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The implications of current and future urbanization for global protected areas and biodiversity conservation

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ABSTRACT

Due to human population growth and migration, there will be nearly 2 billion new urban residents by 2030, yet the consequences of both current and future urbanization for biodiversity conservation are poorly known. Here we show that urban growth will have impacts on ecoregions, rare species, and protected areas that are localized but cumulatively significant. Currently, 29 of the world's 825 ecoregions have over one-third of their area urbanized, and these 29 ecoregions are the only home of 213 endemic terrestrial vertebrate species. Our analyses suggest that 8% of terrestrial vertebrate species on the IUCN Red List are imperiled largely because of urban development. By 2030, 15 additional ecoregions are expected to lose more than 5% of their remaining undeveloped area, and they contain 118 vertebrate species found nowhere else. Of the 779 rare species with only one known population globally, 24 are expected to be impacted by urban growth. In addition, the distance between protected areas and cities is predicted to shrink dramatically in some regions: for example, the median distance from a protected area to a city in Eastern Asia is predicted to fall from 43 km to 23 km by 2030. Most protected areas likely to be impacted by new urban growth (88%) are in countries of low to moderate income, potentially limiting institutional capacity to adapt to new anthropogenic stresses on protected areas. In short, trends in global ecoregions, rare species, and protected areas suggest localized but significant biodiversity degradation associated with current and upcoming urbanization.

1. Introduction

For decades, conservation effort has primarily but not exclusively focused on designating lands as "protected areas" where biodiversity is presumed safe from human threats (Brandon and Wells, 1992; Scott et al., 2001; Rodrigues et al., 2004). Roughly 11.5% of the Earth's land surface is in the global protected area system (Rodrigues et al., 2004), and further protection of particularly biodiverse ecoregions is a conservation priority. Meanwhile humanity has undergone a transition in which the majority of people now live in urban areas rather than rural ones. Worldwide 1.75 billion new urban residents are expected by 2030, most concentrated around fairly small cities in developing countries, with 45% of total urban population growth in cities with fewer than 500,000 residents (UNPD, 2005). Total urban area will continue to expand, driven by urban population growth in developing nations and low

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population density of newly urbanized areas in the developed world (Jackson, 1985; Liu et al., 2003; Angel et al., 2005).

This massive urbanization will likely have significant effects on the natural environment and the services it can supply to humanity (Bolund and Hunhammar, 1999; McGranahan et al., 2006; Forman, 2008), both directly through the expansion of urban area and indirectly through changes in consumption and pollution as people migrate into cities (McKinney, 2002; Liu et al., 2003; McGranahan and Satterthwaite, 2003). A number of detailed case studies have examined the link between urbanization and the environment (Bolger et al., 1997; Clergeau et al., 1998; McIntyre et al., 2001; Riley et al., 2003). However, urbanization as a global trend has received scant attention from conservationists, with some noteworthy exceptions (Bolund and Hunhammar, 1999; Luck et al., 2001; McGranahan and Satterthwaite, 2002, 2003; McGranahan et al., 2006).

Here we analyze data from several sources with the objective of quantifying the direct effect of expansion of urban area by 2030 on biodiversity conservation. Using different assumptions about the density of new settlements, we constructed three scenarios of urban growth out to 2030: baseline, compact, and dispersed. In this paper, we use the term "urbanization" to refer to the general demographic processes by which the world's cities are expanding, "urban area" to refer to current amounts of urban land cover, and "urban growth" to refer to the expanded amount of urban land cover by 2030. We examine three key dimensions of biodiversity conservation: global ecoregions, rare species, and protected areas. We relate each dimension to global patterns of current urban area and predicted urban growth. Where possible, we also present quantitative evidence that current urban area has already caused measurable negative impacts on biodiversity conservation.

2. Materials and methods

2.1. *Urban-growth scenarios*

We based our scenarios of urban area growth on a map of "current" urban land taken from the Global Rural/Urban Mapping Project (GRUMP alpha, 2004), which estimated urban area extent for 1994–1995 using the Defense Meteorological Satellite Program–Operational Linescan System (DMSP–OLS) night time light data (Elvidge et al., 1997) and ancillary databases of population and urban-extent. Due to the characteristics of the DMSP–OLS sensor, which is quite sensitive to night time light emissions, the GRUMP urban-extent layer is not considered to be a map of areas completely or predominately covered by built-up surfaces, but rather as a map of areas with a significant proportion of their surface urbanized. The GRUMP dataset also supplies a relatively complete list of more than 60,000 settlement points and their population in 1995 and 2000, which allowed us to include the expected growth of small towns that do not appear in the 1 km^2 resolution urban-extent data layer. The GRUMP extent layer has a nominal resolution of 30 arc s, and we projected it and all subsequent layers to a 1 km resolution Mollweide equal-area projection.

We applied United Nations Population Division national projections for urban population growth rate to the GRUMP settlement point data to arrive at city-level population estimates over time. The next step was to convert urban population growth to expansion of urban area. The link between urban population growth and urban area growth has recently been quantified by Angel et al. (2005), who found that on average for each new resident, rich countries add 355 m^2 of built-up area, middle-income countries add 125 m^2, and low-income countries add 85 m^2. Three income categories, measured in US$2005 GDP (Purchasing Power Parity) per-capita, were used: Highest income (>$17,000), middle-income ($3000–$17,000), and low (<$3000). We used these averages to construct three scenarios of urban area growth spanning a likely range of possible futures: (1) baseline (per-capita area of new settlements stays the same), (2) compact (per-capita area of new settlements is 50% less than current), and (3) dispersed (per-capita area of new settlements is 50% more than current). Given the significant difference in spatial resolution of the Angel et al. study and this study, our growth estimates should not be considered as precise numerical forecasts but rather as scenarios that capture the essential pattern of global urban growth. In our construction of scenarios, the use of higher per-capita consumption of urban land in rich countries accounts for the trend toward lower density settlements in these countries (i.e., "sprawl"), except in a few special cases like the former USSR where urban population has sometimes decreased while urban area actually increased, apparently related to changes in municipal governance (Golubchikov, 2004). Unless noted in the text, the results presented below are from the baseline scenario.

2.2. *Ecoregional analysis*

We analyse current and future urban impacts at the scale of ecoregions – these are the geographical units typically used for conservation priority-setting (Omernik, 1995; Olson and Dinerstein, 1998, 2002; Olson et al., 2001; Krupnick and Kress, 2003; Magnusson, 2004; Kier et al., 2005; Brooks et al., 2006). Ecoregions delineate areas of relatively homogeneous environmental conditions and species composition. Ecoregions thus range widely in size, from large areas such as the Sahara Desert Ecoregion (4,650,000 ha) to small, globally-unique areas such as the Northwestern Hawaii Scrub Ecoregion (14.8 ha).

Ecoregional definitions are taken from the World Wildlife Fund (Olson and Dinerstein, 1998, 2002; Ricketts et al., 1999; Olson et al., 2001), which also lists the vertebrate species in each ecoregion (Wildfinder Database). In cases where urban regions crossed ecoregion boundaries, future urban growth was assigned proportional to the percent of an urban region currently in each ecoregion.

To quantify urban growth impacts at the ecoregional scale, we calculated the percent of each of the world's 825 ecoregions that has been converted into urban land and the proportion of the remaining "natural" (i.e., non-urban) land expected to be lost to urban growth by 2030. For two subsets of the world's ecoregions, those highly-urbanized in 1995 and those expected to have rapid urban area growth by 2030, we examined the vertebrate species composition, and tabulated the species contained within (i.e., occur in) or endemic to (i.e., occur only in) the subsets.

To compare our subsets' vertebrate species richness and endemism to the global average we used a random draw approach. We compared the median attributes of our special subsets to the median of the same number of ecoregions randomly drawn 1000 times from the total set of all global ecoregions. One thousand permutations were used because we believed this number of permutations would be sufficient to estimate statistical significance accurately. The statistical question posed by this permutation test is, do the highly-urbanized or at-risk ecoregions have higher vertebrate species richness or endemism than you would expect from a random draw of ecoregions? Significance values are based on the proportion of times the actual value of a characteristic lay outside the distribution of values from our resample sets of ecoregions. Species-area curves were graphically examined to determine if the differences in sizes among ecoregions were affecting our analysis.

Finally, it is possible with Wildfinder data (WWF, 2006), in conjunction with International Union for Conservation of Nature (IUCN) Red List data available from the same source, to examine whether there is evidence that high levels of urbanization are actually correlated to a threat to species persistence. For all vertebrate species, we calculated the total area of the land in ecoregion(s) in which it occurs (its "range"). We also calculated the percent of the range urbanized, by taking the weighted mean of the percent urbanization in each of the component ecoregions, with the weights equal to the area of each ecoregion. These were treated as an explanatory variable in an ordered logistic regression analysis of the probability of a vertebrate taxa being listed as threatened on the IUCN Red List in one of four categories: "Near Threatened", "Vulnerable," "Endangered," or "Critically Endangered". A fifth category was also included in the model as a baseline, those species listed as "Least Concern" by the IUCN or those species not yet evaluated by the IUCN (and presumed not threatened in our analysis). To improve normality and reduce potential problems with heteroscedasticity, the range of a species was log-transformed before analysis. The final model included both main effect terms, plus an interaction term. Model fitting was done using the *polr* function in the MASS library of SPLUS. Statistical significance was assessed using likelihood-ratio tests of nested model subsets. Strictly speaking, the resulting regression model describes how current levels of urbanization affect the probability of a vertebrate taxa currently being threatened, and cannot be used to make statements about how future levels of urbanization might affect future levels of threat.

2.3. Rare species analysis

We evaluate the impact of urban growth on rare species using the Alliance for Zero Extinction (AZE) database (Ricketts et al., 2005), which lists extremely rare species with only one known population in the world. These are by definition endemic species that are both rare and threatened. The AZE database covers all known mammals, birds, amphibians, conifers, and selected reptiles.

We quantified the potential effect of urban growth on specific rare species by overlaying maps of current and projected urban area with the AZE database, calculating expected urban growth within a 10-km zone around each species' population. AZE species were classified as at-risk if more than 10% of the remaining unbuilt area within this 10-km zone was urbanized by 2030. For at-risk AZE species, we used information from the AZE database to evaluate the extent of land protection for that species.

All 776 AZE species are listed as endangered or worse on the IUCN Red List, in part because of the actions of the Alliance for Zero Extinction (Ricketts et al., 2005). We compared the rankings of our at-risk AZE species to those of the general AZE species, to see if urbanization had significantly worsened their rankings. We also searched the IUCN descriptions of our at-risk species, to see if the threats listed by the IUCN's panel of experts included "Habitat loss-human settlement."

2.4. Protected area analysis

We analyze the likely impact of urban growth on existing protected areas using two metrics: the amount of urban growth in the immediate surroundings of a protected area, and the distance from protected areas to the nearest large city. The distance of protected areas from cities is especially important because proximity increases the likelihood of resource extraction and other negative human impacts on biodiversity (Cole and Landres, 1996). For example, the bushmeat trade in West Africa may increase due to increased proximity of wildlife areas to urban markets (Nielsen, 2006).

To quantify the potential impacts of urban growth on existing urban areas, we calculated the distance from each protected area to existing cities of at least 50,000 people, as well as the distance to cities of the same minimum size expected in 2030. We filtered the World Protected Area Database (WDPA Consortium, 2006) to include only terrestrial protected areas of greater than 1 km^2 in area, as that is the minimum spatial resolution of our urban-extent data. Some protected areas did not have boundary information available, but did have a known centroid and park size. In those cases we buffered the centroid to create a circular park of the appropriate size. Distance was measured from the edge of a protected area to the edge of the nearest urban-extent. In the case of existing cities not visible in the GRUMP urban-extent map, distance was measured from the edge of a protected area to the settlement point in the GRUMP data. This makes the conservative assumption that the cities of tomorrow will arise out of the existing small settlement points in the GRUMP data, and will not appear de novo. To assess whether there were statistically-significant differences among geographical regions in the median distance from protected area to city, we conducted a Kruskal–Wallis rank sum test.

Protected areas were classified as at-risk if more than 10% of the area in a 10-km zone around each protected area was expected to be urbanized by 2030. This 10% threshold is admittedly arbitrary, and other more or less stringent thresholds would have classified fewer or more parks as at-risk. However, preliminary investigations found our results to be qualitatively insensitive to the value of this threshold. For each at-risk protected area, the income category of its country was classified into three groups (High, Middle, or Low), consistent with the income categories used in the development of our urban-growth scenarios. All per-capita GDP data were taken from the International Monetary Fund, World Economic Outlook Database, for the year 2005. To assess whether differences among the three groups were statistically significant, we conducted a Kruskal–Wallis rank sum text. The correlation between the percent urban in a 10-km zone around a protected area and the distance from that protected area to a city was weak but significant ($r = -0.2$, $P < 0.0001$).

3. Results

3.1. *Ecoregional analysis*

Most ecoregions, representing 62% of the world's terrestrial surface, currently have <1% of their area urban, and will be essentially unaffected by the coming urban growth (Supplementary Table 1). However, the threat to biodiversity is real in the most urbanized ecoregions, concentrated near coasts and on islands. Currently 29 ecoregions have more than one-third of their area urban (Fig. 1, Supplementary Table 1). Although these 29 ecoregions amount to only 0.3% of the global land area they are home to 12% of the world's terrestrial vertebrate species, 3056 species in total. These ecoregions are significantly smaller than would be expected if 29 ecoregions were selected randomly from the global pool of ecoregions ($P < 0.001$), but the vertebrate species density (Hurlbert, 1971), in species/ha, is greater than would be expected by chance alone ($P < 0.001$). A graphical representation of these statistical tests shows the tendency of highly-urban-

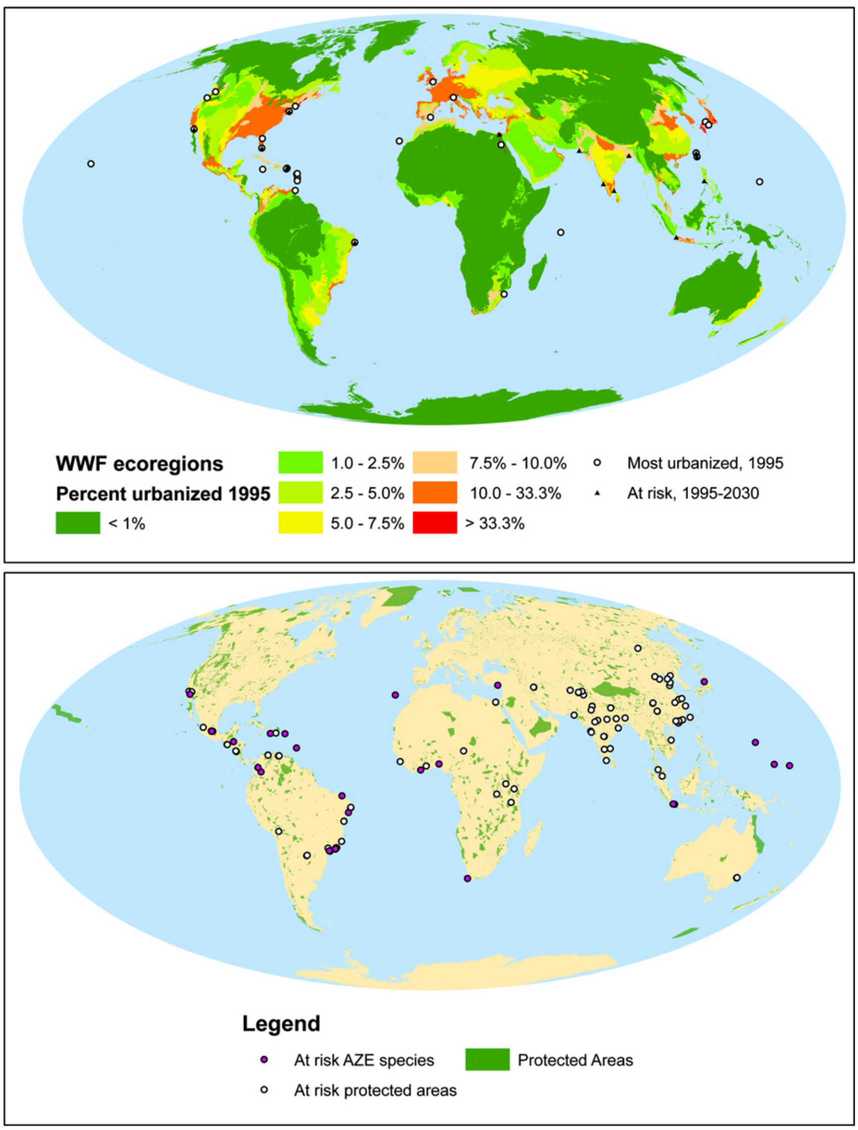

Fig. 1 – The effect of urban growth on ecoregions (top panel) and protected areas (bottom panel). ***Top panel*****: percent of an ecoregion's area urban in 1995, where the ecoregion boundaries follow those of the World Wildlife Fund (Olson et al., 2001). The ecoregions with more than 1/3 of their area urban in 1995 are marked. Fifteen at-risk ecoregions, which will lose more than 5% of their remaining undeveloped area by 2030, are also marked.** ***Lower panel:*** **The distribution of global protected areas, in green. Twenty-four species from the Alliance for Zero Extinction Database that have more than 10% new urban growth in a 10 km buffer zone are marked. One hundred and twelve at-risk parks, with more than 10% new urban growth in 10 km buffer zones by 2030, are also marked.**

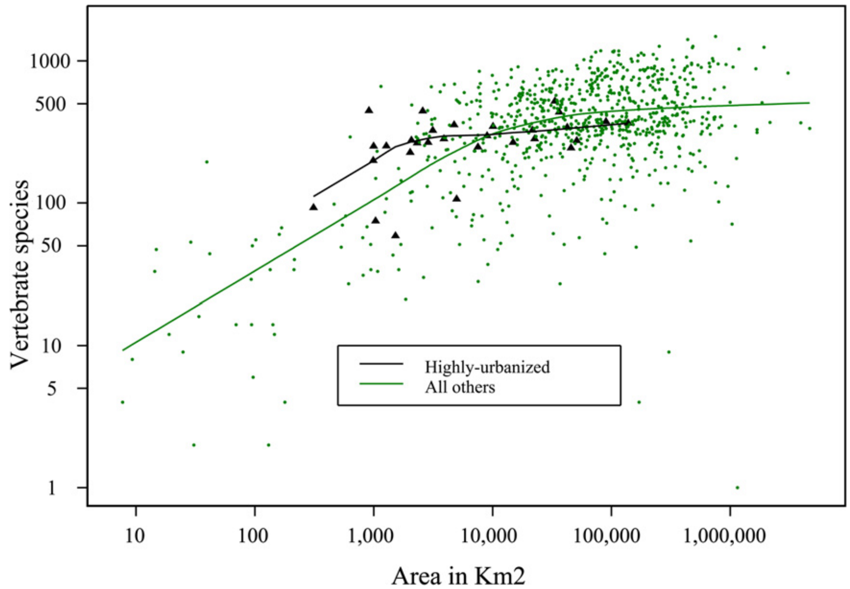

Fig. 2 – The relationship between ecoregion area and vertebrate species richness, for ecoregions affected and unaffected by urbanization. Note that both axes are logarithmic. Twenty-nine highly-urbanized ecoregions, with more than 1/3 of their area urbanized in 1995, are marked in black, with a lowess smoothing line to show the general trend. The remaining other ecoregions are shown in green, with a lowess trend line as well.

ized ecoregions to have more diversity than other similarly-sized ecoregions (Fig. 2), at least for highly-urbanized ecoregions of less than 10,000 km^2 in area. Of course, vertebrates often have broad ranges, relative to other taxonomic groups, and many of the 3056 species in these 29 highly-urbanized ecoregions also occur in other ecoregions. Still, 213 vertebrate species are found only in these 29 ecoregions, a greater endemic density than would be expected by chance alone ($P = 0.009$). Of these 213 vertebrate species, 89 are listed on the IUCN Red List (IUCN, 2006) with a status of Near Threatened or worse. Overall, at the ecoregion scale urbanization seems to have targeted areas of high biodiversity value.

A key question concerns the increase in extinction risk one might expect as a result of urbanization. We find clear evidence that the likelihood of a vertebrate being listed as threatened increases with the proportion of a species range that is urbanized (Fig. 3). The degree of threat also tends to be higher with increasing urban area. The total area of a vertebrate species range is an important covariate, both as a main effect and in interaction with the percent of the range urbanized. Species with smaller ranges need a smaller increase in percent urban to have an increase in the probability of being listed than do species with bigger ranges (Table 1). To assess the overall effect of urbanization on the IUCN Red List, we calculated the expected number of species that would remain listed if there had been no urbanization but other factors had stayed the same. Under this hypothetical case, we would expect around 420 fewer species to be listed than currently, suggesting that urbanization is implicated in the listing of around 8% of species on the Red List.

The potential for negative impacts on biodiversity from urban area expansion between 1995 and 2030 is also substantial. For example, 15 ecoregions will lose more than 5% of their remaining non-urban area by 2030 under the baseline scenario (Fig. 1). These ecoregions are significantly smaller than would be expected if 15 ecoregions were selected randomly from the pool of all global ecoregions ($P < 0.001$). Once again, at-risk ecoregions below 10,000 km^2 have more species than other similarly-sized ecoregions. Ten percent of the world's vertebrates occur in, and 118 vertebrate species endemic to, these 15 ecoregions – a greater

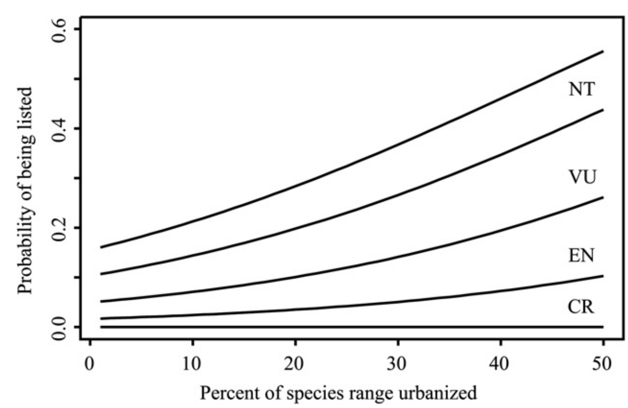

Fig. 3 – The probability of a terrestrial vertebrate species being listed on the IUCN Red List as a function of the percent of that species range that is urbanized. Abbreviations are, from most to least threatened: CR, Critically Endangered; EN, Endangered; VU, Vulnerable; and NT, Near Threatened. Results are from an ordered logistic regression analysis, which included the total area of a species range as a covariate. The curves shown are for the median species range, 550,000 km^2. Results are shown as a stacked area chart. For example, if 30% of such a species range is urbanized it will have a 37% chance of being listed as Near Threatened or worse (i.e., NT + VU + EN + CR).

Table 1 – Ordered regression summary

Model coefficients:		Value	Standard error	
Log(range) term		−0.335	0.0082	
Urbanization term		−5.666	0.95	
Interaction term		0.718	0.095	
Intercept coefficients:		Value	Standard error	
LC|NT		−2.740	0.11	
NT|VU		−2.268	0.11	
VU|EN		−1.478	0.11	
EN|CR		0.355	0.11	
Term removed:	Df	A/C	Likelihood ratio	P
Full model		38201.23		
Without log(range) term	1	39941.63	1742.397	< 0.001
Without urbanization term	1	38234.96	35.726	< 0.001
Without interaction term	1	38255.42	56.183	< 0.001

Details of the ordered regression conducted, including the values of regression coefficients and intercepts. Also included are likelihood-ratio tests of the full model versus the model minus one term, to assess statistical significance of each term. See text for details. Abbreviations are, from most to least threatened: CR, Critically Endangered; EN, Endangered; VU, Vulnerable; NT, Near Threatened; and LC, Least Concern (which includes vertebrate taxa not yet evaluated).

concentration of both species and endemics than would be expected by chance alone ($P < 0.001$ in both cases). Of the 118 vertebrate species endemic to at-risk ecoregions, 43 are already listed on the IUCN Red List with a status of Near Threatened or worse.

3.2. *Rare species analysis*

Under the baseline urban-growth scenario, 24 out of 776 AZE species will have more than 10% of their surrounding unbuilt area urbanized by 2030. If we examine the distribution of the 24 at-risk species under our baseline scenario (Fig. 1), they tend to be concentrated in coastal areas and islands. Under the dispersed scenario (low-density development), where per-capita consumption of urban land increases by 50%, the number of at-risk AZE species increases to 28. Conversely, under the compact scenario (high-density development), where per-capita consumption of urban land decreases by 50% compared to baseline projections, the number of at-risk AZE species declines from 24 to 18. This suggests that for at least 10 AZE species the pattern of urban growth (compact versus highly dispersed) of their surrounding urban areas will affect the threat to their existence.

While all AZE species are listed as Endangered or worse under the IUCN Red List categories, the 24 at-risk AZE species under the baseline scenario appear to have already been negatively affected by urban growth. At-risk AZE species have significantly worse rankings than the average AZE species ($\chi^2 = 11.5$, $P = 0.003$), with 71% of at-risk AZE species classified as Critically Endangered. Additional evidence of the effect of urban growth on the at-risk AZE species can be found by reading their listed major threats within the IUCN Red List database. Of the 24 at-risk AZE species, 12 explicitly list habitat loss due to human settlement or infrastructure development as a major threat, eight list habitat loss to agriculture as a major threat but do not list human settlement, and four do not have enough information to evaluate their major threats. This suggests that documented negative effects of urban area on many of the at-risk species already exist, which will presumably increase in intensity as urbanization continues. It is worth noting that while many of these at-risk AZE species have some of their habitat protected, 9 of the 24 currently have no associated protected areas, and could be the focus of future conservation efforts.

3.3. *Protected area analysis*

Currently, 25% of the world's protected areas are within 17 km of a city of at least 50,000 people. This distance is expected to decline to 15 km by 2030 (Table 2). The median distance from protected area to city varies significantly among geographic regions (Kruskal–Wallis $\chi^2 = 6256$, $P < 0.001$), and in some geographic regions protected areas and cities are in exceptionally close proximity. For example, in Eastern Asia the median distance is expected to decrease from 43 km in 1995 to 23 km by 2030, and 25% of the protected areas will be within only 10 km of a city.

Another way of quantifying the confrontation between urban and protected areas is to calculate the percent of the landscape urbanized within a 10-km zone around each protected area, under current conditions and under each of the three future scenarios. Using the dispersed urbanization scenario, we estimate that 112 protected areas (0.4% of the world's total) will have with more than 10% new urban growth in their 10-km buffer zones by 2030 (Fig. 1). Eighty-four percent of these urban-impacted protected areas will be in middle-income ($3000–$17,000 per-capita GDP) nations. Interestingly, only 6% of the urban-impacted protected areas occur in the lowest-income (<$3000 per-capita GDP), in part because fewer protected areas are present in countries with less economic development (overall Kruskal–Wallis $\chi^2 = 235.9$, $P < 0.001$). The proportion of protected areas at-risk is statistically indistinguishable between middle- and low-income nations ($P > 0.05$), but both of these groups have a significantly higher proportion of protected areas at-risk than high-income countries ($P < 0.001$ in both cases).

Table 2 – Distance from a protected area to the nearest city

Region name	In 1995			In 2030		
	First quartile	Median	Third quartile	First quartile	Median	Third quartile
Africa	40	81	152	28	54	98
Eastern Africa	52	100[a]	176	26	55[a]	102
Middle Africa	65	159	235	53	87[b]	148
Northern Africa	8	39[b]	104	6	27[c]	85
Southern Africa	30	58[c]	102	23	46[d]	83
Western Africa	40	82[a,d]	137	23	43[a,d]	82
Asia	21	47	85	16	36	71
Eastern Asia	18	43[b]	84	10	23[c,e]	45
South-central Asia	19	38[b]	80	13	28[c]	58
South-eastern Asia	27	57[c]	94	20	40[d]	74
Western Asia	7	26	57	4	21[e]	48
Europe	8	22	42	8	22	41
Eastern Europe	17	36[b]	66	18	38[c]	68
Northern Europe	11	34[b]	71	10	33[c]	71
Southern Europe	3	15	32	3	13	30
Western Europe	4	13	25	3	12	23
Caribbean and Central America	18	41[b]	108	15	32[c]	66
South America	46	115[a]	338	35	108[b]	327
Northern America	26	74[d]	182	21	63[a]	160
Australia/New Zealand and Oceania	50	110[a]	193	42	93[b]	169
World	17	44	99	15	38	83

Distance from a protected area (km) to the nearest city of >50,000 people, in 1995 and 2030. Shown are the first quartile (25% of protected areas are closer than this to a city), the median (50% of protected areas are closer than this to a city), and the third quartile (75% of protected areas are closer than this to a city). Medians between particular pairs of geographic regions are not statistically different if they share the same superscript. Geographic region definitions match those used by the United Nations Population Division (UNPD, 2005).

4. Discussion

The effect of urban area and urban growth on biodiversity conservation is localized, but cumulatively significant, with important ecoregions, rare species, and protected areas all affected. The global ecoregion data perhaps shows this most clearly. Ecoregions that cover almost two-thirds of the Earth's land surface are essentially unaffected by urban area, and will likely remain unaffected by future urban growth. However, those ecoregions most affected by urban area or urban growth tend to be small, but contain significant concentrations of endemic species. The association of high urbanization with small ecoregions may arise simply because it is easier numerically for an urban area of a given size to cover a large proportion of a smaller ecoregion than of a larger ecoregion. It may also reflect the general tendency of small ecoregions, which have unique flora and fauna, to be near major human settlements, part of the general correlation between biodiversity and human population (Cincotta et al., 2000; Luck et al., 2004). The cause of this correlation is unclear, but it may because of the increased energy available at productive, species-rich sites (Luck, 2007a,b).

We present clear evidence that urban area has already increased the threat to the survival of some vertebrate species. Species with more highly-urbanized ranges are significantly more likely to be on the IUCN Red List. This trend is stronger for species with smaller ranges. Our analysis suggests that urbanization is implicated in the listing of around 8% of the IUCN vertebrate species. Our estimates should be further refined when more spatially and temporally precise estimates of vertebrate species ranges and urbanization become available.

The effect of future urban growth on rare species seems also localized but cumulatively significant. A relatively small percentage of AZE species (3%) is classified as at-risk from urban growth by our analysis, especially compared to the threat levels that may emerge from other processes such as global warming, which has been predicted to cause greater than 18% extinction (Thomas et al., 2004). However, those rare species affected by urbanization tend to be near coasts or on islands, which are centers of endemism (Ricketts et al., 2005) and regions with generally fast urban growth. We hope to concentrate the attention of conservationists on some of these extremely rare species that seem likely to be affected by urban growth. For instance, Wimmer's Shrew (*Crocidura wimmeri*) lives only on the outskirts of the capitol of the Cote D'Ivoire, and seems unlikely to survive the expansion of Abidjan without the attention of conservationists.

Moreover, by 2030 a substantial portion of the world's protected areas will be within a day's walk or a half-hour drive of city-dwellers. The existing emphasis of conservationists on expanding the boundaries of protected areas can not protect biodiversity by itself (Newmark, 1995, 1996; Brooks et al., 2004; Rodrigues et al., 2004), and needs to be supplemented with strategies for guarding protected areas against intense pressure from nearby urban populations (Ervin, 2003; Theobald, 2003). Such strategies need not be implemented everywhere. Instead, attention can focus on a small number of at-risk parks, which occur principally in Southeast Asia

(Fig. 1). Another strategy that is important but perhaps more challenging is thinking of ways that urban growth might be made compatible with biodiversity protection, and the conflict between people and nature minimized at the urban–wildlands interface (Goldstein et al., 2006). Only by addressing this growing conflict between cities and biodiversity can society achieve genuine conservation in an urbanizing world.

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Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at doi:10.1016/j.biocon.2008.04.025.

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