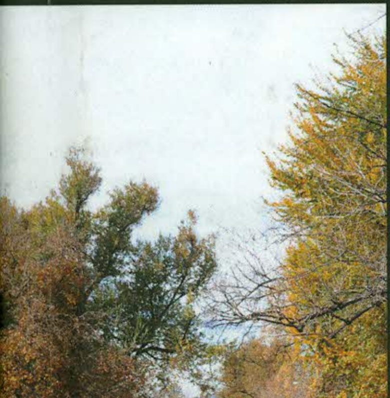
Urban Expansion, Land Cover and Soil Ecosytem Services



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To Sofia and Maria Isabella, to stimulate them struggling for a better world.

Urban Expansion, Land Cover and Soil Ecosystem Services

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Urban Expansion, Land Cover and Soil Ecosystem Services

More than half of the world population now lives in cities, and urban expansion continues as rural people move to cities. This results in the loss of land for other purposes, particularly soil for agriculture and drainage. This book presents a review of current knowledge of the extension and projected expansion of urban areas at a global scale.

Focusing on the impact of the process of 'land take' on soil resources and the ecosystem services that they provide, it describes approaches and methodologies for detecting and measuring urban areas, based mainly on remote sensing, together with a review of models and projected data on urban expansion. The most innovative aspect includes an analysis of the drivers and especially the impacts of soil sealing and land take on ecosystem services, including agriculture and food security, biodiversity, hydrology, climate and landscape.

Case studies of cities from Europe, China and Latin America are included. The aim is not only to present and analyse this important environmental challenge, but also to propose and discuss solutions for the limitation, mitigation and compensation of this process.

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15 Urbanization in Latin America with a particular emphasis on Mexico

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Introduction

Most Latin American cities were established by the sixteenth century. These urbanized core areas were symbols of territorial possession and centers from which the surrounding countryside could be administered and exploited. In Central American and Andean countries they are often located away from the coast and build upon pre-colonial settlements. The most important towns in colonial Latin America were political and cultural centers, for example, Mexico City, Lima and Buenos Aires, which were also capitals of viceroyalties. Other economically important cities were mining centers (Taxco, Potosi) and major ports along the coast of the Caribbean sea and Atlantic ocean such as Cartagena, Santo Domingo, Rio de Janeiro and Montevideo. The political and administrative centers of the past remain the major urban centers in Latin America today.

By the mid-twentieth century industrialized countries such as Argentina, Brazil and Mexico achieved rapid growth with manufacturing activities concentrated in the capitals and chief ports. This pattern of concentration became most prominent after World War II and it had an impact on urban growth, migration and regional development strategies. Away from these manufacturing cores, export-processing industries created economic enclaves in intermediate cities and peripheral zones. Urban primacy became a distinctive geographic feature in most of Latin America (Aguilar and Vieyra 2008).

In the early 1980s, Latin America adopted a free-market economic model. Opening-up national economies led to increasing deindustrialization, deteriorated labor conditions, growth of the informal sector and an increase in urban poverty. This, in turn, shifted growth from large metropolitan areas towards middle-sized urban centers that became more competitive in the global economy, such as border towns like Tijuana in Mexico, export-oriented manufacturing poles such as Medellin in Colombia or Ciudad Juarez in Mexico, and tourist centers like Cancun, Panama City or Rio de Janeiro (Aguilar and Vieyra 2008).

Data sets

In the following sections regional definitions from the United Nations (UN 2014a) were adapted in the following way: Latin America was defined as all land from Mexico to Tierra del Fuego including all Caribbean islands. This area was subdivided into three regions: Central America (Mexico to Panama), Caribbean (islands of Greater and Lesser Antilles) and South America (the remainder). For population analysis statistical data of the World Urbanization Prospects 2014 were employed with population data from 1950 to 2050 and urban agglomerations (more than 300,000 inhabitants) from 1950 to 2030 (UN 2014b), excluding countries with an area smaller than 5,000 km^2. The National Institute for Statistics and Geography (INEGI) provides population census data for Mexico for 1950, 1960, 1970 and 1990 to 2010 at five-year intervals (INEGI 2014). Urban areas were defined as localities with more than 2,500 inhabitants, but city analysis only focused on agglomerations with more than 15,000 people.

Defense Meteorological Satellite Program – Operational Linescan System (DMSP-OLS, Elvidge *et al.* 1997) images of annual average stable lights from 1992 to 2009 were cross-calibrated (Elvidge *et al.* 2009) and employed for defining urban areas uniformly in space and time using threshold value DN>=55 or 87 percent of the data range (Imhoff *et al.* 1997, Small *et al.* 2005). For countries and states with more than 200 urban pixels linear least-square regression was used for trends estimation and F-test for statistical significance analysis of the regression model.

Land take was analyzed using a land cover map of Latin America derived from 500 m Moderate Resolution Imaging Spectroradiometer (MODIS) images for the year 2008 (Blanco *et al.* 2013). For the country of Mexico and local analysis of Cancun and Merida a 250 m MODIS-based land cover time series (2005–2011) was employed (Colditz *et al.* 2012, Colditz *et al.* 2014a, Colditz *et al.* 2014b). INEGI vegetation data (1970, 2012) were used for studying the urban expansion of Mexico City (INEGI-INE 1999, INEGI 2013).

Urbanization in Latin America, its regions and countries

In 2015, the estimated population of Latin America was 630 million or 8.6 percent of the world's population (Table 15.1; UN 2014b). Over the course of time from 1950 to 2050 the total population growth rate declined more rapidly than global numbers. The reason for slower population growth in Latin America is the stable low rate of mortality and decreasing rate of fertility which puts most countries in stage 3 out of 4 of the demographic transition model (Pacione 2009). Latin America comprises a total area of 2,055 million ha or 15.1 percent of the global land surface excluding Antarctica (Table 15.1). In 2015, population density in Latin America was only 30.7 people/km^2 (53.8 people/km^2 for the world) with notable regional disparities.

Table 15.1 Area, total population and urban population (selected years) for the World, Latin America and its regions and Mexico which were used to calculate population density and urban proportions

	Area [million ha]	*Total population [millions]*				*Urban population [millions]*			
		1950	*2000*	*2015*	*2050*	*1950*	*2000*	*2015*	*2050*
World	13,616	2,525.8	6,127.7	7,324.8	9,550.9	746.5	2,856.1	3,957.3	6,338.6
Latin America	2,055	167.9	526.3	630.1	781.6	69.3	396.3	502.8	673.6
Caribbean	23	17.1	38.4	43.1	47.6	6.2	23.5	30.3	38.4
Central America	248	38.3	139.6	171.9	228.8	15.0	96.1	126.9	187.2
South America	1,783	112.5	348.2	415.1	505.1	48.1	276.6	345.6	448.0
Mexico	196	28.3	103.9	125.2	156.1	12.1	77.6	99.2	134.8

Source: UN (2014b).

Note: Area for the world excludes Antarctica.

The Caribbean, by far the smallest region (1.1 percent), also hosts the smallest population proportion of 6.8 percent, but the population density of 184.2 people/km^2 is the highest among global regions (UN 2014b). Central America, with 12.1 percent of the land surface and 27.3 percent of the population, shows an intermediate density of 69.3 people/km^2. South America is the largest region but population density is low (23.3 people/km^2), also because of large, nearly uninhabited areas like the Amazon, which puts it among the sparsely populated regions of the world.

In 2015, in Latin America 502.8 million people, that is 79.8 percent, live in urban areas (Table 15.1). This puts it in second place with a slightly lower urban population proportion than North America (81.6 percent) and well above the global average (54.0 percent, UN 2014b). While there is a relatively linear increase in global urban population by approximately 0.37 percent per year, Figure 15.1A shows for Latin America an increase of, on average, 0.69 percent until 2000 and since then 0.21 percent. It should be noted that the growth of urban population was above the growth of total population; hence there is a steady decline in rural population proportion and for most countries also a decrease in absolute numbers due to rural-to-urban migration. Regional disparities can be noted in Figure 15.1B, e.g. Guatemala, Guyana, Honduras, Nicaragua and Paraguay show lower than average Latin American percentages of urban population in 2015, while Argentina and Uruguay are well above average. Most countries show increasing trends in urban population proportion (Figure 15.1C) with Brazil, Costa Rica, the Dominican Republic, Haiti, Honduras and Puerto Rico clearly above Latin American and global trends.

The percent urban area, estimated from DMSP between 1992 and 2009 (Elvidge *et al.* 1997, 2009), replicates the above-described pattern of population density (Figure 15.1D). While the world shows a nearly zero trend over 18 years, Latin America and regional tendencies are all positive but not

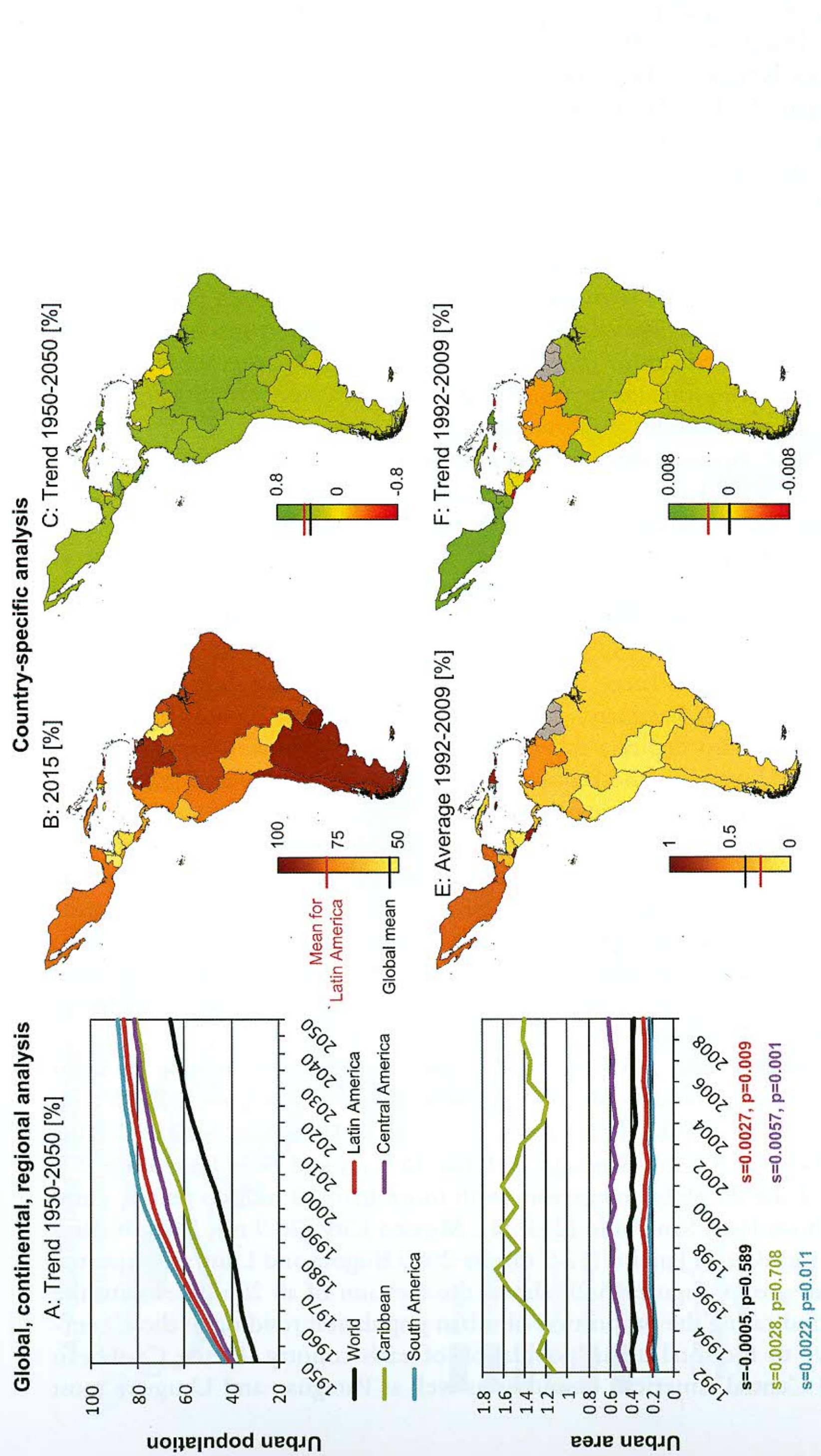

Figure 15.1 Urban population proportion and urban area for the World, Latin America and its regions and countries (sources: UN 2014b and DMSP)

Note: s. . .linear trend, p. . .significance of F-test for linear regression model. Lines in scale bars indicate global and Latin American average. Grey indicates countries not analyzed due to too few urban area pixels.

always significant (p>5 percent). Percent urban area in Bolivia, Nicaragua and Peru is clearly below the Latin American average, while Costa Rica, Dominican Republic, El Salvador, Jamaica, Mexico and Puerto Rico are above (Figure 15.1E). Trends also vary widely (Figure 15.1F) with Guatemala, Mexico and Trinidad and Tobago showing significant, above-average trends of urban area growth. All negative trends, e.g. for Colombia, Costa Rica, El Salvador, Jamaica, Puerto Rico, Uruguay and Venezuela, were not significant (p>0.05). These countries indicate a particular tendency to urban densification, e.g. constructing higher buildings or reducing individual space with smaller apartments to accommodate the growing urban population in nearly the same area. This development may be fostered in countries with a small national territory or large cities in mountainous areas which, due to construction in floodplains or steep slopes increases susceptibility to natural hazards such as mudslides and inundations.

Land transformation due to urban growth is difficult to analyze due to lacking long time series of spatially-explicit land cover information. A simple attempt was undertaken using a MODIS-based land cover map of Latin America for the year 2008 (Blanco *et al.* 2013) and assuming uniform urban growth of 2 km around each urban agglomeration. The proportion of land cover classes potentially transformed to urban was summarized for each country in pie charts (Figure 15.2A). Notable is the high proportion of cropland loss in many countries. Large reductions of forested land are shown for Brazil, Colombia, Ecuador, Paraguay, Trinidad and Tobago and Venezuela. Bolivia, Chile and Peru also depict a transformation of high elevation barren land to urban areas. However, land transformation is a local process and depends on local actors and the dominating land cover in this region.

The majority of the world's urban population lives in centers smaller than 300,000 inhabitants, but this proportion is declining as more people agglomerate in large cities (above 1 million) and megacities (above 10 million) (UN 2014b). Latin America is no exception; the urban population proportion of bigger settlement categories of Argentina, Chile, Colombia, Mexico and Peru have already or will soon surpass the group with fewer than 300,000 inhabitants.

In 2015, there are 205 cities with more than 300,000 people in Latin America: 83 with 300,000–500,000, 55 with 500,000–1 million, and 59 with 1–5 million (UN 2014b). There are 4 cities with 5–10 million habitants: Lima (9.8 m), Bogota (9.7 m), Santiago de Chile (6.5 m) and Belo Horizonte (5.7 m). Out of the 29 global megacities with more than 10 million people Latin America hosts four: Sao Paulo (21.0 m), Mexico City (20.9 m), Buenos Aires (15.1 m) and Rio de Janeiro (12.9 m); by 2030 Bogota and Lima are expected to join this group. Figure 15.2B shows the location of all 205 cities with the diameter indicating the proportion of urban population residing in those centers relative to the total urban population of each country. In the Caribbean and small Central American countries as well as Paraguay and Uruguay most

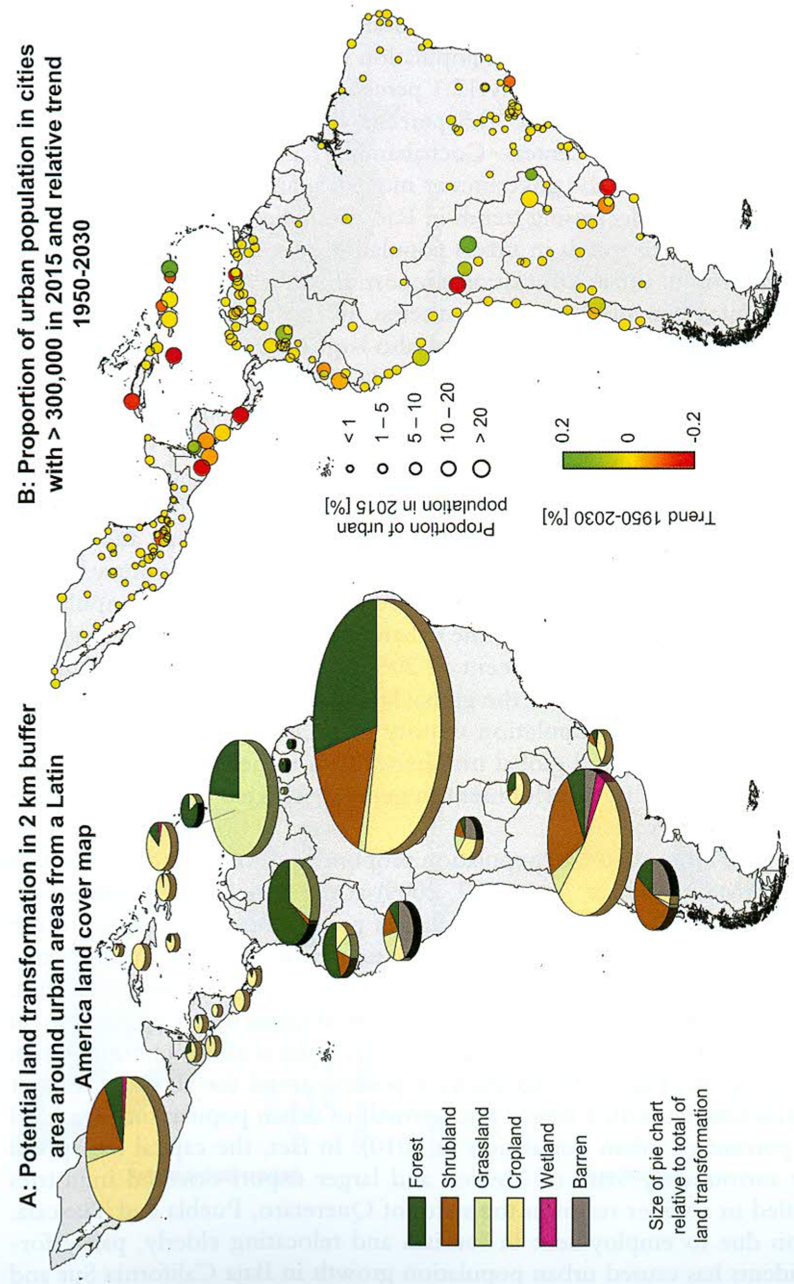

Figure 15.2 A: Potential land cover change in 2 km buffer zone around urban areas from a MODIS-based land cover map of 2008 (source: Blanco et al. 2013). B: Urban population proportion for cities with more than 300,000 inhabitants in 2015 (urban population of city in relation to urban population of each country) (source: UN 2014b)

of the urban population concentrates in one city, usually the capital. In other counties, despite a higher number of urban centers, one agglomeration clearly dominates with 20–40 percent of the total urban population, e.g. Argentina, Chile, Colombia, Cuba, Ecuador, Mexico and Peru. This concentration reflects the above-mentioned centralized political and economic development of most Latin American countries. Brazil and Venezuela form a group in which, despite large cities, urban population proportion is not concentrated in only one major center, e.g. only 12.1 percent of the Brazilian urban population resides in Sao Paolo and 10.5 percent in Caracas. A singular case is Bolivia with three major centers: Cochabamba, La Paz and Santa Cruz. In both, Brazil and Bolivia the government moved to another city which led to notable proportional decreasing trends in Rio de Janeiro and La Paz (colors in Figure 15.2B indicate trends in urban population proportion). Other notable decreasing trends of urban population proportion are noted for Buenos Aires, Caracas, Montevideo and Quito, nevertheless, all cites have gained population in absolute numbers. However, there are also large urban centers with relative increases, e.g. Bogota, Lima, Santiago de Chile, San Juan (Puerto Rico), Santa Cruz (Bolivia) and Ciudad de Este (Panama).

Urbanization in Mexico at the national and state level

In 2015, Mexico was home to 1.7 percent of the global and almost 20 percent of Latin Americas population (Table 15.1). The country multiplied its population almost five times between 1950 and 2015 but population growth is slowing down. In 2015, the urban population is almost 80 percent and is expected to reach 86 percent in 2050. In terms of area the country makes up almost 1.5 percent of the global land surface and nearly 10 percent of Latin America. The population density of 63.8 people/km^2 in 2015 is above Latin American and global numbers. With respect to urban population, urban area and city development in general, Mexico is a representative example for Latin America.

Figure 15.3 indicates urban population proportion (INEGI 2014) and urban area from DMSP (Elvidge *et al.* 1997, 2009) at the state level (for names see Figure 15.3B). While high urban population proportion in the center of the country is due to the highly centralized system around Mexico City, concentration in the northern states (Figure 15.3A) is due to water scarcity. Touristic development is the reason for above-average urban population in Quintana Roo. Chiapas and Oaxaca are the only states with a higher rural than urban population. Figure 15.3B shows a positive trend for all states, except the Federal District with a nearly zero growth of urban population (at a level of 99.5 percent of urban population in 2010). In fact, the capital has spread into the surrounding State of Mexico and larger export-oriented industries have settled in a wider realm in the states of Queretaro, Puebla and Tlaxcala. Migration due to employment in tourism and relocating elderly, partly foreign residents has caused urban population growth in Baja California Sur and

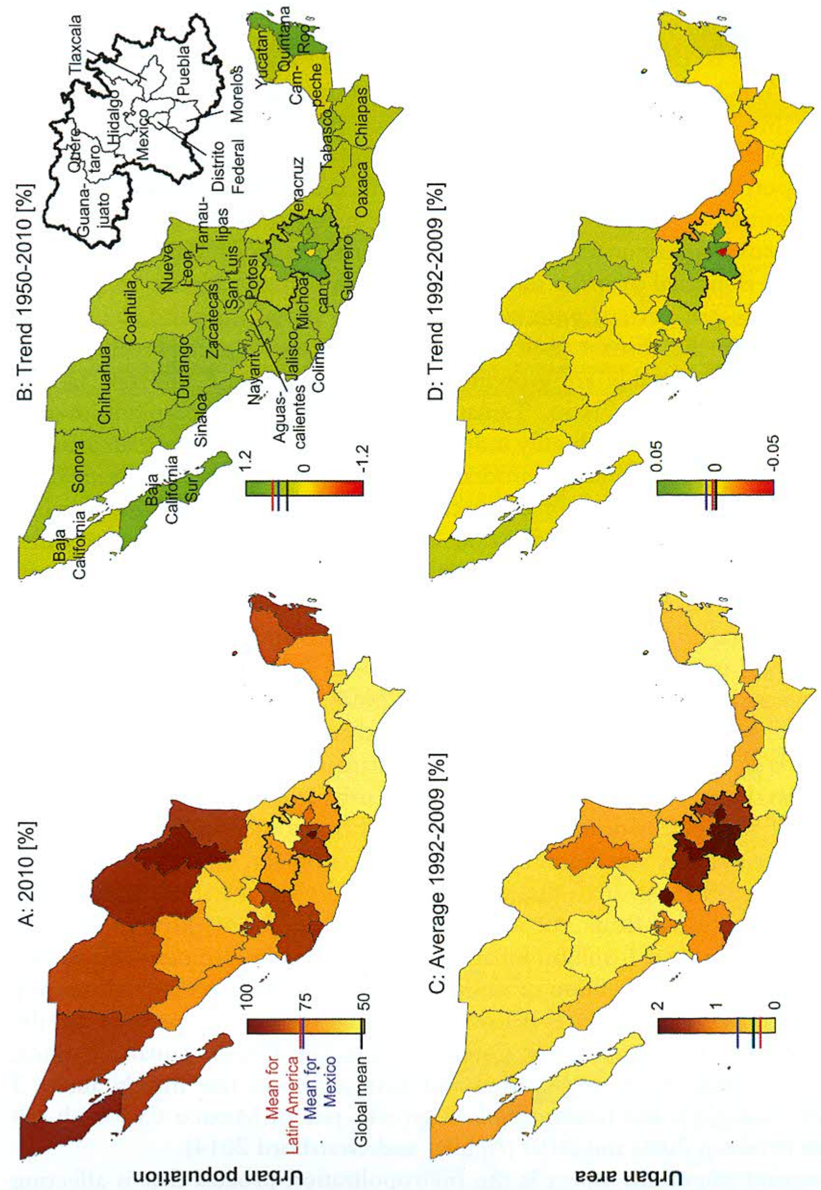

Figure 15.3 Urban population proportion and urban area for the states of Mexico (source: INEGI 2014 and DMSP)

Note: For state names see 15.3B. Lines in scale bars indicate the average for Mexico, Latin America and the world.

Quintana Roo. Also, there is a national migration pattern towards the northern states and in particular border towns to the United States due to employment in local export-oriented manufacturing industries and the eventual goal of working in the United States. Over time regional disparities at the state-level have increased as rural states such as Campeche, Veracruz, Oaxaca and Chiapas depict lower than average trends.

In contrast to the average of 0.62 percent urban area on the national level (Figure 15.3C), 60.5 percent of the Federal District is urban, 9.7 percent in State of Mexico, 5.9 percent in Morelos, 5.4 percent in Tlaxcala, 1.9 percent in Queretaro and 1.5 percent in Puebla (data from DMSP). The urban area proportion below the national average in the north and south indicates for the former that few people live in larger agglomerations due to limiting environmental factors and for the latter a generally higher population in small settlements dispersed over the state territory. The trends in Figure 15.3D indicate the expected pattern with substantial urban growth around the Federal District, while the district itself shows non-significant (p>5 percent) negative tendencies. Notable are growing urban areas in Baja California, Jalisco, Nuevo Leon, Quintana Roo, Tamaulipas and Yucatan. A particular case is Aguascalientes, a small but highly industrial state with significant urban growth.

A spatially-explicit change product based on 250 m MODIS data from 2005–2011 was employed for estimating land take due to growth of urban areas (Colditz *et al.* 2014a, Colditz *et al.* 2014b). The total annual change varies between 0.08 and 0.11 percent of which 2 to 4 percent were urban changes. The bar totals in Figure 15.4 depict gain and loss of class urban for each bi-annual comparison and the colors indicate class-specific from-to change. The smallest urban expansion occurred between 2005 and 2006 and highest between 2008 and 2009. Even though almost 30 percent of the national territory is forested land, 37 percent shrubland and nearly 9 percent grassland (Colditz *et al.* 2012), few of these semi-natural areas were transformed to urban. In all years the majority of area transformed to urban was managed cropland (20 percent of the total national territory). Transformations from water to urban is a result of spatially unconstrained change detection and unlikely in reality.

In the period 1990–2010 the number of urban centers with at least 15,000 inhabitants increased from 312 to 384 (Figure 15.5). In 2010, there were 11 cities with more than 1 million inhabitants, which can be distinguished in two groups, cities with 2.5 million or more (Guadalajara, Mexico City, Monterrey and Puebla), with growth rates below the national average of 2 percent and the remainder (Ciudad Juarez, Leon, Queretaro, San Luis Potosi, Tijuana, Toluca, Torreon), which are more dynamic and with a growth rate mostly above 3 percent. Notable is the historically low growth rate of Mexico City with 0.9 percent between 2000 and 2010 (Aguilar and Graizbord 2014).

A second important aspect is the metropolization process that is affecting mostly the bigger cities. Whereas in 1990 there were 37 metropolitan zones in the country with 31.5 million people living in them, by 2010 there were 50 of these zones with 63.8 million inhabitants. These metropolitan centers have

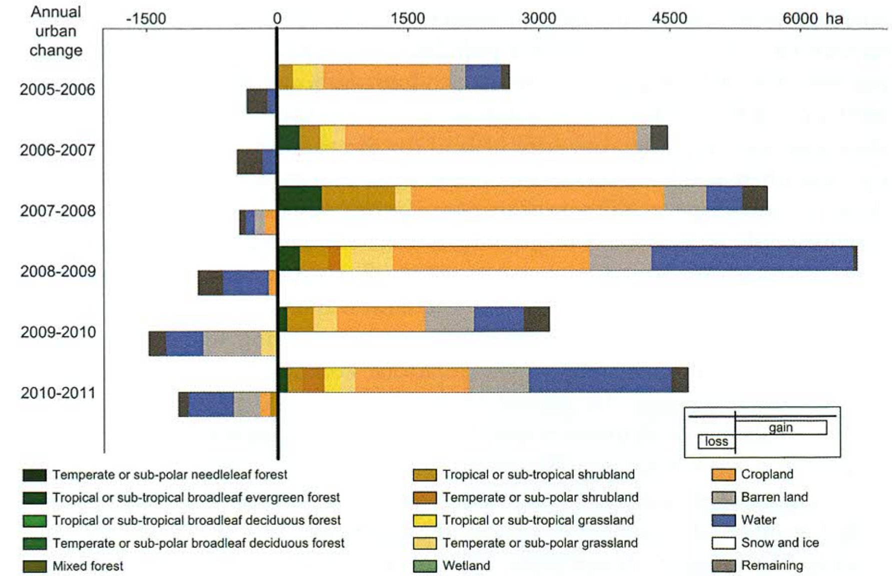

Figure 15.4 Gain and loss of urban area in hectares for bi-annual comparisons (2005–2011) of MODIS-based land cover maps (source: Colditz *et al.*, 2014a)

Note: Colors indicate class-specific from-to changes.

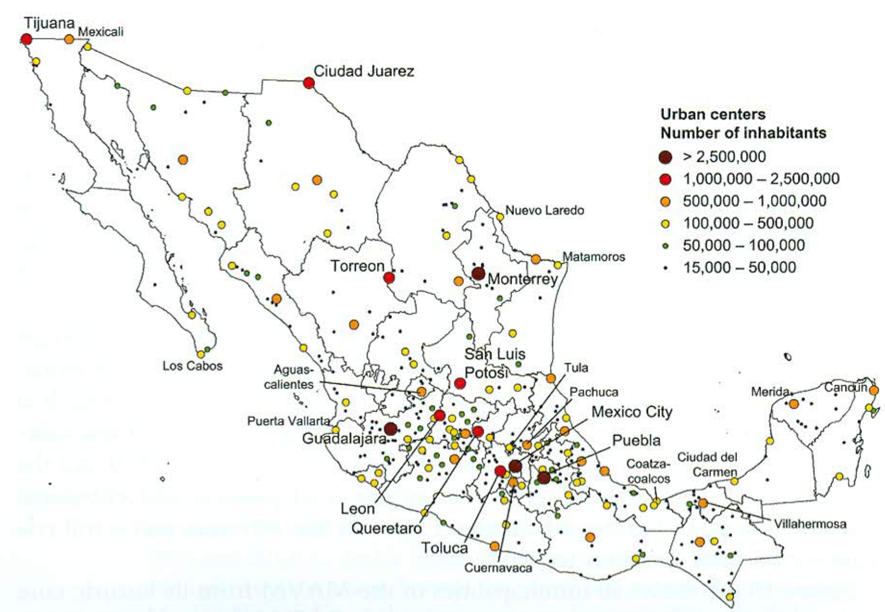

Figure 15.5 Location and population of urban areas of Mexico in 2010

emerged as the nodes of higher hierarchy in the urban system because they concentrate 56.8 percent of total population and generate approximately 75 percent of the national gross domestic product. Although they have a favorable influence in their respective regions to impulse socioeconomic development, they also demand a high quantity of land for the excessive expansion of built-up areas often with a notable peri-urbanization process accompanied by lower densities and disperse urbanization (Aguilar 2014). This corresponds to the above-noted loss of managed agricultural areas and indirectly moves the frontiers reducing also natural land and its supporting, provisioning and regulating ecosystem services such as forests, water retention and purification, biodiversity etc. In addition, a great proportion of population living in peripheral areas constitute informal settlements in precarious conditions that contribute to environmental damage. In general terms, in the last 30 years, during which urban population in all urban centers has doubled, the expansion of their built-up areas has, on average, multiplied by a factor of seven (SEDESOL 2011).

Mid-sized cities with a population between 100,000 and 1 million have multiplied in different regions and are now the nodes of the urban deconcentration process. In the last 20 years (1990–2010) this number increased from 55 to 84 and its inhabitants almost doubled passing from 17.6 to 30.30 million people. They are now important centers for productive activities such as oil exploitation (Ciudad del Carmen, Coatzacoalcos, Villahermosa) or new export-oriented manufacturing centers (Aguascalientes, Leon, Queretaro, San Luis Potosi), thriving border towns with significant service for the US market (Matamoros, Mexicali, Nuevo Laredo, Tijuana) or touristic centers which are also the preferred destiny of foreign migrants (Cancun, Los Cabos, Puerto Vallarta).

Moving the frontiers—the expansion of Mexico City

Administratively, Mexico City consists of 16 boroughs (delegations) which form the Ciudad de México (before January 29, 2016, Federal District), but has grown beyond those borders into the surrounding State of Mexico. In 2005/2006 the Metropolitan Area of the Valley of Mexico (MAVM) was established which today consists of all 16 boroughs, 59 municipalities of the State of Mexico and one of the state of Hidalgo.

In 1325, the settlement was founded on islands in the Texcoco lake as the capital of the empire of the Mexica from which also originates its name. The early urban growth of Mexico City is related to historic processes such as the arrival of the Spanish conquerors in 1521 and establishment of the viceroyalty of New Spain in 1535, the independence from Spain in 1810 and the Mexican revolution in 1910. The concentration of political and economic power in one place has shaped Mexico City over the centuries and is still relevant for business decisions today.

Figure 15.6A shows all municipalities of the MAVM from its historic core to the most recent expansions. Between the end of the Mexican revolution in 1929 and the first decade of the twenty-first century several authors found

seven phases of urban growth and associated them to models of concentric rings (Negrete *et al.* 1993, Delgado 1988, SEDESOL CONAPO INEGI 2012). Starting with the expansion from its core in Cuauhtémoc into the boroughs of Miguel Hidalgo, Venustiano Carranza and Benito Juarez from 1930 to 1950, the second phase (1950–1970) followed due to significant industrial development, extending in all cardinal directions and for the first time including four municipalities from the State of Mexico. The third phase (1970–1986) incorporated four boroughs in the south, six municipalities to the north and two to the east. By 1990, among others, the last borough of the

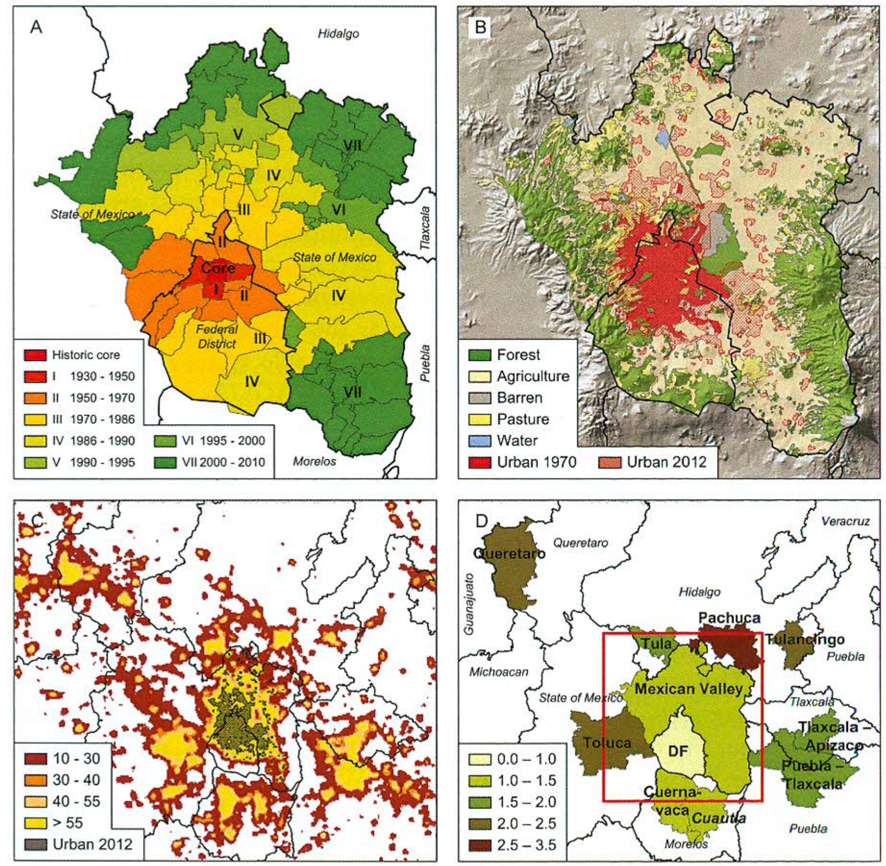

Figure 15.6 Urban expansion of Mexico City. A: Seven phases of urban growth between 1930 and 2010. B: Land take due to urban expansion between 1970 and 2012. C: Stable lights (2009) in the larger Mexico City area and light contamination beyond the urban area extent. D: Megalopolis Mexico City and growth rates in percent between 2000 and 2010

Note: The red box indicates the subset for Figures 15.6A and 15.6B.

Federal District (Milpa Alta) was included. During this time the growth of Mexico City was fostered by the growing cities outside the Mexican Valley (Toluca, Cuernavaca, Puebla and Pachuca). The fifth phase (1990–1995) includes four large municipalities in the north including one from Hidalgo and during the sixth (1995–2000) there is an expansion to the northeast and division of previously included municipalities in the east and north. During the last phase (2000–2010) 24 municipalities were added. Today, more than 20 million people (18 percent of the total population) live in the MAVM with an area of only 7,800 km^2 (0.4 percent of the national territory). This corresponds to 2,564 people per square kilometer, the highest population concentration in the country (INEGI 2010).

Figure 15.6B shows the state of the urban area in 1970 in red, in red cross-hairs the built-up area in 2012 and in different colors the land use and land cover, such as grassland, agriculture, forest and shrubland (INEGI-INE 1999, INEGI 2013). Over the four decades the city grew by 235 percent from 610 km^2 in 1970 to 1,440 km^2 in 2012. Over 90 percent of the land take affected agricultural area and grassland in relatively flat terrain to the north and east. Approximately 8 percent of the expansion has affected forested areas at the western and southern edge of the valley, mainly during the last two decades. In those areas steep slopes limit the growth by increasing construction costs and loss of valuable environments and related ecosystem services.

In particular water is a scarce resource as the city requires a supply of 35.2 m^3/s with a current deficit of 3 m^3/s of potable water (FCEA 2015). Statistics of the National Water Commission (CONAGUA) indicate that the natural water supply of the Mexican Valley for all land uses (urban, agriculture, industry) is far from being self-sustainable. 54 percent of the water is therefore supplied by other hydrologic regions several hundred kilometers away and 46 percent by internal sources such as the Rio Magdalena and ground water (GDF 2008). All forms of water supply cause serious and large-scale secondary effects on the environment. Energy is needed to pump water from lower hydrologic regions into the city. In addition there are conflicts in water use and amount of water extraction with local municipalities and other large cities. The over-exploration of the local aquifer causes significant subsidence as large parts of the city were constructed on sediments of the former Texcoco lake. For instance, the city center has subsided by approximately 10 m over the last 60 years (SACMEX 2012). Water infiltration is achieved in conservation areas but expansion of the impervious cover has reduced its surface area and percolation to the subsiding areas is slow. Wastewater removal is another issue, for which drainage systems and retention bodies were constructed to limit ground water contamination. Wastewater treatment is just in its initial stages.

Air contamination is another pressing environmental problem in Mexico City, in particular due to its topographic location in a valley and frequent formation of atmospheric inversions. High aerosol ozone concentrations affect many citizens by respiratory and skin sickness and cause high societal costs

for health care. The main cause for emissions is transportation (45 percent), followed by industry (21 percent), housing (20 percent) and 14 percent by others (GDF 2015). The list of environmental issues caused by urban agglomerations can be continued, e.g. soil reduction, contamination and erosion with increasing risks during earthquakes, biodiversity loss and changes in species behaviors in surrounding areas, nutrient loss, fuel consumption including fossil fuel, high water and energy use, waste dumping, treatment and recycling, increased velocity of contagious diseases, etc.

A less studied issue is nighttime light contamination and its effect on surrounding areas. Figure 15.6C shows data of the DMSP sensor for the year 2009 in tones from brown to yellow and black cross hairs marking the urban area of Mexico City in 2012. Considering values of 55 and higher in yellow the area is 17 percent larger than urban mapped from official sources (INEGI 2013) and includes several natural areas in the southern mountainous region. Disturbance by artificial light not only affects the behavior of nocturnal species but the functioning of ecosystems in general (López Acosta *et al.* 2009, Meyer and Sullivan 2013, Gaston *et al.* 2013).

The continuing expansion of Mexico City today needs to be seen in a larger context. Although there is a physical separation by high mountain ranges, the pass elevation to the south, east and west entrance is above 3,000 m, the city is highly interconnected with small and large surrounding cities (Figure 15.6C), which by themselves often form metropolitan areas. Altogether they form the megalopolis Mexico City, and colors in Figure 15.6D indicate their growth between 2000 and 2010. The higher positive trend of surrounding cities in comparison to the core area, also known as polarization reversal (Aguilar and Rodríguez 1995), is in line with our previous analysis at state level using DMSP. The attractive location in a large megalopolis with short connections to business partners and political stakeholders, space for larger industrial plants and proximity to recreational facilities, but still with the option to take advantage of the cultural urban life in the core area and not suffering from all the negative issues, is the main reason for increased growth in the periphery, either by new businesses or relocation. It needs to be seen if at some point urban areas completely connect even across physical barriers. First tendencies can be noted, e.g. between Mexico City and Pachuca, Toluca and Tula (Figure 15.6C).

Selected drivers for urbanization

Tourism—Cancun

The state of Quintana Roo on the Yucatan peninsula is internationally recognized for its beautiful white beaches with excellent offshore reef snorkeling and diving opportunities along the Mexican Caribbean coast, known as the Riviera Maya and Costa Maya. The tourist development started in the late 1960s, primarily as a result of a government-initiated study to develop a counterbalance to the Mexican Riviera on the Pacific coast and also to compete with resort destinations on several Caribbean islands (Collins 1979). In 1968, the Tourism Infrastructure Promotion Fund (INFRATUR, later FONATUR) was created and together with the Bank of Mexico they promoted six sites for major tourist developments, among those Cancun. At that time the fisherman's village of Cancun accounted for 120 inhabitants and increased rapidly during the different development stages in the 1970s, 1980s and 1990s to a population of 628,306 in 2010 (INEGI 2010). Cancun has undergone a radical transformation, becoming the most important tourist resort of the country. Already in 1990, Cancun accounted for 110 hotels, with more than 17,000 rooms and received approximately 1.5 million visitors annually (FONATUR 2001). Successively the entire Caribbean coast south of Cancun to the border of Belize has been developed with significant impact on coastal ecosystems and the environment.

The urbanization trends in Cancun and surrounding areas are dramatic with increased dynamics since 1990. The spatial changes of these trends can be easily detected with satellite remote sensing. For instance, analysis of 250 m MODIS land cover maps between 2005 and 2010 (Colditz *et al.* 2014b) revealed an increase of 2,500 ha of urban area around Cancun, that is 500 ha per year, which corresponds to public statistics reporting an annual growth rate of 616 ha or 3.1 percent for the Benito Juarez municipality to which Cancun belongs (Veloz Avilés 2011). Urban growth spatially occurs around the airport and along the western part of the city with new commercial and housing sections to accommodate the increasing population, but fewer hotel developments were detected along the coastal strip during this period in comparison to previous times.

Commerce—Merida

The rise of Merida, capital of the state of Yucatan, started in the late nineteenth century as one of the centers of sisal (*henequén*) cultivation, a fibrous plant for twine and rope production, also known as the "green gold" (Duch Colell 1998).

Until the beginning of the twentieth century agriculture was the primary activity in the area around Merida. Over the course of the twentieth century Merida gained importance as the peninsula's center of commerce, in particular based on many assembly plants that were established since 1980 and tourism. All these factors progressively attracted the rural population on the Yucatan peninsula migrating to and working in Merida, which resulted also in a strong increase of accompanying service industries. In 2010, 78.7 percent of the economically active population of Merida was occupied in the tertiary sector, 20.3 percent in the secondary and only 1 percent in the primary sector (SEDESOL 2013).

According to the 2010 census, the population of Merida reached 777,615 inhabitants (INEGI 2010). High birth rates and a continuous rural-to-urban

migration result in constant urban sprawl, which is also expressed by the high population density of 938 people/km^2 in the municipality (SEDESOL 2013). These demographic and socioeconomic changes in the region have caused pressure on the city of Merida. The resulting spatial consequences of regional migration can be documented with satellite imagery. For instance, there are significant expansions and new developments of urban area between 2005 and 2010 in Merida, which can even be noted in coarse resolution MODIS satellite data (Colditz *et al.* 2014a). The "Fraccionamiento Las Américas" was constructed for an expected population of 20,000 habitants, which was mapped as a newly constructed urban area of 225 ha in the land cover map of 2010. The largest new city section, Ciudad Caucel west of Merida, encompasses an area of 875 ha and is designed for 30,000 new houses and an expected population of 100,000 new residents. In fact, Ciudad Caucel was found to be the largest single patch of newly constructed urban surface between 2005 and 2010 in entire Mexico. Annual images of this site indicate that most of the construction occurred in the years 2007 and 2009.

International migration—Tijuana

Over the last 110 years Tijuana has transformed from a ranch with 224 inhabitants in 1900 to one of the 10 most important cities in Mexico. In 2010 the population was more than 1.5 million (INEGI 2010), and with San Diego it forms the largest binational conurbation in the world. Located directly along the border to the state of California the city attracts large groups of legal and illegal emigrants. Most migrants are from the Federal District, Jalisco, Michoacán, Oaxaca and Sinaloa of which most work in factories, often awaiting permission of entry to the United States. There is also a significant number of immigrants, mainly from China, Central American and Andean countries and ultimately from the United States due to lower living costs. Daily or weekly commuters as well as visitors from all over the world make Tijuana–San Diego the busiest land-border passage in the world with more than 300,000 daily crossings.

The growth of Tijuana was always linked to the political and economic situation of the United States. For instance, during the years of prohibition (1919–1933) in the United States, Tijuana offered the respective services of alcohol retail and consumption in bars and night clubs, which caused a population increase by 1,000 percent. During the Great Depression, foreigners working in the United States were forced to return to their country. Approximately 400,000 Mexicans returned, of which many stayed in Tijuana, mostly in precarious conditions hoping for permission of reentry. During World War II the United States required manual laborers in the agricultural areas and implemented programs such as Braceros (1942–1964). Thousands of migrants arrived in Tijuana and those who were not allowed to enter the United States frequently stayed in this city. Another boost occurred upon the end of Braceros when returning workers often remained close to the border.

This rapid population growth is also reflected in the growth of the urban area. By 1950 the urban area was approximately 1,450 ha (Padilla 1985), by 1973 it had expanded to 6,620 ha, which coincides with the major population growth during the 1960s. In 1993 the urban area had grown to 16,830 ha (Bocco and Sánchez 1996) and reached 24,240 ha in 2010 (INEGI 2010). It is estimated that by 2030 the city of Tijuana will have 2.8 million inhabitants (IMPLAN 2010) which poses substantial challenges to urban planners to provide the urgently needed public services.

Perspectives

The urban population of Latin America is expected to reach 673.6 million in 2050, which is 86.1 percent of its total population (UN 2014b). The further growth of already overpopulated cities will have additional consequences on the environment and requires innovative solutions for already existing social issues. Successful sustainable urbanization requires competent, responsive and accountable governments charged with the management of cities and urban expansion. Attention not only has to go to big cities, but also to new urban forms that have acquired importance in recent years like peri-urbanization, rural–urban transition zones, and intermediate and small cities, that suffer similar problems to those of a big metropolis.

Water availability and wastewater treatment, increasing needs of energy, higher demands on agricultural lands also in distant regions to feed the rural and urban population, transportation of commodities and people, and air and water contamination are worrisome environmental concerns as many large cities and megacities already seem on the "verge of collapse." In addition the existing social conflicts will intensify, such as the gap between the rich and poor living together on very limited space, a still too-small middle class, lack of education, violence and crime, corruption and lack of law enforcement or even impunity. Therefore, a change in policies is needed, away from the highly centralized political and economic power present in most Latin American countries and towards a more balanced distribution across several cities in various regions. These policies can help responding to the challenges of providing urban infrastructure and basic social services for the urban poor, and mitigating the negative environmental impacts associated with large and rapidly growing urban agglomerations.

There are indicators that the growth of megacities larger than 10 million people attracts fewer businesses and population growth is slower in comparison to cities with 1–5 million inhabitants. However, there is a risk that those cities undergo unplanned and uncontrolled growth which soon will expose them to similar negative environmental issues and social conflicts. Urbanization will continue to be the distinctive geographical feature for Latin America at an even faster pace affecting all levels of society and environment.

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