Report

Tania del Mar López, T. Mitchell Aide, John R. Thomlinson

Urban Expansion and the Loss of Prime Agricultural Lands in Puerto Rico

In many countries where the economy has shifted from mainly agricultural to industrial, abandoned agricultural lands are lost to urbanization. For more than 4 centuries the Puerto Rican economy depended almost entirely on agriculture, but sociopolitical changes early in the 20th century resulted in a shift to industry. This shift in the economy, and an increase in population, has resulted in an increase in urban areas. This study describes the rate and distribution of urban growth on the island of Puerto Rico from 1977 to 1994 and the resulting influence on potential agricultural lands. Urban extent and growth were determined by interpreting aerial photographs and satellite imagery. The 1994 urban coverage was combined with a soil coverage based on agricultural potential to determine the distribution of urban areas relative to potential farmlands. Analyses showed that in 1977, 11.3% of Puerto Rico was classified as urban. After 17 years, urban areas had increased by 27.4% and urban growth on soils suitable for agriculture had increased by 41.6%. This represents a loss of 6% of potential agricultural lands. If this pattern of encroachment by urban growth into potential farmlands continues, Puerto Rico's potential for food production in the future could be greatly limited.

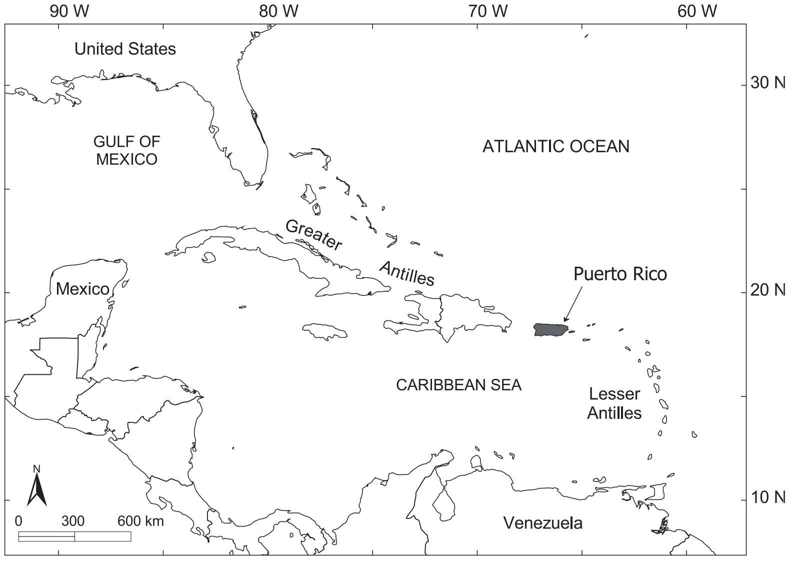
INTRODUCTION

Food scarcity and increasing losses of agricultural lands have become an issue of global concern (1–4). The continued increase in human population, a decrease in freshwater supplies, loss of croplands, and the changing global climate are all factors that may influence the ability of societies to produce sufficient food to feed the world's inhabitants. Global food security is further threatened by socioeconomic changes in China. Given its large and growing percentage of the global population, and the recent economic shift from agriculture to industry, China is fast becoming a major food importer. In a globalized world economy, increases in food imports to China will affect all nations and could increase global food prices, creating political and social instability, particularly in Third World countries (2, 5). If, as predicted, global demand for food doubles by the year 2030 (3), the prospect of increasing food production to meet future demands will require more land and water, or significant increases in crop production. Food production has increased in this century because of advances in the use of fertilization, irrigation, and pesticides (6, 7). However, the rate of increase in food production has slowed in the last 3 decades, and concerns have developed over the long-term sustainability and environmental consequences of the intensification of agricultural systems (7).

Population growth and economic changes are two important factors influencing land-use changes (8–11), and the distribution and amount of available agricultural lands. In many countries where there has been a shift from an agrarian to an industrial economy, abandoned agricultural lands are often converted to urban uses. These rapid losses of croplands are further intensified in countries that were densely populated before industrialization. Based on examples from Japan, South Korea and Taiwan, Brown (2) showed how these countries went from being grain exporters to importers. Japan's grainland area declined 52% from 1955 to 1994 (approximately 1.4% yr^{-1}). In South Korea, the area has declined 46% since 1965 (1.2% yr^{-1}), and Taiwan lost 42% from 1962 to 1994 (1.2% yr^{-1}). In China, between 1990 and 1994 total grain area harvested dropped from 90.8 million ha to 85.7 million, which represented a decline of 5.6% in 4 years. This loss in productive cropland in China, combined with a population increase of 59 million people (4.9%), represents a 10.5% reduction in harvested grain area per person (12). The strong economies of Japan, South Korea, and Taiwan, and a worldwide grain surplus have allowed these countries to overcome their shortages in cropland by becoming net grain importers. However, if global population growth continues at projected rates, and if China becomes a net grain importer, then current grain production will not be sufficient to meet projected needs.

In the Caribbean, one of the world's most densely populated regions (13, 14), agricultural lands are also under strong pressure from rapid population growth and a high rate of urbanization (4). On the island of Puerto Rico (Fig. 1) human population density has increased more than threefold during the last century (15) (Fig. 2A), resulting in one of the highest densities in the world, with over 400 inhabitants km^{-2} (10, 16). This increase in population density has been accompanied by a drastic change in the island's economic structure. Over the past 60 years, Puerto Rico's economy has shifted from being mainly agricultural to industrial, with an emphasis on manufacture and services (17). In the 1930s, approximately 43% of the island's gross national product (GNP) came from agriculture, mainly sugarcane, coffee, and tobacco (16). By 1996, the contribution of agriculture to Puerto Rico's GNP had decreased to 1.2% (Fig. 2B). Presently, coffee, poultry, and cattle production are the major components of the agricultural sector (16). During the same pe-

Figure 1. Location of Puerto Rico in the Caribbean Basin.



riod, the contribution of industry to GNP increased from 7% in 1934 to 41% in 1996 (18, 19). As agricultural production declined in Puerto Rico, forest cover increased, contrary to the trend of deforestation occurring throughout most of the tropics (20). During the peak of agricultural activity (1930 to 1950), forest cover on the island was reduced to approximately 6%, but by 1985 forests covered 34% of the island (21). Forest recovery occurred mostly in areas with steep topography or on nonagricultural lands. These economic changes have also led to an increase in urban areas, mainly on the coastal plains, areas which contain the most fertile agricultural lands on the island (22–25).

The objective of this study was to relate population growth, socioeconomic changes, and land-use patterns, with their possible relationships to losses of agricultural lands in Puerto Rico. Specifically, we quantified the extent of urban growth in Puerto Rico from 1977 to 1994, and determined the amount of potential agricultural lands available in 1977 that have been lost to urban uses during this period. These data were used to suggest how land-use changes could affect potential food production in Puerto Rico.

METHODS

Database Development

1977 urban/non-urban coverage. Urban uses for 1977 were derived from an island-wide land-use map developed by the Puerto Rico Department of Natural Resources (DNR), based on the interpretation of 1:20 000 aerial photographs. The original map consisted of 14 land-use classes; i.e. agriculture, forests, water resources, wetlands, residential, and recreational areas, nonproductive lands, public, military uses, commercial, industrial areas, extraction, communications, and transportation, and 82 subclasses. For our study, the original land-use classes were reclassified into 2 classes: urban and nonurban. The urban category included the residential, commercial, industrial, transportation, communications, and extraction land uses, as well as developed portions of recreational, public, military, and nonproductive uses. The remaining land uses were grouped into the nonurban category.

1994 urban/nonurban coverage. The 1994 urban/nonurban coverage was developed from a set of three 10 m resolution SPOT panchromatic images of Puerto Rico. We assumed that areas classified as urban in 1977 remained urban in 1994. Urban polygons for 1977 were superimposed on the SPOT image and new urban areas for 1994 were digitized on-screen using the 1977 urban coverage as a guide for interpreting the 1994 image. The 1994 urban/nonurban coverage included urban polygons from 1977 and new urban areas for 1994.

Soil coverage. Soil maps of Puerto Rico (26) were used to classify soils into 2 categories: i) suitable; and ii) unsuitable for agriculture. The United States Department of Agriculture–Natural Resources Conservation Service (USDA-NRCS) prime farmland definitions were used to reclassify the original 185 soils series into these 2 categories. By definition, prime farmlands contained the best combinations of physical and chemical characteristics for producing food, feed, forage, fiber, and oilseed crops (27). We also included those soils of island-wide importance, which are soils selected by the government as suitable for agriculture because of their unique characteristics for the cultivation of certain crops, e.g. coffee plantations, or because they have been traditionally used for specific plantations (Carmen Santiago, USDA-NRCS, pers. comm.). Each soil series was classified as suitable for agriculture if it fit into one of these definitions, otherwise it was classified as unsuitable. The accuracy of the generalized map was assessed with 300 randomly selected points. The classification (suitable/unsuitable) of the map was compared to that for the same location in the original soil survey photographs. Of the 300 verification points, 69 points were excluded

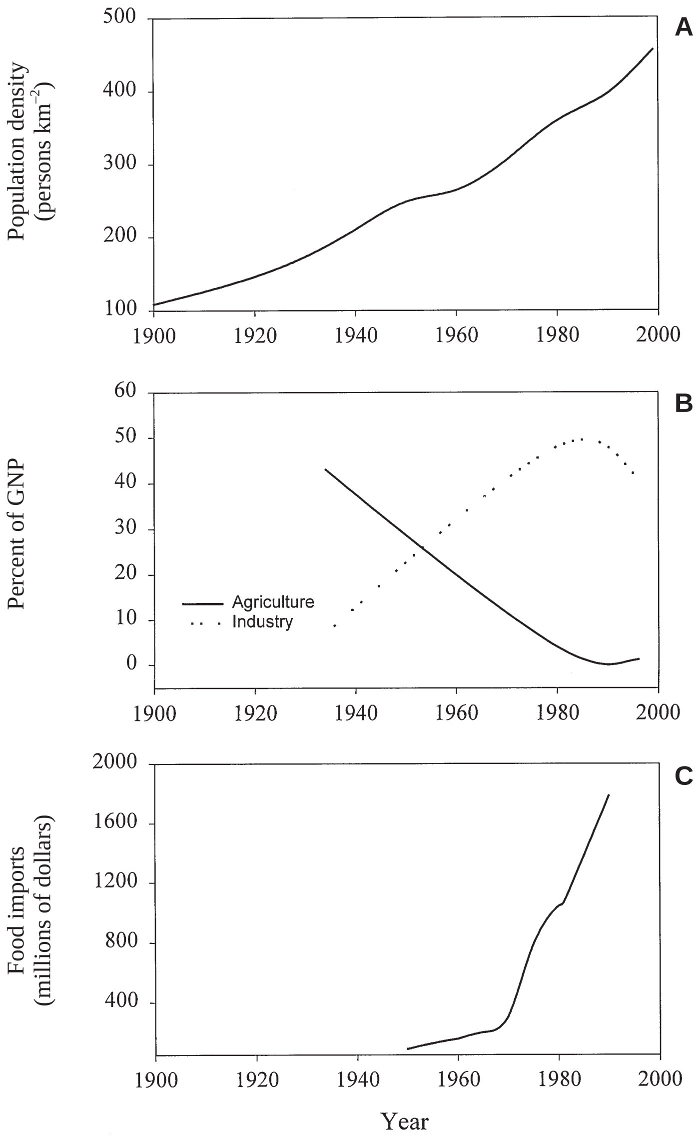


Figure 2. A. Population density (persons km^{-2}) in Puerto Rico from 1900 to 1994. B. Contribution of agriculture and industry to the Gross National Product (GNP) of Puerto Rico between 1934 and 1996. C. Food imports (millions of USD) to Puerto Rico from 1950 to 1990.

because they fell within bodies of water or unsurveyed areas. Of the remaining 231 points, 225 (97.4%) were correctly classified.

Other spatial and socioeconomic data. Additional data layers of elevation, slope, 1977 urban centers, and roads were also included in the analysis. Elevation data were obtained from a 90 x 90 m resolution Digital Elevation Model (DEM) of Puerto Rico which was derived from a 1:250 000 scale topographic map. The slope coverage was derived from the 90 x 90 m resolution DEM. Based on the 1977 urban/nonurban coverage, we generated a coverage of urban centers for each municipality on the island. The road network was obtained from a 1997 road coverage for the island (28). The distribution of 1977 urban centers and the road network were used to derive 2 additional coverages: i) distance from 1977 urban centers; and ii) distance from roads.

Geographic Information System Database and Analysis

Urban/nonurban land use for 1977 and 1994, soil suitability for agriculture, elevation, % slope, distance to 1977 urban centers, and distance to roads coverages comprised the bases of the Geographic Information Systems (GIS) database used for the study. Geographic data were developed and analyzed using PC Arc Info v 3.5 (29), Arc View v 3.1 (30) and Erdas Imagine v 8.3.1 (31).

All coverages were registered using a Lambert Conformal Conic projection (North American Datum 27), which is the coordinate system used on United States Geological Survey topographic maps for Puerto Rico.

To determine if there was a relationship between the spatial distribution of new urban areas in 1994 with elevation, slope, proximity to the 1977 urban centers, or proximity to roads, we randomly selected 100 points from areas of urban change, and 156 points from areas of no urban change. These points were overlain onto the DEM, slope, distance to 1977 urban centers, and the distance to roads coverages, thus obtaining unique values for each point. A 2 sample t-test was used to compare the values of elevation, slope, distance from 1977 urban centers, and distance from roads between areas that were developed and areas not developed. For all statistical analyses we used a significance level of 0.05.

To determine the relationship between urban growth and potential agricultural lands, the coverage of new urban polygons was overlain onto the soil coverage. A Chi-square test was conducted to test the hypothesis of independence between prime agricultural lands and urban development, using a 2 x 2 contingency table in which the total area classified as urban/nonurban was compared with soil type (suitable/unsuitable for agriculture).

RESULTS

Reclassification of the 1977 land-use coverage resulted in an 8:1 ratio between nonurban and urban categories for the total area of Puerto Rico (Table 1, Fig. 3). The reclassification identified 4 major urban centers on the island; i.e. the metropolitan area of San Juan in the northeast, Caguas in the central-east, Ponce in the south, and Mayaguez in the west. With the exception of Caguas, these centers were all located within the coastal plains. Urban uses covered 11.3% of the island in 1977 and 14.4% in 1994. This change represents an increase of 27.4% in urban areas from 1977 and 1994. Nonurban uses decreased from 88.7% to 85.6% over the same period (Table 1; Fig. 3).

The spatial distribution of new urban areas in 1994 was related to elevation, slope, distance from 1977 urban centers, and distance from roads. The distribution of areas of urban change compared to those of no urban change from 1977 to 1994 was significantly related to elevation (t-test, p = 0.001) slope (t-test, p = 0.002). Areas of urban change occurred mostly in lowland regions and on lower slopes, while areas of no change occurred at higher elevations and on steeper slopes (Table 2). We also found differences between the distribution of new urban development with distance from 1977 urban centers (t-test, p = 0.001) and road networks (t-test, p = 0.001). Areas converted to urban use in 1994 tended to occur closer to existing urban centers and roads than nondeveloped areas (Table 2).

In 1977, 24.5% of the nonurban area had soils suitable for agriculture (Table 3; Fig. 4). The majority of these soils occurred within the coastal plains, with the exception of several patches along the central mountain region of the island which have traditionally been dedicated to coffee and plantain production. One of the largest areas of soils suitable for agriculture in the interior of the island occurs in the Caguas valley, in the eastern part of Puerto Rico (Fig. 4).

Figure 3. Distribution of urban areas in Puerto Rico in 1977 and 1994.

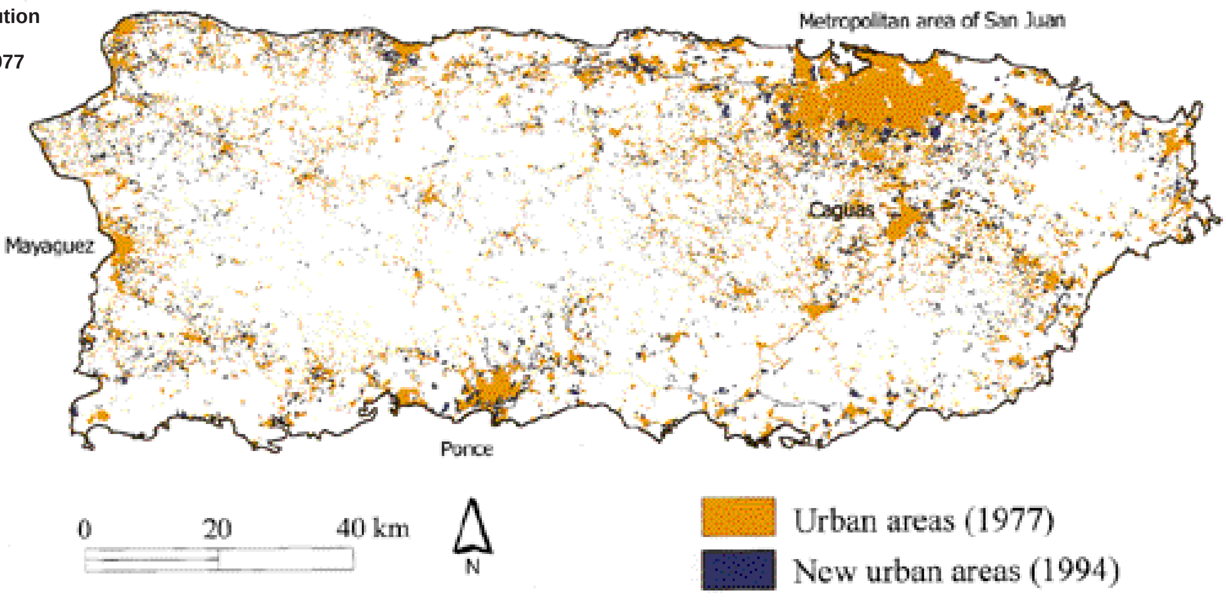


Table 1. Urban and nonurban areas (km^2) in Puerto Rico in 1977 and 1994, and the percent change of each class during the study period. Values in parentheses are the percent cover for each class on the island.

Year	Urban	Nonurban
1977	984 (11.3)	7725 (88.7)
1994	1252 (14.4)	7457 (85.6)
% change	+ 27.4	– 3.5

Table 2. Mean, minimum, and maximum values of elevation (m), slope (%), distance from 1977 urban centers (m), and distance from roads (m), for points of urban change (n = 100) and no urban change (n = 156) from 1977 to 1994.

	Change			No change			
	mean	min	max	mean	min	max	p-value
Elevation	112.0	0	645	235.0	0	978	0.001
Slope	5.7	0	45	9.6	0	64	0.002
Distance (urban centers)	2346.0	50	8599	4355.0	92	12776	0.001
Distance (roads)	904.0	3	4453	1449.0	13	5978	0.001

Productive agricultural lands along the coastal plains of Puerto Rico are being irreversibly lost to urban development. Photo: IITF, USDA-Forest Service.

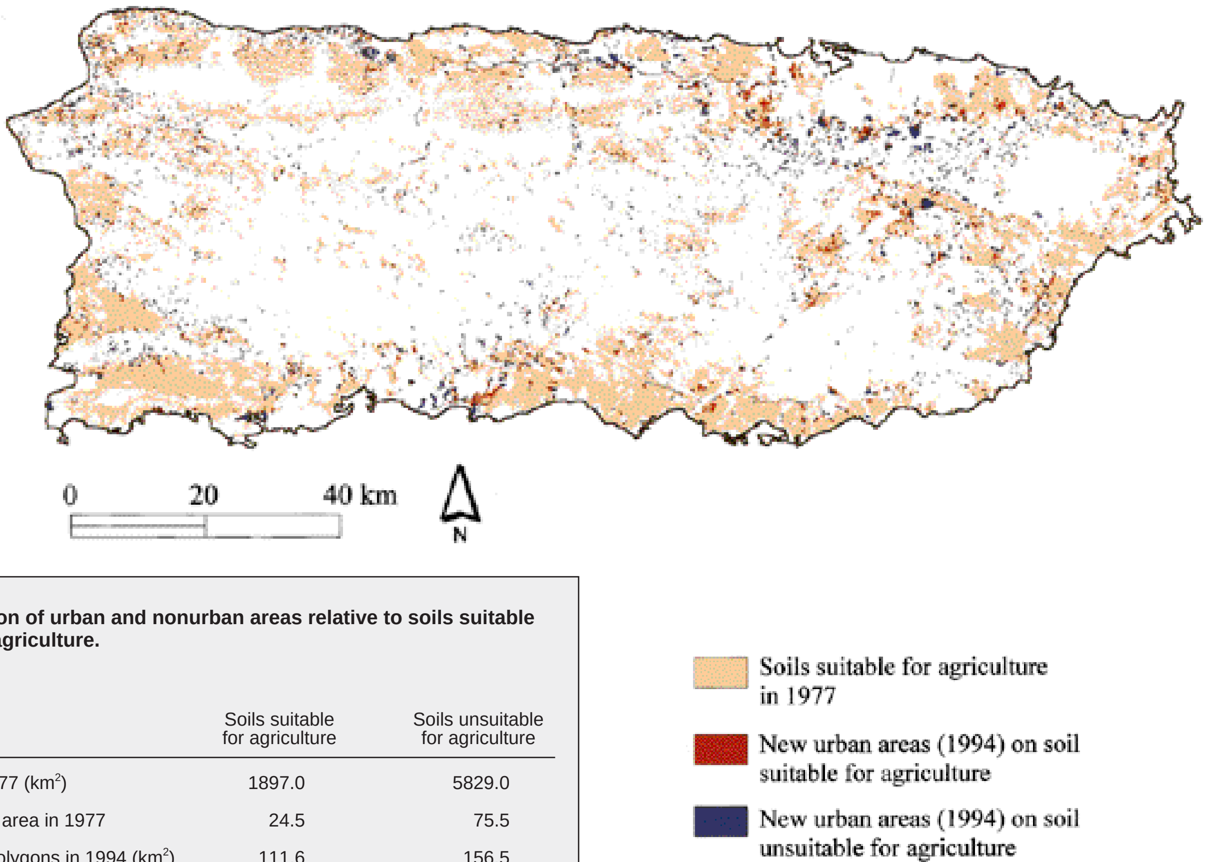
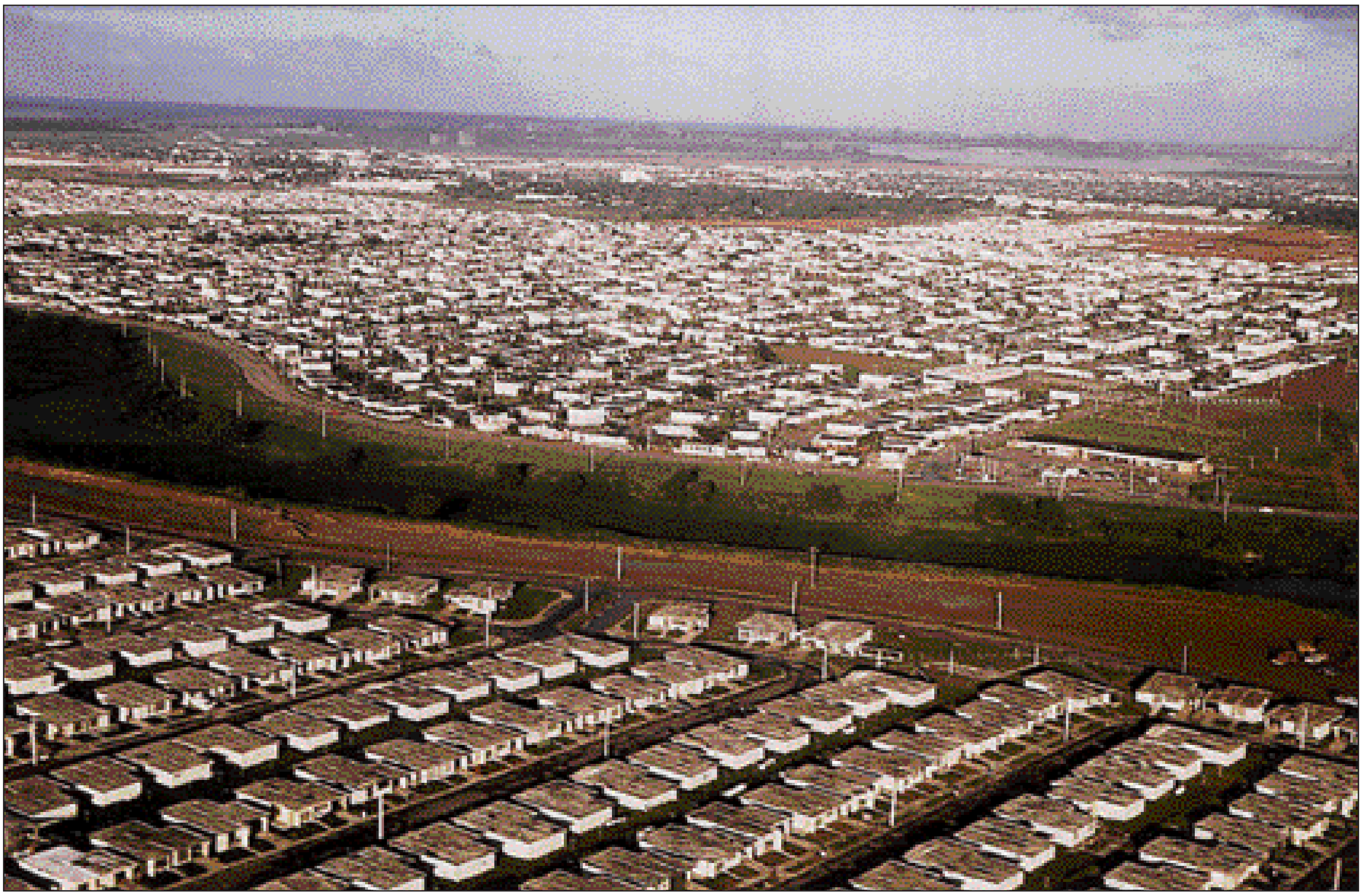


Figure 4. Distribution of new urban areas from 1977 to 1994 in relation to the island's potential agricultural soils.

Table 3. Distribution of urban and nonurban areas relative to soils suitable or unsuitable for agriculture.

	Soils suitable for agriculture	Soils unsuitable for agriculture
Nonurban area in 1977 (km^2)	1897.0	5829.0
Percent of nonurban area in 1977	24.5	75.5
Area of new urban polygons in 1994 (km^2)	111.6	156.5
Percent of new urban area in 1994	41.6	58.4
Percent of land converted to urban from 1977 to 1994	5.9	2.7



Productive agricultural lands along the coastal plains of Puerto Rico are being irreversibly lost to urban development. Photo: IITF, USDA-Forest Service.

New areas of urban uses in 1994 were higher on nonagricultural soils (156.5 km^2) than on potential agricultural soils (111.6 km^2) (Table 3; Fig. 4). However, the percentage of potential agricultural soils converted to urban uses from 1977 to 1994 was more than twice that of nonagricultural lands (5.9% versus 2.7%; Chi-square, $p = 0.001$). The majority of new urban areas were located on the coastal plains or in the Caguas valley.

DISCUSSION

Socioeconomic changes in Puerto Rico during this century promoted a dramatic change in land-use practices (18, 25, 32). The transformation from an agrarian to an industrial economy resulted in the abandonment of agricultural lands, an increase of forest cover on abandoned agricultural lands, and increases in urban areas. Along with these land-use changes, the island has experienced a rapid population increase since the beginning of the century and a migration from rural areas to urban centers. This shift in the economy, which promoted migration to cities, resulted in an increase for the demand of housing, industrial facilities, and roads. Brown (2) observed similar patterns of urbanization in Japan, Taiwan, South Korea, and China, all densely populated countries experiencing a transformation from an agricultural to an industrial economy. In all of these countries, rapid industrialization led to increases in urban areas and losses of open spaces as residential, industrial, and commercial demands increased.

As urban uses increase, prime agricultural lands are threatened because of their lowland location and their vulnerability to conversion to nonfarm uses. In Japan, Taiwan, South Korea, and China, large conversions to urban uses have been at the expense of cropland areas (2). In Puerto Rico, we determined that 42% of the new urban areas between 1977 and 1994 occurred at the expense of potential agricultural lands. The principal agricultural lands occur mainly on the island's coastal plains, which are more susceptible to development. In addition, many of these low-elevation areas are more attractive to development because of their high touristic and economic value. Many of Puerto Rico's public lands are also along the coastal plains, and these are areas of high rates of industrial rental. The rental or sale of these lands is resulting in a transition of nonurban uses to irreversible urban uses; e.g. industrial or touristic development, housing, shopping centers, and roads.

Our analysis suggests that urban growth is not randomly distributed, and that it tends to occur on prime farmland. The island's potential agricultural lands are more likely to be developed because of their location near existing urban centers and the principal roads of the island. Puerto Rico has the highest road density of any Caribbean island, with 2.5 km of paved roads km^{-2} (10). This high road density is resulting in urban growth throughout the island's landscape. A similar expansion of urban areas at the expense of agricultural lands occurring near existing developed areas and along road networks has been documented in southeastern coastal states of the United States (33). Also, in rapidly growing areas of the United States, more than half of the agricultural land has been converted to urban uses (34).

The conversion of lands to urban uses is reducing the cropland area available on the island. In 17 years Puerto Rico lost potential agricultural lands at a rate of 0.35% yr^{-1}. This value is lower than those reported by Brown (2) for Japan, South Korea, Taiwan, and China (1.4, 1.2, 1.2, and 1.4% yr^{-1}, respectively), but these data covered the peak period of transformation from an agricultural to an industrial economy. In Puerto Rico, agricultural censuses show that rapid losses of agricultural lands have occurred since 1950, with the highest rate of change occurring between 1964 and 1974 (35). In this study we do not report data for loss of agricultural land prior to 1977, when losses were greatest. Our findings show, however, that after the initial transition period, Puerto Rico continues to lose potential agricultural lands at a high rate.

As a consequence of the loss of large areas of cropland due to their conversion to urban uses, several countries have gone from being largely self-sufficient to net grain importers. In a period of 44 years (1950–1994) Japan lost more than half of its cropland which contributed to greater dependence on grain imports (70% in 1985, 25% in 1950). This pattern of increased dependence on imports has also occurred in South Korea and Taiwan (2). In Puerto Rico, food imports have increased 18-fold from 1950 to 1980 (16, 18) (Fig. 2C). In the cases of Japan, South Korea, and Taiwan the increase of imports was a response to a reduction in production due to a loss of agricultural lands. In Puerto Rico, in spite of the availability of potential agricultural lands with suitable soils and climate to produce many crops such as fruits and root crops, the island is not producing food at its full capacity. Possible reasons for the low agricultural production in Puerto Rico are high costs of production, low productivity, and lower prices in external markets. Even though the government provides incentives to promote the agricultural sector, e.g. financial aid, employment, seeds, fertilizers, there is a lack of long-term planning and effective implementation of existing policies. Although Puerto Rico is not self-sufficient in food production, the loss of potential agricultural lands to irreversible nonagricultural uses reduces its capacity for becoming so in the future.

A major consequence of population growth and a shift to a nonagricultural economy is the permanent loss of agricultural lands. Governments should revise zoning regulations to ensure that potential farmlands remain undeveloped. In order to preserve potential agricultural lands, we should (a) concentrate development in certain areas; (b) encourage vertical construction; (c) improve systems of mass transportation; (d) assess any economic activity in terms of land scarcity and its possible impacts on natural resources; and (e) promote the acquisition and preservation of agriculturally important public lands. It is essential that these and other policies are enacted to reduce the losses of agricultural lands around the world, particularly given the continued increase of the world's population and food needs.

References and Notes

1. Bender, W.H. 1997. How much food we will need in the 21st Century? Environment 39, 7–11.
2. Brown, L.R. 1995. Who Will Feed China? W.W. Norton and Company, New York, New York, USA.
3. Crosson, P. 1997. Will erosion threaten agricultural productivity? Environment 39, 4–31.
4. Gajraj, A.M. 1981. Threats to the terrestrial resources of the Caribbean. Ambio 10, 307–311.
5. Reid, T.R. 1998. Feeding the Planet. Natl. Geogr. 4, 56–74.
6. Postel, S.L. 1998. Water for food production: will there be enough in 2025? BioScience 48, 629–637.
7. Matson, P.A., Parton, W.J., Power, A.G. and Swift, M.J. 1997. Agricultural intensification and ecosystem properties. Science 277, 504–509.
8. Bilsborrow, R.E. and Okoth-Ogendo, H.W.O. 1992. Population driven changes in land use in developing countries. Ambio 21, 37–45.
9. Helmer, E.H. 2000. The landscape ecology of secondary tropical forest in montane Costa Rica. Ecosystems 3, 98–114.
10. Lugo, A.E. 1996. Caribbean island landscape: indicators of the effect of economic growth on the region. Envir. Dev. Econ. 1, 128–136.
11. Turner, M.G., Wear, D.N. and Flamm, R.O. 1996. Land ownership and land-cover change in the southern Appalacian highlands and the Olympic peninsula. Ecol. Applic. 6, 1150–1172.
12. Data from the United States Department of Agriculture—Economic Research Service 1994, and United States Bureau of Census 1993; as cited in Brown (2).
13. Lugo, A.E., Schmidt, R. and Brown, S. 1981. Tropical forests in the Caribbean. Ambio 10, 318–324.
14. Potter, R.B. 1993. Urbanization in the Caribbean and trends of global convergence-divergence. Geogr. J. 159, 1–21.
15. Data of population density from the United States Bureau of Census, selected years: 1900 to 1994. U.S. Department of Commerce, Washington, D.C., USA.
16. Cruz-Baez, A.D. 1998. Está preparada para la globalización la agricultura de Puerto Rico? In: Globalization in America: a Geographical Approach. Seguinot-Barbosa, J.(ed.). Instituto de Estudios del Caribe, San Juan, Puerto Rico, pp. 187–205. (In Spanish).
17. Morales-Carrión, A. 1983. Puerto Rico, a Political and Social History. Norton, New York, New York, USA.
18. Dietz, J.L. 1989. Historia Económica de Puerto Rico. Ediciones Huracan, Inc., Río Piedras, Puerto Rico. (In Spanish).
19. Data of Gross National Product from the Puerto Rico Planning Board—Economic Report 1996. Government of Puerto Rico. San Juan, Puerto Rico.
20. Brown, S. and Lugo, A.E. 1990. Tropical secondary forest. J. Trop. Ecol. 6, 1–32.
21. Birdsey, R.A. and Weaver, P.L. 1987. Forest Area Trends in Puerto Rico. US Department of Agriculture. Forest Service Research Note SO 331. San Juan, Puerto Rico, 5 pp.
22. Berrios-Saez, A. 1998. Evaluación de los Recursos Naturales del Bosque Estatal de Cambalache, Puerto Rico y el desarrollo de un Plan Estratégico para su manejo sostenible. MSc Thesis, Universidad Metropolitana, San Juan, Puerto Rico. (In Spanish).
23. Lugo, A.E., Ramos, O., Molina, S., Scatena, F.N. and Velez-Rogríguez, L.L. 1996. A Fifty-three Year Record of Landuse Change in the Guánica Forest Biosphere Reserve and its Vicinity. International Institute of Tropical Forestry, USDA Forest Service, San Juan, Puerto Rico, 16 pp.
24. Ramos, O. 1996. Assessing Northeastern Puerto Rico Vegetation Changes Using Remote Sensing and Geographic Information Systems. MA Thesis, Clark University, Worcester, Massachusetts, USA.
25. Thomlinson, J.R., Serrano, M.I., López, T. del M., Aide, T.M. and Zimmerman, J.K. 1996. Landuse dynamics in a post-agricultural Puerto Rican landscape (1936–1988). Biotropica 28, 525–536.
26. Digital soils coverages from the Puerto Rico Department of Natural Resources, based on 1977 United States Department of Agriculture—Natural Resources Conservation Service Soils Surveys.
27. USDA Natural Resources Conservation Service 1993. Soil Survey Manual. USDA Handbook No. 18. Washington, DC, USA.
28. Road coverage developed by the Puerto Rico Highway Authority 1998. Government of Puerto Rico, San Juan, Puerto Rico.
29. ESRI 1997. Arc-Info version 3.5.1. Environmental Systems Research Institute, Inc., Redlands, California, USA.
30. ESRI 1998. Arc View GIS version 3.1. Environmental Systems Research Institute, Inc., Redlands, California, USA.
31. ERDAS 1997. Imagine version 8.3.1. ERDAS, Inc., Atlanta, Georgia, USA.
32. García-Montiel, D.C. and Scatena, F.N. 1994. The effect of human activity on the structure and composition of a tropical forest in Puerto Rico. Forest Ecol. Mgmt 63, 57–78.
33. Dillman, B.L. and Cousins, C.F. 1982. Urban encroachment on prime agricultural land: A case study. Int. Reg. Sci. Rev. 7, 285–292.
34. Heimlich, R.E. and Krupa, K.S. 1994. Changes in land quality accompanying urbanization in US fast-growth counties. J. Soil Water Conserv. 49, 367–374.
35. González, G.M. 1995. Cambios en usos de terrenos agrícolas en Puerto Rico y sus ímpactos en la agricultura. Acta Cient. 9, 3–14. (In Spanish).

36. We acknowledge Carmen Santiago (USDA-NRCS) for providing soils information. The accuracy assesment of the soil coverage was done by Eileen Crespo of the Institute for Tropical Ecosystem Studies. The comments and reviews of Fred Scatena, Eileen Helmer, Ariel Lugo, Frank H. Wadsworth, Francisco de Castro, Julio Figueroa, and two reviewers helped to improve the manuscript. This study was funded by IITF, USDA-Forest Service and NASA-IRA.
37. First submitted 26 Oct. 1999. Accepted for publication after revision 27 April 2000.

Tania del Mar López is a remote sensing/GIS analyst at the International Institute for Tropical Forestry. Her research interests include land-use change, especially the spread of urban cover in Puerto Rico, and its implications for natural resources. Her address: International Institute of Tropical Forestry, USDA Forest Service, P.O. Box 25000, San Juan, Puerto Rico.
E-mail: tdl131@psu.edu

T. Mitchell Aide is professor of biology at the University of Puerto Rico, Río Piedras. His research and teaching interests include community and restoration ecology. His address: Department of Biology, University of Puerto Rico, P.O. Box 23360, San Juan, Puerto Rico.
E-mail: maide@upracd.upr.clu.edu

John R. Thomlinson is assistant professor in the Institute for Tropical Ecosystem Studies at the University of Puerto Rico, Río Piedras. He teaches remote sensing and landscape ecology and conducts research into landscape patterns and land-use change. His address: Institute for Tropical Ecosystem Studies, University of Puerto Rico, P.O. Box 363682, San Juan, Puerto Rico.
E-mail: thomlins@sunites.upr.clu.edu