Consequences of residential development for biodiversity and human well-being

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Residential development is a leading driver of land-use change, with important implications for biodiversity, ecosystem processes, and human well-being. We reviewed over 500 published scientific articles on the biophysical, economic, and social effects of residential development and open space in the US. We concluded that current knowledge of the effects of this type of development on social and natural systems is inadequate for achieving key objectives of sustainability, including a viable environment, a robust economy, and an equitable society. Most biophysical studies measured species- or population-level responses to development, rather than attempting to understand the mechanisms underlying these responses or the associated ecosystem processes. Economic and social studies were biased toward assessing the values and benefits to individual people, with little attention given to community-level effects. Of the small number of interdisciplinary studies – less than 3% of the total examined – many reported that development patterns with positive biophysical or economic outcomes were perceived negatively from a social perspective. As a result, we propose a research and action agenda that moves beyond current areas of specialization to design and maintain sustainable communities in an increasingly developed world.

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Residential development is a leading driver of land-use change and has transformed human and natural communities around the world (McMichael 2000; Alberti 2005; Hansen *et al.* 2005). The density and extent of housing is a strong predictor of atmospheric carbon emissions from the combustion of fossil fuels (MacKellar *et al.* 1995) and of the decline of native species populations (Liu *et al.* 2007; Lepczyk *et al.* 2008). Even as human population growth rates are stabilizing in the US and other developed countries, housing development continues to expand as a result of fewer people occupying each household, and the increasing prevalence of second homes (Bradbury *et al.* 2014). Today, residential development covers 27% of the land area in the US, representing a fivefold expansion over the past 50 years (Brown *et al.* 2005). Yet our understanding of how the extent and configuration of our homes and communities affect nature and society is markedly incomplete (McKinney 2002).

In a nutshell:

- Residential housing development is widespread and expanding globally, with far-reaching consequences for biodiversity and human well-being
- To achieve sustainable communities, we need to better understand how the density, extent, patterns, and proximity of such developments and adjacent open space affect natural and human systems
- We assessed the research-oriented strengths and gaps in 566 empirical studies of residential development in the US, published between 1961 and 2011
- Less than 3% of the articles reviewed were interdisciplinary; scientists and practitioners need to more fully evaluate the overlapping environmental, economic, and social impacts of development on sustainability

Urbanization has a strong influence on biodiversity and ecosystem function (Hansen *et al.* 2005; McKinney 2008; Groffman *et al.* 2014), and on human well-being (Ewing *et al.* 2003; Turner *et al.* 2004). There is also compelling evidence that proximity to open space (undeveloped land maintained in a natural or semi-natural state) has an important effect on home values and homeowner attitudes (Figure 1; Geoghegan 2002; Irwin 2002). To design communities that meet the triple "bottom line" of sustainability – a viable environment, a thriving economy, and an equitable society (Figure 2a; WCED 1987) – planners, developers, and land managers must understand how the characteristics that define residential development (eg housing extent, density, age, configuration, and stewardship, as well as proximity to open space) affect natural and human systems (McKinney 2008; Cook *et al.* 2012). Despite widespread support for the concept of sustainability (Leiserowitz *et al.* 2006), scientific research, planning, and practice related to the built environment may reflect neither the core principles of this concept (Berke and Conroy 2000) nor the interdisciplinary problem-solving approaches that are urgently needed (Kates *et al.* 2001).

This review is the first comprehensive and interdisciplinary synthesis of the literature on the biophysical, eco-

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Figure 1. *(a) Residential development is expanding into open space, with diverse consequences for biodiversity and human communities. (b) The density and extent of residential development affects species richness and occurrence. (c) Homes in close proximity to open space have higher economic value. (d) The configuration of housing and open space has implications for human well-being.*

nomic, and social effects of residential development and open space in the US. We pose the following questions: what characteristics and effects of housing development are best understood? At what spatiotemporal scales and geographic locations do we study housing and open space? To what degree are these studies interdisciplinary in their approach and execution? Who conducts and funds this research? How can we focus future research efforts to identify how to design and build communities that sustain biodiversity and human well-being?

■ Scientific literature on residential development

We conducted a systematic review of empirical, peer-reviewed articles on residential development and open space preservation in the US. We searched three databases (Web of Science, EconLit, and Academic Search Premier) with keywords appropriate for each discipline (see WebTable 1). We excluded opinion essays, theoretical models, reviews, and articles focused on identifying the drivers (as opposed to the effects) of patterns of development or open space.

Articles were included in our review only if they assessed empirically how the density, extent, pattern, age, or proximity of residential development to open space influenced biophysical, economic, or social outcomes. We made initial decisions on whether to include articles based on the title and abstract, after which we read the full text to ensure that they met our criteria for inclusion. All articles that were published and available online or in print through August 2011 were stored in a Zotero database (www.zotero.org).

We coded each article, recording author(s) name and institution, year of publication, disciplinary perspective (biophysical, economic, social), methodological approach (quantitative, qualitative, mixed), scale of analysis (within development, county, multiple counties, statewide, counties across multiple states, nationwide), taxonomic focus, funding sources, and a maximum of three predictor and response variables per article. We developed and defined our list of predictors (eg housing density, configuration, age) and response variables (eg bird species richness, home sales price, sense of place) collaboratively as a team. The response variables were

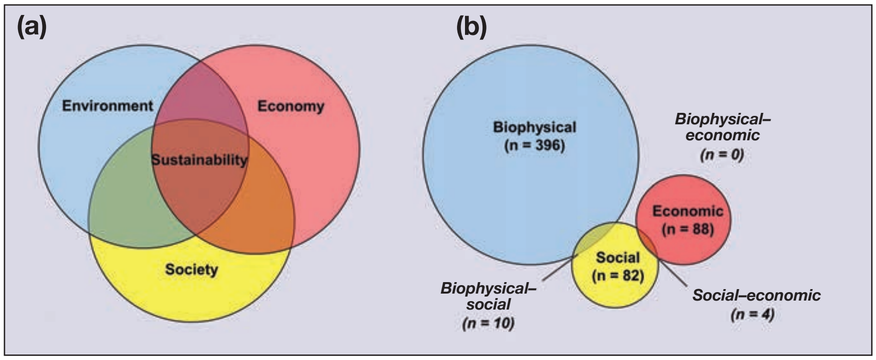

Figure 2. *(a) Sustainability is achieved at the center of three substantially overlapping circles representing the environment, the economy, and society. (b) The outcome of our review showing the number of studies published on the effects of residential development in each discipline; the circles are proportional in area to the number of studies. Those studies that are explicitly interdisciplinary (eg a study that measured response variables across two or more disciplines) are shown as overlapping areas. No studies included all three disciplines.*

used to categorize the articles by discipline (WebTable 2). To ensure consistent data collection among all team members, we randomly selected the first set of articles (representing 100 of the 566 total articles, or 17%), which were coded by at least two team members. We calculated an intercoding reliability score (the number of agreements divided by the number of articles evaluated; Neuendorf 2002) for each category of data. As a group, we clarified those variables with low intercoding reliability scores (<80%; Miles and Huberman 1994) and resolved all discrepancies in those categories. Articles in the next round (275 out of 566 articles, or 49%) were similarly coded by at least two team members, after which we reached a minimum of 80% agreement in all categories. The remaining articles (191 out of 566 articles, or 34%) were randomly assigned and coded by team members working independently. We synthesized these data in a spreadsheet, calculated summary statistics, and conducted linear regression using JMP software (SAS Institute, Cary, NC) to evaluate spatial and temporal trends in the number of articles published relative to US demographic data as of 2010 (US Census 2010).

Outcome of comprehensive review

A total of 566 articles met our criteria for inclusion (see http://bit.ly/1ChZWM2 for the full list of references). The scientific literature on this topic was dominated by biophysical studies (n = 396; 70%), with far fewer studies investigating economic (n = 88; 16%) or social (n = 82; 14%) effects of residential development and open space. Only 2.5% (n = 14) of all studies were interdisciplinary, in that they explicitly measured response variables from at least two disciplines. No studies included all three disciplines (Figure 2b). Most authors based their results solely on quantitative methods (96%) and relatively few included qualitative data (4%).

The number of studies published annually on residential development was near zero in 1968 but increased rapidly in the 1990s, until 2005. This pattern is consistent with the expansion of residential development, as reflected by the annual number of new home sales during the same period. Since 2005, the number of studies published annually has remained relatively stable but home sales have dropped dramatically (Figure 3).

Studies were not evenly distributed throughout the US, even when accounting for population size (Figure 4a). The five states where the most studies per capita occurred (> 7 studies per 1 million people) were Wyoming, Montana, Rhode Island, Colorado, and Maryland, and the geographic distribution of studies was relatively similar among disciplines (Figure 4, b–d). There was a positive relationship between the number of studies published in each state and some characteristics of the state (population, number of housing units, and number of colleges and universities; $R^2 = 0.4$; $P < 0.0001$). However, there was no relationship between the number of studies published in each state and its total land area, population density, or housing density. Across all disciplines, most studies were based on data collected at a local scale ("municipal to county" or "multiple counties within a state"; Figure 5). A much greater proportion of social studies were national in scope (21%) as compared with biophysical (4%) and economic (7%) studies.

Much of the research focused on documenting the effects of the intensity or extent of development. This

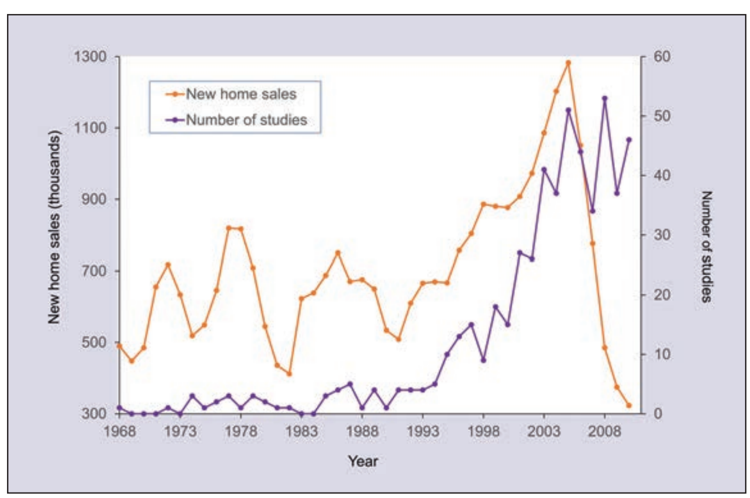

Figure 3. *The number of studies published on the effects of residential development (purple line) and the expansion of residential development in the US, as indicated by the number of new home sales (thousands; orange line), from 1968 to 2010, according to the US Census (2010).*

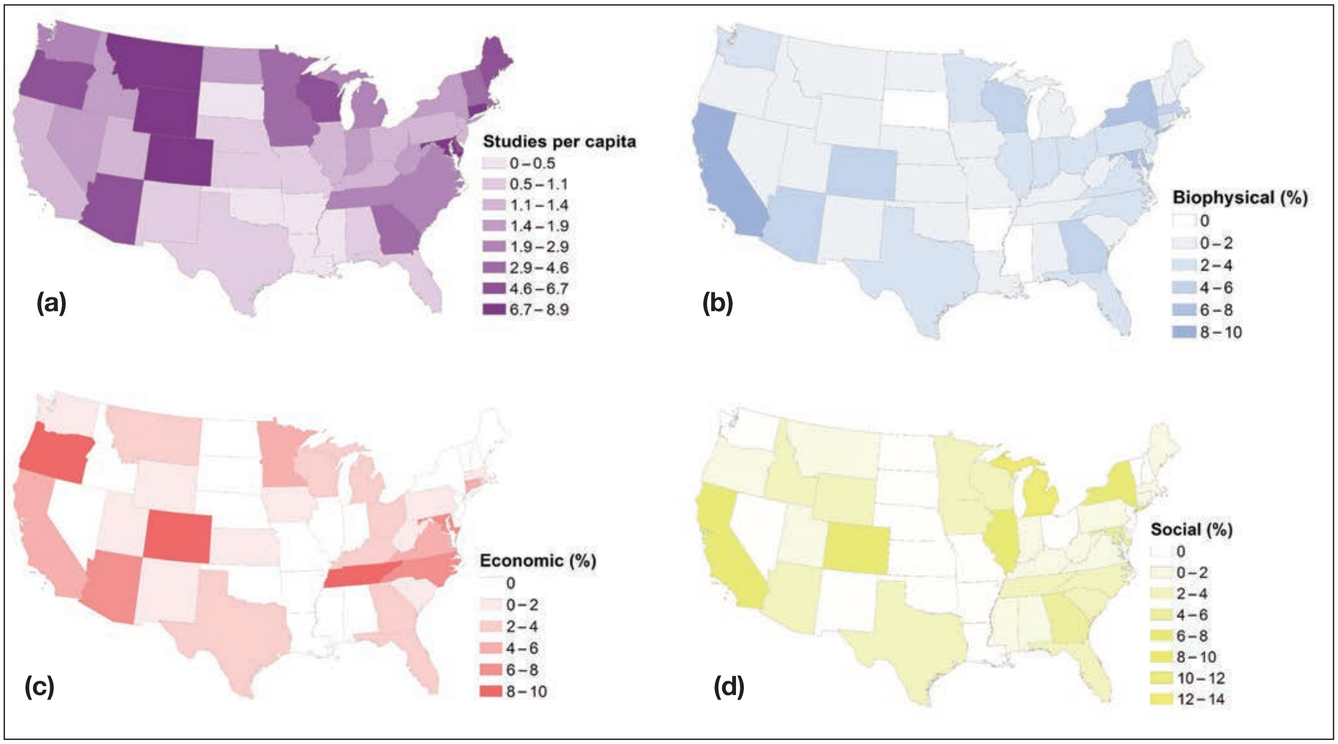

Figure 4. *The distribution of studies on the effect of development patterns on nature and society among the 48 contiguous US states (no such studies were conducted in Alaska or Hawaii). These distributions are shown as (a) studies per million residents across all disciplines, and the percentage of studies with (b) biophysical, (c) economic, and (d) social response variables published in each state.*

was measured either categorically (eg urban versus rural) or by using continuous measures, such as the size or proportion of developed area or open space. Predictor variables differed substantially among disciplines (Figure 6). Most biophysical (94%) and social (70%) studies focused on the negative impacts of development on natural and human systems, respectively, whereas most economic studies (61%) investigated the positive effect of open space on home and land values. Articles with social response variables had the highest proportion of studies (31%) focused on housing configuration, including residential developments that incorporate open space (eg conservation development; Pejchar *et al.* 2007).

Biophysical studies most commonly examined species abundance (38%), richness (38%), and community composition (33%) in response to development. Habitat structure (8%), habitat use (7%), and habitat loss (6%) were also important response variables. Only a handful of biophysical studies incorporated demography (ie survival and reproductive rates; 6%) or movement or dispersal of animals and plants (5%). The taxonomic focus of biophysical articles was biased in favor of birds and mammals for terrestrial studies, and plants and invertebrates for aquatic systems (Figure 7). Less than 5% of the articles focused on the effects of housing development on ecosystem parameters and processes, such as nutrient cycling, soil properties, water quantity, carbon regime, and litter decomposition. However, a large number of studies did examine impacts on water quality (24%).

Articles with economic and social response variables focused more frequently on individual perspectives than on community values. For example, economic studies often measured value from the perspective of an individual buyer or seller (home value/sales price: 66%; land/lot value: 14%), and nearly half (48%) of the social studies evaluated individual values and attitudes regarding natural resource stewardship. Far fewer papers focused on economic costs and benefits to the broader community (cost of services: 6%; ecosystem services: 4%; property taxes: 3%), or how development patterns shape social interactions (social capital: 10%) and serve diverse populations (equity: 5%).

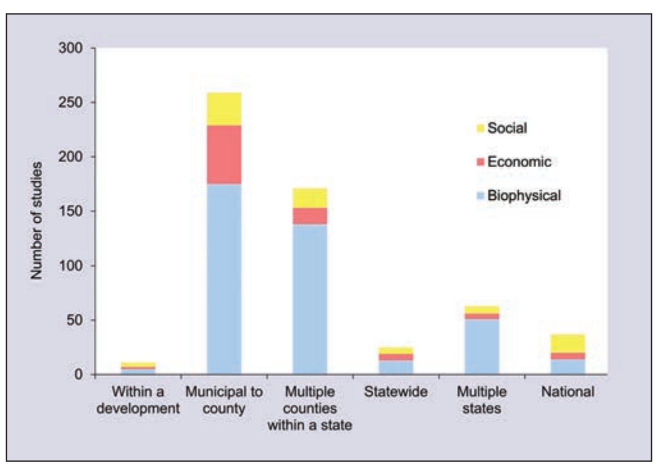

Figure 5. *The number of studies that included data collected within a single development, within a municipality or a county, within multiple counties within a state, statewide, across multiple states, and at a national scale for each discipline.*

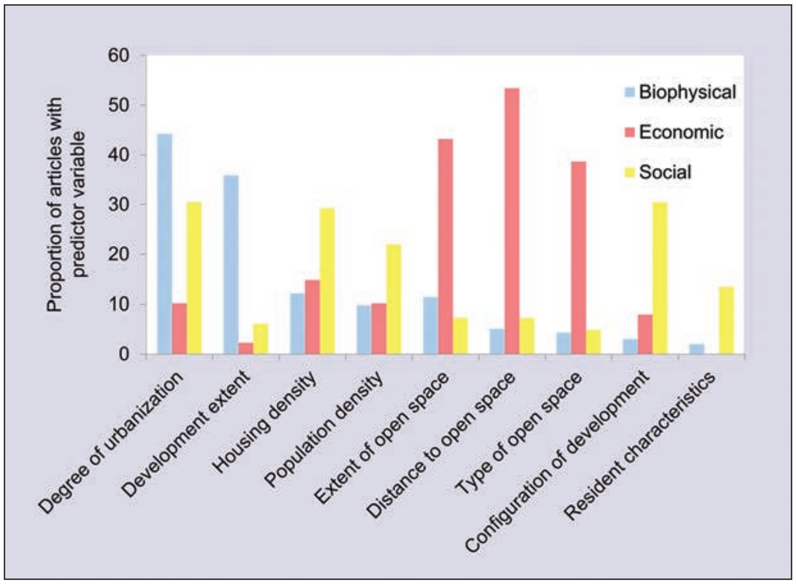

***Figure 6.** The most frequently evaluated characteristics of development (by proportion of all studies examining each predictor variable) differed substantially by discipline. Only predictor variables that appeared in >10% of the studies in at least one discipline are shown.*

Articles on the effects of residential development were most commonly authored by academic researchers (*n* = 493; 88%) and funded by universities (*n* = 132; 24%). State agencies also authored (10%) and funded (16%) a large number of studies. Federal agencies, such as the US National Science Foundation (NSF; 17%), the US Forest Service (7%), the Environmental Protection Agency (10%), and the US Geological Survey (5%), as well as non-governmental organizations (8%) were also important sources of funding. The types of institutions funding research on the effects of residential development were similar among disciplines; however, social and economic studies were more likely to be unfunded (56% and 35%, respectively) as compared with biophysical studies (21%).

Synthesizing key findings for science and practice

Integrating across disciplines

Given the magnitude and complexity of the effects of residential development on biophysical, economic, and social outcomes, we found surprisingly few interdisciplinary studies (Figure 2b). However, the geographic focus (Figure 4) and temporal pattern of studies were similar across disciplines, as were the organizations conducting and funding the work. Disciplinary research has made, and will continue to make, substantial contributions to understanding human-dominated ecosystems. Yet our findings suggest that there is tremendous opportunity – thus far largely neglected – for collaboration across disciplines.

Despite a recent expansion of graduate programs (Golde and Gallagher 1999), enhanced funding opportunities for interdisciplinary scholarship (Roy *et al.* 2013), and a strong emphasis in the literature on the importance of interdisciplinary collaboration (Liu *et al.* 2007), our review suggests that studies involving more than one disciplinary perspective remain rare. The lack of published interdisciplinary studies could be explained in several ways. Major institutional barriers against interdisciplinary scholarship still exist (Roy *et al.* 2013), including the single-discipline coverage of most scientific journals. In addition, there may simply be a time lag between the establishment of new training programs and funding opportunities, and an increased prevalence of interdisciplinary articles on the effects of residential development (Figure 3). Finally, we suggest that differences in the variables of greatest interest to each discipline (Figure 6), the extent and resolution of data available, and the nature of the tools available to each discipline may influence the scale of research and limit hypothesis testing across fields. For example, social studies often draw upon widely collected demographic data that are summarized at a particular resolution (eg census blocks), whereas many biophysical papers focus on measuring taxa at either site or landscape scales.

The few articles in our review that did adopt an interdisciplinary approach illustrate the value of overcoming these challenges. In many of these studies, the authors found that efforts to enhance biophysical sustainability were inconsistent with social or economic values. One such study reported that landowners strongly preferred ponds with non-native sport fish in an urbanizing landscape, despite demonstrated impacts of such fish on

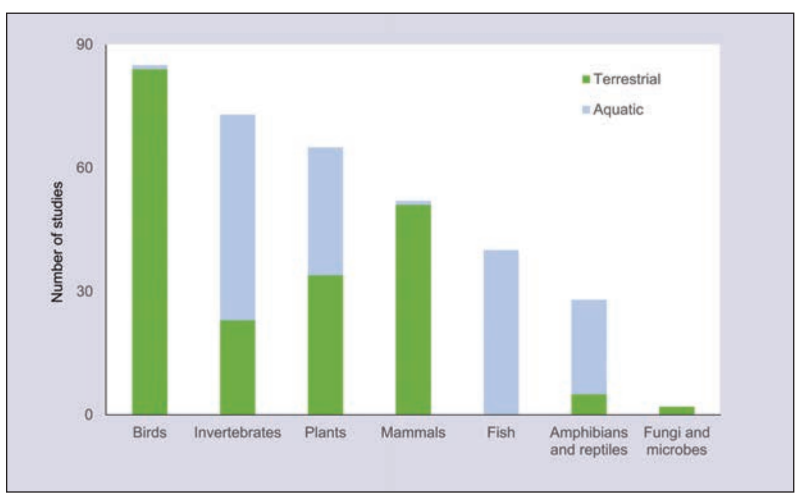

***Figure 7.** The number of terrestrial and aquatic studies examining biophysical response variables that included various organismal taxonomic groups.*

threatened amphibians (Goldberg and Waits 2009). In another analysis, although higher density of lakeshore development did not appear to have an effect on water quality, residents perceived that it did (Stedman and Hammer 2006). Other studies revealed important synergies among biophysical, economic, and social objectives, which could help build support for sustainable decision making. Nassauer *et al.* (2004), for instance, demonstrated that the measured impact of various development patterns on water quality was consistent with landowner perceptions of landscape attractiveness.

These cases demonstrate how interdisciplinary approaches provide novel insights that would not be possible when the effects of residential development are viewed through the lens of one discipline alone. A comprehensive understanding of the social, economic, and biophysical dimensions of development is fundamental to formulating effective policies that are consistent with the values of local communities. Walker *et al.* (2003) observed that an increase in development extent and intensity in a county in eastern California had negative ecological consequences. Surveys showed that although residents were deeply concerned about these impacts and agreed that the county needed strong environmental protection, they were opposed to growth regulations. In this scenario, pursuing policy actions based on both ecological data and social information (ie local perspectives about development and open space) is more likely to be effective.

Moving from impacts to mechanisms of change

We found that the biophysical literature focuses almost exclusively on the effects of development on species richness and abundance of individual taxa, a trend that is also reflected in a recent meta-analysis (Aronson *et al.* 2014). Although this focus is important, we suggest that it is time for ecologists to move beyond observational studies to understand the mechanisms behind these responses (eg demography, behavior, habitat use and activity patterns, species interactions; Shochat *et al.* 2006). For instance, the increasing dominance of human-adapted species in urbanizing areas (Groffman *et al.* 2014) may alter trophic dynamics and limit the ability of species sensitive to human disturbance to persist in these landscapes (Faeth *et al.* 2005). The prevalence of studies of birds, mammals, aquatic plants, and freshwater invertebrates (Figure 7) is not surprising, and is consistent with the taxonomic bias observed across the field of applied ecology (Fazey *et al.* 2005), but it is a cause for concern that so few studies focus on globally threatened, disturbance-sensitive taxa such as amphibians (Stuart *et al.* 2004).

More attention on the effects of development patterns on ecosystem services, such as carbon storage and nutrient cycling, is warranted. The provision of these services fundamentally affects natural systems, both in the degree to which they can support humans and other species, and their resilience to disturbances such as climate change (Foley *et al.* 2005). The design and stewardship of the open space associated with residential development clearly influences pollination, water and air quality, and climate regulation (regulating services); primary production and nutrient cycling (supporting services); the production of goods (provisioning services); and sense of place (cultural services; MA 2005). The design of urbanizing landscapes could thus incur costs or provide benefits to society through ecosystem services (Grimm *et al.* 2008b) in ways that are distinct from the services that flow from natural biomes (Cook *et al.* 2012).

The strong emphasis on the interests of individuals in the economic and social articles – and the lack of information on costs and benefits to the broader community – may interfere with sustainability goals. Capturing the full economic value of ecosystem services that change as a function of development patterns (Alberti 2005) and understanding the effects of these patterns on community cohesion, social capital, and equity are critical for achieving the three elements of sustainability (Figure 2a). Advancing research to understand how development shapes the economic and social viability of human communities is therefore vital for creating a sustainable environment beyond the scale of an individual home or development.

Potential to advance sustainability science

We found that the NSF is funding a notable proportion (16%) of the studies in urban or urbanizing landscapes, which we partially attribute to two highly productive urban Long Term Ecological Research (LTER) sites, as well as to scientific interest in the rapidly emerging field of urban ecology (Grimm *et al.* 2008a). Most of the growth in urbanized landscapes over the past several decades has been suburban and exurban (low density development that occurs outside cities and towns; Katz *et al.* 2003). We suggest that there is tremendous potential to develop additional long-term research sites (eg LTER and National Ecological Observatory Network sites) in suburban and exurban areas, to improve scientific understanding of the landscapes that lie between high-density urban landscapes and remote natural areas.

The establishment of long-term, interdisciplinary research centers in urbanizing regions would help scientists (1) develop and test theories about how human-dominated environments function as part of an integrated social–ecological system (Groffman *et al.* 2014), (2) understand the mechanisms behind the responses observed (Grimm *et al.* 2008b), and (3) predict the biophysical, economic, and social outcomes of alternative growth scenarios for biodiversity and human well-being. Such studies could further articulate how landscape patchiness, habitat connectivity, and development configuration and intensity affect species interactions and ecosystem processes (Alberti 2005). They could also address how the biophysical characteristics of developing landscapes influence emerging social patterns and processes, and how these patterns and processes advance and interact to influence the use of biophysical resources by humans over time (Redman *et al.* 2004). The importance of spatial scale in structuring the biophysical, economic, and social effects of development also warrants attention, as there is increasing evidence of scale dependence (Germaine *et al.* 2001).

Achieving sustainability in urbanizing landscapes may also require more creative methods. Less than 5% of the articles in our review included qualitative data. Social scientists have demonstrated that qualitative research can help enhance quantitative measurements by contributing context-specific data (Mason 2006). Understanding how to achieve sustainability in landscapes undergoing development from the diverse perspectives of developers, planners, and homeowners represents an ideal scenario for using multiple methods to gather information. Indeed, Wallace *et al.* (2008) found that the value of conserved private land in a developed landscape was explained in complementary ways by document analysis, surveys with homeowners, and spatial analysis of biophysical features.

Potential to advance conservation and development planning

Maintaining open space within urbanizing landscapes benefits biodiversity (Aronson *et al.* 2014) and human well-being (Fuller *et al.* 2007), and has positive effects on home sales (Hannum *et al.* 2012). Studies that produce results more likely to be applicable to sustainable land-use planning should therefore include predictor variables such as development design and configuration, proximity to open space, and characteristics of the open space (eg type, age). Only a small fraction of studies included in our review addressed these characteristics of development (Figure 6).

Residential development has the potential to affect sustainability at three stages: design, construction, and long-term stewardship (Hostetler 2012). The few studies in our review that reported on development design (8%) addressed attitudes and values related to conservation, or cluster development (CD), where a portion of the developed parcel is set aside as open space (Pejchar *et al.* 2007). Expanding understanding of the biophysical and economic effects of CD would be beneficial to land-use planners because CD is increasingly permitted and encouraged through local and state-level land-use ordinances (Reed *et al.* 2014). Construction, and particularly stewardship of open space within the development, appear to be equally critical to long-term sustainability but are understudied in comparison with development design (Cook *et al.* 2012).

Emphasis on various characteristics of development and open space varied substantially among disciplines (Figure 6), which could compromise decision making based on findings from multiple perspectives. For instance, economic studies focused primarily on the effect of open space on home sales, whereas social and biophysical studies focused almost exclusively on the effects of development on individual attitudes, and plant and animal species richness and abundance, respectively. As a result of this disconnect, scientists and society as a whole may be undervaluing open space by not quantifying the benefits, beyond changes in home values, that accrue to people and other species in urbanizing areas. Similarly, development patterns may have unforeseen costs or benefits in terms of the economic value of open space, but this question was also poorly addressed in the literature.

In summary, understanding the effects of residential development patterns is critical in a rapidly urbanizing world. By filling the knowledge gaps highlighted in this review, we have the opportunity to use science to inform land-use planning through interdisciplinary scholarship. Ultimately, such research will help us design and care for backyards, neighborhoods, cities, and watersheds that foster native species, resilient ecosystems, and thriving human communities.

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