Global urbanization: can ecologists identify a sustainable way forward?

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The year 2007 was the first year in which more than half of humanity lived in cities. Over the next 25 years, the world will see the addition of nearly one million km^2 of urban area, occurring in tens of thousands of cities around the globe. The form these new neighborhoods take will affect our planet's ecology profoundly. Here, I highlight the connection between urban form and ecosystem service generation and consumption. I also discuss how urban form controls energy use, and hence oil security and climate change. I argue that only by directly addressing the implications of urban growth as a research subject will ecologists meet their responsibility to provide a foundation for a sustainable biosphere, a mandate of the Ecological Society of America.

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Sometime in 2007, humanity crossed a momentous milestone: for the first time ever, the majority of humans are living in cities (UNPD 2005a). In the next 25 years, 1.7 billion new people will move into urban areas (UNPD 2005b), and new settlements in the developing world will spread to cover an area the size of California (Angel *et al.* 2005). Most of these settlements will be in the developing world (UN–HABITAT 2006), where new-found urban lifestyles and increased affluence could lead to dramatically increased resource use. This resource use, especially of oil and other fossil fuels, will have implications for global warming and the security of nations. Humanity is building the equivalent of a city the size of Vancouver – about 600 000 people – twice every week (Peñalosa 2006; Figure 1). What does the form of these new cities mean for the goal of sustainable development? And what role can ecologists play in helping to realize that goal?

The coming urbanization

The ongoing process of urbanization occurring in the world's poorer countries is the result of a predictable demographic shift: as a country's development proceeds, an increasing proportion of its population lives in urban areas. The increase in urban population is partly due to natural growth – the greater number of births than deaths among people already living in cities – and partly due to migration from rural areas to urban areas (NRC 2003). Lack of employment or safety sometimes pushes migrants from rural areas, while the increased economic and personal opportunities in cities can also attract migrants (eg Ma 2002). The precise mix of drivers for rural–urban migration seems to vary by region, and is still the subject of much debate (eg Roy *et al.* 1992; deHaan 1997).

The best quantitative source of global data on urbanization comes from the UN Population Division, although some concerns remain about the varying definitions of "urban" used by different member countries (Cohen 2004). These data show that urbanization has already largely ceased in the US (80.1% urban), Europe (72.2% urban), Latin America and the Caribbean (77.4% urban), and South America (81.6% urban). However, Africa (38.3% urban) and countries in Southeast Asia, such as China (40.4% urban) and India (28.7% urban), are just beginning their shift, and will undergo rapid urbanization over the next several decades. Global urban population is predicted to increase from 3.2 billion to 4.9 billion over the next 25 years (UNPD 2005b). For comparison, the population of Europe in 2000 was 729 million (US Census Bureau, Population Division nd) and average household size was around 2.5 people per household (UNECE 2005), which means that there were approximately 291 million housing units. A 1.7 billion increase in urban dwellers, assuming five persons per household (typical for developing countries), would mean that more housing units will be built in the next 25 years than currently exist in all of Europe (Figure 2).

Recent work by the World Bank allows us to translate urban population growth to urban area growth. In a survey of more than 120 cities from around the world, Angel *et al.* (2005) found that the biggest single variable con-

In a nutshell:

- Urban growth in both the developed and developing world will be the main obstacle to achieving sustainable development
- The form of new urban areas will determine per capita resource use, now and for decades to come
- Urbanization in developing countries could dramatically increase oil consumption, with implications for global warming and energy security
- Conducting multiple before-and-after assessments of urban sustainability projects may be the greatest contribution ecologists can make to sustainable development

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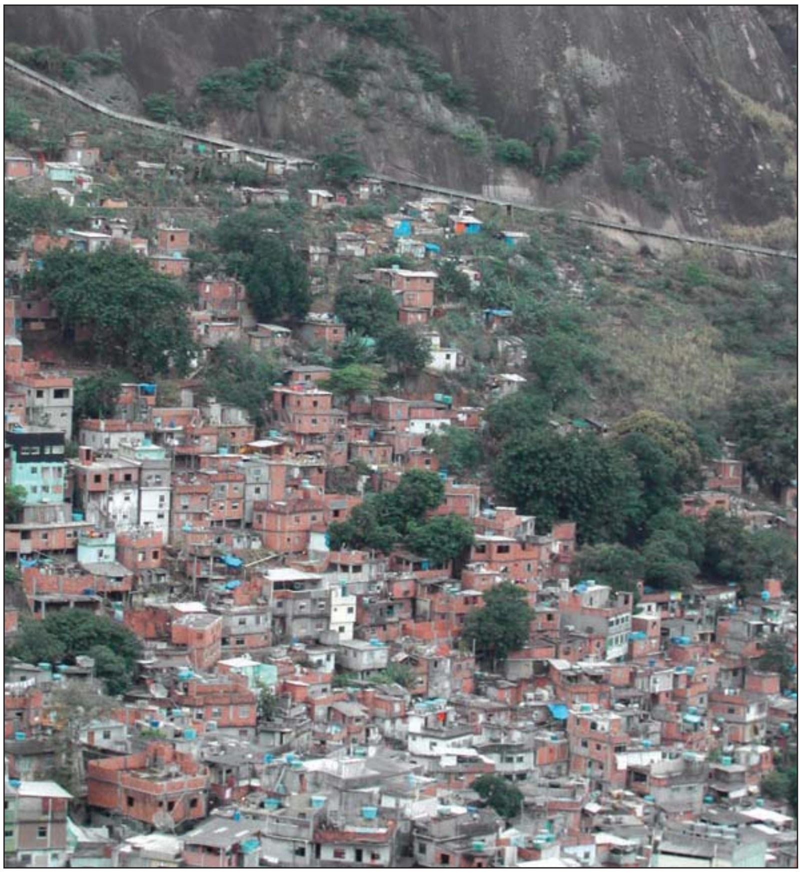

Figure 1. Rapid urbanization is occurring in unplanned settlements in much of the developing world, such as Rocinha, a favela *(shanty town) in Rio de Janeiro. In the background is Tijuca National Park, a spectacular example of Atlantic rainforest.*

trolling the per capita growth in area of a city was its income. On average, each new resident in a city adds 355 m^2 of developed area in a rich country, 125 m^2 in a middle-income country, and 85 m^2 in a poor country. As with any estimate of urban area, the values obtained are dependent on the definition of "urban" used in the particular study. However, if we accept this definition of "urban", and assume the current shift toward lower urban population density continues at the same rate, a reasonable estimate of total new urban area by 2030 is around 900 000 km^2. This will be split fairly evenly between the developed and developing nations, although its causes are quite different in each case: in the former, the driver is predominantly low-density settlement patterns (Jackson 1985), while in the latter, the driver is predominantly urban population growth (UN–HABITAT 2006). It is also important to note that around 46% of all urban population growth will occur in relatively small cities, with populations of fewer than 500 000 people (UNPD 2005b). Urbanization is therefore a fundamentally dispersed process, occurring in tens of thousands of cities.

Total urban area will remain a relatively small fraction of the Earth's terrestrial surface, from 0.3% today to 1% in 2030 (Angel *et al.* 2005). However, the ecological footprint of these cities will encompass an area many hundreds of times larger (eg Rees 1999; McGranahan and Satterthwaite 2003). Humanity will be entering a new world, a world of the city, by the city, and for the city. Urbanization will be the main obstacle to, and opportunity for, sustainable development.

Urban form matters

Humanity is building the grand cities of the 21st century, and their design, good or bad, is fundamentally a human decision. Even in capitalist economies, where urban development decisions are made by millions of different landowners, the pattern of development is largely a result of specific human plans, a joint consequence of topography (eg Muller 2001), zoning law (eg Munroe *et al.* 2005), and the geography of highways, rail lines, and mass transit (Handy 2005). This overall pattern of development can be referred to generally as urban form, and quantified using landscape metrics (cf Alberti 2005) of land-use intensity (eg people ha^{-1}), land-use heterogeneity (eg the number of different functional land uses), and land-use connectivity (eg degree of aggregation of land uses).

There is abundant evidence in the literature to show that urban form affects resource use (eg Folke *et al.* 1997; Pickett *et al.* 2001), although the exact relationship between the two seems to vary substantially, depending on the resource in question and the socioeconomic context of the city. In general, there is a great need for high-quality, municipal-level data that can be used to build mechanistic models of how resource use responds to changes in urban form (Pataki *et al.* 2006). The form of the new cities in the developing world is doubly important, because of the tendency for patterns of past urban development to remain locked in the future. Past patterns tend to persist because major infrastructure (eg a road corridor) creates a physical imprint that lasts for decades. Moreover, past development patterns tend to condition the shape of new development. Therefore, the form of urban development today will control resource use for generations to come. Below, I focus on one particular facet: the link between urban form and energy use (Figure 3).

One crucial way in which urban form affects energy use is through its control of, and mutual relationship with, the transportation sector (Banister *et al.* 1997). In developing countries, migration from the countryside to the city is typically associated with an increase in income, which in turn generates an increase in per-capita environmental consumption rates. If we control for the level of economic development, we can examine more closely how, at a given income level, alternative urban forms result in different resource utilization rates. For example, the average resident of Tokyo drives one-sixth as many kilometers per year as the average resident of Sacramento, despite having similar incomes (Kenworthy and Laube 1999). Personal automobile use is usually correlated with the density of an urban region, with use increasing dramatically at densities below 30 people per ha (Cameron *et al.* 2004). Finally, more energy-efficient public transportation systems require a density above a similar minimum threshold to be successful (Badoe and Miller 2000; Bento *et al.* 2005). While the empirical correlation between density and energy efficiency of transportation is clear, the exact mechanisms underlying this correlation are still uncertain (eg Anderson *et al.* 1996; Alberti 1999; Mindali *et al.* 2004).

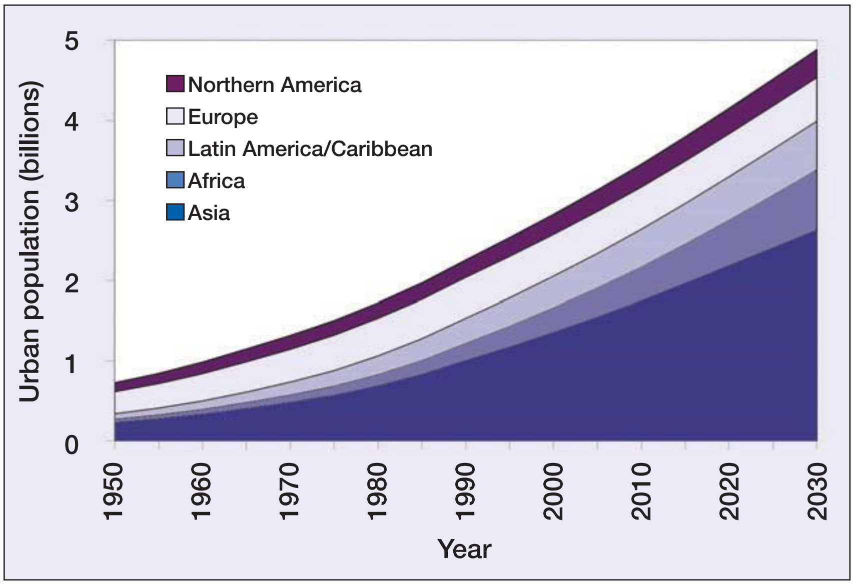

Figure 2. *Global urban population from 1950 to 2030, by region. Total urban population is expected to approach 5 billion by 2030, with much of the growth occurring in Asia and Africa. Other regions are already largely urbanized. Australia, New Zealand, and Oceania are not shown, due to the relatively small size of their urban populations.*

Another way in which urban form affects energy use is through the heating and cooling of buildings (Steemers 2003). Heating a single-family, detached home in Oslo usually consumes 10 000 KW hr^{-1} per person per year, whereas heating an apartment in a larger building usually costs 7000 KW hr^{-1} per person per year, (Holden and Norland 2005). Generally, heating and cooling a single-family, detached home is less efficient than for row houses or multi-unit buildings. The quality of building construction also has an important influence on per-capita energy use, based on numerous factors, including building orientation, insulation, and choice of heating/cooling system. For example, new homes in Oslo consume 3000 fewer kW hr^{-1} annually than older homes in Oslo, correcting for house size, presumably because of improvements in some of the design components (Holden and Norland 2005).

■ Ecological ramifications

Energy use in cities generally results in CO_2 emissions in one form or another. Essentially all motorized personal transport burns gasoline or diesel; US oil use alone accounts for 10% of global emissions (EIA 2006). Most heating and cooling of homes is either directly powered by fossil fuels or by electricity from power plants that burn fossil fuels. Given this link between urban form, energy use, and CO_2 emissions, it is clear that the urban form of cities in the developing world has serious implications for global warming. Although the Kyoto Protocol does not set binding emissions reduction targets for developing countries, it creates one of the first working examples of a payment-for-ecosystem-services scheme, via the Clean Development Mechanism (CDM). The CDM allows carbon trading between First World countries (ie Annex 1 countries) and the developing world. If countries exceed their quota of greenhouse-gas emissions, they can purchase carbon credits from a developing country that has implemented some project to reduce their emissions. For example, Dhakal (2003) shows that a modest increase in electric vehicle use in Kathmandu, converting all three-wheeled passenger travel to electric motors and 20% of the bus-travel to trolley buses run on overhead electric lines, would save 20 400 tons of CO_2 annually. As this upgrade could claim credit for several years' worth of decreases in emissions, the value of the project on the global carbon market could be in excess of US$500 000, which would cover a sizeable portion of the cost of the project.

Urbanization in the developing world, along with rising incomes, may dramatically increase the number of potential oil consumers (Riley 2002), raising concerns about global oil security. Most discussions about oil security focus on the potential supply of oil, which is key for oil price and availability over the short term (Cleveland and Kaufmann 2003). It seems reasonable, however, to examine not just supply-side issues but demand-side issues as well, and the aggregate effect on oil prices (cf Awerbuch and Sauter 2006). While oil-industry forecasts are notoriously uncertain, there is general agreement that, over the medium to long term, demand will grow faster than supply for the simple reason that, while desire for oil may increase without bound, oil supply is limited, in part by geologic constraints (for a pessimistic view on this issue, see Bentley [2002]). If the price of oil rises in response (cf Skeer and Wang 2007), some new sources of oil, such as oil shales, will become economically viable, and demand will abate somewhat; however, these adjustments will probably not alter the general long-term trend toward higher oil prices (IEA 2006). It is

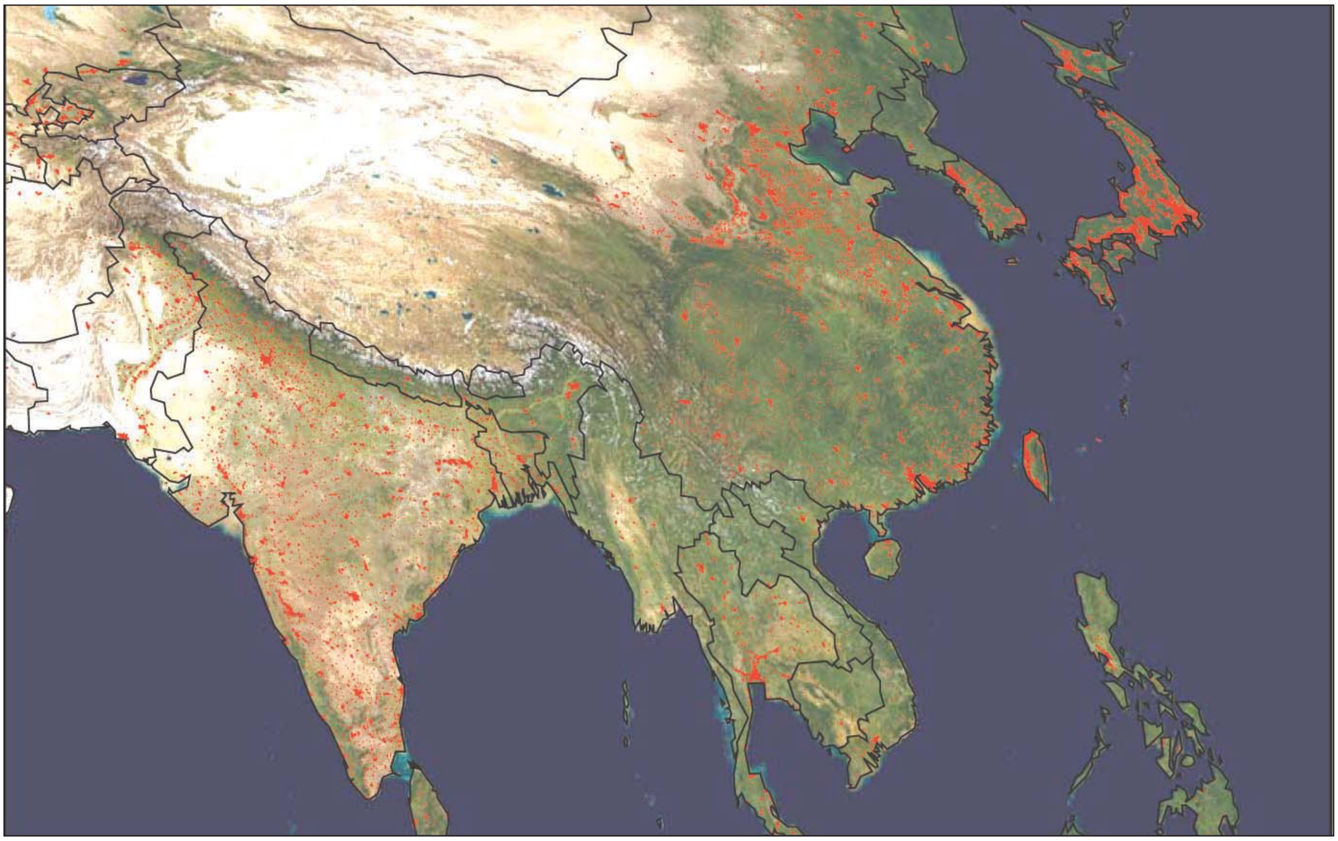

Figure 3. Urban land cover in 1995 in southeast Asia (red), as defined by the Global Rural/Urban Mapping Program. For reference, national boundaries are shown in black, and urban land cover is superimposed over a true-color composite satellite image of the region.

important to realize that the rise in global energy consumption is not preordained, but depends on the energy efficiency of rapidly growing cities, particularly their density and use of public transit (Kenworthy and Laube 1999). It is not far-fetched, therefore, to argue that the oil demand created by rapidly urbanizing countries is of great importance in terms of security, because it threatens to drive oil prices upward and to increase the likelihood of conflicts over oil supply.

Urbanization will also profoundly affect ecosystem services and the underlying biodiversity that maintains them (McGranahan *et al.* 2006). For example, the spatial concentration of humanity in cities results in the surrounding sources of freshwater being partially or fully appropriated for urban use. Over time, cities in many parts of the world may have to seach farther afield to find sufficient freshwater (cf MA 2005), often constructing major hydrological diversions in the process (eg Righter 2005). Similarly, the concentration of people in cities inevitably leads to increases in the concentration of the pollution they generate as well (eg Van der Zee *et al.* 1998), surpassing the ability of natural ecosystems to successfully absorb pollutants without becoming degraded (Pouyat *et al.* 1995). The political power of cities also often means that residents' desire for aesthetic and recreational pursuits substantially affects nearby natural resource management practices (eg Rothman 2004). Finally, the expansion of urban area has impacts on biodiversity that, while localized to a small portion of the Earth's surface, can cumulatively be quite considerable (McDonald *et al.* in review).

Payment for sustainable urbanization

The form of urban development is fundamentally a local decision, both for democratic and pragmatic reasons. Local citizens have the right to shape their city's development and the local knowledge necessary to make wise decisions. Many policy responses to urbanization, such as zoning and tax regimes, must be decided at this local level. However, the developed nations have a role to play in fostering sustainable development. First, they have a moral responsibility to help alleviate extreme poverty and environmental degradation. Second, there is a subset of sustainable development issues in which developed country aid appears to be a win–win scenario. Economists might call this an example of Coasian bargaining, in which a negative environmental externality is averted by a payment from another group affected by the externality. A classic example is when a downstream user of water pays an upstream polluter to stop polluting. Conservation NGOs have taken to calling it "payment for ecosystem service" (PES). The rapidly urbanizing countries, which have a legal and moral right to develop, as defined in the UN Declaration on the Right to Development, are creating substantial environmental "externalities". The developed countries could produce environmental benefits for themselves and reduce this "externality" by paying to promote more responsible urbanization in the rapidly urbanizing countries.

PES schemes have become increasingly common, with one review documenting more than 287 examples of payment for forest ecosystem services (Landell-Mills and Porras 2002). Lessons can be learned from these past markets (Salzman 2005) and applied to future PES schemes involving urbanization and the environment. First, it is important to clearly define what ecosystem services are important, how much service provision is needed, and who will ultimately pay for it. Given the vast difference in wealth, it is likely that developed countries will pay developing countries for more sustainable urban development (ie the beneficiary pays rather than the polluter). Second, the spatial scale of a particular ecosystem service, as well as the governance structure, will determine if PES is feasible and desirable (Chan *et al.* 2006). For ecosystem services that must be generated close to those receiving the service, it may be fairly easy to establish PES, as fewer institutions will be involved in the administration of the scheme. However, these local PES schemes may not have much potential in cities with few financial resources. For example, day-to-day recreation opportunities can best be provided by local governments responding to their citizens' desires, but in poorer countries, adequate funds for the purchase of parklands may be lacking. On the other hand, for ecosystem services that may be generated far from those receiving them, it may be difficult to set up a PES scheme due to the large number of institutions involved, as well as the consensual nature of international environmental treaties. However, PES schemes at this larger spatial scale may generate a far more active market between developed and undeveloped countries. For example, an increase in sequestration of CO_2 is of global value, in that everyone is affected by global warming, and it may therefore be relatively well-funded as a PES scheme. However, a working international market like the Clean Development Mechanism has been very difficult to construct due to the many groups involved in the negotiations.

The dispersed nature of future urbanization means that technologies or strategies aimed at increasing urban sustainability must have several characteristics. First, they must be scalable, that is, feasible to implement in thousands of cities. Second, they must be flexible, able to be adapted to myriad local circumstances. Third, they must be fairly inexpensive, within the budget of most developing countries. This may seem a tall order, but numerous projects seeking sustainable solutions are currently underway.

Treating sustainable development projects as experiments

One way for ecologists and environmental scientists to make a major contribution to sustainable urban development would be to view particular sustainability projects as experiments. This, while perhaps difficult for ecologists used to studying the workings of "natural" ecosystems, is quite similar in spirit to the new paradigm of evidence-based development work (Banerjee 2007), evidence-based conservation (Sutherland *et al.* 2004), and adaptive experimentation (Cook *et al.* 2004). Before any sustainability project is undertaken, assessments should be made of the current ecosystem services at the project site and at a set of similar control sites. After implementation, the effect on ecosystem services at the project site can be compared with the change in ecosystem services at control sites. In this way, sustainability science can move beyond a plethora of case studies of specific places and topics to a more solid scientific understanding of the measured benefits of sustainability projects.

This evidence-based philosophy will require ecologists and conservation biologists to change their focus from the elaboration of theories internal to their field to a more inherently collaborative venture. These sustainability projects will require a team of ecologists, economists, policy makers, and development advocates. While pleas for interdisciplinary collaboration are now commonplace in ecology, much further integration is needed. Only then will the scientific community begin to play its crucial role, describing how practical changes in urban forms can make future urbanization compatible with the dream of sustainable development. Sustainability is currently a policy goal and a platitude – it needs to be transformed into an evidence-based and empirically grounded science, with close links to ecology and the study of ecosystem services.

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