-2004

It has been argued that achieving sustainable use of renewable resources is difficult, particularly due to lack of consensus on resource status among researchers and managers (Ludwig *et al.* 1993). Sustainable exploitation requires harvesting strategies that maximize yield while accounting for stochastic dynamics, uncertainty, and risk of population extinction. Considering that exploited populations are highly variable (Myers and Rothman 1995), the risk of depletion or extinction of small populations increases as a consequence of demographic stochasticity arising from random events in individual mortality and reproduction (May 1974). If sustainable use is to be achieved, managers must have information about variables related to exploitation of the target resource.

In some exploited populations, harvesting is the most important source of mortality, and it also could potentially affect the temporal dynamics of those populations (Jonzén *et al.* 2003). Different harvesting strategies could modify the natural cycling patterns of exploited populations, changing the periodicity and/or magnitude of variation in number of individuals which may have important implications for the management of the species. When no data are available on population dynamics of a harvested species, a description of the dynamics of harvest through time and the ability to forecast number of animals to be harvested represent one of the first steps toward the development of a formal management plan for that species.

River otter (*Lontra canadensis*) is among the most valued species in the fur market, particularly in Louisiana, where otters have been an important furbearer species for almost a century (St. Amant 1959). Because understanding temporal dynamics of river otter harvest has potential far-reaching implications for river otter management and conservation, time series analysis was used to describe temporal behavior of variables associated with river otter harvesting, such as number of otters harvested, number of licensed trappers, and otter pelt price during 1957-2004. The primary goal was to identify simple models to describe patterns and

associations among variables mentioned above, and provide to state wildlife managers a tool to forecast number of otters harvested several seasons in advance.

Methods

I analyzed harvest data for river otter collected by the Louisiana Department of Wildlife and Fisheries (LDWF) with a time series approach. Complete time series for 1957-2004 existed for number of otters harvested (*PELT*), number of licensed trappers (*LIC*), and otter pelt price. Series for the period 1957-2003 were used for all the analysis and model development, and data from trapping season 2004 was used as an out-of-range sample for model forecast evaluation. Time plots were used as preliminary descriptive tools to identify trends in the series and needed transformation of the data. Nominal river otter pelt price (*NPRICE*) was adjusted by the consumer price index (*CPI*) (Bureau of Labor Statistics 2004) to generate the real pelt price (*RPRICE*), a pelt price adjusted by the cost of many of the major commodities a trapper needs to buy. The relationship is given by $RPRICE = NPRICE / CPI$. Fifteen trapping seasons for the period 1984-2003 also included number of licensed trappers that actually caught at least one river otter. This data set was used to estimate number of otters captured per trapper for those seasons.

Some Concepts and Nomenclature Used in Time Series Analysis

Time series analysis differs from other statistical problems in that the observed time series is the unique sample of the process X_t that will ever be observed. An observation at time t, namely x_t, is considered as being an observation of the random variable X_t, where the observed time series is commonly named a *realization* of the stochastic process and the population of all possible realizations is called the *ensemble*. Much of the theory developed to analyze time series assume stationarity. Formally, a stochastic process is said to be stationary if the mean, $E[X_t]$, and variance $V[X_t]$ are constant for all values of t and the covariance between X_t and X_{t+k} depends only on the separation lag k and not on t. I identified non-stationary processes based on the analysis of their sample autocorrelation function (sACF), and their spectrum density function (Chatfield 2001). A time series was considered as representing a non-stationary process if its

sACF approached zero very slowly with the lag (Wilson 2001). In the presence of a trend in a time series, its spectral density function will show high values at low frequencies.

For an observed time series $\{x_1, x_2, ..., x_n\}$ the sample autocovariance coefficient at lag k is calculated by

$$c_k = \sum_{t=1}^{n-k} (x_t - \bar{x})(x_{t+k} - \bar{x}) / n$$

for $k = 0, 1, 2, ...$ The sample autocorrelation coefficient at lag k can be calculated by

$$r_k = c_k / c_o$$

where r_k represents the autocorrelation at lag k, c_k is the covariance between observations at lag k, and c_o is the variance. The graph of the sample autocorrelation coefficient r_k against k (lag) is called correlogram. Correlogram for each time series was used as descriptive tools, but also as part of the procedure for identifying appropriate models. Another function is the partial autocorrelation function (PACF) which essentially measures the correlation at lag k after removing the effect of associations at lower lags (Gottman 1981). Sample ACF and sPACF were used to identify plausible models.

Because the analysis of sACF is a subjective tool for the identification of stationarity, I used formal statistical tests for stationarity detection in time series such as the Augmented Dickey-Fuller (ADF) test (Brocklebank and Dickey 2003, Enders 2004) as an objective tool even though it has been noted that this kind of test generally has poor power because the alternative hypothesis is too 'close' to the null hypothesis, offering a small contribution to the task of identifying stationarity and time series forecasting (Chatfield 2001).

The presence of autocorrelation imposes some problems for the analysis of time series. Classical statistical methods have been developed to analyze data sets where the entries are independent. However, these methods do not work well when correlation exists between successive values in a time series. To describe the dynamics of number of otters harvested through time, I used four different approaches within time series analysis, (i) regression analysis

(Ostrom 1990), (ii) linear autoregressive integrated moving-average models (ARIMA), (iii) transfer function models, and (iv) spectral analysis.

Cross-correlation

To identify associations at different lags between number of pelts and trapper participation, and between pelt price and number of pelts harvested I used cross-correlation analysis. A sample cross-correlation function is given by

$$r_{xy}(k) = c_{xy}(k) / \sqrt{[c_{xx}(0)c_{yy}(0)]}$$

where r_{xy} represents the correlation at lag k between time series x and y, c_{xy} (k) provides an estimate of the population cross-covariance coefficient, and c_{xx} (0) and c_{yy} (0) are the sample variances of the observations on the x- and y-series, respectively. Since the cross-correlation function is not an even function (i.e., correlation at lag k differs from correlation at lag $-k$), the value of the lag which gives the maximum cross-correlation gives some indications on which series is 'leading' the other (Chatfield 2001, Gottman 1981).

Regression Analysis

In time series regression analysis a structural equation in the form

$$Y_t = a + bX_t + e_t$$

is used to describe the data. Y_t represents the value of the response variable at time t, a and b represent constant parameters, X_t is the value of the explanatory variable at time t, and e_t represents the error term. Writing a regression model assuming that successive values of e are independent will produce a flawed model because it will ignore the temporal dependence among the observed variables and among the error terms.

Because in time series the error terms e_t usually are autocorrelated, SAS PROC AUTOREG (SAS Institute v 8.2) with parameter estimation using the Yule-Walker method to account for that autocorrelation and identify the structural equation was used to describe the association between the response variable number of otter pelts at time t ($PELT_t$) and the

explanatory variables number of pelts lagged 1 to 6 trapping seasons ($PELT_{t-1}$ to $PELT_{t-6}$), number of licensed trappers at time *t* (LIC_t) and lagged up to 6 trapping seasons (LIC_{t-1} to LIC_{t-6}), and nominal pelt price at time *t* ($NPRICE_t$) and also lagged 1 to 6 seasons ($NPRICE_{t-1}$ to $NPRICE_{t-6}$). All these explanatory variables were entered in the model development step and selected using backward variable selection in SAS PROC AUTOREG.

ARIMA Models

ARIMA models (Box and Jenkins 1970) were used to describe and forecast time series *PELT*, as an univariate series. In general, a model for a time series, X_t, can be formally stated as

$$X_t = f(X_{t-1}, \ldots.., X_1) + e_t$$

where $f(X_{t-1}, \ldots.., X_1)$ is a function of the past values of the series, to be determined from the data, and e_t is a noise part. Since the systematic part $f(X_{t-1}, \ldots.., X_1)$ depends on past values, it can be forecasted. ARIMA models assume that the function f has a linear form that can be written as

$$f(X_{t-1}, \ldots.., X_1) = \mathrm{B}_1 X_{t-1} + \ldots... + \mathrm{B}_{t-1} X_1$$

and the basic idea of ARIMA models is to approximate a sequence of weights (B_1, B_2, ...) by using a small number of parameters (Wilson 2001).

In ARIMA modeling methodology, a very flexible class of models is introduced in the analysis, and one member of that class is fit to the time series, which also is the model used to forecast the series. This methodology has 3 steps (i) identification of the model, (ii) estimation of parameters, and (iii) forecasting. I used SAS PROC ARIMA to identify the set of plausible models to describe the *PELT* time series. The *Q*-statistics (Box *et al.* 1994, Ljung and Box 1978) in the identification stage generated by SAS PROC ARIMA using the autocorrelation coefficients was used to test the null hypothesis that the series represented a purely random process, i.e., that the process was uncorrelated or *white noise*. In the estimation stage this same statistic is calculated on the model residuals, and was used to test the null hypothesis that these residuals were white noise. Maximum likelihood method was used for parameter estimation. Among all the models that showed residuals as white noise, which indicated a good fit of that particular model to the data, the model that minimized the Akaike's Information criterion (AIC)

was selected as the final model to describe the series and forecast number of pelts harvested one trapping season in advance. Given the relatively small sample size, no test was performed on the forecasting capability of different models (Chatfield 2001); however, I used the error for trapping season 2004 as an indicator of the forecasting power of each model. This indicates that as more data are collected the proposed model for forecasting should be revisited and adjusted to new findings.

Transfer Function Models

Transfer function models (Box and Jenkins 1970 see Chatfield 1980) were used to forecast the time series *PELT* one trapping season ahead incorporating series *LIC* and *NPRICE* as explanatory variables in the model. The general structure of this model is given by

$$Y_t = v(B)\, X_t + n_t$$

where $v(B) = v_0 + v_1 B + v_2 B + \ldots$ is a polynomial in the backward shift operator, B (see Chatfield 2001 for details), and $\{n_t\}$ represents the error term. This analysis was performed using SAS PROC ARIMA with maximum likelihood method for parameter estimation.

Spectral Analysis

Spectral decomposition analysis (Gottan 1981, Wilson 2001) was used to identify the existence of cycles and its period (p) in the time series *PELT* and *LIC*. This approach assumes that the function f given above in the ARIMA model section can be represented as a sum of sine and cosine waves.

The spectral decomposition theorem states that the variance of any time series can be broken into the contribution of statistically independent oscillations of different frequencies. The graph of variances accounted for by all the frequencies is called the spectral distribution function; peaks in this graph indicate frequencies at which the largest variances occur. Sample spectral functions were generated using SAS PROC SPECTRA. If time plots indicated change in patterns or trends, spectral analysis was applied for the series before and after the trapping season when the change occurred. Conversion between frequency *freq* and period p is given by

$$p = (1/freq)\ 2B$$

Results

For comparison purposes, time plot for series pelt price (*NPRICE*) has been overlaid with time plots for series number of pelts (*PELT*) and licensed trappers (*LIC*) (Figures 3.1, 3.2, see Table 3.1). Time series *PELT* does not show a clear trend in the series when considered for the whole period, whereas time series *LIC, NPRICE*, and *RPRICE* show different trends when broken down into different time periods. The pelt price time series nominal and real price (*NPRICE* and *RPRICE,* respectively) shows a decline in otter pelt price during the 1980s and an increasing trend from the early 1990s until 2003 (Figure 3.3). The series *LIC* shows an increasing trend before 1980, and a continuous decline since then.

Prewhitened time series *LIC* and *NPRICE* were cross-correlated with number of pelts harvested to identify associations at different lags. Correlograms are presented in Figure 3.4. The correlogram for number of licensed trappers series indicates that number of pelts at time t is positively correlated with past number of trappers (significant positive correlation in positive lags), whereas pelt price at time t is negatively associated with past number of otter pelts harvested (significant negative correlation at positive lags).

Regression Analysis

The structural equation identified in time series regression analysis is

$$PELT_{t} = 5700 + 0.7\ (LIC_{t}) - 0.43\ (LIC_{t\text{-}5}) - 0.39\ (PELT_{t\text{-}5}) + e_t$$

which indicates that the linear combination of number of licensed trappers at present time and lagged 5 years, and number of pelts lagged 5 years as the explanatory variables explained 73% (R^2 = 0.727) of the variation in the number of otters harvested at time t. All coefficients were significant at " = 0.05. The time series for actual and predicted number of pelts and the time plot or the regression errors which indicates a good fit for the regression model (Figure 3.5).

The absence of conspicuous trends in the time plot of the *PELT* series, and the patterns shown by the time plots for the *LIC* and *NPRICE* series were confirmed by their sACF and sPACF (Figure 3.6). This sACF for *PELT* declines very quickly, which is an indication of stationarity in

the time series. The sACF for *LIC* and *NPRICE* shows a relatively slow decline, indicating nonstationarity.

The analysis of time plots and sACF and sPACF regarding stationarity was confirmed by the ADF test, which indicated stationarity in the pelt time series (J = -3.65, P = 0.03), and nonstationarity for *LIC* time series (J = -1.08, P = 0.92) and pelt price time series (J = -1.53, P = 0.80). Time series licensed trappers and pelt price were detrended by differencing (Chatfield 2001, Enders 2004). ADF tests for number of licenses and pelt price series (J = -5.55, P = 0.0002; J = -7.94, P = <0.0001, respectively), and their sACF, and sPACF (not shown) gave no indication of thte presence of trends in the differenced time series.

ARIMA Models

Seven models were developed to describe the *PELT* series and evaluated based on the analysis of its sACF and sPACF, a first-order autoregressive model AR(1), a fifth-order autoregressive model with alternate parameters AR(1,5), a first-order moving averages model MA(1), a fourth-order moving averages model MA(4), a fifth-order moving averages model MA(5), and two mixed model ARMA (1,4) and ARMA (1,5). The MA(4), MA(5), and mixed models were included in the analysis in an attempt to capture the almost significant peak observed in the sPACF at lags 4-5. Table 3.2 shows parameter estimates, *Q*-statistics, and AIC for all models with all parameter estimates significantly different from zero at " = 0.1 .

The evaluation of AIC and *Q*-statistics, and significance of parameter estimates indicated that the autoregressive models AR(1) and moving average model MA(4) performed similarly well describing the time series. Model AR(1,5) had the lowest AIC, and for that reason it was selected even though one of its parameter estimates was marginally nonsignificant. The equations describing each model are:

AR(1): $PELT_t = 5053 + 0.547\ (PELT_{t-1} - 5053)$

AR(1,5): $PELT_t = 5115 + 0.6\ (PELT_{t-1} - 5115) - 0.26\ (PELT_{t-5} - 5115)$

MA(4): $PELT_t = 5173 + e_t + 0.45\ e_{t-1} + 0.43\ e_{t-2} + 0.4\ e_{t-3} + 0.35\ e_{t-4}$

where e_t,..., e_{t-4} represent points of a random time series (for details see Gottman 1981).

Table 3.1. Number of otter pelts harvested, licensed trappers, otters per trappers who caught at least one otter, and pelt price for the period 1957-2004 in Louisiana. (Source LDWF)

Trapping season	Number of pelts	Number licensed trappers	Number of otter per trappers	Pelt price (U$)
1957	5261	4211	-	16
1958	4382	3868	-	14
1959	5166	3932	-	14
1960	5559	3743	-	18
1961	3602	3613	-	17
1962	4195	3004	-	16
1963	8484	3666	-	17
1964	4274	3029	-	18
1965	3288	3061	-	25
1966	3588	3088	-	20
1967	4118	3492	-	18
1968	3466	2495	-	14
1969	5426	3601	-	20
1970	6632	4444	-	23
1971	4808	3510	-	25
1972	5440	2761	-	38
1973	7668	4741	-	42
1974	5989	6295	-	30
1975	6113	7528	-	25
1976	5730	6404	-	25
1977	11900	9329	-	45
1978	6597	12069	-	25
1979	9745	11106	-	35
1980	9324	12239	-	40
1981	10411	11801	-	26
1982	5905	10867	-	22
1983	3126	10668	-	13.5

Table 3.1. (cont.).

Trapping season	Number of pelts	Number licensed trappers	Number of otter per trappers	Pelt price (U$)
1984	4122	8793	3.85	12
1985	5727	10935	5.41	12
1986	3529	9458	3.82	10
1987	5074	6947	3.41	12
1988	4021	5038	3.19	12.4
1989	1924	2888	-	10
1990	1365	1877	-	12
1991	1203	1414	-	12
1992	1779	1543	-	16
1993	1983	1189	9.73	16.6
1994	4063	1274	9.18	30
1995	6418	1686	9.88	30
1996	7555	1700	16.05	26.4
1997	5649	2691	-	25
1998	7200	2442	7.18	28.45
1999	2483	1578	8.95	27.2
2000	2872	1024	10.31	37.3
2001	4593	987	20.73	33
2002	2579	871	15.83	50
2003	3932	1589	11.61	59.1
2004	5713	1432	-	86

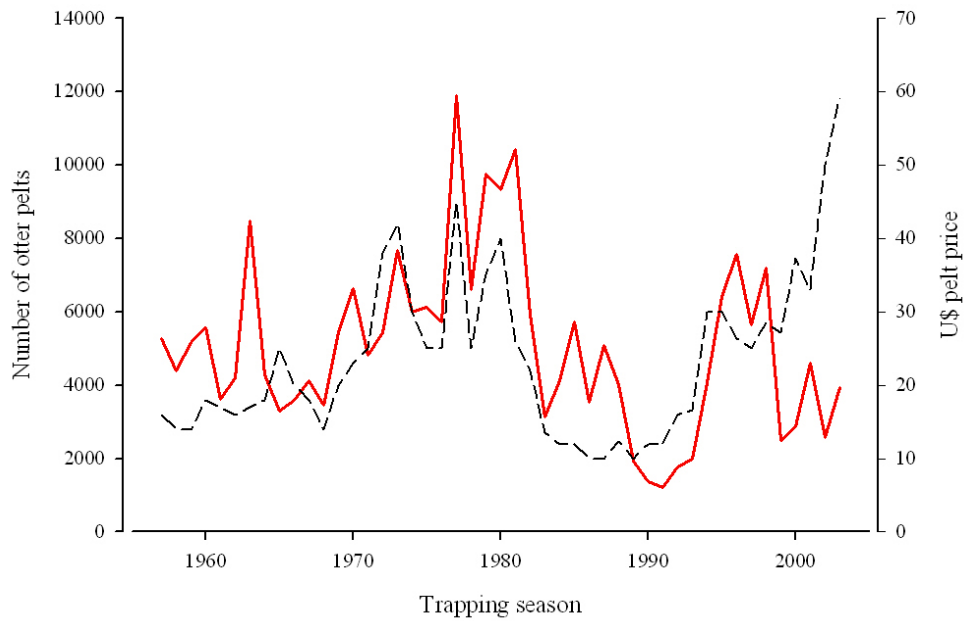


Figure 3.1. Time plot of number of otter pelts harvested (continuous line) and otter pelt price (dashed line) in Louisiana during trapping seasons 1957-2003. (Source: Louisiana Department of Wildlife and Fisheries)

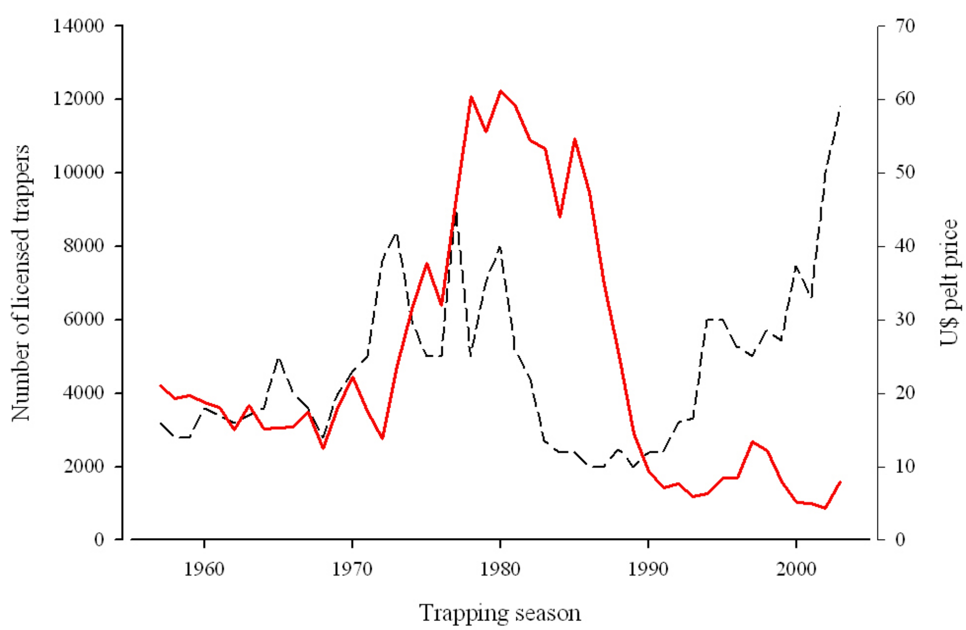


Figure 3.2. Time plot of number of licensed trappers (continuous line) and pelt price (dashed line) in Louisiana during trapping seasons 1957-2003.(Source: Louisiana Department of Wildlife and Fisheries)

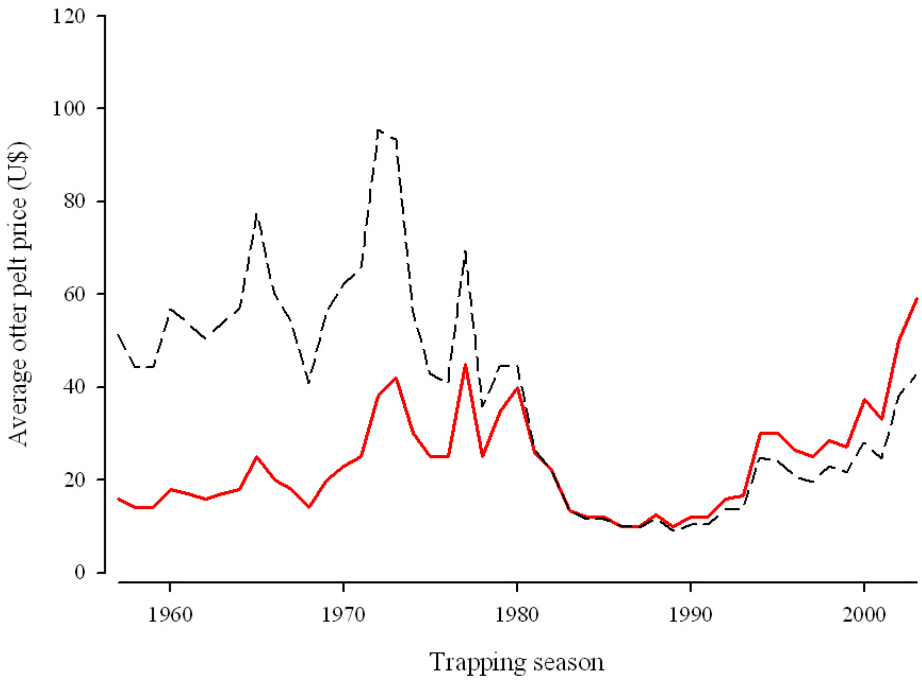


Figure 3.3. Nominal (continuous line) and real (dashed line) otter pelt price paid in Louisiana during 1957-2003. (Source: Louisiana Department of Wildlife and Fisheries)

a)

b)

c)

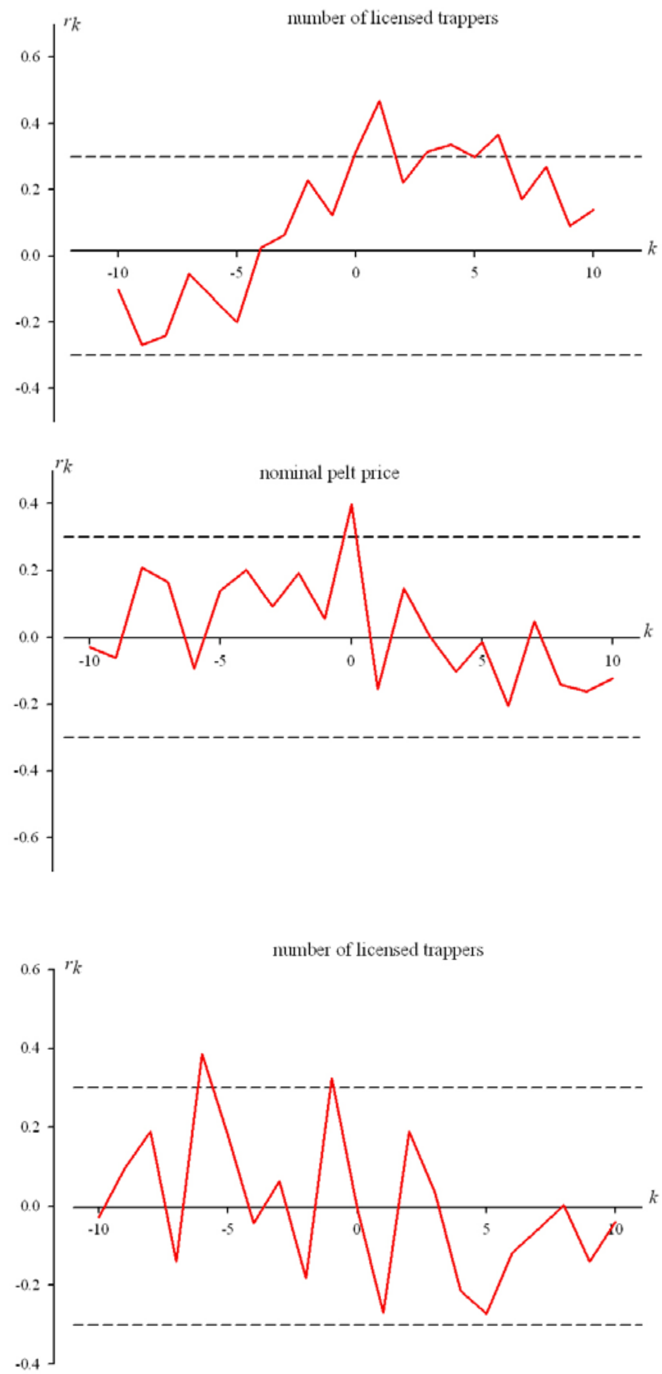
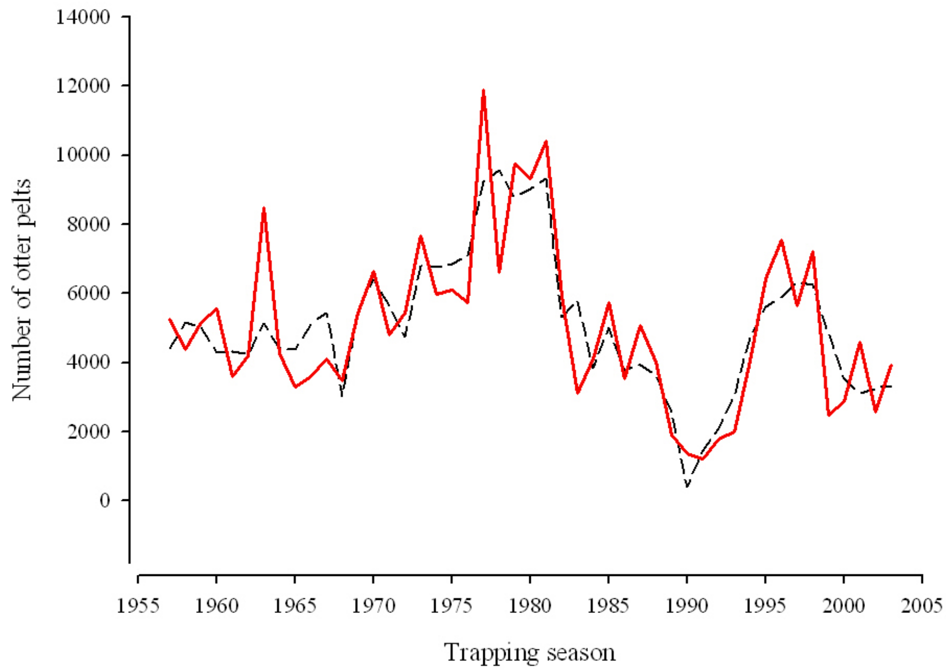


Figure 3.4. Cross-correlogram for number of otter pelts harvested in Louisiana during 1957-2003 and number of licensed trappers (a) and nominal pelt price (b). Diagram c represents correlogram between number of licensed trappers and pelt price. Dashed lines indicate estimated 95% confidence interval. k :lag, r_k = correlation coefficient at lag k



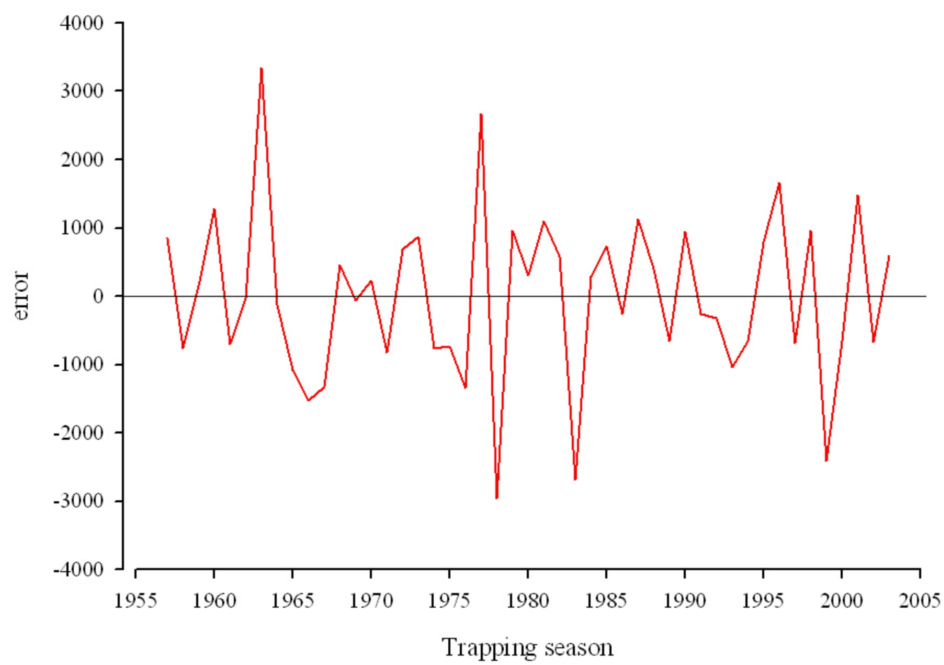


Figure 3.5. Actual (continuous line) and predicted (dashed line) number of otter pelts harvested in Louisiana during 1957-2003 (top) and time plot of errors from time series regression (bottom)

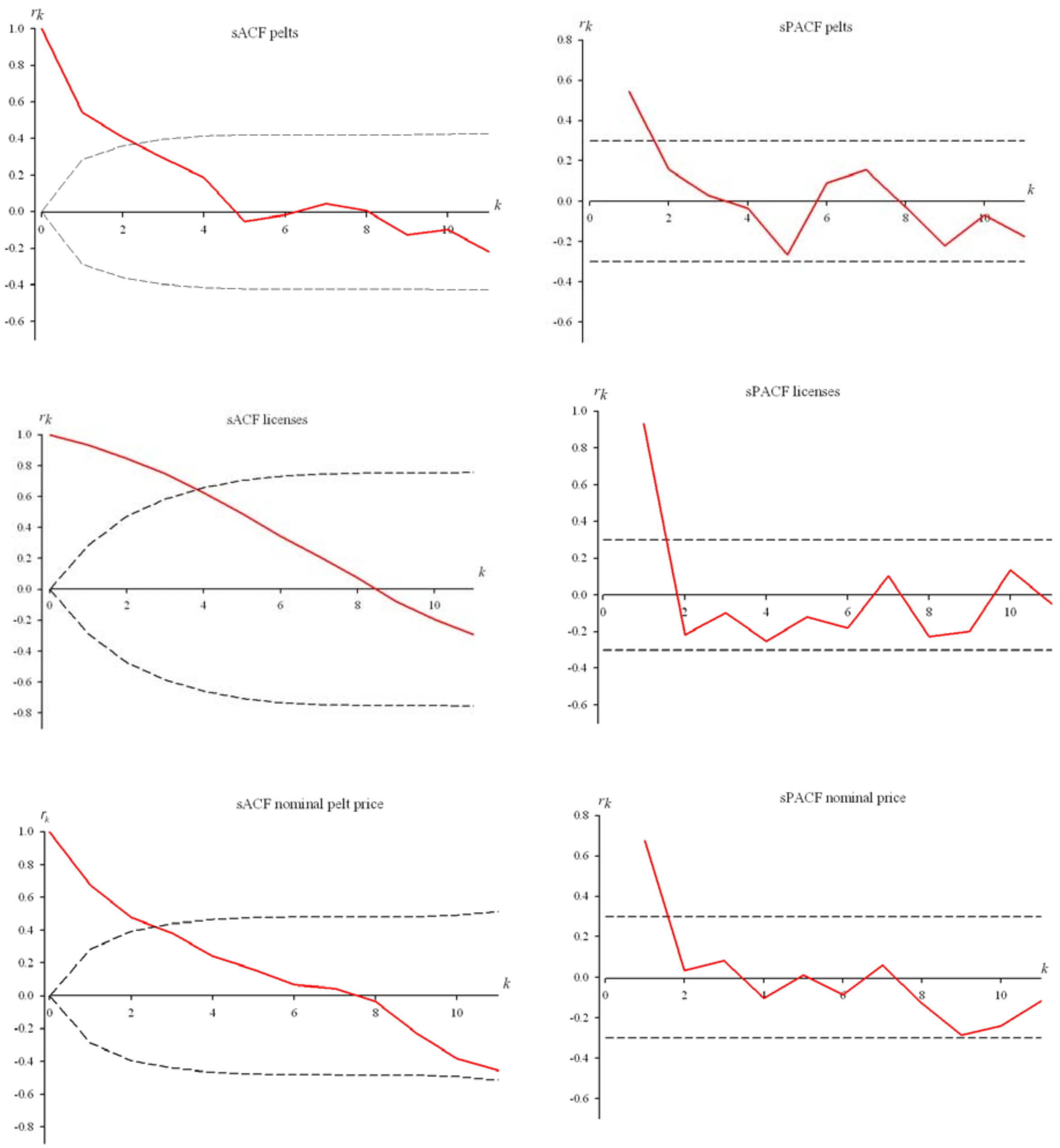


Figure 3.6. Sample autocorrelation function (sACF) (left) and sample partial autocorrelation function (sPACF) (right) for time series number of otter pelts harvested (top), number of licensed trappers (center), and otter pelt price (bottom) in Louisiana during 1957-2003. Dashed lines indicate 95% confidence interval, *k* represents lag, and r_k correlation coefficient at lag *k*.

Even though parsimony indicates that model AR(1) should be selected over models AR(1,5) and MA(4), the three models were used to forecast trapping season 2004, where actual number of pelts harvested was 5713. Figure 3.7 shows the last five trapping seasons of this time series, including season 2004, and forecasted values for this last season using the selected models. Forecasted number of pelts, error values, and 95% confidence intervals are presented in Table 3.3.

Transfer Function Models

Twelve models were evaluated based on the sACF and sPACF of the *PELT* series (Figure 3.6) using *LIC* as the only regressor, and the same models were evaluated including both *LIC* and *NPRICE* as regressors. The models were AR(1), AR(1,5), AR(2), MA(1), MA(2), MA(3), MA(4), MA(5), ARMA(1,1), ARMA(1,2), ARMA(1,4), and ARMA(1,5). Information for models with all parameter estimates significantly different from zero at " = 0.1 are presented in Table 3.4. Based on their AIC, transfer function, model AR(1) with *LIC* and with *LIC* and *NPRICE* as regressors, and model MA(3) with both regressors were selected to forecast the *PELT* series. Forecast for number of pelt in trapping season 2004 and errors for these 3 models are presented in Table 3.5. Equations for AR(1) models are

AR(1): 5057 + 0.49 ($PELT_{t-1}$ - 5057) - 0.59 L*LIC*

AR(1): 4973 + 0.57 ($PELT_{t-1}$ - 4973) - 0.56 L*LIC* - 61.57 L*NPRICE*

where L*LIC* and L*NPRICE* represent the first difference of the series *LIC* and *NPRICE*, respectively (for details see Chatfield 2001).

Given the changes observed in the time series number of licenses in the mid-80s, spectral analysis was performed for series number of pelts and licenses before and after trapping season 1983 to test for the presence of the same cycles before and after the change in trend in the licenses time series. Although the sample spectral density function for number of licenses did not show any peaks (Figure 3.7), indicating no cycles, number of pelts series showed peaks before and after the 1983 trapping season (Figure 3.8). Before season 1983 the peak at frequencies 0.6383 indicates the presence of cycles at 10-year periods. Spectral analysis for the

series after 1983 indicates the presence of 2 well defined cycles with 9-year and 3.4-year periods (frequencies 0.6981 and 1.8617, respectively). A third peak appears in the number of pelts series after 1984 at frequency 1.3963 (period = 6.28).

Table 3.2. ARIMA model comparison for time series *PELT*.

Model	parameter	estimate	p-value	Q-statistic		d.f	p-value	AIC
AR(1)	AR 1,1:	0.54	<0.001	*Q* lag 6	5.27	5	0.38	850
				Q lag 12	11.89	11	0.37	
				Q lag 18	17.20	17	0.44	
AR(1,5)	AR 1,1:	0.6	<0.001	*Q* lag 6	3.08	4	0.54	849
	AR 1,5:	-0.26	0.11	*Q* lag 12	6.84	10	0.74	
				Q lag 18	11.74	16	0.76	
MA(1)	MA 1,1:	-0.39	<0.05	*Q* lag 6	11.44	5	0.04	855
				Q lag 12	18.71	11	0.06	
				Q lag 18	25.86	17	0.07	
MA(4)	MA 1,1:	-0.45	<0.05	*Q* lag 6	0.25	2	0.88	850
	MA 1,2:	-0.43	<0.05	*Q* lag 12	5.05	8	0.75	
	MA 1,3:	-0.39	<0.05	*Q* lag 18	11.32	14	0.66	
	MA 1,4:	-0.35	<0.05					

Table 3.3. Forecasted values of number of pelts harvested, errors and 95% confidence interval for number of otters pelts harvested in trapping season 2004 in Louisiana using selected ARIMA models.

Model	forecast	95% CI	error
AR(1)	4439	(526 , 8353)	1274
AR(1,5)	5415	(1570 , 9261)	298
MA(4)	5006	(1192 , 8819)	707

Discussion

The international fur trade market suffered a significant transformation in the mid-80s with the rise of the Animal Rights Movement (Finsen and Finsen 1994). This transformation is clearly reflected in the time plot for *LIC* time series, which shows a downward trend in number of licensed trappers since that time in Louisiana. This trend also is evident in the sample spectral density function for that series, as indicated by the high values at low frequencies. The downward trend in number of trappers in Louisiana is concurrent with a nationwide decline in number of people involved in furbearer trapping, which has been related to lack of trapper recruitment, a general decline in pelt prices among all furbearer species, and an increase in anti-trapping sentiment (Armstrong and Rossi 2000).

The time plot for nominal and real pelt price shows that otter fur had a greater real value before the 1980s than it has now, and although the nominal price has been increasing for the last 15-18 years, the real price does not represent for the trappers what it did in the early 1970s, when each pelt was worth twice as much as it was in 2003 for the trapper's economy. Nevertheless, the stationarity observed in the time series *PELT* in Louisiana during 1957-2003 could be a consequence of the relatively high value of river otter pelts in the fur market. This relatively high value of otter pelts compared to other furbearer species in Louisiana (St. Amant 1957, Linscombe and Kinler 1985) could have led active trappers to target this species more in recent years, which also could explain the increase in number of otters harvested per trapper. Thus, a change in trapper attitude could be why number of pelts harvested has remained relatively stable, even though number of trappers has been declining during the last 20-25 years.

A decline in number of trappers could lead to an increase in abundance of furbearer species (Caughley 1977), but with no data available on trapping effort for Louisiana, it is unclear whether the stationarity in number of pelts harvested is consequence of an increase in the abundance of otters with no changes in harvesting effort, or due to a renewed interest of trappers in river otters considering the sustained high price of otter pelts compared to other furbearer species. Regardless, it seems reasonable to assume that the dramatic decline in number of

Table 3.4. Transfer function models for time series *PELT*: parameter estimates, *Q*-statistics, and AIC for selected models using time series *LIC* as the only regressor, and *LIC* and *NPRICE* as regressors.

model	parameter	estimate	p-value	Q		d.f	p-value	AIC
AR(1)	intercept (lag 0)	4973	<0.001	*Q* lag 6:	5.27	5	0.81	826.61
	PELT (lag 1)	0.57	<0.001	*Q* lag 12:	11.89	11	0.87	
	LIC (lag 0)	0.56	0.01	*Q* lag 18:	17.20	17	0.70	
	NPRICE (lag 0)	61.57	0.04					
MA(1)	intercept (lag 0)	5034	<0.001	*Q* lag 6:	7.02	5	0.21	831.84
	PELT (lag 1)	-0.46	<0.01	*Q* lag 12:	10.84	11	0.46	
	LIC (lag 0)	0.64	0.0075	*Q* lag 18:	18.37	17	0.37	
	NPRICE (lag 0)	65.44	0.0501					
MA(3)	intercept (lag 0)	4993	<0.001	*Q* lag 6:	0.27	3	0.96	827.88
	PELT (lag 1)	-0.48	0.001	*Q* lag 12:	3.08	9	0.96	
	PELT (lag 2)	-0.37	0.018	*Q* lag 18:	7.9	15	0.93	
	PELT (lag 3)	-0.39	0.012					
	LIC (lag 0)	0.71	0.001					
	NPRICE (lag 0)	75	0.001					
AR(1)	intercept (lag 0)	5057	<0.001	*Q* lag 6:	2.78	5	0.73	828.55
	PELT (lag 1)	0.49	<0.001	*Q* lag 12:	6.98	11	0.80	
	LIC (lag 0)	0.59	0.01	*Q* lag 18:	15.18	17	0.58	
MA(1)	intercept (lag 0)	5097	<0.001	*Q* lag 6:	6.55	5	0.25	832.77
	PELT (lag 1)	-0.33	0.025	*Q* lag 12:	11.89	11	0.37	
	LIC (lag 0)	0.71	0.0063	*Q* lag 18:	21.05	17	0.22	
MA(2)	intercept (lag 0)	5063	<0.001	*Q* lag 6:	2.7	4	0.61	830.55
	PELT (lag 1)	-0.36	0.022	*Q* lag 12:	8.58	10	0.57	
	PELT (lag 2)	-0.29	0.061	*Q* lag 18:	16.8	16	0.40	
	LIC (lag 0)	0.70	0.005					
MA(3)	intercept (lag 0)	5071	<0.001	*Q* lag 6:	1.33	3	0.72	830.44
	PELT (lag 1)	-0.35	0.02	*Q* lag 12:	5.98	9	0.74	
	PELT (lag 2)	-0.34	0.02	*Q* lag 18:	13.00	15	0.60	
	PELT (lag 3)	-0.25	0.10					
	LIC (lag 0)	0.67	0.005					

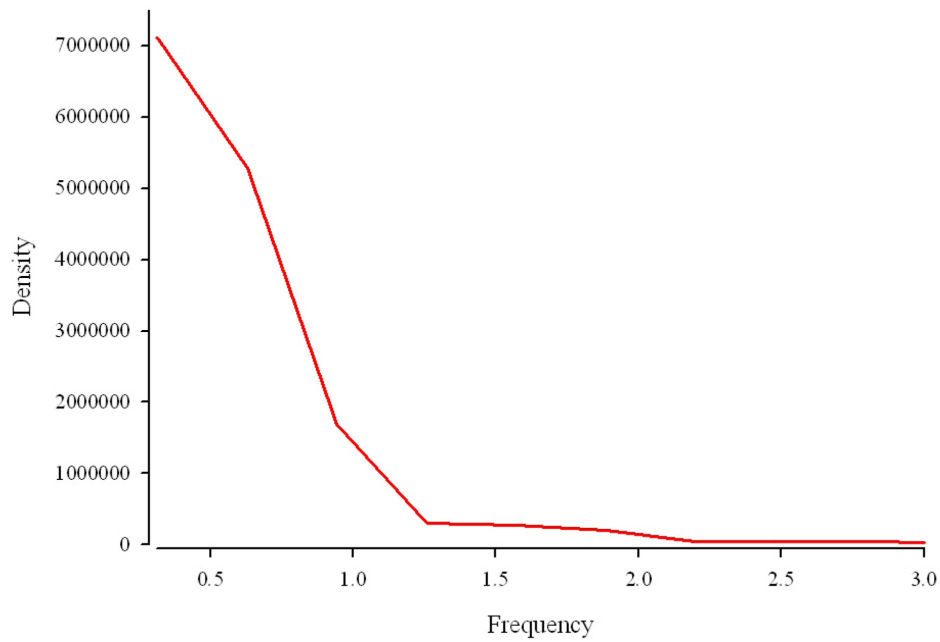
Table 3.5. Forecasted values of number of pelts harvested, errors and 95% confidence interval for number of otters pelts harvested in trapping season 2004 in Louisiana using selected transfer function models.(*) AR(1) model with only *LIC* time series as regressor.

model	forecast	95% CI	error
AR(1)	5398	(1782 , 9015)	315
MA(3)	5822	(2237 , 9408)	109
*AR(1)	4204	(468 , 7938)	1509

licensed trappers must have positively affected abundance of river otters in Louisiana at some level, independently of whether active trappers have an increased interest in the species in recent years.

Cross-correlation analysis identified associations existing between number of pelts, and number of licenses and pelt price. As mentioned before, the significant positive correlation at positive lags in Figure 3.4a indicates that the present number of licensed trappers is correlated to past number of pelts harvested. This suggests that the *PELT* time series leads the *LIC* time series, and that any changes in the *PELT* series will be followed by changes in the same direction in the *LIC* series. This association could be explained assuming that a string of successful or unsuccessful trapping seasons could encourage new people to participate or quit trapping activities during the next few trapping seasons (Berryman 1991). Cross-correlation also indicates that the association between number of pelts and pelt price could be purely contemporaneous, meaning that no time series lead the other, and that the average pelt price paid in any of the previous trapping season does not have an effect on the number of pelts harvested during present or future trapping seasons.

This non-effect of pelt price on future number of pelts harvested agrees with the well studied time series representing lynx fur returns from the Hudson's Bay Company (Brand and Keith 1979, Royama 1992). The correlogram representing the association between pelt price and number of licensed trappers (Figure 3.4c) indicated that changes in pelt price may positively affect future number of licensed trappers. Notably, the correlogram showed 2 peaks, one at lag -1 and another at lag -6. Some authors have suggested that beaver pelt price may have some effect of trapper participation in the following trapping season (Runge 1999). However this study fails to demonstrate the existence of a similar effect between otter pelt price and number of licensed trappers in the next trapping season (lag -1). While the cross-correlation coefficient at lag -6 was significant, it was relatively weak ($r<0.4$), and because it seems very difficult to identify a process that could relate present number of licensed trappers to otter pelt price 6 years ago, it is likely a random occurrence.



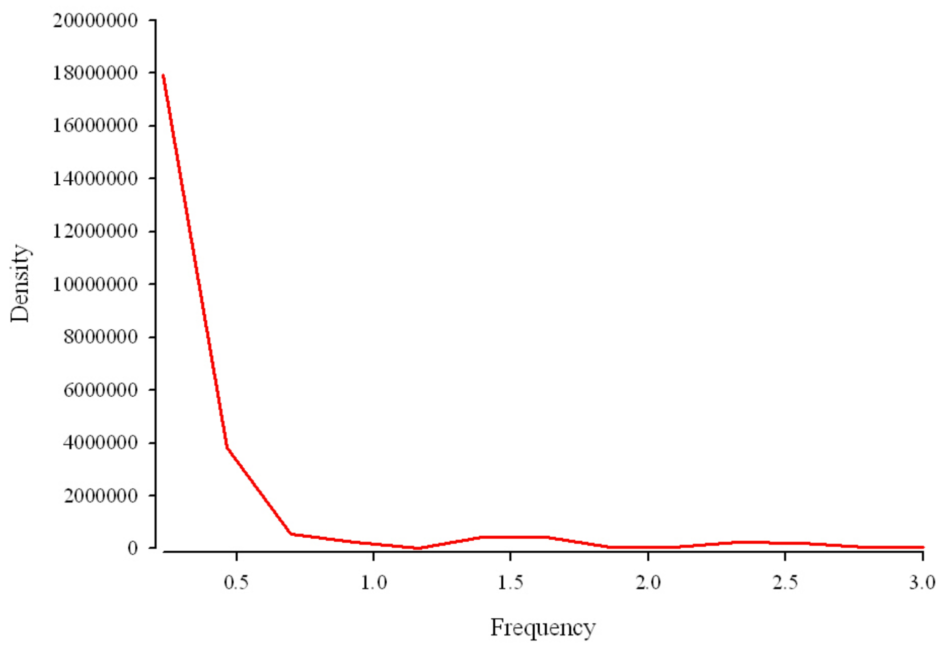


Figure 3.7. Estimated spectral density function. Trapping licenses time series for 1957-1983 (top) and 1984-2003 (bottom)

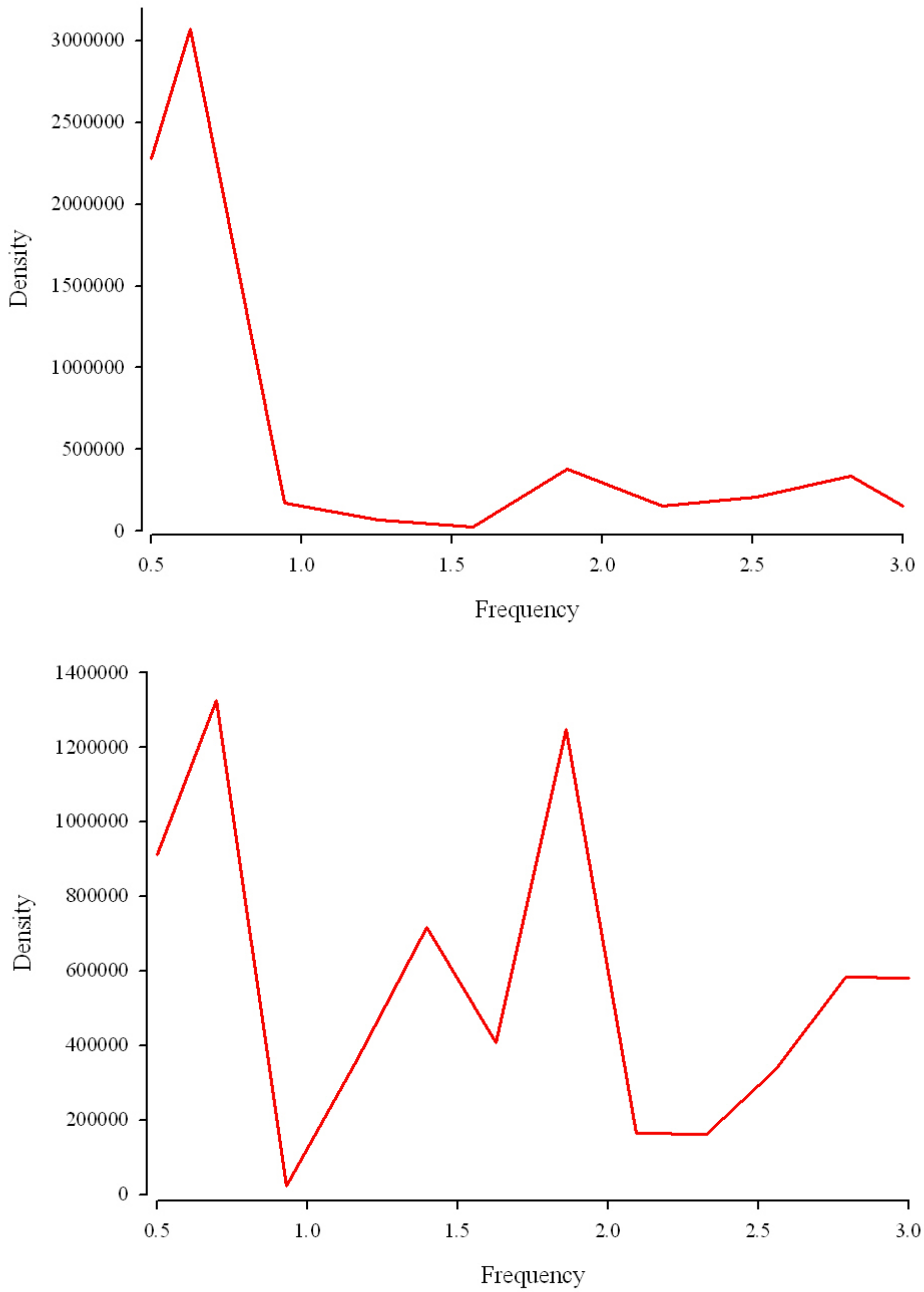


Figure 3.8. Estimated spectral density function. Pelts time series for 1957-1983 (top) and 1984-2003 (bottom)

Five of the 12 models selected, the regression equation, the AR(1,5) and MA(4) among the ARIMA models, and the two MA(3) models from the transfer function model family, share some significant characteristics that warrant discussion. Regression analysis indicated that number of trappers and otters harvested five years prior have a negative effect on number of otters trapped at present time. Similar effects of past trapping seasons at variable negative lags are indicated by the ARIMA and transfer function model development (MA(4) and MA(3) models respectively), which show negative parameter estimates for the lagged *PELT* time series. Reproductive biology of river otters in southern populations could offer a biological interpretation for the inclusion of those lagged terms in the models.

Latitude has been identified as having an effect on the age at which river otters achieve sexual maturity, and although individuals from southern populations could be sexually mature at 18-24 months of age (Melquist *et al*. 2003), males may not reach the full status of breeders until they are 5-8 years old (Liers 1951). If we consider that for many species reproductive males exhibit higher catchability, reflecting intense sexual activity (Lourdais *et al.* 2002), it seems reasonable to hypothesize that removing a certain number of reproductively active male otters could have an impact on size of the harvestable population 4-5 years later. This seems a plausible scenario in Louisiana, where more than 60% of the harvested otters in the trapping seasons 2002 and 2003 were aged as young adult males (2-3 years old) based on tooth ware pattern (unpublished data).

The selected models including lagged terms and the lagged cross-correlation between number of trappers and pelts agree with the existence of 3-4 year period cycles indicated by the spectral density function for the *PELT* series during 1984-2003. Relationships between number of harvested individuals and the effect of harvesting pressure have been synthesized by the Economic-Ecological feedback loop model developed for the cyclic dynamics in catch records of Dungeness crabs (Berryman 1991). This model relates the cyclic dynamics to the response of fishery to previous harvest success by modifying direct and indirect mortality rates in the crab population.

Other authors also have suggested that cycles in wild populations could be a consequence of harvesting pressure (Jonzén *et al.* 2003). Considering that this 3-4 year peak was evident only from 1984 to 2003 and not before, it could be hypothesized that the reason why this peak did not appear during 1957-1983 is because a more intense interaction between otter populations and harvesting activities existed during 1984-2003. Specifically, trappers during 1957-1983 targeted other furbearer species besides river otters, but after the profound changes in the fur market in the mid-80s, river otters became a more targetable furbearer species because the value of its fur remained relatively high.

There are reasons to believe that there is certain variability in the 3-4 year cycle. Of note is that sharpness of the peak is related to sample size and variability in periodicity. Peaks in the sample spectral function are commonly wider than 1/n, indicating that the cycle associated with that peak is irregular in some way, which implies that its phase, amplitude, or frequency could change. This variation is shown by the different frequency at which the sample spectral density diagrams for number of pelts peak, variation that also is reflected by the inclusion of different lags in the regression equation (lag 5) and the moving average models. The presence of a 10-year cycle in the pelt time series before and after 1983 could indicate that this cycle is not a consequence of harvesting activities, but rather of intrinsic population processes (see chapter 4).

Many considerations are required to select the appropriate model to be used as a forecasting tool by state managers. Model MA(3) with *LIC* and *NPRICE* as regressors in the transfer function family showed the smallest error; however, this model requires the present number of licensed trappers and pelt price to forecast number of pelts, and these values are usually only available at the end of each season. For that reason, this model may not represent a suitable tool for managers who are interested in estimating number of otter pelts harvested at the beginning of the trapping season. Fortunately, ARIMA model AR(1,5) had a similar performance and does not require values from the present trapping season to forecast. The equation that describes this model and that could be used by state wildlife managers to forecast number of pelts is: $PELT_t = \text{mean} + 0.6\ (PLET_{t-1} - \text{mean}) - 0.26\ (PELT_{t-5} - \text{mean}) + \text{error}$

When more data are available, new analyses will have to be conducted to re-evaluate this model and adapt it to new findings. Future research on the ecology and dynamics of otters in Louisiana will further contribute to the performance of this model.

CHAPTER 4

RIVER OTTER PELTS TIME SERIES AND ITS BIOLOGICAL INTERPRETATION

For more than 60 years, the analysis of the time series representing fur-return for Canadian lynx (*Lynxs canadensis*), has been at the core of attempts to understand cyclic populations (Elton and Nicholson 1942, Royama 1992). This time series represents records kept by the Hudson's Bay Company of number of lynx pelts harvested in Canadian territories during 1821-1939. First analyzed in 1942 (Elton and Nicholson in 1942), the series continues to be a source of debate and new models in population dynamics (Moran 1953a, 1953b, Tong 1977, Haggan and Ozaki 1981, Royama 1992).

Many authors have criticized the assumption that fur-return statistics legitimately represented actual abundance of lynx populations, arguing that cycles in the lynx fur-return time series were the consequence of changes in trapper effort responding to variations in snowshoe hare abundance (Gilpin 1973, Weinstein 1977, Winterhalder 1980) and not actual fluctuations in lynx populations. But recent field data (Nellis *et al*. 1972, Brand *et al*. 1976, Brand and Keith 1979) and theoretical evidence (Royama 1992, Cattadori *et al*. 2003) support the use of harvest data as indirect measures of population abundance. Notably, for many species harvest data are the only source of information available, and some of the most revealing studies on population dynamics have used harvest data (Elton and Nicholson 1942, Moran 1952, 1953, Botsford *et al*. 1983, Hankin 1985, Berryman 1991, Royama 1992).

The statistical analysis of time series has several strengths, such as a quantitatively defined notion of goodness of fit, a good understanding of sampling properties of the statistics, and few assumptions about the data (Kendall *et al*. 1999). However, although statistically sound, processes governing the series are ignored in this approach (Kendall *et al*. 1999, Turchin 2003). At the other end of the spectrum are the mechanistic models. Although lacking some quantitative rigor, they improve our understanding of processes generating the cycles by explicitly including in the modeling process factors controlling the dynamics, and also by considering available information on the dynamic besides the information given by the time series (Kendall *et al*.

1999). Most models lie between these two extremes, depending on the knowledge of the species being modeled.

Few studies have used a combination of these two approaches, and one of those is the description of the lynx cycles based on the fur-return time series by Royama (1992). Some authors used a second-order autoregressive model AR(2) to describe these same data (Moran 1953, Royama 1992), whereas a more realistic model incorporates the dynamics of the lynx prey, the snowshoe hare, in a predator-prey mechanistic model (Royama 1992).

The goal for this chapter is to develop a model that would describe the dynamics of the river otter population in Louisiana. Rather than an accurate representation of these dynamics, the model developed in this chapter has to be considered an intellectual tool that could be used by local management and conservation agencies to define and understand problems related to river otter populations, to understand data, to test hypotheses, and make predictions.

Methods

A basic assumption of this chapter is that the structure of the pelt time series reflects the structure of the dynamics of the actual river otter populations. Two elements of the structure of the pelt time series that were identified in Chapter 3 are considered for the development of the population model, *i*) the effect of number of otters (or pelts in Chapter 3) at times t_{-1} and t_{-5} on the number of otters (or pelts) at time t_0., and *ii*) the periodic oscillations identified by the spectral analysis.

Oscillations have been recognized in many animal populations (Kendall *et al*. 1999). Moran (1953a) used an autoregressive model with periodic perturbations to describe the lynx cycle. A simple model of time series using sinusoidal components could be represented by

$$Y_t = : + " (\sin(o t + *)) + g_t$$

where : represents the mean of the time series Y, " represents the amplitude of the wave, o is the frequency, * is the phase of the wave, and g_t describes a random effect.

Using the structure described by the ARIMA model AR(1,5) presented in Chapter 3, and information from the spectral analysis of the time series, an autoregressive model with periodic

perturbations was developed to describe cyclic dynamics in the otter population. The combination of the sinusoidal model and the AR(1,5) model gives

$$Y_t = \mu + [\gamma Y_{t-1} + \lambda Y_{t-5}] + \alpha (\sin(\omega t + \phi)) + \varepsilon_t$$

where the terms between brackets describe the autoregressive effect.

To start running the simulations with this model, population estimates for *t-1* and *t-5* are needed. In coastal Louisiana, the harvest rate was estimated from 17-28% during 1973-1984 (Shirley *et al*. 1988). Considering that no trend was identified in the pelt time series in Chapter 3, and it has been estimated that stability of river otter populations could be maintained with a harvest of 15-17% of the available autumn population (Berg and Kuehn cited by Melquist *et al*. 2003), a mean harvest rate of 22% was used to estimate otter abundance in Louisiana during 1973-1984. The estimated abundances were used to simulate otter abundance for 1985-2008 with the model

$$OTTER_t = \eta_{73\text{-}84} + 0.6\,(OTTER_{t-1} - \eta_{73\text{-}84}) - 0.23\,(OTTER_{t-5} - \eta_{73\text{-}84}) +$$
$$+ \eta_{73\text{-}84}\,\alpha \sin[(t - 1977)\,2\pi/P_1] - \eta_{73\text{-}84}\,\alpha \sin[(t - 1977)\,2\pi/P_2]$$

where $OTTER_t$ is the number of otters at time *t*, $\eta_{73\text{-}84}$ represents the estimated mean number of river otters during 1973-1984, $OTTER_{t-1}$ and $OTTER_{t-5}$ are the number of otters at time *t-1* and *t-5*, respectively, α is the amplitude, *t* is the time (year) at which otter abundance will be estimated, and P_1 and P_2 are 2 different periods of the oscillation. Simulations were generated with α = 0.18 and 0.22, P_1 = 8, 9 and 10 years, and P_2 = 4 and 5 years. Software MAPLE v.9.5 was used for all the simulations (Waterloo Maple Inc. 2005). Models giving the best correspondence with the harvest data, in terms of year at which peaks and troughs occurs, during 1973-2003 were considered good approximations to the otter population dynamics.

Results

A total of six simulations were generated with the following combination of parameters,

sim1: $\alpha = 0.22$, $P_1 = 10$, $P_2 = 5$ sim2: $\alpha = 0.18$, $P_1 = 10$, $P_2 = 5$

sim3: $\alpha = 0.22$, $P_1 = 9$, $P_2 = 4.5$ sim4: $\alpha = 0.18$, $P_1 = 9$, $P_2 = 4.5$

sim5: $\alpha = 0.22$, $P_1 = 8$, $P_2 = 4$ sim6: $\alpha = 0.18$, $P_1 = 8$, $P_2 = 4$

Population estimates for the 12 years used to initiate the simulations and harvest data during 1973-2003 indicated that not all simulations showed a good approximation to the oscillations observed in the harvest data (Figures 4.1- 4.4). Simulations with periods P1 = 8 and P2 = 4 gave the best correspondence with the peaks and troughs in the harvest data (Figure 4.4).

Discussion

A basic assumption in the analysis presented in this chapter was that there is a correspondence between patterns in time series of harvest data and ecological mechanisms generating population fluctuations. The analysis of the time plots comparing the occurrence of peaks and troughs in the modeled populations and the harvest data suggested that the structure of the model with $P_1 = 8$ and $P_2 = 4$ may offer a reasonable approximation to the actual cyclic dynamics of otter populations in Louisiana. As suggested by the spectral analysis in Chapter 3, 2 cyclic patterns with different periods were very likely to occur in the river otter population. This analysis also indicated certain variability in the periodicity of these cycles. The model presented in this chapter suggests that river otter populations in Louisiana may have cyclic dynamics with 8-year and 4-year periods. As discussed in Chapter 3, the 4-year period cycle could be explained by a disproportionate catch of juvenile males. However, the biological explanation of the 8-year period cycle is difficult given the current knowledge of the processes governing the dynamics of otter populations. The actual magnitude of the amplitude of the oscillation remains unclear, and may require additional data and analysis for its proper estimation.

It has been noted that harvest data seemed to exaggerate the cyclic changes in a population. For instance, for the Canadian lynx data, it was estimated that the population increased 4.3-fold over 5 years, whereas the harvest data showed a 20-fold increase for the same period (Brant and Keith 1979, Royama 1992). An estimate of the probable maximum average rate of increase for lynx was estimated as not being higher than 1.57 (or 57%). The same rate can be estimated for river otters based on information of its reproductive biology with the equation

$$(P_{af})\ (PR)\ (ULS)\ (S_p) + (S_a)$$

Figure 4.1. Number of harvested otter pelts (dashed line) in Louisiana during 1973-1984, and estimated number of otters (solid line) for the same period based on an estimated mean harvest rate of 22%.

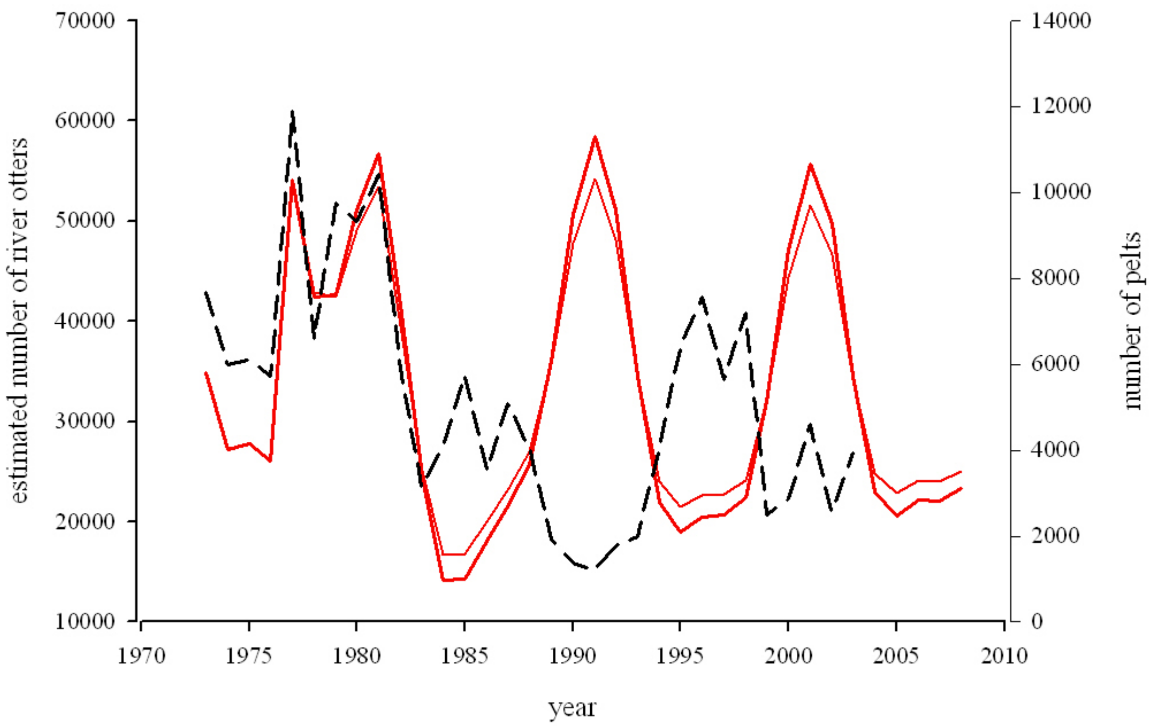


Figure 4.2. Simulation of river otter population dynamics (continuous lines) for period 1973-2008. Parameters were: amplitude = 0.22 (thick line), and 0.18 (thin line), both simulations used the same periods, P_1 = 10 years and P_2 = 5 years. Dashed line represents number of river otters harvested during 1973-2003.

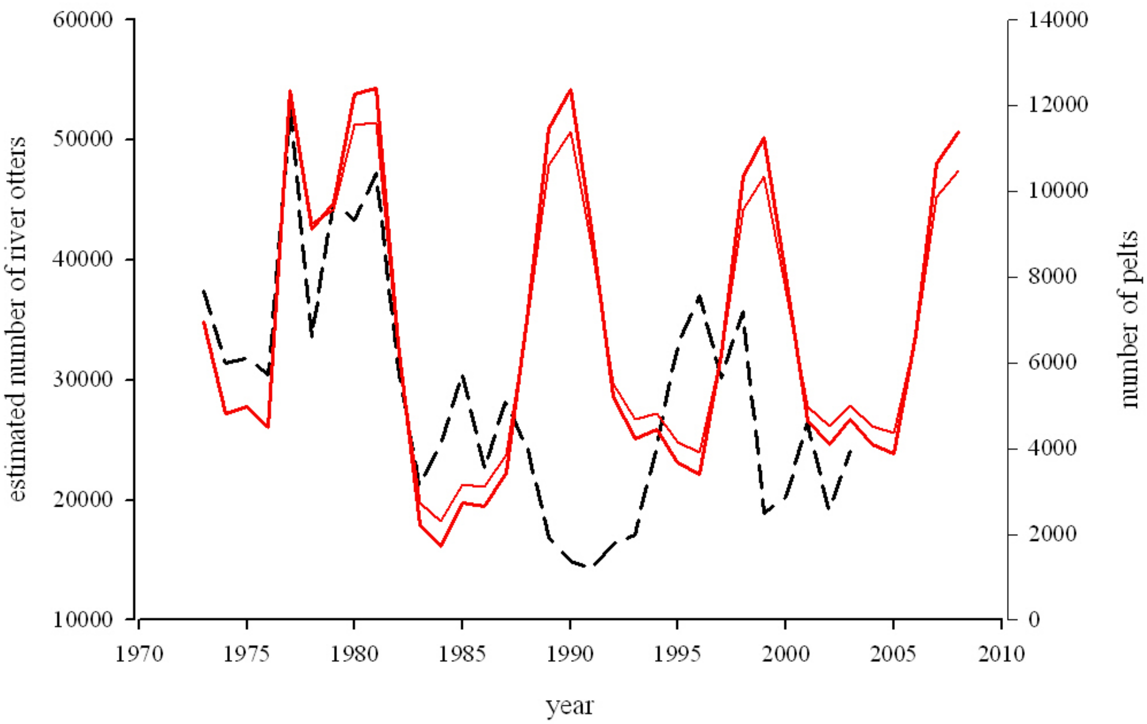


Figure 4.3. Simulation of river otter population dynamics (continuous lines) for period 1973-2008. Parameters were: amplitude = 0.22 (thick line), and 0.18 (thin line), both simulations used the same periods, $P_1 = 9$ years and $P_2 = 4.5$ years. Dashed line represents number of river otters harvested during 1973-2003.

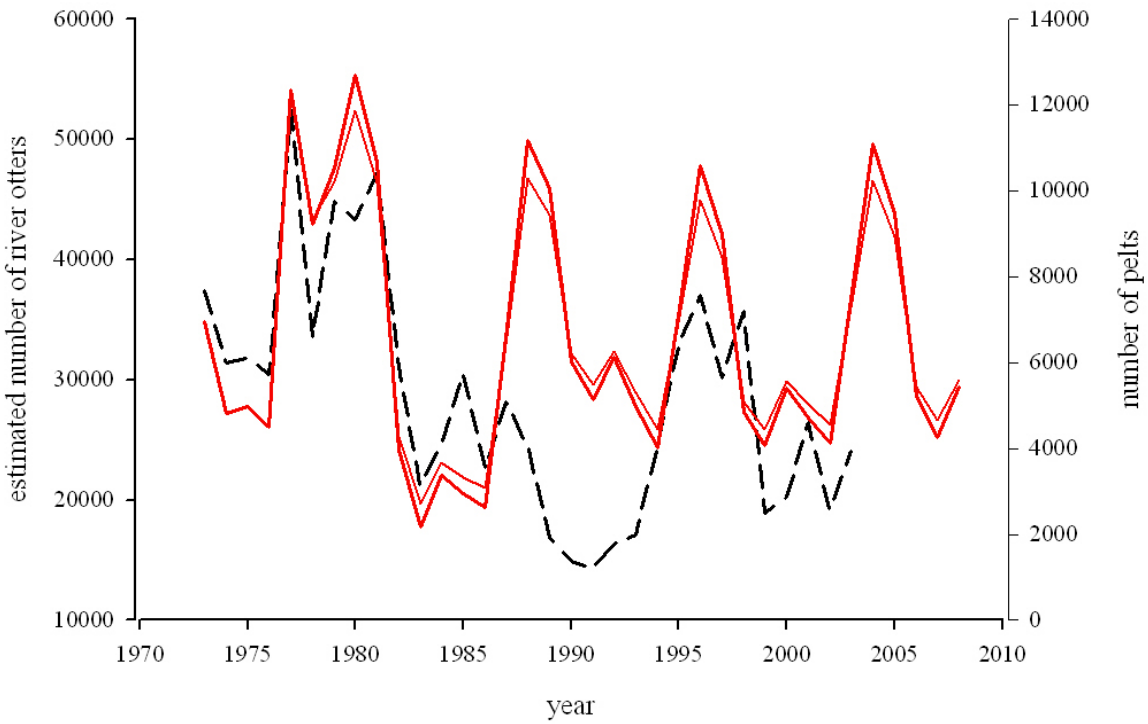


Figure 4.4. Simulation of river otter population dynamics (continuous lines) for period 1973-2008. Parameters were: amplitude = 0.22 (thick line), and 0.18 (thin line), both simulations used the same periods, P_1 = 8 years and P_2 = 4 years. Dashed line represents number of river otters harvested during 1973-2003.

where P_{af} is the proportion of adult females in the population, *PR* is the pregnancy rate, *ULS* is the *in utero* litter size, S_p is the survival of pups, and S_a is the survival of adults.

A literature review indicated that proportion of adult females in a population has been estimated as 50% (Lizotte 1994); pregnancy rate for otters as 0.88 (Lizotte 1994), *in utero* average litter size has been reported to be 2.6 fetuses (Lizotte 1994), and survival was 0.87 for pups and 0.75 for adults (Melquist and Hornocker 1983). These data suggest that the maximum average rate of river otter population increase could not be much higher than 1.74 (or 74%); however, harvest data indicate a 6.3-fold increase during 1991-1996, more than 3 times the estimated maximum rate of increase for the population.

Different factors have been identified as potentially causing the discrepancy between harvest data and population estimates: trap bias, sampling error, and trapper's effort. As mentioned in Chapter 3, juvenile males are more likely to be caught (Lourdais *et al*. 2002), which may contribute to the exaggerated amplitude. Sampling error is believed to be low given the regulations imposed by the LDWF and the possession tags needed for otter pelt commercialization. Trappers and fur dealers have to report their catch to LDWF to get the possession tags and be able to commercialize otter pelts. Another possible cause of the exaggerated amplitude in the harvest data could be trapper effort. Higher pelt price may lead trappers to spend more time/traps trying to catch otters. However time series analysis presented in Chapter 3 does not support this argument. Furthermore, it has been suggested that otters in Louisiana may be taken in traps set for other furbearer species (Edwards 1983), which not only discounts the argument of trapper effort as a source of exaggerated amplitudes, but also supports the assumption that changes in harvest data indicate actual changes in otter population. Updated information on trapper activities is needed for a better understanding of the associations between harvest data and trapper effort. At the time of writing legal issues did not allow a trapper survey to be conducted, making it impossible to discuss this topic with solid data.

Although the model presented in this chapter does not provide insight into the ecological mechanisms responsible for the population dynamics, it still could represent a valuable tool for

state management and conservation agencies in their attempt to manage river otters in Louisiana. Being a purely phenomenological model, the next steps should be to collect the needed information for the development of a model with a mechanistic approach such as age and sex structure, and make the arrangements to conduct a trapper's survey that could provide insight on the actual processes governing otter harvest and population dynamics in Louisiana.

CHAPTER 5

RIVER OTTER AS AN INDICATOR SPECIES OF WATER QUALITY IN LOUISIANA

With power plants as its main source, elemental mercury (Hg) is efficiently transported as a gas around the globe, resulting in the contamination of areas far away from pollution sources. By microbial activity, the inorganic form is methylated and enters the biota where it is accumulated by organisms at various levels of the food chain. This organic form has been detected in many remote lakes and streams in the United States, resulting in fish containing mercury levels that posed health risks for human consumption (Swain *et al.* 1992).

Fishing and fish consumption are very popular in Louisiana and for that reason, the Louisiana Department of Environmental Quality (LDEQ) developed a program to monitor mercury levels in all popular public-fishing areas in the state by sampling fish, water, and sediments, and identifying water bodies of concern if mercury levels in fish were 0.5 ppm (parts per million) or higher (LDEQ 2003). Although LDEQ has approximately 400 sites on file that are regularly sampled (LDEQ 2003), that number may not be large enough to estimate the actual status of many water bodies in Louisiana, as almost 17,000 miles of stream are distributed among 2014 mappable systems (Louisiana GIS CD v.2.0.). Furthermore, considering that all efforts are concentrated on popular public-fishing areas, a large proportion of small streams in rural areas, where locals tend to catch their fish, may not be currently monitored.

Including rural streams in the regular LDEQ's sampling schedule may involve some logistic constraints, such as limited human resources available to collect samples, and geomorphological and hydrological characteristics of these streams that could make fish sampling very difficult. For instance, no fishes were collected during preliminary field activities of this study in areas where local people were known to fish after sampling 10 streams. Electrofishing, a standard technique used in fish sampling by LDEQ, was used during the sampling. Alternative ways to better monitor mercury levels in fish in Louisiana are needed if areas with low fishing activity are to be included. One approach would be finding a surrogate

species that is included in the same food chain as the fish community, that occurs in those secondary streams, and that is available in numbers that would offer a valid sample size.

Many intrinsic and extrinsic characteristics of river otters indicate that this species could be a suitable surrogate species to identify areas of concern in Louisiana regarding mercury levels in fish. River otters bioconcentrate, bioaccumulate, and biomagnify mercury, three processes that put otters at the top of the list of potential candidate species to be used as a monitor of aquatic ecosystems. Bioconcentration is the net accumulation of a substance by an aquatic organisms as a result of uptake directly from aqueous solution (Suter 1993, ASTM 1998). In contrast, bioaccumulation represents the net accumulation of a substance by an organism as a result of uptake directly from all environmental sources and as a result of uptake from all routes of exposure (Connell 1990, Suter 1993, ASTM 1998). Bioaccumulation often refers to the process by which a chemical moves into the organism from the food or water it ingested. Finally, biomagnification is the increase in tissue concentration of poorly depurated materials in organisms along a series of predator-prey associations, primarily through the mechanism of dietary accumulation (ASTM 1998). Thus the processes of bioconcentration and bioaccumulation make river otter a suitable species to monitor mercury concentration in aquatic ecosystems, and since otters also may biomagnify mercury, measuring mercury levels in otters offers the possibility of early detection of areas of concern.

Such a monitoring program based on river otters could be an option for Louisiana considering the species has a statewide distribution (Lowery 1974), normally inhabits areas with low human activity (Chabreck *et al*. 1985), and that 3,500 otters are harvested on average per year (Linscombe and Kinler 1985). In this chapter, different components that would be important for the development of the final program are evaluated, such as feasibility of sample collection in terms of numbers and origin of the samples, comparison of mercury levels in river otters and fish, and tools for detection of areas of concern. Furthermore, because historic data on mercury levels on river otter existed for the Atchafalaya Basin area (Beck 1977), a comparison of

those levels to current values is presented as a way to estimate changes in aquatic systems in the area through time.

Methods

Local fur dealers were contacted in 2002 and asked to collect otter carcasses from trappers. Whole carcasses were kept frozen at the dealer's facilities and collected for analysis every 2-3 weeks. Every carcass was marked with a tag describing date of the catch and location, which in most cases included stream name and the name of some landmark close to the catch site. The decision to contact dealers and not trappers was based on the assumption that trappers would trust fur dealers more than a third unknown person, which would produce better data quality, particularly in terms of accuracy in the description of the catch site.

Frozen samples of liver were sent to the Wetland Biochemistry Lab at Louisiana State University for mercury analysis. Total mercury level in liver samples was analyzed by cold vapor atomic absorption spectroscopy. Mercury levels in river otter tissue were compared to levels in fish. Most recent data on fish were provided by LDEQ for the areas where otter samples were collected. No attempt was made to discriminate mercury level by age, because either no differences have been found among age classes (Evans *et al*. 1998) or contradictory trends were reported on the relationship between mercury level and age (Kucera 1983, Wren *et al*. 1986, Francis and Bennett 1994).

Data were tested for normality using the Shapiro-Wilk test and, if needed, log transformation was used to satisfy the assumption of normality. Boxplots were used to summarize the data. Because collecting enough otter samples from a single stream or watershed is difficult, all samples, otter and fish, were grouped by parish for analysis. One-way and two-way ANOVA (SAS PROC GLM, SAS Institute v 8.02) was used to determine differences in mercury between fish and otter samples, and differences among parishes. Data from 1976 on mercury levels in otter from the Atchafalaya basin (Beck 1977) were compared to samples collected during 2002-2003 with one-way ANOVA (" = 0.05, or otherwise noted). Mercury concentration surfaces were generated by spatial interpolation (kriging) (Isaaks and Srivastava

1989) of fish and otter data with software GS+ v. 5.0. (Gamma Design 2000), and overlaid to stream maps with ArcView 3.3 (ESRI 2002) to identify new streams where further evaluation of mercury level might be required.

Results

A total of 83 otter samples were collected from 2 fur dealers during 2002-2003. Samples came from a large area in central Louisiana, but I considered for further analysis only samples having an accurate location of the catch site. A subset of 59 samples collected from Rapides (n = 18), St. Landry (n = 37), and Avoyelles (n = 4) parishes were considered for analysis. Mercury levels in fish collected in those same parishes in 2002-2003 were provided by LDEQ. Mercury levels in otters ranged from 0.146 parts per million (ppm) to 4.08 ppm, with a mean value of 0.98 ppm, (SD = 0.97 ppm). A total of 87 fish samples were collected by LDEQ during that period in Rapides parish (n = 21), St. Landry parish (n = 54), and Avoyelles parish (n = 12). For fish the range of mercury concentration in tissue was 0.037-2.234 ppm, with a mean value of 0.47 ppm (SD = 0.43 ppm) (Table 5.1, Figure 5.1); a left skewed distribution was evident for both the fish and otter data.

The data did not support the assumption of normality ($W = 0.77$, $P<0.0001$; $W = 0.76$, $P<0.0001$, for fish and otter respectively), the dataset was log-transformed. Analysis of samples from 2002-2003 indicated that, in general, mercury levels in otter samples were greater than in fish (F = 19.86, d.f. = 1, $P<0.001$). A comparison by parish of mercury levels in otter tissue indicated that otters from Rapides parish had greater mercury level than samples from Avoyelles and St. Landry (F = 5.44, d.f. =2, P = 0.007). Mercury concentrations in fish were greater in Rapides parish than in the other 2 parishes at " = 0.1 (F = 2.84, d.f. = 2, P = 0.06). Samples from St. Landry were compared to samples from the upper Atchafalaya basin collected by Beck in 1996 (Beck 1977), and indicated that mercury levels in otters in 2002-2003 were significantly lower than samples collected during 1976 (F = 17.03, d.f. = 1, $P<0.001$).

The otter mercury surface shows areas of concern in the northeast part of Rapides parish, more precisely around the city of Alexandria (Figures 5.2, 5.3). The surface based on fish data

indicates potential areas of concern south of Alexandria and north central part of St. Landry parish around the towns Lebeau and Bolden (Figure 5.3). Figure 5.4 shows a diagram of the areas with the highest mercury concentration based on the otter and fish mercury concentration surfaces shown in Figure 5.3.

Discussion

Concentration of toxic metals in the environment has increased several orders of magnitude over the last century as a consequence of human activities, with mercury among the toxic metals that is most frequently found in aquatic ecosystems and a major cause of concern for human health (Morel *et al*. 1998). Historically the main sources were discharges from industrial plants, and the contaminated areas were more localized. In recent decades those sources have changed, creating a widespread contamination as a consequence of atmospheric transport of mercury produced by the combustion of fossil fuels. Thus, there is a need for a mercury monitoring program that would offer access to areas that may not be recognized as areas of concern based on the level of human activity. Results from this study support the use of river otters as a complementary species, along with fish, to be used as a monitoring species of mercury levels in streams of Louisiana.

Previous studies have suggested that otters could be used as a bioindicator of environmental quality if their populations were periodically sampled to determine presence and concentration of contaminants (Halbrook *et al*. 1996). However, sample size has been indicated as an issue in studies on river otters and contaminants, making it difficult to use this species to monitor habitat quality (Evans *et al*. 1998). For Louisiana, sample size should not be an issue at current levels of harvest, which would provide enough samples to monitor numerous streams that are not currently being monitored. There are approximately 20 fur dealers and > 1,400 licensed trappers in Louisiana, and during the 2003-2004 trapping season 2003-2004 more than 5,700 otters were harvested by more than 1,400 licensed trappers. Thus, collecting a small fraction of the total harvest is possible annually, particularly considering that fur dealers and trappers were cooperative collecting carcasses for this study.

Table 5.1. Mercury level(Hg) in otter tissue samples collected in Rapides (RPS), St. Landry (SLD), and Avoyelles (AVY) parish, Louisiana, during 2002-2003. ppm: parts per million.

Parish	Hg (ppm)	Parish	Hg (ppm)	Parish	Hg (ppm)
AVY	0.24	SLD	0.19	SLD	1.17
AVY	0.80	SLD	0.22	SLD	1.31
AVY	1.43	SLD	1.08	SLD	1.42
AVY	0.71	SLD	0.28	SLD	0.97
RPS	0.19	SLD	0.14	SLD	0.52
RPS	0.28	SLD	0.25	SLD	3.20
RPS	4.08	SLD	0.19	SLD	0.50
RPS	2.52	SLD	1.18	SLD	0.43
RPS	0.86	SLD	1.58	SLD	0.19
RPS	3.70	SLD	1.41	SLD	0.26
RPS	1.50	SLD	0.24	SLD	0.55
RPS	2.07	SLD	0.27	SLD	1.00
RPS	1.00	SLD	0.25	SLD	0.49
RPS	3.17	SLD	0.29	SLD	0.63
RPS	0.23	SLD	0.58	SLD	1.05
RPS	0.99	SLD	0.52		
RPS	0.17	SLD	0.55		
RPS	0.27	SLD	1.18		
RPS	0.80	SLD	0.25		
RPS	0.46	SLD	0.60		
RPS	1.9	SLD	0.90		
RPS	4.00	SLD	0.58		

Table 5.2. Mercury level (Hg) in fish tissue samples collected in Rapides (RPS), St. Landry (SLD), and Avoyelles (AVY) parish by the Louisiana Department of Environmental Quality during 2002-2003. ppm: parts per million.

Parish	Hg (ppm)	Parish	Hg (ppm)	Parish	Hg (ppm)	Parish	Hg (ppm)
AVY	0.28	RPS	1.14	SLD	0.76	SLD	0.34
AVY	0.31	RPS	1.14	SLD	0.43	SLD	0.25
AVY	0.33	RPS	0.25	SLD	0.21	SLD	0.32
AVY	0.38	RPS	1.08	SLD	0.24	SLD	0.31
AVY	0.39	RPS	0.59	SLD	0.64	SLD	0.51
AVY	0.17	RPS	0.82	SLD	0.45	SLD	0.18
AVY	0.24	RPS	1.65	SLD	0.27	SLD	0.50
AVY	0.48	RPS	1.72	SLD	0.68	SLD	0.53
AVY	0.24	RPS	1.87	SLD	0.54	SLD	0.21
AVY	0.75	RPS	1.78	SLD	0.44	SLD	0.22
AVY	0.70	SLD	0.22	SLD	2.23	SLD	0.27
AVY	0.82	SLD	0.22	SLD	0.45	SLD	0.34
RPS	0.12	SLD	0.26	SLD	0.40	SLD	1.04
RPS	0.11	SLD	0.33	SLD	0.61	SLD	0.98
RPS	0.16	SLD	0.08	SLD	0.47	SLD	0.20
RPS	0.17	SLD	0.15	SLD	0.19	SLD	0.15
RPS	0.33	SLD	0.12	SLD	0.11	SLD	0.24
RPS	0.04	SLD	0.16	SLD	0.13	SLD	0.19
RPS	0.08	SLD	0.77	SLD	0.30		
RPS	0.03	SLD	0.65	SLD	0.31		
RPS	0.04	SLD	0.24	SLD	0.60		
RPS	0.13	SLD	0.57	SLD	0.17		
RPS	0.72	SLD	0.67	SLD	0.29		

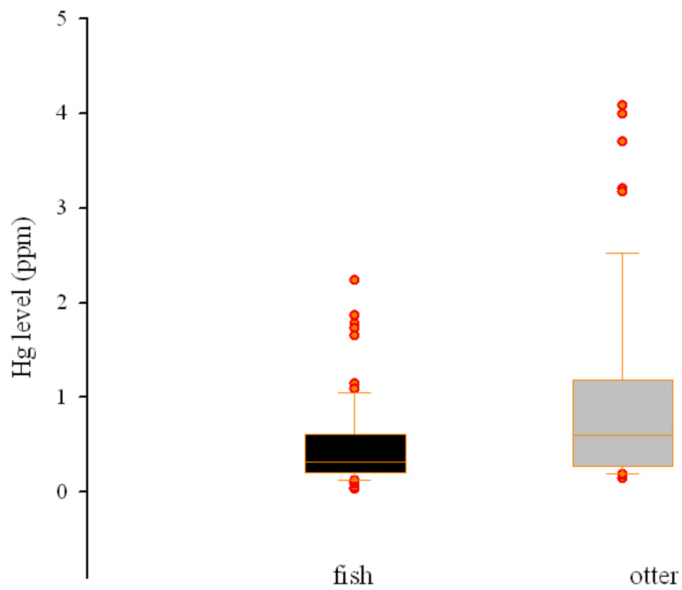


Figure 5.1. 5th/95th percentile boxplots describing mercury levels (ppm) in fish and otters in central Louisiana. 2002-2003.

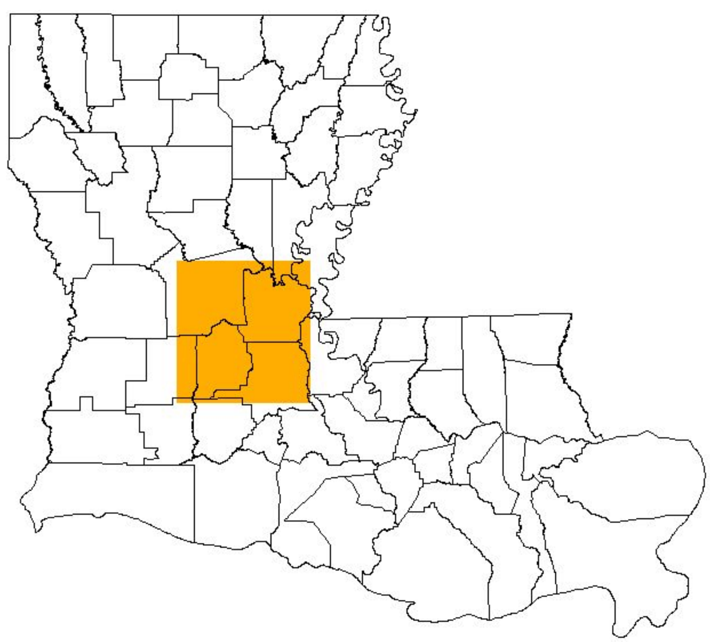


Figure 5.2. Area in central Louisiana where mercury concentration surfaces were generated by kriging using mercury levels in otter and fish sampled during 2002-2003.

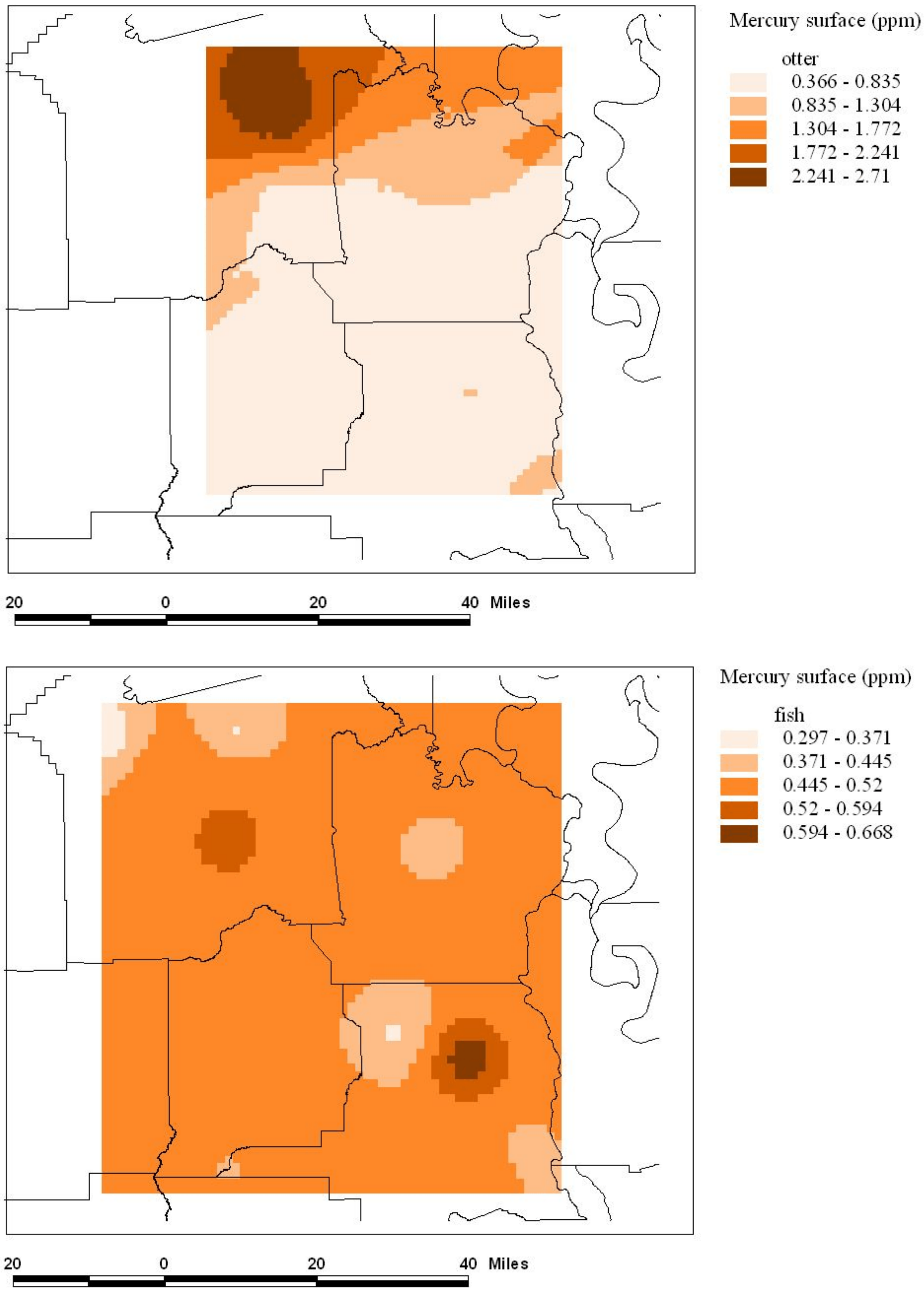


Figure 5.3. Mercury concentration surfaces generated by kriging using concentrations in otter (top) and fish (bottom) from samples collected in central Louisiana during 2002-2003.

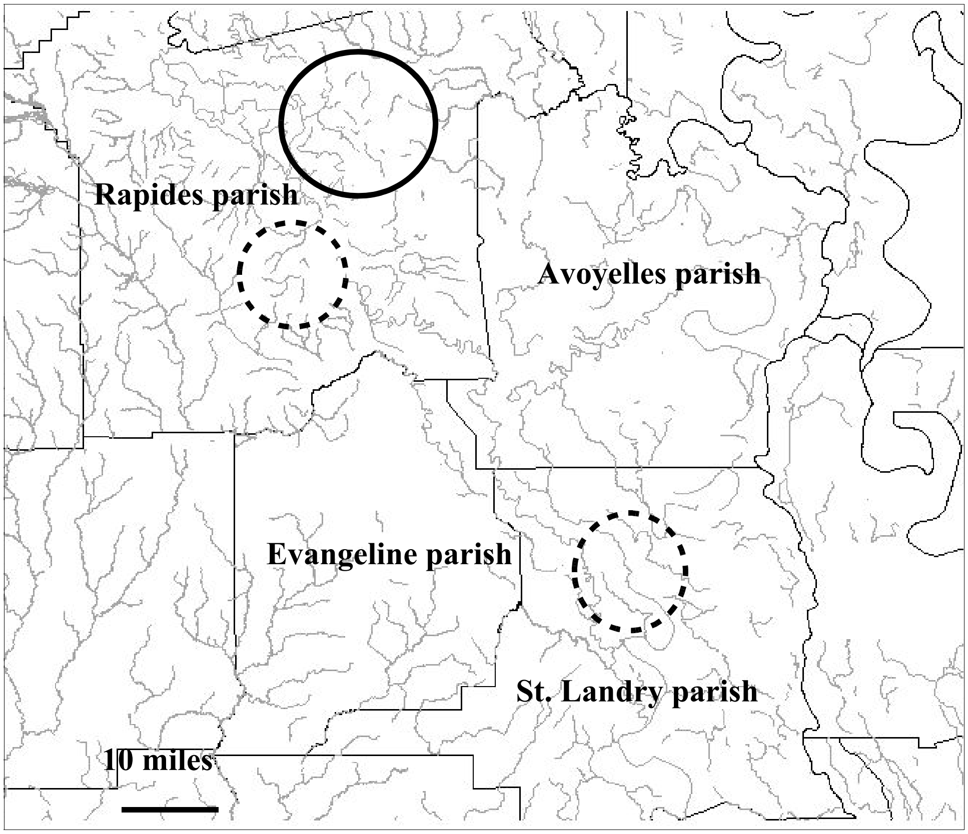


Figure 5.4. Diagram showing streams in potential areas of concern for further analysis of mercury levels in fish based on fish data from the Louisiana Department of Environmental Quality (dashed line) and from river otter data (solid line).

Mercury levels in otters were greater than levels in fish in the same area, suggesting that river otters could be used as an early indicator of areas of concern regarding mercury levels in aquatic ecosystems. This is an important element to be considered in any monitoring program where the minimum detection level of the chemical being analyzed could become an issue.

Mercury levels reported here, although higher than in fish, were lower than levels reported in the last 2 decades for other areas in the United States and Canada (Kucera 1983, Wren *et al.* 1986, Foley *et al*. 1988, Halbrook *et al*. 1996, Evans *et al*. 1998). Without any other evidences, this could be considered as an encouraging indication of better water quality in Louisiana streams. In this regard, it is worth noting that the range of current mercury level in otters in Louisiana is very similar to the range reported for the early ‘80s in Connecticut and Massachusetts for areas with no known mercury contamination (O’Connor and Nielsen 1981).

Examining historical data on mercury levels in otters from the upper Atchafalaya basin (see Beck 1977) offered a unique opportunity to make a temporal comparison for samples collected in the same area. Interestingly, the mercury levels in otters reported by Beck in 1977 were coincident with the enactment of the Clear Water Act, which established the basic structure for regulating discharges of pollutants into the waters of the United States (US EPA 2005). As a result, the amount of emissions of human-caused mercury dropped from 220 tons/year in 1990 to 48 tons/year in 2004 (US EPA 2005). Thus, it seems valid to assume that the decline in mercury levels in river otters from the upper Atchafalaya basin could be the result of a reduction in the amount of mercury released in the atmosphere, which also may be indicating an improvement in aquatic systems in the area in terms of mercury contents.

A third element in the evaluation of river otters as an indicator species of water quality in Louisiana was the potential to identify streams or areas where further analysis of mercury levels in fish could be beneficial and where sampling fish was infeasible. Mercury concentration surfaces generated with otter and fish data supported the use of otters as a surrogate species to monitor mercury levels in the biota when sampling fish was difficult. Streams for further analysis identified in the surface generated by otter data, but not in the surface based on fish data, were Little Horsepen Creek, Wiggins Bayou, Persimmon Bayou, Hynson Bayou, Bayou Rapides, Bayou Maria, and Flagon Bayou, all in Rapides parish.

Although results of this study indicate that a monitoring program based on river otters seems possible for Louisiana, some aspects of such a program should be defined before implementation. One of those aspects is to develop a network that will guarantee a reliable sample collection scheme, where LDEQ personnel support and instruct trappers and fur dealers in the process of sample collection and preservation. Another aspect to be consider is a form to compensate trappers and dealer for their participation in the program; a nominal monetary value paid for each carcass collected could be a possibility since currently most of the carcasses are being thrown away.

Intensive monitoring of movement and fate of otters has been recommended to determine changes in abundance and distribution (Halbrook *et al*. 1996). Because relating presence of toxic chemicals in otters to specific sources is difficult due to otter movements and the relation of these movements to habitat features, conducting a radiotelemetry study of otter movements would presumably clarify patterns and may elucidate movement patterns relative to pollution sources or the effect of habitat quality (i.e. mercury concentration in fish/water, on river otter home range size, or habitat used).

CHAPTER 6

CONCLUSIONS AND FUTURE RESEARCH ON RIVER OTTER

As emphasized in a recent publication, natural systems are complex, interconnected and dynamic, and influenced by an inordinate number of factors (Newton and Freyfogle 2005). These intrinsic characteristics of natural systems make them very difficult to monitor and synthesize, creating important levels of uncertainty that could lead exploited populations to extinction. The ultimate goal in renewable resource management is its sustainable use which, although denied by many, continues to be the backbone of any program of resource exploitation. A solid understanding of the mechanisms governing natural systems is probably the most important goal of any person directly involved with the management and conservation of exploited natural resources.

Previous chapters have identified and described patterns in otter harvest in Louisiana. Given the poor understanding of the processes and dynamics of this activity in Louisiana, the identification of spatial harvest patterns described in this study represents a first step in the development of a management program for the sustainable use of river otters in the state. Without information on otter population dynamics, a management plan based on the same philosophical principles considered in fisheries for the development of marine protected areas (MPA) seems a reasonable option in Louisiana.

Pursuing the development of a management program based on MPAs also is supported by the high spatial variability in otter habitat in Louisiana and the effects of environmental stochasticity. It has been noted in other studies that variation in otter occurrence has a spatial structure (Barbosa *et al*. 2001). Considering the important variation in habitat structure for river otters in Louisiana, ranging from coastal wetlands and marshes, to streams and forested wetlands in upland regions, this spatial structure also is expected to occur in Louisiana. Uncertainty from environmental stochasticity also could play a major role in a management plan for the species in Louisiana, and indication of the potential effects of changes in the environment could be

changes in distribution and high mortality registered for nutria (*Myocastor coypus*) as consequence of hurricanes affecting Louisiana (Carter *et al.* 1999, Carter and Leonard 2002).

These arguments indicate that a management plan based on harvest quotas to achieve sustainable use of river otters could be difficult to achieve in Louisiana; levels of uncertainty coming from lack of knowledge on dynamics of the population in coastal and upland areas make it difficult to estimate and adjust a quota for a sustainable harvest program. Establishing spatial harvest controls for river otters in Louisiana could offer the possibility of managing a number of protected areas where ecological baseline information could be collected (Arcese and Sinclair 1997); this information currently impossible to obtain given the confounding effects of human activity (i.e., trapping) on river otter populations and other furbearer species..

Temporal patterns in otter harvest also should be considered. The ARIMA model proposed in this study as a tool to forecast number of otters to be harvested in future trapping seasons represents an advance in the development of a management program for otters in Louisiana. Although the ARIMA model does not incorporate biological information, but rather only past number of pelts harvested in previous trapping seasons, the model offers state managers the opportunity to adjust other variables in the system, such as the number of licensed trappers, and foresee potential changes or trends in the harvest activity.

Patterns and models proposed in this study are based on the analysis of harvest data; consequently, there are limitations in the quality of hypotheses that can be generated. Baseline data on population ecology are needed for river otters in Louisiana. Much of this information could be collected directly from the analysis and study of carcasses collected from trappers and fur dealers. Information on age, sex, reproductive status, and presence of parasites is valuable information that could be recorded from carcasses, all of which is needed to develop a sound management plan. A survey among trappers also should be a priority. Without a clear understanding of the dynamics of the trapper populations, a realistic approach to the sustainable use of river otters in Louisiana will never reach its full effectiveness.

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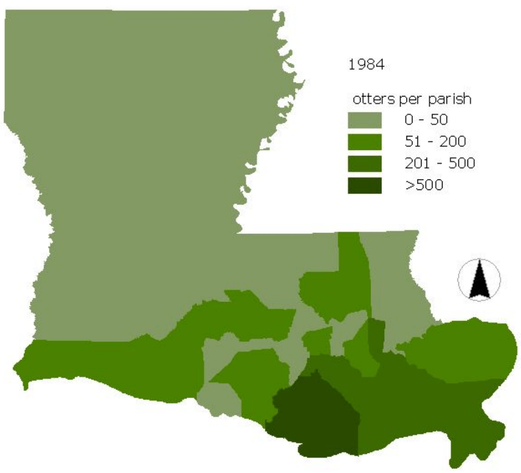
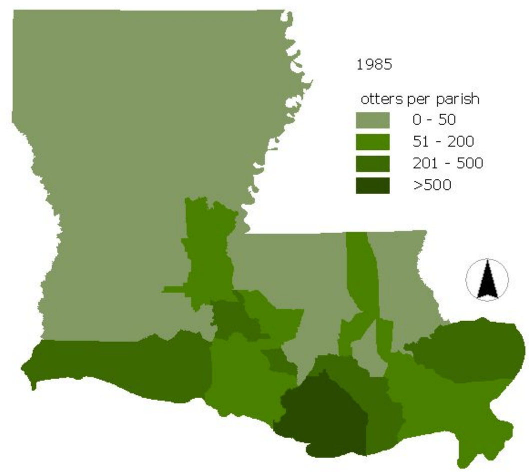
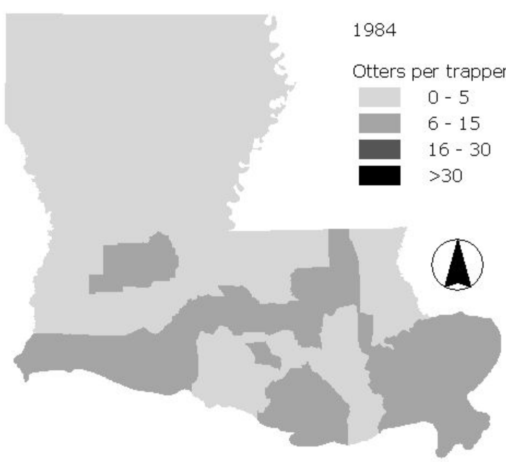
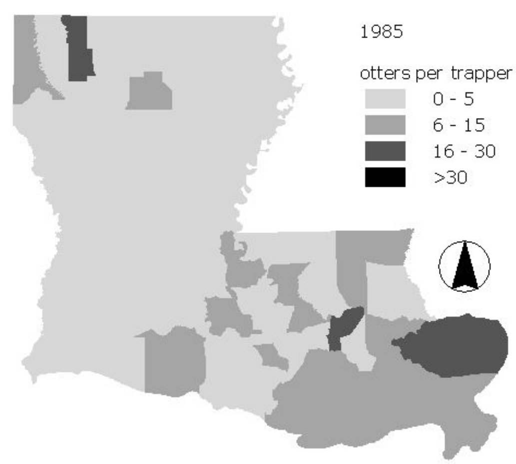
APPENDIX

SPATIAL DISTRIBUTION OF NUMBER OF OTTER PELTS HARVESTED AND OTTERS PER TRAPPER IN LOUISIANA 1984-2003.









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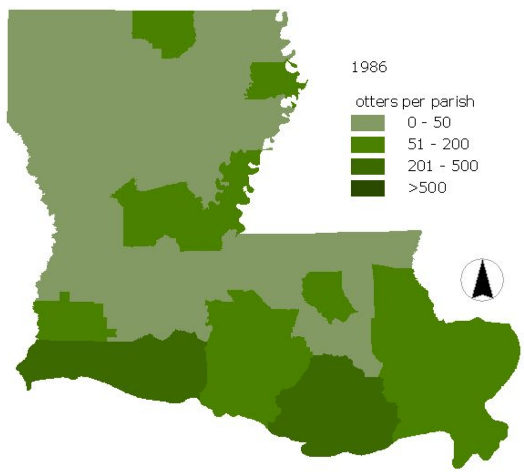

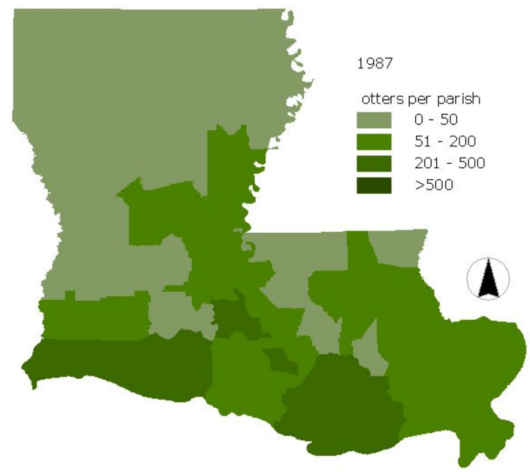

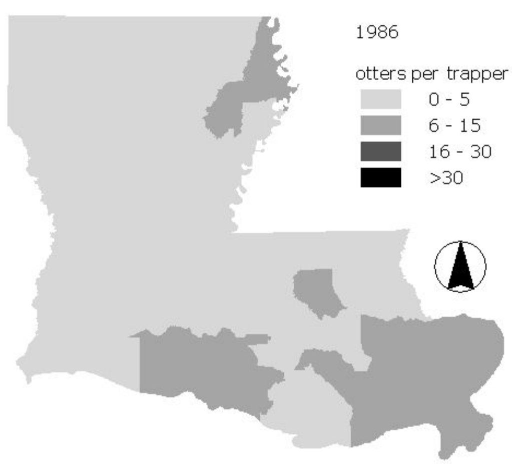

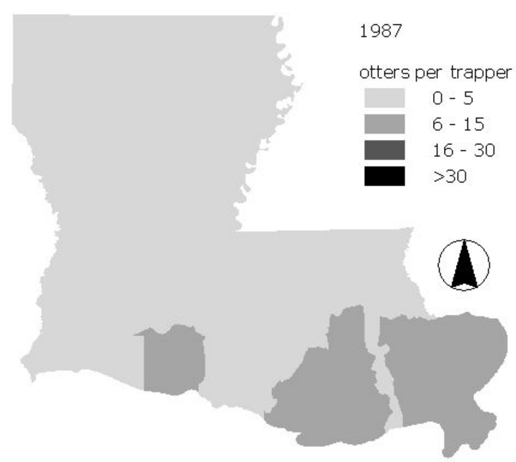

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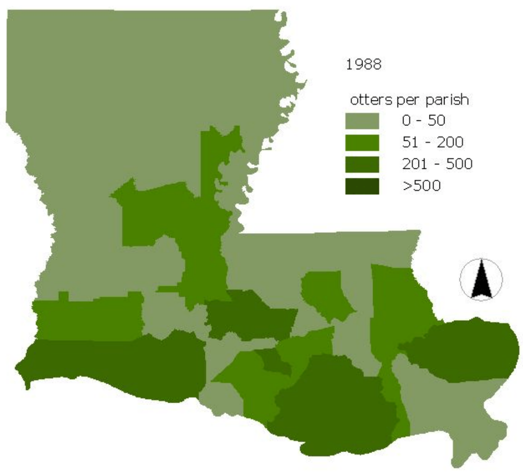

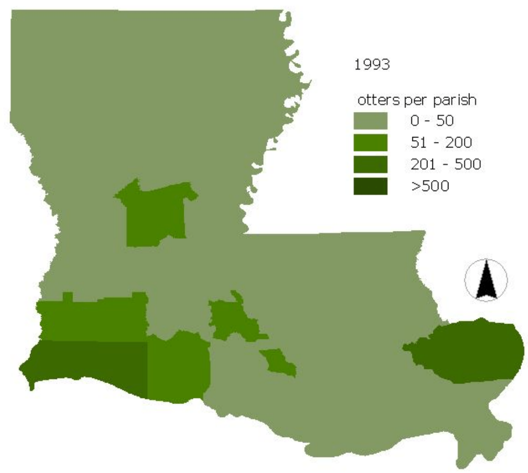

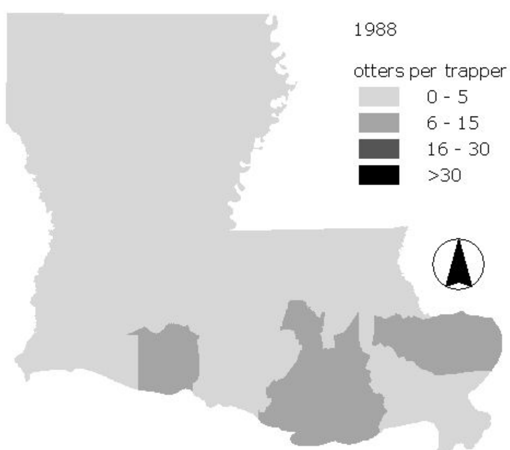

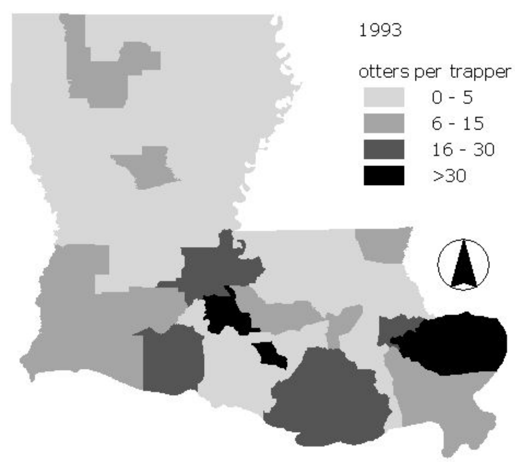

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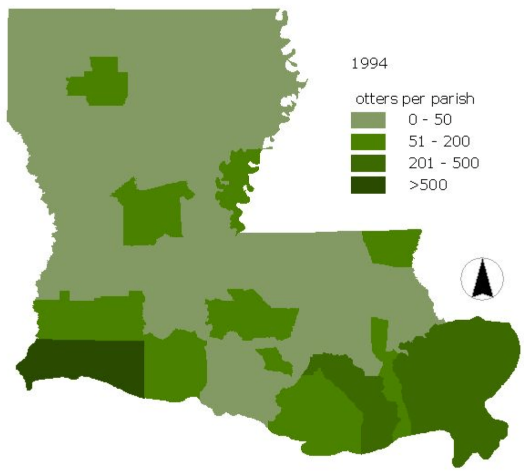

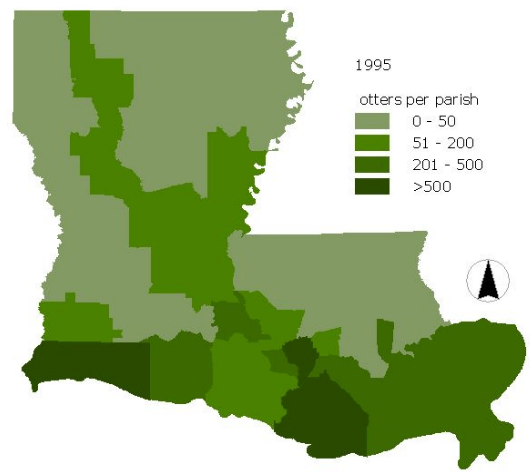

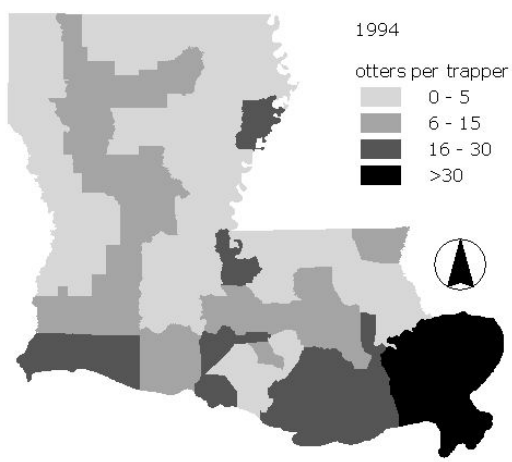

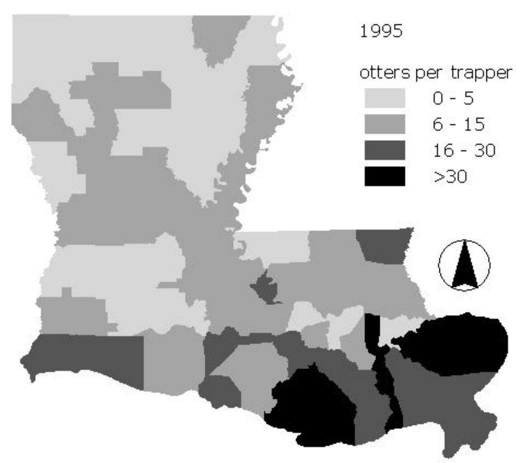

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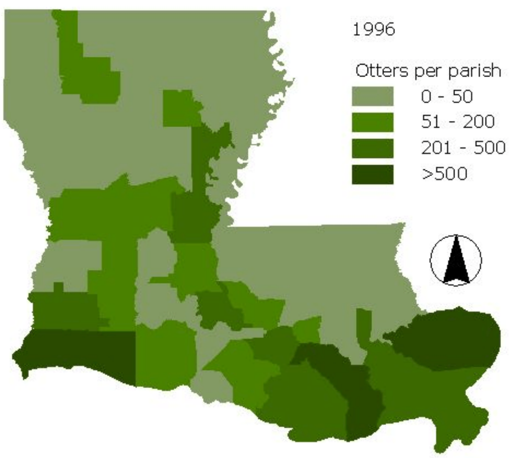

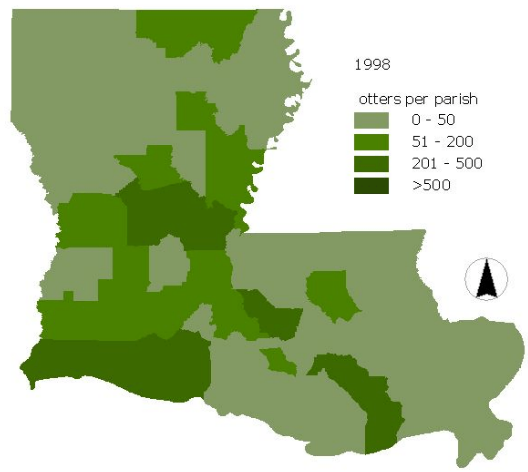

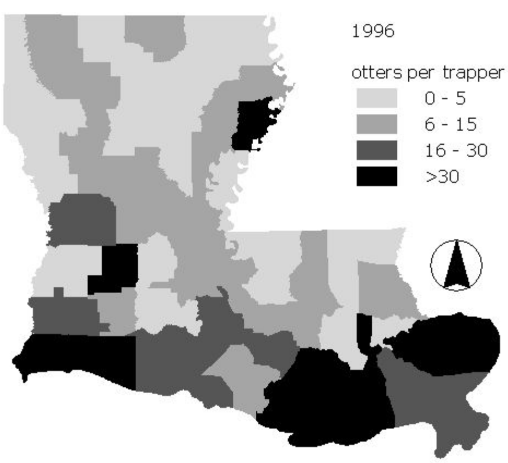

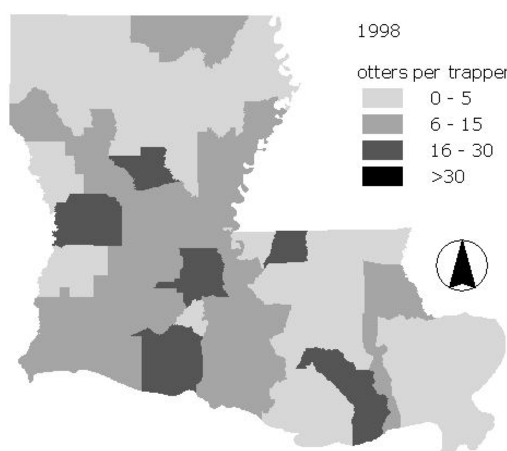

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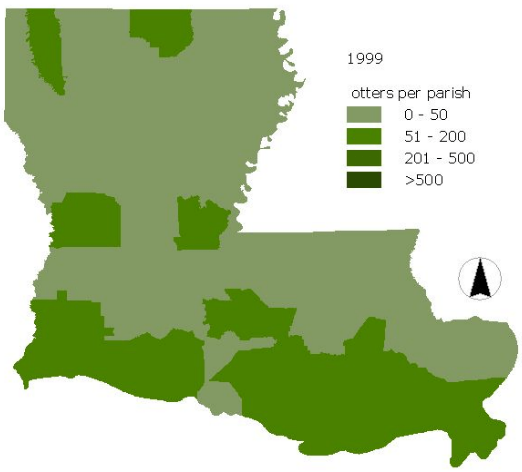

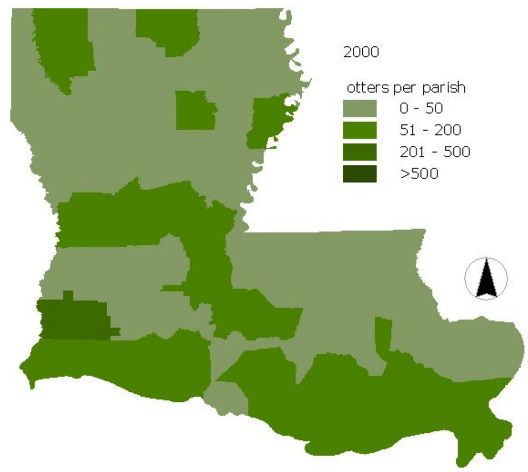

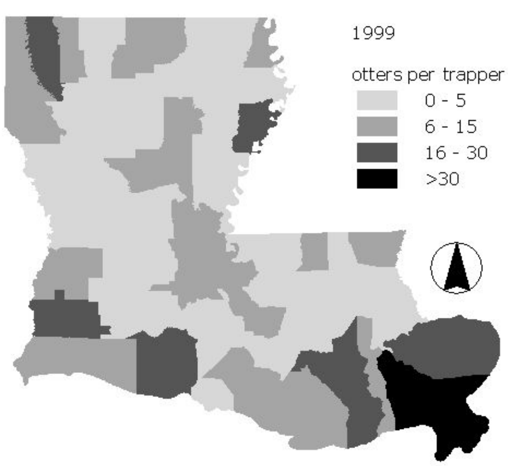

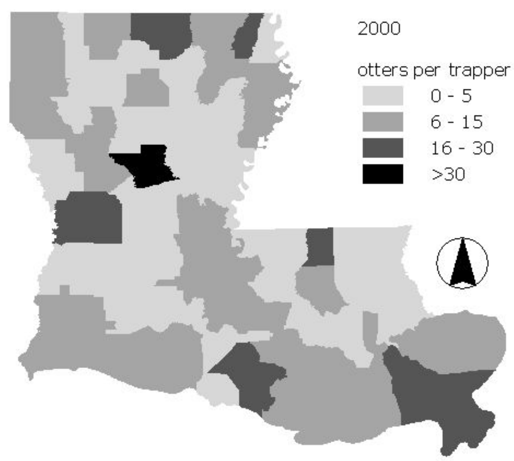

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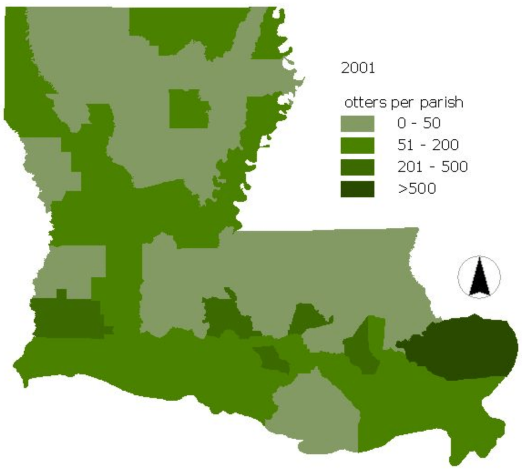

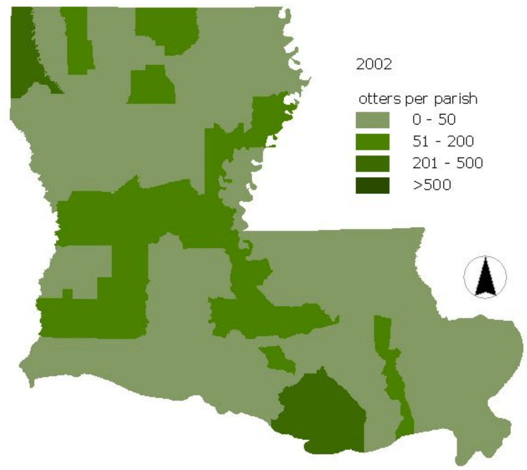

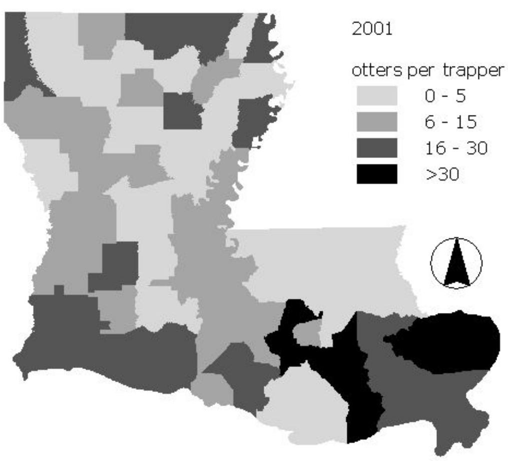

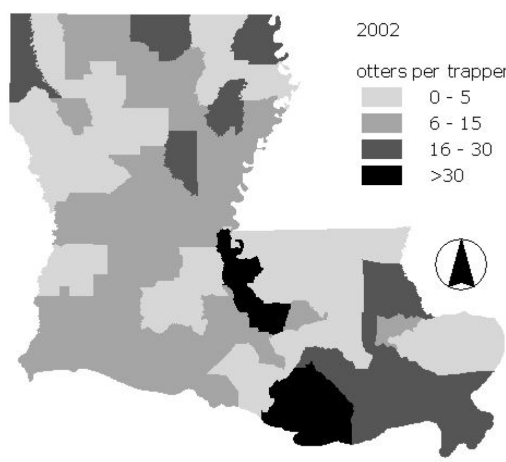

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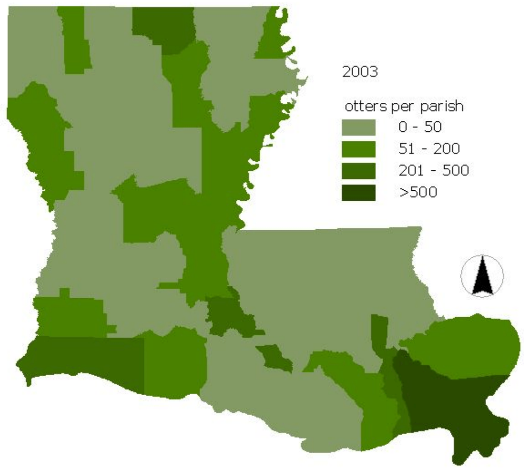

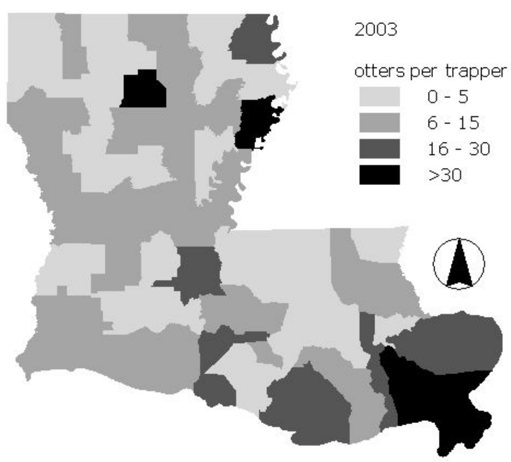

VITA

Daniel G. Scognamillo, a native to Argentina, received is B.S form the Universidad Nacional de Mar del Plata in 1993. He also completed a master degree in Wildlife Ecology and Conservation at the University of Florida in 2001. In August 2001, he enrolled in the doctoral program in the School of Renewable Natural Resources at the Louisiana State University. He will receive his degree in the Spring commencements in May 2005.