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KUNGL. VETENSKAPS-AKADEMIEN
THE ROYAL SWEDISH ACADEMY OF SCIENCES

The Beijer Institute of Ecological Economics
The Royal Swedish Academy of Sciences
Box 50005 SE-104 05 Stockholm Sweden
Phone: +46 8 673 95 00 Fax: +46 8 15 24 64
E-mail: beijer@beijer.kva.se

SPATIAL RELATIONS OF AQUATIC BIRD SPECIES AND WATER MANAGEMENT IN THE LOWER RIO GRANDE VALLEY

Enrique H. Weir *, Neal Wilkins** and William E. Grant*

* The Beijer International Institute, The International Institute of Environmental Economics, The Royal Swedish Academy of Sciences, Box 50005, SE-104 05, Stockholm, Sweden

** Texas A&M University, WFSC, 210 Nagle Hall, College Station, Texas 77843-2258

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Abstract

Alteration of water quantity and river flow regimes associated with water management is one cause of the imperilment of aquatic birds, which represent an important economic, as well as ecological, resource for the Lower Rio Grande Valley (LRGV). There is concern that the proposed modification of LRGV irrigation systems from open canals to pipelines may further restrict water availability for aquatic birds, both directly, by reducing surface area of open canals, and indirectly, by reducing runoff into the Rio Grande Wildlife Refuges Complex (RGWRC). Due to the functions and services that the RGWRC provides to wildlife it plays an important role in maintaining bird diversity in the region. We developed an object-oriented, spatially-explicit, simulation model. The model represents change in water availability in irrigation systems, and wetlands and changes in richness and abundance of aquatic birds. The impact on richness and abundance of aquatic birds from increasing the surface area of lagoons in wildlife refuges was simulated. We spatially joined data bases in ArcGIS 9.0 (ESRI 2004), generated maps overlaying aquatic bird richness, abundance and distributions, on the irrigation systems, resacas, and lagoons and wetland areas in the wildlife refuges and state parks in the LRGV. We then (non-spatially) correlated aquatic bird abundance (data base from Weller and Weller 2000) with the area of irrigation canals, resacas and wetlands of wildlife refuges (data from Flahive and Fipps (2002) and TNRIS (2002) using the statistical program SPSS 11.0. We ran two series of 5-year simulations in which (1) the area of canals decreased by 1, 2, 3, 4, 5, 6, and 7% per year, respectively, and (2) the surface area of lagoons in wildlife refuges increased by 1, 2, 3, 4, 5, 6, and 7% per year, respectively. Simulation results indicate that with the current annual decrease in surface area of canals of 3%, it would take an annual increase in surface area of lagoons of 2 % to maintain the current abundance and species richness of the aquatic birds in the LRGV

Key words: aquatic bird community; bird species-water area relationship; water management; spatial explicit model; lower Rio Grande valley.

INTRODUCTION

Remote sensing technology and spatial modeling techniques provide new research tools for investigating questions such as: how the variation in the landscape-level pattern of habitats may be affecting migrant birds, distribution and movement patterns of mammals (Bousquet et al. 2001, Comiskey et al. 1997) and birth-death dynamics in predator-prey systems (Donalson 1999); how different current or potential disturbance regimes determine the structure and dynamics of forest landscape (Pennanen et al. 2001), wetlands (Fitz et al. 2002), how the interrelation between ecological, hydrological and socio-economics processes produce changes in a watershed system (Costanza et al. 2002) or how habitat fragmentation process and habitat quality affect wildlife and fisheries population dynamics (Hiebeler 2000, Luecke et al. 1999) and contribute to spreading plagues and alien species (Storer 2003, Higgins et al. 2001).

Process-based models and spatially explicit models in particular, are playing an important role in predicting the impacts of future environmental change (Higgins et al. 2001). Spatial simulation models of bird abundance-water availability dynamics in the LRGV are needed for investigating how different actual or potential water availability scenarios determine patterns of distribution and abundance of aquatic birds in the LRGV.

The Rio Grande once formed a broad, meandering waterway as it flowed through what is now the border between Texas and Mexico, with numerous oxbows within its floodplain and an extensive marsh where it emptied into the Gulf of Mexico. Prior to the construction of Falcon Dam the Rio Grande overflowed its banks annually depositing new sediment and moving water into the meander channels in the delta. These floodwaters constituted significant freshwater input into the wetlands of the Rio Grande Delta (Judd and Lonard 2004). After 50 years, dams and flood control projects have eliminated this source of fresh water (Jahrsdoerfer and Leslie 1988) and they have negatively affected native wildlife (Oberholser 1974). Today, agriculture and urban development dominate land use in the Lower Rio Grande Valley (LRGV) and their expansion has negatively affected native wildlife (Oberholser 1974), although the region still contains several unique ecological communities, including wetlands (Ricketts et al. 1999, Abell et al. 2000).

Alteration of water quantity and river flow regimes associated with water management is one cause of the imperilment of aquatic birds (Richter et al. 1997, 2003, Abell et al. 2000, Weller 1999, Bolen and Robinson 1999). There is concern that the proposed modification of LRGV irrigation systems from open canals to pipelines may further restrict water availability for aquatic birds, both directly, by reducing surface area of open canals, and indirectly, by reducing runoff into the Rio Grande Wildlife Refuges Complex (RGWRC); due to the functions and services that the RGWRC provides to wildlife (habitat availability for stopover, protection, perching, feeding and reproduction), it plays an important role in maintaining bird diversity in the region (Butcher, 2003) .

Since the loss of natural areas to agriculture and urban development is likely to continue as 25% of current natural areas may be developed over the next two decades (Rickets et al. 1999), there is an urgent need to develop strategies for maintaining the quality of remaining natural areas as habitat for aquatic birds. In the naturally semi-arid LRGV, habitat quality for wildlife is intimately linked to water availability; obviously, so is agricultural production and urban development. One proposed strategy for increasing the efficiency of agricultural water use involves replacement of irrigation canals with pipelines to reduce evaporative water loss.

The objective of the present study was to develop a spatially explicit simulation model to evaluate the effect on aquatic birds of replacing irrigation canals with pipelines in the LRGV, and to explore alternative scenarios to compensate for the loss of surface water in canals by increasing surface area of selected lagoons in LRGV.

METHODS

Description of the model

The model represents changes in water availability in the irrigation system, resacas and reservoirs, changes in the surface area of lagoons in wildlife refuges and changes in distribution, abundance and species richness of aquatic birds for the three counties where the irrigation system is located. The model describes temporal patterns in water use and aquatic bird distribution and abundance over time, and could be used to project possible spatial and temporal dynamics of water use and aquatic bird distribution and abundance into the future, assuming several water management scenarios (current situation, a total change of canals to underground pipelines without or with water replenishment to resacas and wildlife refuges, partial change of canals to underground pipelines) that likely would affect water use.

Overview of model structure

The model is spatially-explicit, and is programmed in an object-oriented language. Input data are imported from Excel (cit.) files, simulations are run in Visual Basic.Net (cit.), and results are exported to Excel files and to data base files (.dbf); the data base files are linked to shapefiles which are connected to a Geographical Information System (ArcGIS 9.0, ESRI 2004).

Habitat cells are represented as classes, and the processes that generate system dynamics are represented in modules, which are executed sequentially each year of simulated time.

Attributes of habitat cells

Habitat cells represent 2 km by 2 km areas characterized with regard to (1) the X and Y coordinates of the center point of the cell, the surface area of water in (2) canals, (3) resacas, and (4) reservoirs within the cell, (5) the abundance of aquatic birds within the cell, and (6) the species richness of aquatic birds within the cell. There are a total of 2400 habitat cells arranged in a 40 by 60 grid geo-referenced to the physical area encompassed by Cameron, Hidalgo, and Willacy counties.

Representation of water attributes of habitat cells

We compiled geo-referenced information on the surface area of water in the canals and resacas of the irrigation systems in the LRGV (Flahive and Fipps 2002) and geo-referenced information on the surface area of reservoirs in the LRGV (Texas Natural Resources Information System (TNRIS) 2002). From Flahive and Fipps (2002), we extracted the surface area of water (acres) in each of 78 resacas, within the counties of Cameron, Hidalgo, and Willacy, and the length (miles) and width (feet) of each of 1378 open (as opposed to buried) canal segments. From TNRIS (2002), we obtained the surface area of water (acres) in each of 7 reservoirs: (1) Laguna Atascosa, (2) Harlingen Sanctuary, (3) Sabal Palm Audubon Sanctuary, (4) Llano Grande Lake, (5) Santa Ana National Wildlife Refuge, (6) Bentsen Río Grande State Park/Anzalduas County Park, and (7) Falcon Dam. We spatially joined these data to the grid of habitat cells to parameterize the water attributes of the cells (Fig. 1).

Relationship of aquatic bird abundance and richness to water surface area

To relate aquatic bird abundance and species richness to surface area of water, we drew upon Weller and Weller (2000), who related the surface area of water in each of 16 wetlands located near Riviera, Texas, in the southern Texas coastal prairie, to the number of individuals, and the number of species, of aquatic birds seen at each of these wetlands from 1994 to 1998; birds were sampled monthly from October, 1994 through December, 1998 (Weller and Weller, 2000). We got a best representation of the relationship between birds abundance (or richness) with water management based on the Preston relation of Species – Area (MacArthur and Wilson 1967, Preston 1962), relating mean (averaged over the 39 monthly samples) (1) abundance and (2) species richness of aquatic birds to mean surface area of water in the wetlands: Log A (or Log R) $= \beta_0 + \beta_1 * \text{Log}(SA + 1) + \varepsilon$, where A represents mean abundance (mean number of individuals seen), R represents mean species richness (mean number of different species seen) and SA represents mean surface area of water (ha) in the wetland (Table 1). Mean abundance was correlated positively with surface area of water: $\text{Log } A = 0.72 + 1.11 * \text{Log}(SA + 1)$; $r^2 = 0.62$, $F_{15,\ 0.000} = 23.271$ (Fig. 2a). Mean species richness also was correlated positively with surface area of water: $\text{Log } R = 0.28 + 0.78 * \text{Log}(SA + 1)$; $r^2 = 0.497$, $F_{15,\ 0.002} = 13.852$ (Fig. 2b). We used these two equations, adjusted as described in next section, to estimate the abundance and species richness, respectively, of aquatic birds within each habitat cell based on the surface area of water in the cell.

Adjustment of aquatic bird/surface water relationships based on surrounding vegetation

Direct use of the regressions from the previous section to relate aquatic bird abundance and species richness to surface area of water in irrigation canals is necessarily based on the assumption that 1 unit of surface water in a canal is equivalent to 1 unit of surface water in a wetland. This assumption lacks direct empirical support, and remains tentative due to the potentially great differences in the vegetation surrounding canals compared to the vegetation surrounding more natural wetlands. To address this uncertainty, we drew upon Teter and McNelly (1995), who compared abundance and species richness of aquatic birds seen at two resacas that had surrounding vegetation that differed greatly. They sampled birds weekly from February, 1992 through January, 1993, at the Fort Brown Resaca and at the Banco Lozano Resaca; both resacas are located near Brownsville, Texas, and have approximately 0.1 km^2 of water surface (Teter and McNelly 1995). The Fort Brown Resaca is located in an urban area, with banks consisting primarily of vertical retention walls, and surrounding vegetation consisting almost exclusively of mowed lawn. The Banco Lozano Resaca is located in an abandoned agricultural area, with naturally-sloping banks, and is surrounded by dense terrestrial vegetation consisting of both native and introduced trees and shrubs. We calculated indexes relating relative abundance (θ_A) (or species richness (θ_R)) of aquatic birds to amount of vegetation surrounding water surfaces as the logarithm of the mean number of individuals (or species) seen at the Banco Lozano Resaca divided by the logarithm of the mean number of individuals (or species) seen at the Fort Brown Resaca ($\theta_A = 0.616$ and $\theta_R = 0.575$; Table 2). We then used these indexes to adjust the relationships from the previous section to reflect the effect of surrounding vegetation: $\text{Log } A = 0.72 + 1.11 * \text{Log } (SA + 1) * \theta_A$ and $\text{Log } R = 0.28 + 0.78 * \text{Log } (SA + 1) * \theta_R$. We also calculated θ_A (θ_R) in a similar manner based on the minimum number of individuals (or species) seen at the 2 resacas ($\theta_A = 0.496$ and $\theta_R = 0.387$; Table 2).

Simulation of alternative management scenarios

We ran two series of seven, 5-year simulations in which (1) the area of canals decreased by 1, 2, 3, 4, 5, 6, and 7% per year, respectively, and (2) the surface area of lagoons in wildlife refuges increased by 1, 2, 3, 4, 5, 6, and 7% per year, respectively. We selected these scenarios based on current projects planned by the North American Development Bank; approximately 3% of the canals have been or will be buried between 2003 and 2007. At the beginning and end of each simulation, we recorded the surface area of water in canals, resacas, and reservoirs, as well as the abundance and species richness of aquatic birds, within each habitat cell; we also summed each of these attributes over the entire study areas.

RESULTS

Simulation results indicate that with the current annual decrease in surface area of canals of 3%, it would take an annual increase in surface area of lagoons of 2 % to maintain the current abundance and species richness of the aquatic birds in the LRGV (Figs. 3 and 4).

In Fig. 4 changes in aquatic bird abundance and species richness in the canals and lagoons for the scenarios of area changes of 1 and 3 percent are compared. In Fig. 4 it is shown that a range of 1.3 to 2.5 percent (depending on the habitat condition) of increment of lagoon area is needed to compensate the abundance lost in the canals, while only 1 percent it required for the maintenance of bird richness.

In the Figures 5, 6, 7 and 8 it shows the results of simulation in GIS maps. In the Figures it shows the results during the 5-years simulation, where increase of water in the lagoons (Fig. 8) are compensated the lost of water area in the canals irrigation system (Figs. 6 and 7). Time 0 show the current relation between bird richness and abundance with canal area and lagoon area. Time 5 show reductions in these parameters with reduction of canal area and increase of these parameters with increase of lagoon area, and also shows the higher impact of natural coverage on richness and abundance.

DISCUSSION

Since that exist a relation between bird richness and abundance with the size of the water (Weller and Weller 2000) and the habitat coverage that surrounded the ponds (Teater and McNelly, 1995), a tradeoff as increase water of reservoirs maintain the equilibrium of the biodiversity when the water loss occur in the irrigation system.

The importance of open canals, resacas and reservoirs for the maintenance of bird diversity has been documented by Teeter and McNeely (1995), and Wainwright (1998). Teeter and McNeely (1995) observed significantly higher bird abundance in resacas with dense vegetation and a low level of human disturbance compared to resacas with less dense vegetation that were located closer to urban areas.

It is important to note the function of the refuges and parks in relation to the abundance of aquatic birds in the LRGV. The South Texas Nature Refuge Complex represents 10% of the total area of the 4 counties of the Rio Grande delta (Butcher 2003), and supplies much of the aquatic bird habitat, for both migrants and residents, in the LRGV. Both extent and quality of these habitats is dependant on the availability of water (Ruegg 2001, Weller and Weller 2000).

It is possible that the levels of these water bodies are related to the availability of irrigation water via runoff from agricultural areas. Water level is important in the establishment of different groups of aquatic birds; large and diving species use deep reservoirs, whereas small species use shallow water, typical of floodplains (Dubowy 1996, Weller 1999, Weller and Weller 2000).

The maintenance of resacas with different depths, and the occurrence of periodic runoff to maintain floodplains and riparian zones, both could promote the diversity and abundance of aquatic birds, because it would help to maintenance of the riparian vegetation in the zone (Judd y

Lonard. 2004). The periodic pumping of water into floodplain forests has shown promising effects on the germination of tree seedlings (Castillo 1997). This practice may need to be continued and expanded to restore large tracts of subtropical evergreen and riparian forests and their avian communities in the LRGV.

For diving birds, an increase in drought conditions could be critical for their maintenance in the LRGV. Drought conditions are associated with reduction of food resources and could force birds to abandon the area (Vega and Rappole 1994). When the dry season occurs, only the large canals, reservoirs, ponds and resacas interconnected through the LRGV irrigation system are capable of maintaining the deeper water habitats used by diving birds. But if the accessibility of this resource is reduced in the future, due to the replacement of canals by pipelines and reduction of water infiltration from the canals to the natural areas, the bird community will migrate to areas that provide them with enough water resources and food for their needs.

The current information about the status of canal changes in LRGV irrigation system is that the process is occurring with in a few miles of canals in at least 6 irrigation districts: Bayview ID, Brownsville ID, Delta Lake ID, Donna ID, Edinburgh ID (HCID1) and Harlingen ID (with funds of North American Development Bank), and probably will be ending in 2007. The uncertainty is whether it will have new major changes in canals or it will have changes of all unlined canals to lined canals. The first scenario will produce a complete lack of water available to wildlife; the second scenario will generate a total lack of water infiltration and indirectly will be affecting wildlife through changes in habitat structure.

A hydrological attribute of wetlands is that they maintain equilibrium between the recharging and the discharging of aquifers. Depending on the surface water tables, wetlands perform discharge or recharge functions for groundwater aquifers (van den Bergh et al. 2004). When surface water tables are low, a discharge of groundwater can supply wetland; since this flow is mostly stable and slow, continuous wet conditions are provided. If the compensation strategy to maintenance or increase the lagoons in LRGV is adopted, it will contribute to maintain the diversity and abundance birds, and will also perform discharge or recharge functions for groundwater aquifers.

SUMMARY

We developed an spatially-explicit, simulation model. The model represents change in water availability in irrigation systems, and wetlands and changes in richness and abundance of aquatic birds. The impact on richness and abundance of aquatic birds from increasing the surface area of lagoons in wildlife refuges was simulated. We ran two series of 5-year simulations in which (1) the area of canals decreased by 1, 2, 3, 4, 5, 6, and 7% per year, respectively, and (2) the surface area of lagoons in wildlife refuges increased by 1, 2, 3, 4, 5, 6, and 7% per year, respectively. Simulation results indicate that with the current annual decrease in surface area of canals of 3%, it would take an annual increase in surface area of lagoons of 2 % to maintain the current abundance and species richness of the aquatic birds in the LRGV. The next step is the challenge to implement increases of lagoons area when the changes from canals to pipelines would occur.

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TABLE 1. Mean (of 39 monthly samples) and maximum size (ha) of each of the 16 wetlands near Riviera, Texas studied by Weller and Weller (2000). Also presented are the mean (n = 39) and maximum abundance (total number of individuals seen) and species richness (number of different species seen) of aquatic birds based on data in Weller and Weller (2000).

Wetland Number	Mean wetland size (ha)	Maximum wetland size (ha)	Mean bird abundance	Maximum bird abundance	Mean bird species richness	Maximum bird species richness
1	5.4	15.2	77.9	299	8.8	18
2	1.1	3.5	32.3	528	3.8	19
3	1.4	4.6	10.9	57	2.7	11
4	0.9	4.1	12.3	250	1.2	6
5	2.1	6.1	20.1	141	3.7	14
6	31.9	88.6	131.4	529	8.6	25
7	6	17.7	99.1	516	7.4	22
8	0.7	3.5	4.9	80	0.7	8
9	1.9	7.1	19.7	359	2.6	19
10	0.9	3	1.2	13	0.6	4
11	1.3	6.1	0.9	25	0.1	2
12	11.4	45.6	107.8	708	6.1	3
13	6.5	23	83.3	837	4.5	1
14	1.7	5.1	17	167	2.2	9
15	7.4	18.9	65.7	272	8.1	2
16	4.3	11.1	19.4	91	3.2	9

TABLE 2. Abundance (total number of individuals seen) and species richness (number of different species seen) of aquatic birds at the 2 resacas near Brownsville, Texas with abundant (Banco Lozano) and sparse (Fort Brown) surrounding vegetation studied by Teter y McNeely (1995). Also presented are indexes (θ_A and θ_R) calculated to adjust aquatic bird abundance/surface water and aquatic bird species richness/surface water relationships based on the amount of vegetation surrounding the water surface (θ_A = Log abundance Fort Brown/Log abundance Banco Lozano and θ_R = Log richness Fort Brown/Log richness Banco Lozano)

	Banco Lozano Resaca (abundant surrounding vegetation)				Fort Brown Resaca (sparse surrounding vegetation)				Indexes to adjust aquatic bird/surface water relationships	
Month	Bird abundance	Bird species richness	Log abundance (LABL)	Log richness (LRBL)	Bird abundance	Bird species richness	Log abundance (LAFB)	Log richness (LRFB)	Adjustment for bird abundance (LAFB/LABL)	Adjustment for species richness (LRFB/LRBL)
Feb	80	9	1.903	0.954	50	3	1.699	0.477	0.893	0.5
Mar	110	9	2.041	0.954	50	5	1.699	0.699	0.832	0.631
Apr	110	8	2.041	0.903	20	4	1.301	0.602	0.637	0.666
May	15	2	1.176	0.301	15	2	1.176	0.301	1.0	1.0
Jun	10	3	1.0	0.477	10	2	1.0	0.301	1.0	0.631
Jul	20	5	1.301	0.699	20	2	1.301	0.301	1.0	0.431
Aug	90	10	1.954	1.0	10	3	1.0	0.477	0.512	0.477
Sep	150	8	2.176	0.903	40	5	1.602	0.699	0.736	0.774
Oct	940	9	2.973	0.954	30	5	1.477	0.699	0.497	0.733
Nov	420	9	2.623	0.954	20	3	1.301	0.477	0.496	0.5
Dec	50	7	1.699	0.845	10	1	1.0	0.0	0.589	------
Jan	60	6	1.778	0.778	10	2	1.0	0.301	0.562	0.387
Mean	171.25	7.08	2.234	0.85	23.75	3.08	1.376	0.489	0.616	0.575
Maximum	940	10	2.973	1.0	50	5	1.699	0.699	1.0	1.0
Minimum	10	2	1.0	0.301	10	1	1.0	0.0	0.496	0.387

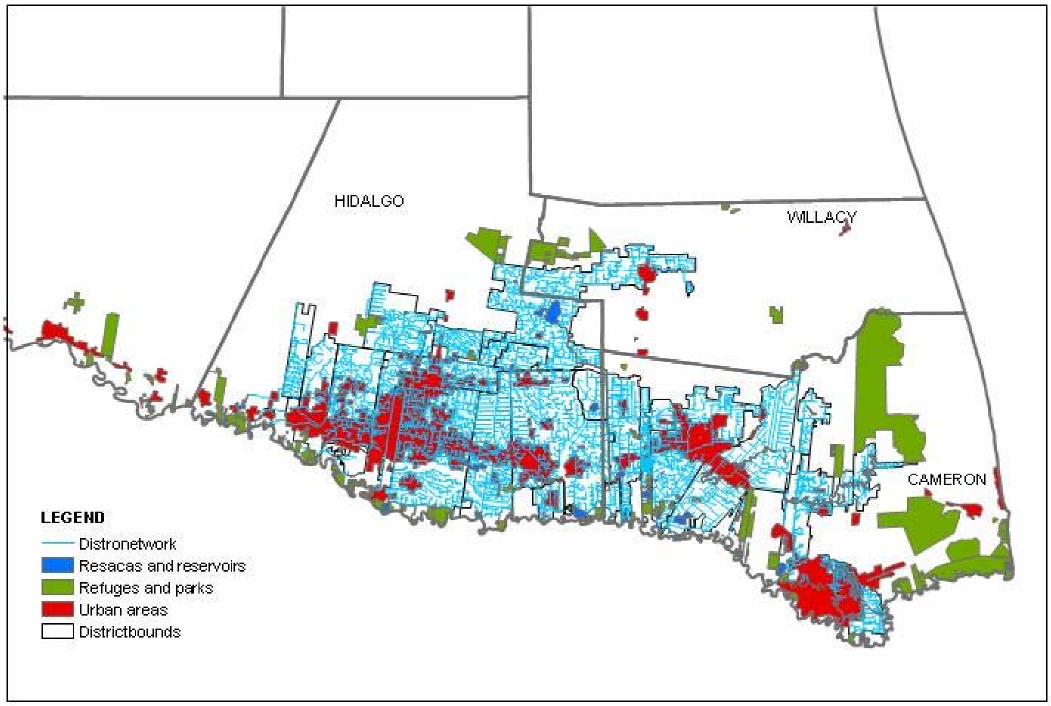

FIG 1. Irrigation systems (distronetwork) (Flahive and Fipps 2002), urban areas, state parks, refuges, and resacas (TNRIS 2003.) in the Lower Rio Grande Valley of Texas.

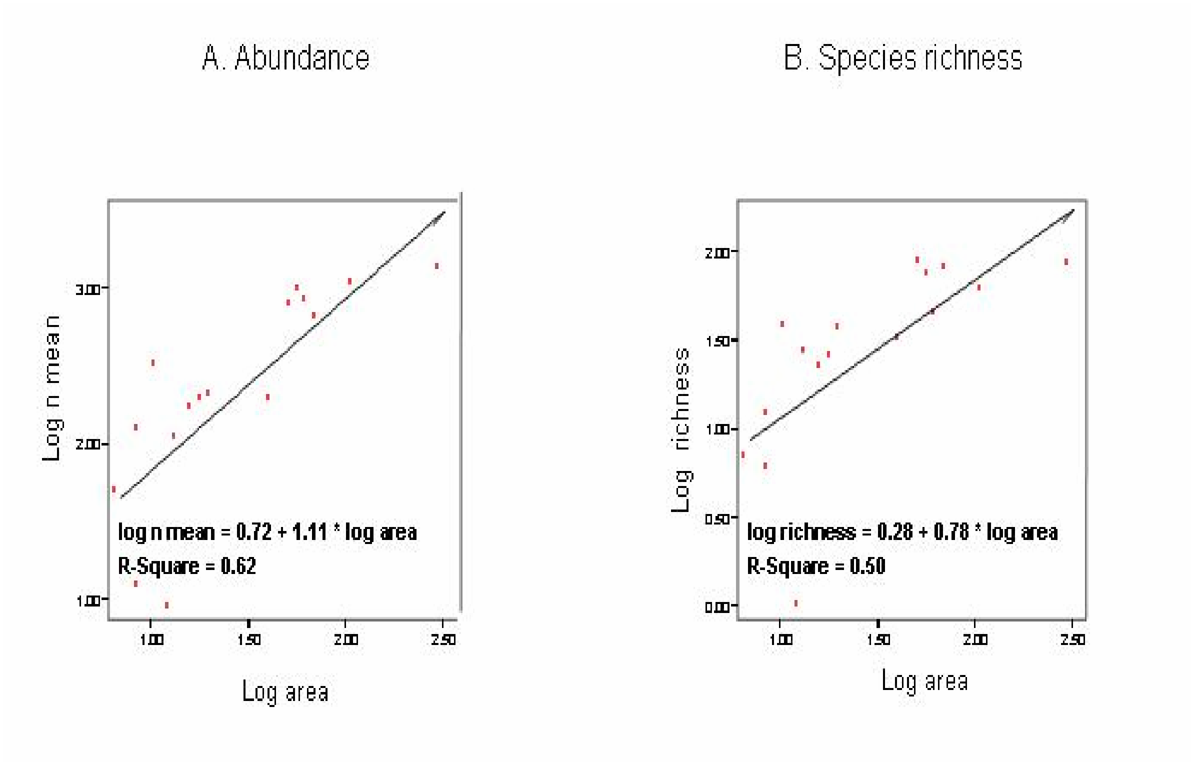

FIG. 2. Mean (A) abundance and (B) species richness (number of different species) of aquatic birds related to area of wetlands in the southern Texas coastal prairie based on data in Weller and Weller (2000).

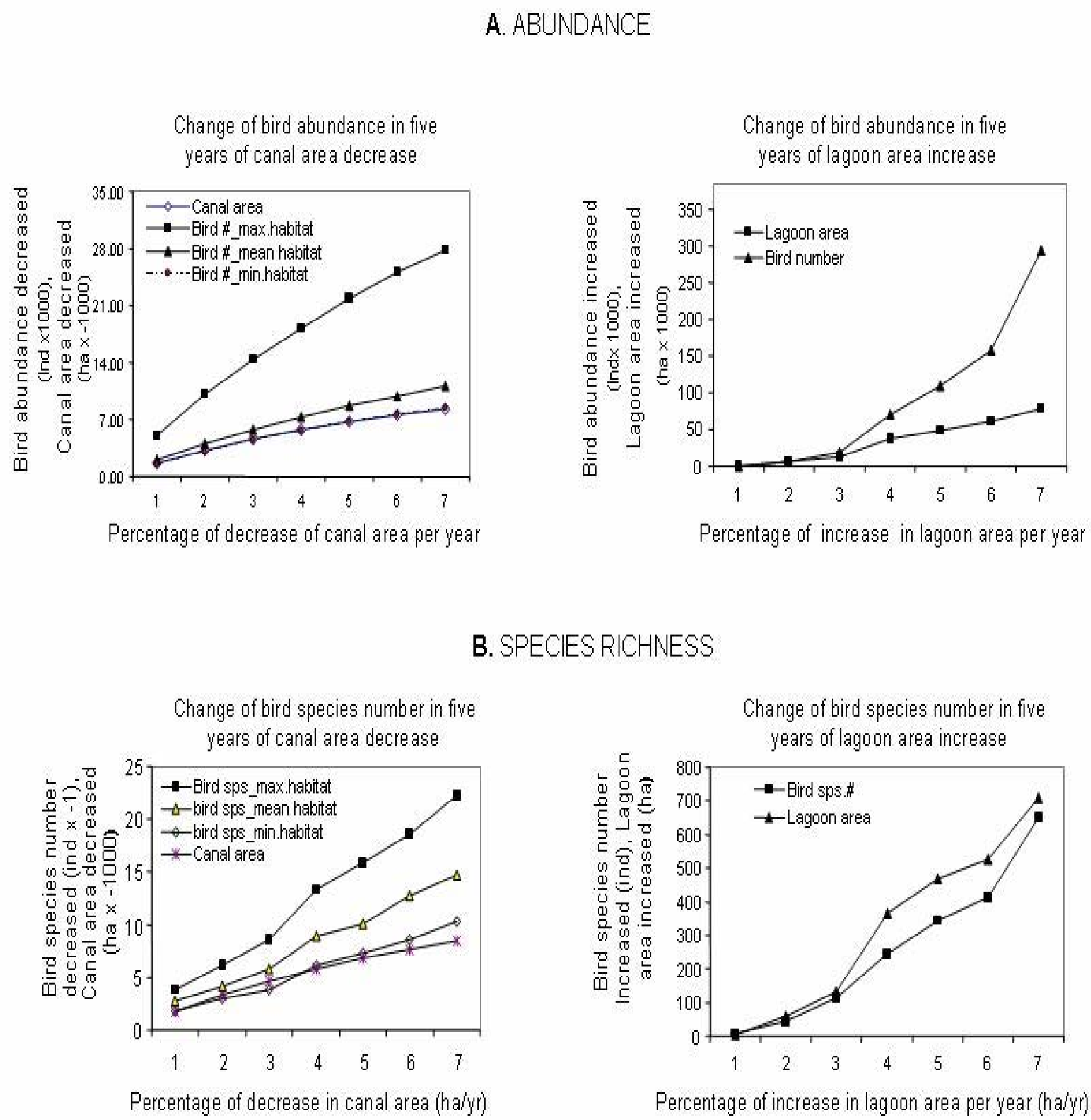

FIG.3. Simulated (A) abundance and (B) species richness (number of different species) of aquatic birds related to annual increases and decreases of 1 to 7% in the total area of canals and lagoons in the Lower Rio Grande Valley.

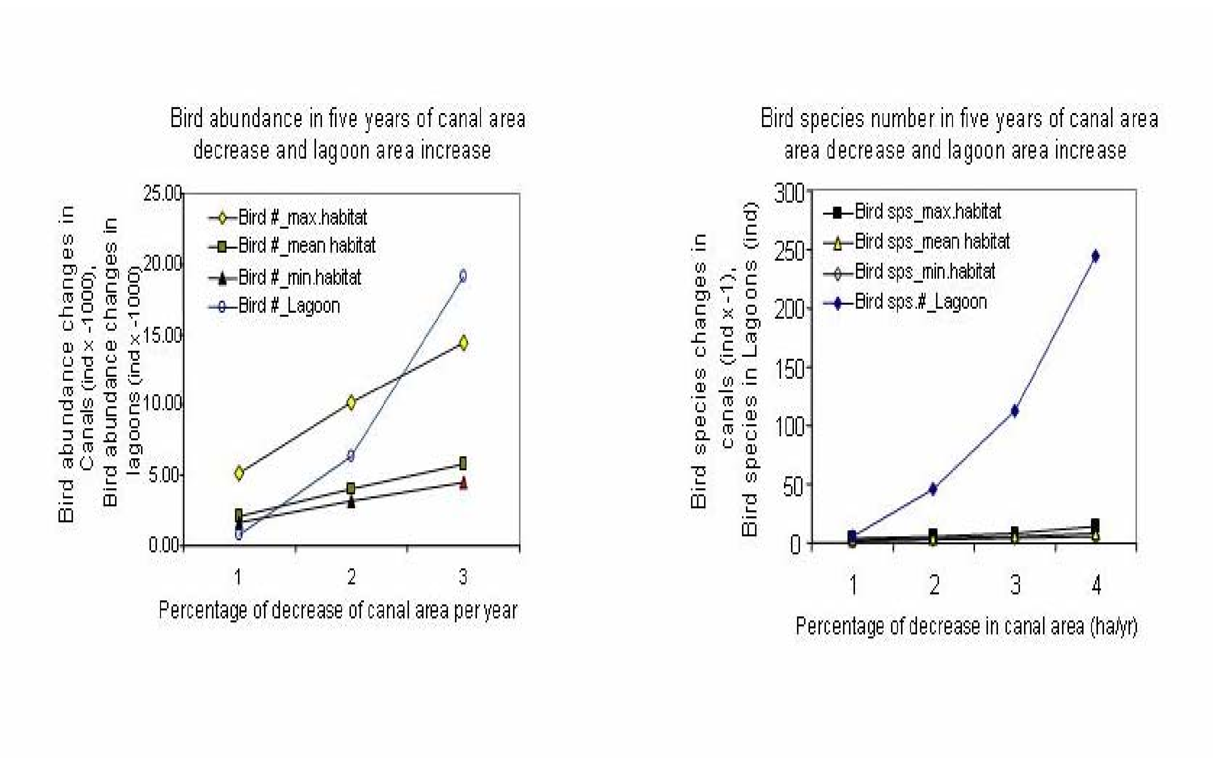

FIG. 4. Simulated abundance and species richness (number of different species) of aquatic birds in canals and lagoons related to the indicated annual decreases in the total area of canals and increases in the total area of lagoons in the Lower Rio Grande Valley.

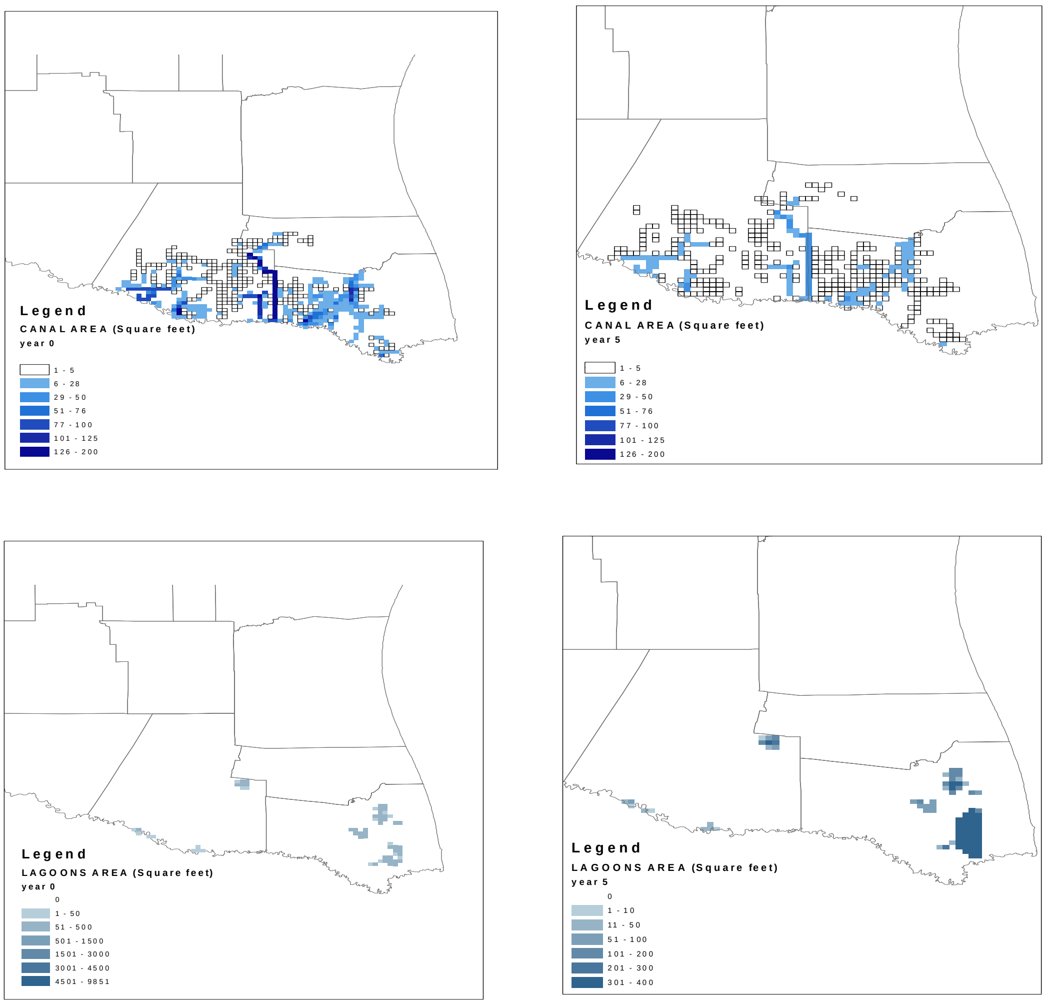

FIG. 5. Simulated changes in area of canals and lagoons over the next 5 years, assuming a 3% annual reduction in area of canals and a 2% annual increase in area of lagoons area. Only beginning (time 0) and ending (time 5) maps are presented.

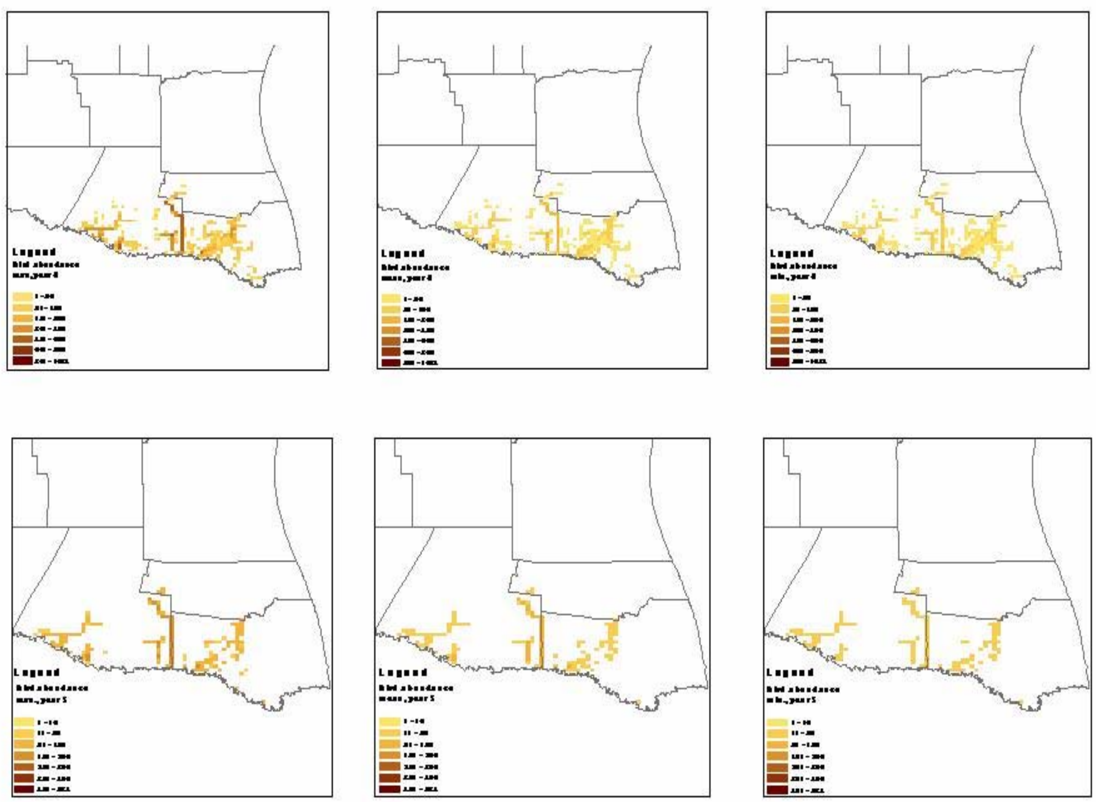

FIG. 6. Simulated changes in abundance of aquatic birds over the next 5 years resulting from a 3% annual reduction in area of canals. Only beginning (time 0) and ending (time 5) maps are presented.

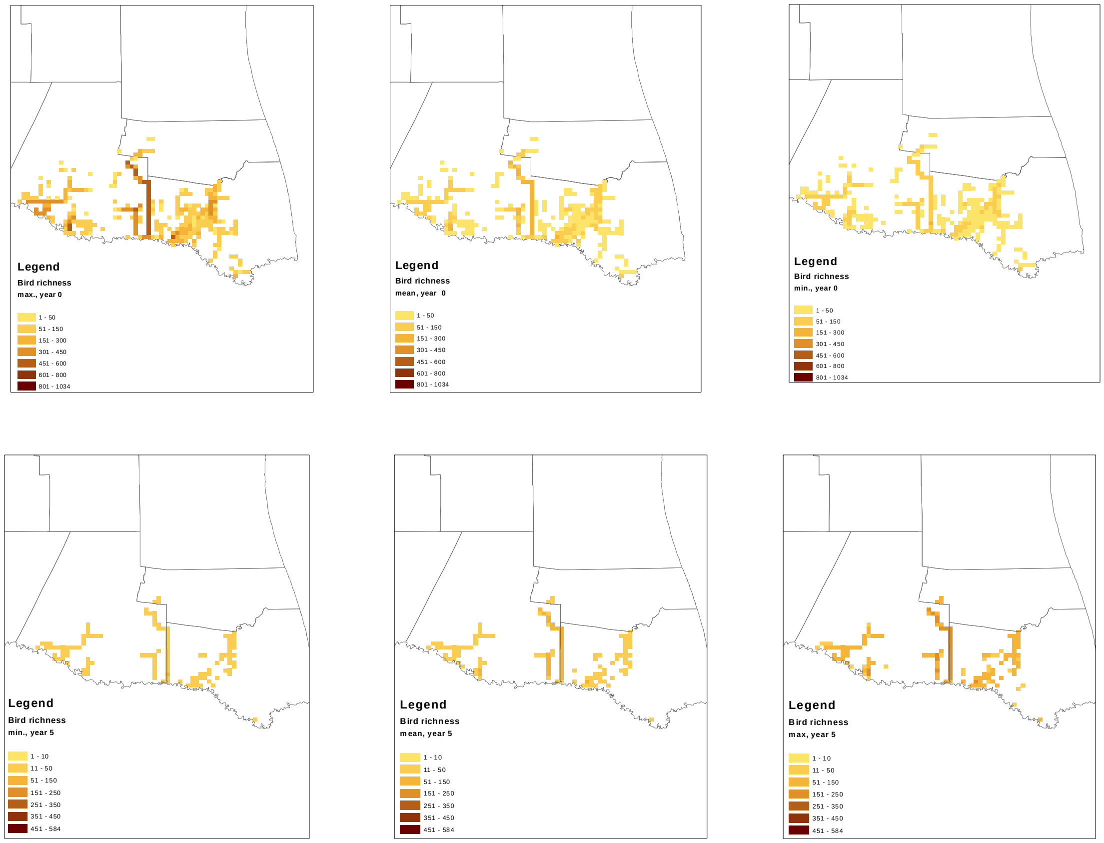

FIG. 7. Simulated changes in species richness (number of different species) of aquatic birds over the next 5 years resulting from a 3% annual reduction in canal area. Only beginning (time 0) and ending (time 5) maps are presented.

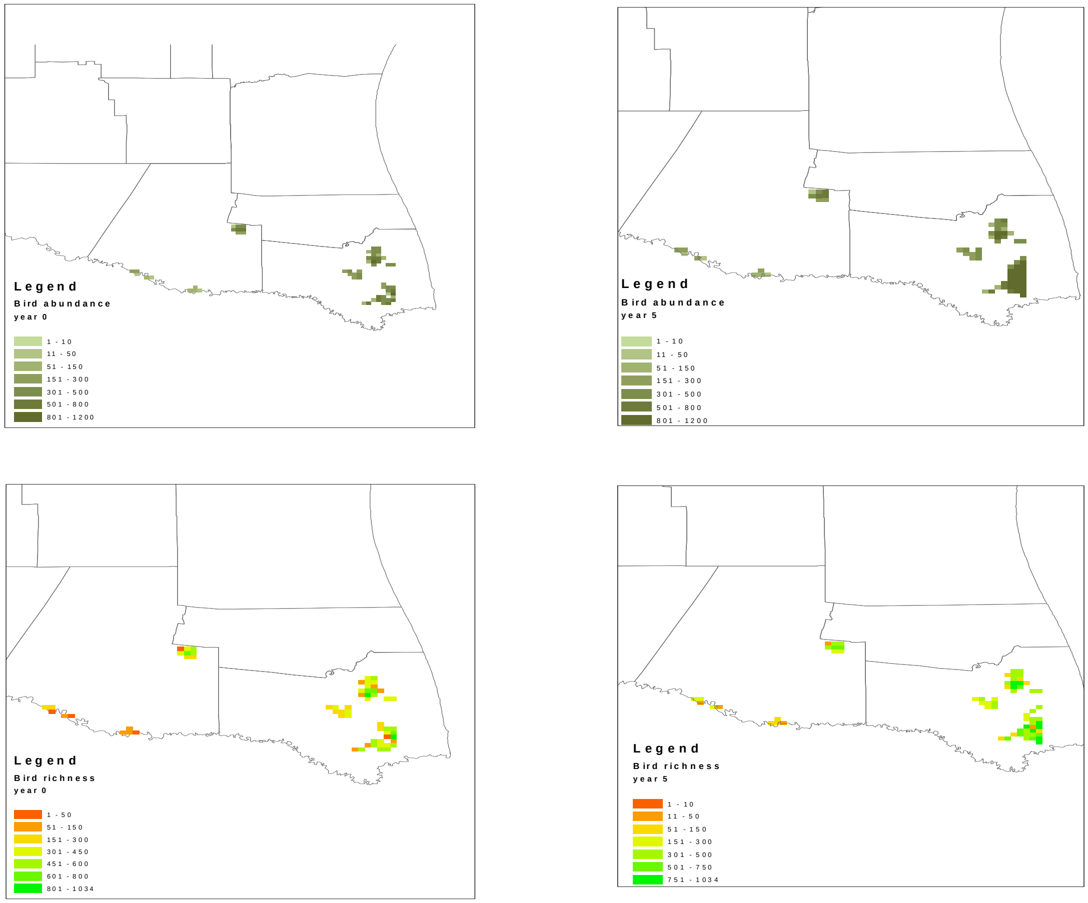

FIG. 8. Simulated changes in abundance of aquatic birds, and species richness (number of different species) of aquatic birds over the next 5 years resulting from a 2% annual increase in area of lagoons area. Only beginning (time 0) and ending (time 5) maps are presented.