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Golley F.B., Bellot J., Odum E.P.

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DYNAMIC ANALYSIS OF THE BEHAVIOR OF TWO LANDSCAPE SYSTEMS

F.B. GOLLEY (1); J. BELLOT (2) and E.P. ODUM (1)
(1) Institute of Ecology, University of Georgia, Athens, Georgia, USA and
(2) Instituto Agronómico Mediterráneo de Zaragoza, Spain.

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Abstract: This study describes the analysis of two ecological systems of different sizes: Georgia State (USA) with 150,500 Km² and La Violada irrigation area (Huesca, Spain) with 0.5 Km². Systems Analysis theory was used to interpret energy and matter flows in both systems and their environement.

The conclusion is that both systems are driven by external forces acting through human management. First, they build an artificial environment and, secondly they use energy supplies as a subsidy or stress with either possitive or negative effects.

INTRODUCTION

In this essay we intend to focus on the application of ecology to problem solving at the scale of the landscape; that is at the scale of one to many square kilometers. Basic and applied ecologists have be-come interested in landscapes because environmental problems may occur at large sca-les. Fur-ther, questions about the distribution and paleoecology of organisms are frequently addres-sed at this scale. Landscapes also provide a context in which to understand the role of ecosystems. Land-scape ecology has been treated in four recent books, is being reported in a new journal, and has been organized into an international society. Thus, it appears as if landscape ecology is a paradigm, in the sense of Kuhn, which is in an early stage of development.

Our approach will be to illustrate the application of landscape ecology to problem solving at two scales. The first example will discuss change in the properties of the State of Georgia and describes the first stage in landscape analysis; definition, the re-shaping of questions, inventory of information, and the identification of needs. The second example will summarize some of the results of a study done by a group of Master of Science students at the Instituto Agronómico Mediterráneo de Zaragoza and describes the dynamics of a landscape through the flows of water and nutrients of an irrigated landscape in northern Aragon.

CHANGE IN THE GEORGIA ENVIRONMENT.

The Georgia study was organized and directed by E.P. Odum and M. Turner, and was carried out through a task force of scientists at the University of Georgia, as an evaluation of the physical and environmental resources of the state. Like many landscapes, Georgia has undergone extremely rapid changes and faces an even more dynamic future. The approach of the task force was to define the nature of landscape changes over the last 50 years and to project management from these patterns, identifying potential problems, and suggesting a general approach to future problem solving.

Georgia is the largest state in the eastern United States (150,500 square kilometers) and can be divided geographically into a broad, flat coastal plain, a hilly piedmont, the Appalachian Mountains and, several other physiographic areas. Politically, Georgia is divided into over 180 small units, called counties, which often consist of a small town and the surrounding rural area.

Land use was inventoried in Georgia by selecting a sample of counties from each physiographic region and determining change in land use from aerial photographs over the past 50 years. In addition, the variation in agricultural and forest production, human and domestic animal populations, energy and water use, and wildlife populations was examined. These data were used to show how the resource base and natural resource use had changed and the consequences of change on net primary production, human attitudes and market and nonmarket values of resources.

Here we can only summarize some of the highlights of the two year long study:

The original forest vegetation of the state, present when the European settlers arrived in 1750, declined from about 18 x 10^6 acres (about 1 millon hectares) to a minimum of 3 x 10^6 (100 thousand hectares) in 1850. Since 1850 the forest has recovered and now it occupies about half of its original area. Forest land area changed because forest was converted to agricultural land. Agriculture reached a maximum in 1850 and had declined in area since that date.

The human population of Georgia has doubled over the last 50 years, while the population of domestic animals has tripled. This population has required an increased level of energy per capita, but energy has become more effective. Energy use is very different in rural and urban areas. The ratio of energy use per capita is 2 to 1, comparing urban and rural counties. However, the ratio of energy to area (energy density) is 74 to 1. That is, energy is applied (to land area) much more intensely in urban areas. Agricultural yields have increased 4 times over the last 50 years, while the area devoted to agriculture has declined 50%. The use of commercial fertilizer increased 7 times.

Georgia is located in a temperate climate area and has large resources of water in surface, (ground) and aquifer waters. The use of water resources has increased about 3 times over the last 40 years, while the level of some of the aquifers has fallen. Water has become less contaminated by sewage but has become polluted by nonpoint source of nitrate and nitrite nitrogen.

Wildlife populations have responded to land use changes positively and large populations of game and other species are present. However, species requiring agricultural land have declined in numbers.

Overall, the net primary production of the state has increased about 3 times over the last 50 years. This increase from 2.5 to 6.5 tons per hectare reflects an increase in forest area and higher agricultural yields. Since Georgia has only 8% of the land area in reserves, there is an opportunity to establish land reserves for future population growth. Survey of the public attitudes toward change showed that while the public was supportive of environmental measures, they did not fully appreciate the extent of the changes in land use. The major economic and social problem areas present 50 years ago have been largely solved, but the resulting changes have, in turn, created a new set of problems of disequilibrium between urban and rural development, air and water pollution, and overspecialized agriculture, rapid immigration to the State, and insufficient protection of natural reserves. These needs indicate opportunities in education, legislation and research.

From the system perspective the Georgia landscape has been driven by external inputs of energy, immigration, and fertilizers, which have resulted in expanded productivity and shifts in land use. Internal dynamics, especially in use of water resources and in reserved land for providing environmental services are anticipated to control change in the future.

THE VIOLADA LANDSCAPE

In contrast to the State of Georgia, the Violada system is of relatively small size, greater homogeneity, and the relation between flows and performance is more direct. In this analysis we will first consider the performance of the system as a whole. La Violada is about 5,000 hectares in size, is shaped in a triangle by three irrigation canals which bring water to the system. The irrigation water comes from the mountains in the north and passes through a series of dams and canals before reaching La Violada. After passing through the fields the water is collected by drains and exits La Violada at a single point where it passes to the Rio Gallego and, eventually, to the Rio Ebro. The hydrodynamics of the watershed of the polygon has been modelled by Faci et al. (1984) and our work builds upon these studies. The agricultural polygon was put into op-eration about 1950 and consists of about 700 farms. The average field size is about 1.8 hectares. The major crops at present are maize, alfalfa, barley and wheat.

First, we will consider the water and nutrient inputs and outputs in the water from the landscape. The chemical flux in water is shown in table 1 for selected elements. Water input is about 1600 x 10^4 liters per hectare annually. Water output is divided into drainage (941 x 10^4 liters ha^{-1} yr^{-1}) and evapotranspiration (670 x 10^4 liters ha^{-1} yr^{-1}). The largest chemical inputs come from irrigation water for all elements. $CaSO_4$ and NaCl levels in this water are relatively large because the water is derived from runnoff across an arid landscape. Rainfall and lateral flow across the surrounding hillsides to the polygon are much lower. Drainage output is much larger than the input for all elements except phosphorus. The irrigation water dissolves the soil containing large quantities of salts, such as gypsum, and these salts appear in the drainage water. $CaSO_4$ levels are especially high.

Next we consider the chemical balance of the polygon. Added to the inputs and outputs of water are fertilizer inputs and harvest outputs. The high output of Nitrogen in the drainage water (table 1) is explained by the high levels of nitrogen fertilizer (table 1). This large input goes partly to grain, which is harvested, and partly to the drain. The dynamics of the fertilizer inputs over a year clearly show that peak amounts in drainage water (Figure 1) are correlated with fertilization in May and June and September and November. These data illustrate the character of this irrigated landscape which responds to high inputs of water and fertilizer nutrients by producing an agricultural output and water which has an increased load of salts. The polygon is exporting about 11 MT of salts per hectare per year.

The next question is how do the system components perform to produce the system performance?. Since the polygon is divided into fields and fields grow one crop at a time, it is relatively simple to select a sample of fields and determine their input-output performance. We selected 24 fields including maize, barley, alfalfa and wheat in different locations to represent different soils and topographic positions. Within each field samples of plant and soil were collected monthly.

The productivity of the fields differed between crops, as well as between fields. Maize and alfalfa produced about twice as much grain as wheat and barley however, the harvest index for all crops, except alfalfa, is similar. Approximately half of the biomass is recycled to the soil.

If we examine the nutrient fluxes of the crops the differences become clearer. These systems are driven by water and fertilizer. Efficiency of nitrogen uptake is high; about 50% is taken up in biomass and half appears in grain. In contrast, most of the calcium taken up by the crop is recycled to the soil-plant residues. Maize requires more water and fertilizer than wheat and its export of calcium and nitrogen is also higher.

Thus, the Violada system is a throughput system in which water drives a nutrient-production system and produces pollution. The situation is exagerated by maize and therefore, salinization of water could be regulated in part by adjusting the proportions of each crop on the fields. However, even if the entire polygon was devoted to wheat the salt export would only be reduced 50%.

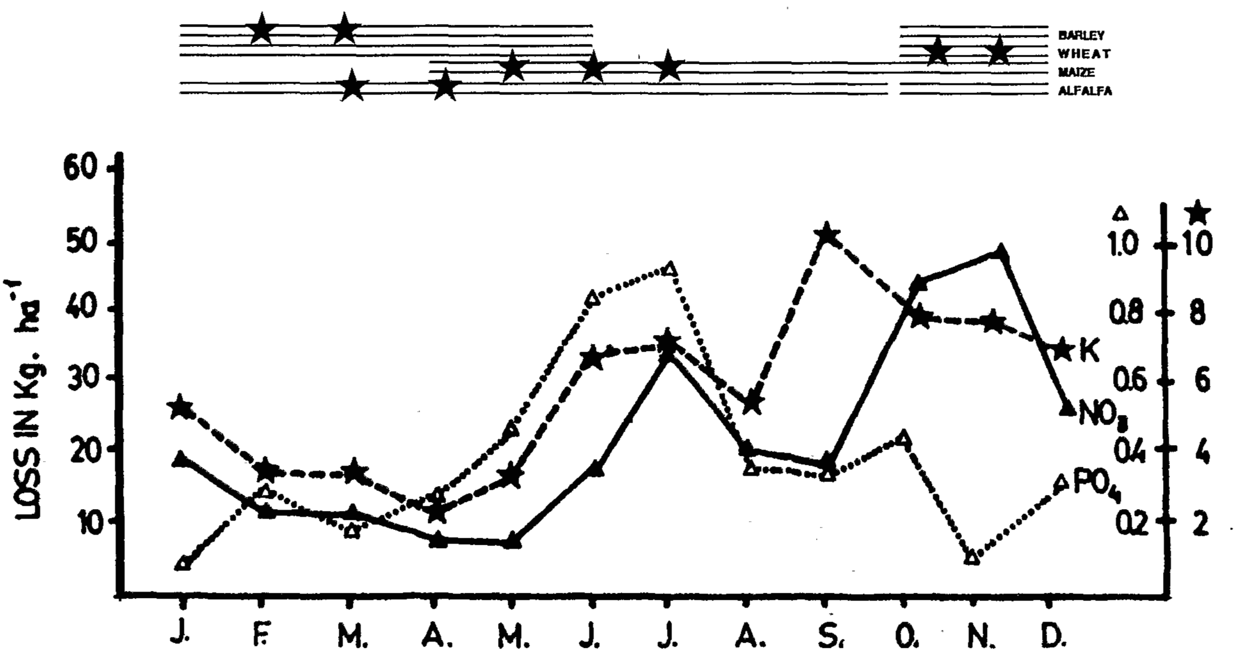
CONCLUSIONS.

Both of these systems have illustrated landscapes driven by external forces. In Georgia these flows represent fossil fuel, fertilizer, investment, and immigration. The consequence has been a change in land use, which, in turn, creates change in production, populations and income. On La Violada, a saline lake bed was converted into a highly productive system at the cost of water pollution.

TABLE 1. ANNUAL CHEMICAL BALANCE OF THE VIOLADA POLYGON FOR SELECTED ELEMENTS (kg /ha).(BELLOT *et al.* 1989)

	Elements							
	Cl	N	S	P	Ca	Mg	Na	K
IMPUTS								
rainfall	3.9	2.2	5.5	-	7.3	0.7	4.3	2.7
Irrigation	307.0	18.3	174.4	1.5	816.0	166.0	220.0	62.0
Lateral flow	1.0	-	0.4	-	2.5	1.0	1.3	0.3
Fertilizer	-	292.0	-	49.8	-	-	-	70.5
Total	311.9	311.5	180.3	51.3	825.8	167.7	225.6	135.5
OUTPUTS								
Grain	-	163.2	-	23.7	37.8	13.6	-	57.0
Drainage	499.0	65.8	3886.0	1.6	4366.0	845.3	578.6	73.0
Total	499.0	229.0	3886.0	25.3	4403.8	858.9	578.6	130.0
Difference	-187.1	+82.5	-3705.7	+26.0	-3578.0	-691.2	-353.0	+5.5

FIGURA 1. LOSS OF IONS IN DRAINAGE CANAL WATER BY MONTH ON LA VIOLADA POLYGON (kg ha^{-1}). THE SOLID LINE REPRESENTS NO_3, THE DASHED LINE K AND THE DOTTED LINE PO_4. FROM BELLOT AND GOLLEY (1989).IN THE TOP OF FIGURE, WE REPRESENT THE PERIOD OF THE YEAR THAT THE CROPS COVER THE FIELD, AND WHID THE STARS THE MONTH OF FERTILIZATION.



These systems illustrate two principles of landscape ecology. First, humans construct built environments which channel and focus driving forces and enhance system productivity and stability. The built environment has structural stability that may be as long as geological time. Second, flows across landscapes can act as subsidy or stress; flows always have positive and negative effects. In management we select on optimum solution. To do so means making a realistic appraisal of system dynamics, within the context of the large system in which the system of interest is placed. In the example of La Violada enhanced productivity is balanced by salinization of water, which reduces its value for other uses.Likewise, the Georgia study document how crop yields were increased four-fold statewide by greatly increased fertilization (ten-fold), but at a cost of decreased water quality resulting from run-off non-point pollution. These principles can be useful to apply in dynamic landscape analysis that is a foundation for environmental planning.

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