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Sébastien Barot, Luc Abbadie, Apolline Auclerc, Carole Barthelemy, Etienne Bérille, Philippe Billet, Philippe Clergeau, Jean-Noël Consalès, Magali Deschamps-Cottin, Ambre David, et al.

► **To cite this version:**

Sébastien Barot, Luc Abbadie, Apolline Auclerc, Carole Barthelemy, Etienne Bérille, et al.. Urban ecology, stakeholders and the future of ecology. *Science of the Total Environment*, 2019, 667, pp.475-484. 10.1016/j.scitotenv.2019.02.410 . hal-02116373

**HAL Id: hal-02116373**

**<https://hal.science/hal-02116373v1>**

Submitted on 3 Jul 2019

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## 1 **Urban ecology, stakeholders and the future of ecology**

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32

### 33 ABSTRACT

34 The goal of our work is fourfold: to describe the diversity of scientific questions in  
35 urban ecology, show how these questions are organized, to assess how these  
36 questions can be built in close interactions with stakeholders, to better understand  
37 the role urban ecology can play within ecological sciences. A workshop with  
38 scientists from all relevant fields (from ecology to sociology) and stakeholders was  
39 organized by the Foundation for Research on Biodiversity (FRB). Three types of  
40 scientific issues were outlined about (1) the biodiversity of organisms living in urban  
41 areas, (2) the functioning of urban organisms and ecosystems, (3) interactions  
42 between human societies and urban ecological systems. For all types of issues we  
43 outlined it was possible to distinguish both fundamental and applied scientific  
44 questions. Overall, the human population is more and more urban. Cities have a  
45 strong impact on the biosphere and increasing the share of Nature within towns is  
46 more and more viewed as crucial for the well-being of town dwellers. Moreover, as all  
47 types of ecological and evolutionary questions can be asked in urban areas, urban  
48 ecology will likely be more and more influential in the development of ecology. The  
49 future of towns, their biodiversity and the life of city dwellers is at stake. Depending

50 on research and the way its results are taken into account, very different towns could  
51 emerge. Urban areas can be viewed as a test and a laboratory for the future of the  
52 interactions between human and ecological systems.

53

54 *Key-words:* biodiversity, ecological engineering, ecosystem services, stakeholders,  
55 research agenda, human sciences

56

## 57 **1. Introduction**

58 It is nowadays fashionable for ecologists to carry out studies in urban ecology. Nearly  
59 all scientific institutions have a group of scientists working on this subject and more  
60 than 14000 articles are currently published each year in this field (Fig. 1, see also the  
61 same trend for urban ecosystem services in Luederitz et al., 2015) and these articles  
62 represent about 14% of all articles published in ecology. This may seem quite  
63 natural, but only 20 years ago the situation was totally different. Prior to 1995, only a  
64 few articles (less than 100) were published each year in the field of urban ecology. It  
65 was more usual for ecologists to work in pristine ecosystems such as tropical forests,  
66 mountains, oceans (Niemelä, 1999)... The number of publications in urban ecology  
67 increased slowly till 2000, and since then has increased exponentially. Many journals  
68 specializing in urban ecology have been created: Landscape and Urban Planning  
69 (1986), Urban Ecosystems (1997), Journal of Urban Ecology (2015).

70 The diversity of scientific issues being tackled has led to the observed  
71 exponential growth of the number of articles published in urban ecology (Fig. 1). This  
72 dynamism means that urban ecology is a quickly changing field, whose structure has  
73 not yet stabilized. For these reasons we sought to build a research agenda for urban  
74 ecology. As a consequence of the pervasive influence of humans on urban ecological

75 systems and the diversity of scientific issues concerning humans the agenda was  
76 conceived right from its inception as a collaboration between scientists from various  
77 fields and stakeholders involved in various aspects of town and city management  
78 (from urbanists and urban planners to citizens). Stakeholders are essential to this  
79 reflection because they know the issues directly at stake in the management of urban  
80 areas, their biodiversity and ecosystems. They know the kind of knowledge they need  
81 to help them make appropriate decisions. Besides scientists from a range of fields in  
82 ecology, scientists from various fields of human sciences were an integral part of this  
83 discussion. Indeed, as one important goal is to study in urban areas the coupling  
84 between ecological systems and humans, human sciences are required to analyse  
85 human aspects of this coupling.

86         The goal of our work was fourfold: (1) to describe the diversity of scientific  
87 questions that can be tackled in urban ecology, (2) to show how these questions can  
88 be organized and linked to each other, (3) to assess how research questions can be  
89 built in close interactions with non-scientists, (4) to better understand the role urban  
90 ecology can play within ecological sciences. In this way, this is close to other  
91 exercises aiming at building research agendas (Sutherland et al., 2013). However,  
92 the goal was not here to prioritize questions but rather to show the whole diversity of  
93 questions and their organization and to outline broad areas where many new  
94 questions are emerging. To achieve this goal a workshop was organized by the  
95 Foundation for Research on Biodiversity (FRB).

## 96 **2. Building a research agenda**

97 The members of the working group, i.e. the authors of this article, originate from the  
98 scientific board of the FRB, for the academic part of the group, and from the Strategic  
99 Orientation Committee of the FRB that gathers stakeholders from all types of

100 activities, from industry to conservationist associations. In addition, a few experts in  
101 urban ecology accepted to join the group. Taken together, half of the group was  
102 composed of scientists with various ecological approaches (soil science, ecosystem  
103 ecology, community ecology, ecological engineering, sociology, law science) and half  
104 of practitioners (e.g. employee of territorial communities, landscape gardener,  
105 member of a consultancy organisation). The general idea behind such an approach  
106 to build a research agenda is that it is often pointed out that the results of science  
107 tend not to be used and that the transfer of knowledge from scientists towards  
108 stakeholders at the end of projects does not guarantee that their results will be used  
109 (Phillipson et al., 2012). There are many ways to engage stakeholders in research  
110 projects (Berkes, 2009). We think that involving stakeholders right from the start,  
111 when scientific questions are delineated, should be fruitful. It should ultimately  
112 facilitate the co-management of towns and their biodiversity using different types of  
113 knowledge. We also think that this should increase the stakeholder capabilities to  
114 understand the relevance of the more fundamental scientific questions and to foster  
115 the development of the corresponding research actions.

116         The workshop was divided into three parts (see Fig. 2). During a first  
117 workshop brainstorming techniques were used to allow the group members to  
118 express the scientific issues related to urban ecology and biodiversity they  
119 considered the most important. Between the first and second workshops, the  
120 participants were asked to fill out tables to aid the construction of a more  
121 comprehensive list of scientific questions. During the second workshop, this list was  
122 discussed and methods and criteria for organizing the list were proposed. Between  
123 the second and third workshop, the lead author transcribed and organized the list.  
124 During the third workshop, the organization of the list was finalized and gaps in the

125 list were detected and remedied. The group met several times after the first three  
126 workshops for further discussion and adjustment of the details of the article.

127         Developing a common list of questions required acquiring a common culture  
128 and a common vocabulary because of the diversity of professional and scientific  
129 backgrounds of the workshop participants. Half of each workshop was always used  
130 for oral presentations (followed by discussions) either about scientific results or  
131 operational projects involving urban ecological systems. Beyond building a list of  
132 questions, our goal was also to analyse the consequences of the development of  
133 urban ecology for the evolution of ecology as a science and for the future of towns  
134 and their sustainability. The result of the corresponding discussions is synthesized  
135 below after the description of the research agenda. Overall, the collective work was  
136 relatively easy. At the beginning of the work, some definitions had to be clarified. For  
137 example, what ecology is as a science was not obvious for non-scientists and for  
138 scientists from other fields. Similarly, the diversity of ecological sub-fields had to be  
139 described and explained. Initially, the scientific questions that were proposed had to  
140 be sorted out and some of the questions were initially too vague or too broad to  
141 constitute a valid scientific question that can be realistically addressed by a set of  
142 experiments and measurements. However, it was relatively easy through discussions  
143 to reach an agreement on the type of questions that were sought.

### 144 **3. The research agenda**

145 All domains of ecology can be studied in urban areas (Alberti, 2007; Collins et al.,  
146 2000). This encompasses all types of organisms from microorganisms to large  
147 mammals and all types of ecosystems: marine ecosystems, fresh waters, terrestrial  
148 ecosystems, soils. This also encompasses all organization scales (population,  
149 community, ecosystem and landscape ecology) and all sub-disciplines of ecology

150 (population genetics, evolutionary ecology, behavioral ecology, functional ecology,  
151 ecophysiology...). The uniqueness of towns is the overwhelming influence of human  
152 activities, i.e. the fact that towns lead to novel man-made ecological systems  
153 (Kowarik, 2011). We thus first chose to organize questions according to three broad  
154 areas (Fig. 3 and Tables 1 to 3): (1) the biodiversity of organisms living in urban  
155 areas, (2) the functioning of urban organisms and ecosystems, (3) the interactions  
156 between human societies and urban ecological systems. The first pertains to  
157 population and community ecology, the second to functional and ecosystem ecology  
158 and the third to various human and social sciences (sociology, economy, geography,  
159 anthropology, philosophy...). The distinction between population and community  
160 ecology on the one hand and functional and ecosystem ecology on the other hand is  
161 classical in ecological sciences (Begon et al., 2005). The former corresponds broadly  
162 to issues related to the dynamics of individuals within populations and species within  
163 communities, while the later corresponds to issues based on fluxes of energy and  
164 matter at various organization scale (from individuals to ecosystems). Social and  
165 human sciences play an important role addressing issues (Table 3) about (1) the  
166 perception by humans of biodiversity and Nature in urban areas, (2) the governance  
167 of urban Nature and biodiversity, (3) ecosystem services and disservices provided by  
168 urban ecosystems. Many issues are at the interface between the three broad  
169 scientific areas (all three Tables). For example, it might be interesting to study how  
170 biodiversity (e.g. species richness of plants chosen by stakeholders for a park)  
171 influences ecosystem functioning (beyond the functioning of each plant species  
172 separately), how this can be translated in terms of ecosystem services (e.g. carbon  
173 storage) and how biodiversity and the provided services are perceived by citizens  
174 (and whether there are differences between different categories of citizens).



175           We have also organized research questions according to their position on the  
176 gradient between purely fundamental and applied scientific issues: the first column of  
177 Tables 1 to 3 lists rather fundamental questions while the second column lists rather  
178 applied questions. It may appear as a surprise that purely fundamental questions can  
179 be asked on the ecology and biodiversity of urban areas. On the one hand, the  
180 pervasive influence of humans in urban areas does not impede asking scientific  
181 questions solely aiming at describing and analysing patterns and mechanisms. It is  
182 possible to study the structure of communities of organisms in urban areas and the  
183 underlying ecological mechanisms, e.g. dispersal and competition, whatever the  
184 human influence on these mechanisms. On the other hand, for nearly all fundamental  
185 questions, it was also possible to find corresponding more applied questions (Table 1  
186 to 3). For example, when communities of organisms have been described and factors  
187 of the structure of these communities have been identified it is possible to ask  
188 questions on the way urban environment (e.g. through the management practices  
189 within parks or through the abundance and distribution of green areas) can be  
190 improved to favour communities with higher species richness. The same logic applies  
191 to questions pertaining to human and social sciences. For example, fundamental  
192 questions can be asked on the perception of urban Nature and biodiversity and  
193 underlying social and psychological mechanisms. This questioning can also be  
194 transformed to ask questions about the best methods to increase the knowledge of  
195 urban citizens on urban Nature and increase their awareness about Nature and the  
196 importance of this Nature for their well-being. Though we insisted during our  
197 discussions on the importance of asking standard fundamental ecological questions  
198 on urban ecological systems, this advocates, as others have done before (Barot et  
199 al., 2015), for a continuum between applied and fundamental questions in ecology

200 and the fact that it is rarely relevant to segregate applied and fundamental ecology.  
201 The main types of questions listed in the tables are outlined below.

202       *Urban biodiversity (Table 1)*. We first listed questions on how to monitor  
203 biodiversity in urban environments. This led to rather fundamental questions about  
204 the different methodologies to be developed but also to questions on the most  
205 adequate methodologies to monitor urban biodiversity with the goal of managing this  
206 biodiversity. The description of urban biodiversity is commonly justified by questions  
207 on the impact of urban environment on biodiversity (Kowarik, 2011). This leads to  
208 very diverse questions on the impact of all aspects of urban environment (from  
209 pollution and the heat-island effect to the spatial structure of the town) on all types of  
210 organisms (from micro-organisms to large mammals and trees). Again, these  
211 questions can be rather fundamental but become applied when the ultimate goal is to  
212 manage urban biodiversity. For example, the management of green spaces can be  
213 adapted to favour various groups of organisms. Besides describing urban biodiversity  
214 and designing means to favour it, many scientific questions arise about ecological  
215 mechanisms underpinning biodiversity: population dynamics, interactions within  
216 communities... We have only listed a few questions in this direction, but basically all  
217 fundamental issues traditionally addressed about the dynamics of biodiversity can be  
218 addressed in towns. This can involve testing general theories in an urban context,  
219 e.g. theories about food web functioning, and testing whether the patterns usually  
220 found in natural ecosystems can also be found in towns. It is obviously also important  
221 to ask questions about the Darwinian evolution of urban biodiversity (Alberti, 2015).  
222 What are the most important evolutionary pressures for urban organisms? Do towns  
223 lead to converging evolutionary dynamics all over the world? Are there cases of rapid  
224 evolution in urban environment?

225            *Functioning of urban ecosystems (Table 2)*. For the sake of clarity we have  
226 separated questions on the functioning of urban vegetation from questions on urban  
227 soils and aquatic ecosystems. As for biodiversity (Table 1), a first category of  
228 questions is about the description of the functioning of urban vegetation (e.g.  
229 photosynthesis, biomass production, uptake of mineral nutrients...) and urban soils  
230 (e.g. mineralization, nitrification...) and the way urban conditions impact this  
231 functioning (Pickett et al., 2008). Again, many of the questions are rather  
232 fundamental because they aim at understanding basic ecological mechanisms. For  
233 example, humans control or influence most water fluxes within towns and the  
234 consequences of these altered fluxes on the growth of street trees are poorly known.  
235 Indeed, the sources of water (e.g. rain water vs. various man-made water networks)  
236 for these trees and their strategy (distribution of roots) to absorb enough water have  
237 rarely been studied. In the same vein, many aspects of soil functioning remain to be  
238 studied. For example, it is poorly known how soil management (urban soils are often  
239 man-made) and the urban environment (e.g. local increases in atmospheric CO<sub>2</sub> due  
240 to fossil fuel combustion or the urban heat island effect) impact soil microbial  
241 communities and the functions they perform (mineralization, nitrification...). From  
242 these questions about ecosystem functioning arise questions about the  
243 consequences of this functioning in terms of provision of ecosystem services and  
244 disservices. What are the types of service provided by urban ecosystems? How  
245 much services are provided? Questions about the relations between human aspects  
246 of ecosystem services are gathered in Table 3 (see below). But it is possible to ask  
247 here (Table 2) questions about the purely ecological aspects of these services, i.e.  
248 depending solely on the measurement of ecosystem functions. These questions  
249 become much more applied if the possible ways to increase the provision of services

250 are addressed (Gómez-Baggethun and Barton, 2013). This leads to questions about  
251 ecological engineering (Barot et al., 2012; Mitsch and Jørgensen, 2003). It could for  
252 example be possible to increase the ability of a green space to reduce the heat island  
253 effect by evapotranspiration through the choice of suitable tree species. It could be  
254 possible to store more carbon in urban soils through suitable inputs of organic matter  
255 or through particular ways to construct the soils. The same types of question can be  
256 asked for totally artificial ecological systems such as green roofs. They have been  
257 shown to provide services, but how to optimize the provision of services through the  
258 design and management of these roofs and facades is not fully known.

259 *Urban systems as socio-ecosystems (Table 3).* Three types of questions have  
260 been listed here at the frontier between ecological and human sciences: questions  
261 about (1) the perception of Nature and biodiversity by city dwellers (Lo and Jim,  
262 2010), (2) the governance of towns (Wilkinson et al., 2013), (3) ecosystem services  
263 (Andersson et al., 2015). The proportion of humans living in cities is rapidly  
264 increasing and, at least in some towns (Europe, North America, some parts of Asia),  
265 the amount of Nature is tending to increase. The contact between humans and  
266 Nature is therefore becoming proportionally more and more frequent within cities  
267 (Shwartz et al., 2014). It is thus important to ask questions about the perception of  
268 urban ecosystems and their biodiversity (Lo and Jim, 2012) and whether this may  
269 also modify the overall perception of Nature by humans (Standish et al., 2013). This  
270 leads to rather fundamental questions pertaining to sociology and psychology. These  
271 questions become applied when research has a precise goal, e.g. finding ways to  
272 increase the awareness of city dwellers of Nature. Many questions arise about the  
273 governance of biodiversity in towns. The actual situation can be described and  
274 analysed: What are the places and government authorities influencing urban

275 biodiversity? Are there specific legislations influencing urban biodiversity? The same  
276 types of question may be addressed to help reach specific goals, i.e. to develop a  
277 suitable governance to favour urban biodiversity. Besides the assessment of  
278 ecological functions leading to ecosystem services (see Table 2) many questions  
279 arise on the links between ecosystem services and the life of urban dwellers (Gómez-  
280 Baggethun et al., 2013). First, it is important to develop sound methodologies to  
281 assess services linked to human health, human psychological well-being and cultural  
282 services. Some basic general questions also arise about services: Are there trade-  
283 offs between the ecosystem services provided by urban ecosystems? Are there  
284 differences in the access to services between socio-professional categories?  
285 Second, the notion of ecosystem services is more and more viewed as a tool to  
286 improve the management of ecosystems. However, the way to incorporate  
287 assessments of ecosystem services in the governance of Nature is not  
288 straightforward (Laurans et al., 2013) and research could be implemented on how to  
289 better use the assessment of ecosystem services in the management of towns.

#### 290 **4. Implementing the research agenda**

291 Some research areas require a particular attention. As usual in biodiversity sciences,  
292 urban ecologists started by studying large organisms such as birds, mammals and  
293 plants. There are currently an increasing number of studies in urban areas on insects  
294 (Madre et al., 2013), soil invertebrates (Vergnes et al., 2017) or microorganisms  
295 (Ramirez et al., 2014) and this trend will likely continue. In the same vein, scientists  
296 often start by describing patterns, e.g. the distribution of organisms within towns, but  
297 it is more difficult to determine the ecological mechanisms behind these patterns, e.g.  
298 measuring dispersal and survival rates. However, ecology is precisely about linking  
299 mechanisms to their consequences and more effort should be directed towards this

300 area of urban ecology. This is true for studies pertaining to population/ community  
301 ecology but also for studies pertaining to functional ecology. For example, there are  
302 few studies on the basic functioning of widespread urban types of vegetation such as  
303 lawns and street trees. It is thus hardly known how the nitrogen budget of urban  
304 lawns is balanced and the respective influence of soil micro-organisms and  
305 atmospheric deposits on this budget. Similarly, while street trees are seen as  
306 providing services (reduction in the heat island effect) and disservices (roots may  
307 damage buildings and pavement)(Mullaney et al., 2015) the ecophysiology of these  
308 trees is poorly known (but see David et al., 2018).

309         The services (and disservices) provided by classical urban ecosystems (parks,  
310 street trees...) and by relatively new types of man-made ecosystems (green roofs,  
311 vegetated facades) are being increasingly assessed (Lundholm and Cadotte, 2015;  
312 Mullaney et al., 2015) and these services are often used as arguments to promote  
313 these ecosystems. However, practices are often developing quicker than the  
314 supporting scientific knowledge or independently of the existing knowledge so that  
315 the real benefits of urban green infrastructures are still not fully documented and a  
316 comprehensive approach of ecological engineering (Barot et al., 2012; Mitsch and  
317 Jørgensen, 2003) is often missing. This is due to a common mismatch between the  
318 research time scale on the one hand and the economic and political timescale on the  
319 other hand. This probably impedes optimizing the design and management of green  
320 infrastructures such as green roofs and vegetated facades. Developing such an  
321 approach requires at least five research steps: (1) identifying the ecosystem services  
322 that can be provided, (2) identifying the links between these services and ecological  
323 functions, (3) determining the links between all features of green infrastructures and  
324 ecological functions, (4) identifying links and trade-offs between services and

325 disservices, (5) assessing the various costs (especially environmental costs) of the  
326 construction and management of these infrastructures (Barot et al., 2017). In the  
327 case of green roofs, steps (1), (2) and (4) have at least partially been achieved  
328 (Madre et al., 2013), while steps (3) and (5) have only been tackled very partially  
329 (Dusza et al., 2017; Lundholm and Cadotte, 2015). This impedes the determination  
330 of the best green roof substrate (e.g. artificial substrate vs. natural soil, clay content  
331 or organic matter content), the best substrate depth, or the best plant combination to  
332 store carbon, regulate stormwater, purify rain water or favour invertebrate  
333 biodiversity. A key issue is that studying the long term dynamics (at least 10 years) of  
334 man-made ecosystems such as green roofs is necessary to assess their  
335 sustainability. However, such long-term studies are scarce.

336         One of the goals of ecology is to delineate general rules and theories.  
337 However, there are hitherto very few general theories about urban biodiversity and  
338 ecosystems. To our knowledge, the only general rule recognized in urban ecology is  
339 that urbanization leads to biotic homogenization. At the global scale, because towns  
340 are built to meet relatively homogenous human needs, they display homogeneous  
341 physical environments (Clergeau et al., 2001) that tend to homogenize the town flora  
342 and fauna (Schwartz et al., 2006). Worldwide, urban environments select organisms  
343 that are adaptable to towns and often replacing native-species. These species tend  
344 to be early-successional species with good dispersal abilities and are often  
345 introduced by humans. Similarly, it is largely recognized that urbanization leads to  
346 unique eco-evolutionary dynamics (Alberti, 2015): rapid feedbacks between  
347 evolutionary and ecological dynamics likely modify community and ecosystem  
348 functioning in urban environments. Much research is still required to describe and  
349 analyse these dynamics. A recent study also suggested that vegetation growth is

350 enhanced in the urban environment of 32 major Chinese cities (Zhao et al., 2016),  
351 but this should be tested further at the global scale in order to disentangle the  
352 underlying mechanisms.

353 Our work focused on European towns. While the types of question we list are  
354 relevant worldwide some of our thoughts and comments are mostly valid for  
355 European towns and partially valid for North-American towns. A difficulty in  
356 developing general theories for urban ecology is that modes of urbanization are  
357 relatively diverse. In particular, urbanization dynamics are now relatively slower in  
358 already developed countries than in developing countries (Seto et al., 2011). In  
359 parallel, towns of the old world may be centuries-old or even millenaries-old while  
360 towns of the new world and developing countries are usually much younger  
361 (Ramalho and Hobbs, 2012). This leads to important differences in the structure of  
362 towns, the type of building or the proportion of green spaces. These differences  
363 between towns and countries will likely impact urban biodiversity and the functioning  
364 of urban ecosystems. These issues deserve further research. In particular, much  
365 fewer studies have been carried on the ecology and biodiversity of towns in  
366 developing countries, e.g. in Africa, which is all the more regrettable as social,  
367 environmental and biodiversity issues are huge in these towns (McHale et al., 2013).

## 368 **5. Impact of urban ecology on the development of ecological sciences**

369 The development of urban ecology is having a profound influence on the  
370 development of ecological sciences. We have shown that this influence is  
371 quantitative (Fig. 1) and outline below some qualitative aspects of this impact.

372 Urban areas represent already ongoing experiments waiting for scientists to  
373 study them. This can, for example, allow the testing in towns of theories developed  
374 independently of urban ecology (Mc Donnell and Pickett, 1990). In particular, towns



375 display gradient of artificialization that can be studied as such (see for example Foti  
376 et al., 2017; Zhao et al., 2016) and towns with different structures and characteristics  
377 can be compared (Clergeau et al., 1998). For example, urban landscapes allow  
378 studying the functioning of meta-populations and meta-communities of urban  
379 organisms (Hamer and McDonnell, 2008; Vergnes et al., 2013) that depend on the  
380 size and the connectivity between patches favourable to these organisms, e.g. green  
381 spaces. Other ecological theories such as the intermediate disturbance hypothesis  
382 can be tested in urban landscapes (Breuste et al., 2008) with the hypothesis that  
383 species richness could be maximum at intermediate positions on the urban-rural  
384 gradient. Towns also provide original situations that can be used in functional  
385 ecology. For example, urban conditions often lead to higher temperatures and higher  
386 CO<sub>2</sub> concentrations mimicking some aspects of climate changes that are difficult to  
387 reproduce in long term experiments on vegetation and soils. Man-made soils in urban  
388 areas also constitute original experiments. For instance, the soils of street trees  
389 hardly receive any aboveground litter since soils are generally sealed a part from a  
390 small opening around trees and since dead leaves are generally gathered and  
391 exported. Overall, while new theories may not be required in urban ecology, urban  
392 ecology should contribute to ecological theories (Niemelä, 1999).

393         Since the proportion of human urban dwellers is still increasing, urban ecology  
394 constitutes a kind of acid test or showcase for ecological sciences, as already  
395 emphasized in the particular case of ecological engineering (Mitsch and Jørgensen,  
396 2003) and the general case of applied ecology (Barot et al., 2015). If ecologists  
397 succeed in (1) understanding urban ecological systems, (2) making precise enough  
398 predictions on these systems and their dynamics, (3) designing efficient ways to  
399 manage these systems and (4) increasing the well-being of urban dwellers using

400 ecosystem services and biodiversity, they will demonstrate the value of their science  
401 that is often underestimated and misunderstood. Indeed, it is important to convince  
402 human societies to change their relation with the biosphere in a context where the  
403 sustainability of this relation is threatened (Steffen et al., 2015). Urban ecology is also  
404 becoming an important showcase for ecological engineering. Towns allow the  
405 creation of totally man-made ecosystems that are inherently more diverse in terms of  
406 the ecosystems services that can be provided than, for example, agricultural lands  
407 that must above all produce food. This should favour the development of a real  
408 ecological engineering of services and multifunctionality that goes far beyond the  
409 mere management of ecosystems. For example, roof complex ecosystems could be  
410 created to recycle wastewater and produce vegetables and fishes.

411         An important still ongoing evolution is that ecologists have first studied ecology  
412 and biodiversity in towns, e.g. studying population of organisms as they would in any  
413 natural ecosystem, but are more and more studying the ecology of towns as complex  
414 ecological systems. In particular, research more and more tackles the complexity of  
415 the nested structure of urban ecosystems (Breuste et al., 2008; Clergeau et al.,  
416 2006). It is possible to study ecological processes at the scale of (1) a local green  
417 space (e.g. demography of a plant population), (2) a network of green spaces (e.g.  
418 the meta-population of a plant and fluxes of propagules between green spaces), (3)  
419 the matrix between green spaces where some organisms live or spend a part of their  
420 time, (4) a town and its urban-rural gradient (e.g. fluxes of plant propagules between  
421 the rural and urban areas), (5) a network of towns (e.g. to study an invasive species  
422 colonizing towns depending on town characteristics and distances between towns).  
423 Of course, with the development of landscape ecology (Forman, 1995), ecological  
424 sciences did not have to wait for the development of urban ecology to study such

425 complex systems. However, the way urban ecology analyses and understands  
426 spatially complex ecological systems is influential beyond the mere community of  
427 urban ecologists.

428         As shown by our tables (Tables 1-3) and by the functioning of our working  
429 group, a particularity of urban ecology is that scientific questions quickly require the  
430 intermingling of questions pertaining to natural sciences and human sciences. This  
431 leads to the study of the complex feedbacks between urban ecosystems and human  
432 societies, i.e. to study towns as complex social-ecological systems (Alberti et al.,  
433 2003). This in turn leads to many new scientific questions at the interface between  
434 various scientific fields. For the same reasons, research on urban ecosystems and  
435 biodiversity nearly always involves stakeholders, from town citizens, to gardeners or  
436 town councillors. This means that research is often orientated by these stakeholders,  
437 which again leads to new scientific questions. Conversely, research results in urban  
438 ecology tend to be quickly disseminated to the stakeholders, who in turn tend to use  
439 them quickly. For example, implementing experiments on green roofs requires  
440 working with the owners of the buildings supporting green roofs, and if results allow  
441 designing efficient green roofs, the owners are likely to develop more green roofs on  
442 new buildings. Overall this gives scientists important responsibilities and leads in  
443 urban ecology to very quick feedbacks between sciences and the society. Again,  
444 ecology has not waited for urban ecology to tackle issues related to social-ecological  
445 systems and the involvement of stakeholders often leads to new ways to practice  
446 science in many areas of ecology. Nevertheless, urban ecology is currently playing a  
447 critical role in developing these aspects, which somehow contributes to the current  
448 evolution of ecological sciences.

449 **6. Conclusion**

450 We have emphasized many scientific issues that deserve research but what is  
451 eventually at stake is the future of towns, the life of city dwellers and urban  
452 biodiversity. Depending on the research that is carried out and the way its results are  
453 taken into account in designing towns, very different towns could emerge in the near  
454 future. One underlying general scientific, social and political issue is: Do we need to  
455 increase biodiversity in towns? For whom? With which goal? One possible model is  
456 the model of smart cities (Batty et al., 2012; Caragliu et al., 2011). The concept is still  
457 fuzzy and there is no strict contradiction between smart cities and the promotion of  
458 urban Nature. However, promoters of smart cities insist on Information and  
459 Communication Technologies (ICT) and the way to optimize traditional infrastructure  
460 (buildings, transportation...) and tend to forget about environmental problems and  
461 biodiversity, besides optimizing the use of energy. Technologies and specifically  
462 information technologies can potentially be used to foster biodiversity or to increase  
463 the provision of ecosystem services, however technologies are often viewed as a  
464 way to replace ecological mechanisms and all technologies have environmental  
465 costs, even information technologies. In fine, we must decide how much air  
466 conditioning will be optimized by ICT and how much the urban heat island will be  
467 attenuated by a profusion of green spaces, in the line of ecological engineering  
468 (Barot et al., 2017). We must also decide how much urban agriculture should be  
469 based on soft technologies and the principles of agro-ecology or ecological  
470 engineering and how much urban agriculture should go towards industrialized  
471 farming and hard technologies (e.g. vegetables cultivated in containers using LEDs  
472 as sources of light or vertical farms in towers). This is a matter of individual, cultural  
473 and political choice but science must document the consequences and the

474 sustainability of the various options. Because the stakes are very high and because  
475 of the pervasive entanglement of fundamental and applied issues, urban ecology  
476 must also develop a strong ethic.

477         More and more humans are living in towns and urban planners are tending  
478 towards an increase in the amount of Nature within towns, creating a situation  
479 propitious for strong feedbacks between Nature and humans in urban areas. It is  
480 therefore possible to see urban areas as a test and a laboratory for the future of the  
481 interactions between human and ecological systems (Elmqvist et al., 2013; Standish  
482 et al., 2013): (1) The perception of Nature by city dwellers is more and more forged  
483 by what they perceive of urban ecosystems and biodiversity. Consequently,  
484 understanding mechanisms behind this perception should help understanding the  
485 general perception of Nature. Conversely, if urban dwellers see more clearly (for  
486 example because of active education programs) their dependence on ecological  
487 systems and biodiversity or the need for more Nature this could help protecting  
488 biodiversity at the biosphere scale, for example because most policy makers are  
489 town dwellers. In this context, citizen sciences dealing with biodiversity and  
490 environmental issues are quickly developing within towns and could further help  
491 changing the perception of Nature (Kobori et al., 2015). Indeed, citizen sciences  
492 allow constructing a shared knowledge and may help convincing urban dwellers that  
493 they depend on biodiversity and ecosystem services. It has also been suggested that  
494 the increase in the proportion of urban dwellers is partially responsible for the  
495 worldwide extinction of experience of biodiversity but that reintroducing biodiversity in  
496 towns is a good leverage to fight this extinction of experience and make the case for  
497 Nature conservation (Miller, 2005). This supports the possibility of an urban  
498 reconciliation ecology (Francis and Lorimer, 2011). (2) The design and management

499 of towns can either leave an important space to biodiversity and Nature or totally  
500 annihilate biodiversity, which is also the alternative at the biosphere scale. Thus,  
501 understanding mechanisms behind the way the future of urban biodiversity is decided  
502 could help understanding feedbacks between humans and ecological systems at the  
503 biosphere scale. An advantage of studying these feedbacks at the town scale is that  
504 they are probably quicker at this scale than at the global scale. (3) Urban areas  
505 condense many environmental problems and have a huge impact on the biosphere  
506 (e.g. consumption of resources and source of pollution) (Seto et al., 2012) so that  
507 solving environmental problems in towns will also aid in solving environmental  
508 problems at larger scales. (4) Urban areas also condense many social problems that  
509 interact with environmental problems, e.g. Nature plays an important role in the  
510 quality of life and there are social inequalities in the availability of green spaces and  
511 Nature (Heynen et al., 2006). It is thus important to jointly solve environmental and  
512 social problems in urban areas. To this end, gathering all the necessary knowledge  
513 using ecological and human sciences is of paramount importance.

514 Finally, the diversity of scientific questions we have listed has been made  
515 possible because of the joint action of stakeholders and scientists from various fields.  
516 We believe that this type of collaborative work could help implementing the research  
517 agenda through a mutual agreement on (1) the relevance of both applied and  
518 fundamental scientific questions, (2) what is at stake behind those questions. The  
519 whole process could, for example, help in raising research funding and favour the  
520 direct involvement of stakeholders in research.

## 521 **Acknowledgments**

522           We thank the Foundation for Research on Biodiversity for its financial support  
523 that was essential for the functioning of the group and the organization of the  
524 workshops.

525

526 **References**

527

528 **Table 1**

529 List of questions on urban biodiversity

<b>Fundamental issues</b>	<b>Applied issues</b>
<b>Methods, measurements and indicators to study biodiversity</b>	
How should urban biodiversity be described and monitored?	Can we define indicators that could help manage urban biodiversity?
How should indicators to monitor urban biodiversity be defined?	
How should long term observatories for urban biodiversity be set up?	
How can citizen sciences be used to study urban biodiversity?	
<b>Impact of urban environment on biodiversity</b>	
Is the biodiversity of the different types of ecosystem (e.g. aquatic vs. terrestrial) impacted in the same way?	
Are all types or organisms (e.g. mammals, birds, insects, fishes, soil fauna, and microorganisms) impacted in the same way?	
<b>How do the characteristics of the urban environment impact biodiversity?</b>	<b>How to increase biodiversity in urban environment?</b>
Impact of artificial light?	How to decrease the negative impact of artificial light?
Impact of various types of pollution in the air, soils and waters?	How to mitigate the impacts of pollution?
Impact of urban climate? (heat island ...)	Is it possible to mitigate negative impacts of urban climate on biodiversity?
Impact of the spatial structure of towns? (connectivity, % of green spaces, size of towns...)	How to improve the structure of towns to increase biodiversity?
	How to reconcile high urban human densities and biodiversity?
	How to reconcile large urban projects (e.g. large shopping centres, towers) and biodiversity?
	How to develop green and blue networks to maximize biodiversity?
	Is it possible to use transport infrastructures to increase biodiversity?
Impact of construction type and the vertical structure of towns (e.g. houses, vs. small building vs. tall buildings)?	Is it possible to favour biodiversity through construction and rehabilitation projects?



Impact of the way constructions are built (e.g. type of materials) at various scales (from the building, to the town and the region)?	Is it possible to develop building materials that are more favourable to the biodiversity living on buildings?
	Is it possible to develop building materials that are less detrimental to biodiversity through their whole life cycle?
Impact of the management of green spaces?	How to optimize green space management for biodiversity?
Impact of urban agriculture?	How to optimize urban agriculture for biodiversity?
Impact of street trees?	How to optimize street trees (species, density, and management) for biodiversity?
Impact of green roofs and vegetated facades?	How to optimize green roofs and vegetated facades for biodiversity?

### Underlying mechanisms

Do species colonizing and living in towns have particular characteristics? (life cycle, dispersion ability, specialist or generalist species...)

Do organisms have the same population dynamics in urban environments and in non-urban environments?

Do communities have particular characteristics in urban environments? (total biodiversity, structure, functional diversity...)

Do food webs have particular characteristics in urban environments?

#### **Does the urban environment lead to the local evolution of organisms?**

What are the most important selection pressures?

How should we take into account the evolution of organisms in towns for the well-being of city-dwellers? For example, in the case of disease vectors such as mosquitos.

What is the respective importance of plasticity and evolution in phenotypic changes?

Do towns lead to converging evolutionary dynamics all over the world?

Are there cases of rapid evolution in urban environments?

530

531 **Table 2**

532 List of questions on the functioning of urban ecosystems

**Fundamental issues**

**Applied issues**

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## Functioning of vegetation

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**What are the impacts of the urban environment on vegetation? (photosynthesis, plant growth, uptake of mineral nutrients, uptake of water...)**

Impact of air pollution (CO<sub>2</sub>, ozone, nitrogen oxides...)?

Impact of climate (e.g. heat island)?

Impact of soil pollution (e.g. heavy metals)?

Impact of light pollution?

Impact of soil management and soil age?

Impact of human control on water fluxes (soil sealing)?

**What are the services provided by vegetation in urban areas? (quantitative and qualitative assessment)**

By street trees?

**How to manage vegetation in urban areas to increase the provision of ecosystem services?**

Influence of the choice of planted species?

By parks?

Influence of watering?

By woods?

Influence of park management?

By green roofs?

Is it possible to optimize green roofs for the provision of services?

By rivers, canals and lakes?

Are there trade-offs between services?

How to increase the provision of several services at the same time?

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## Functioning of soils

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What are the characteristics of urban soils?

What are their dynamics?

Do urban soils have a different functioning from non-urban soils? (e.g. mineralization, nitrification...)

What is the impact of the urban environment (climate, management of parks...) on soil functioning?

**What are the services provided by urban soils?**

**Can we manage urban soils to provide more ecosystem services?**

What is the capacity of urban soils to store carbon?

How can the storage of carbon be increased in urban soils?

What is the capacity of urban soils to release / avoid the release of other greenhouse gases (e.g. N<sub>2</sub>O)?

How can the capacity of urban soils to regulate fluxes of greenhouse gases be increased?

What is the capacity of urban soils to regulate water fluxes (stormwater)?	Is it possible to increase the capacity of urban ecosystems to regulate water fluxes?
	Can urban soils help recycling urban wastes (organic waste, sewage sludge)?
	How to create soils using building waste and other urban waste?
	How to optimize substrates for green roofs?
	How to optimize substrates for urban agriculture?
	Are there sanitary risks related to the recycling of urban wastes?
	Can we optimize the management of soils at the scale of towns and surrounding areas (e.g. fluxes of soils from crop lands to parks, fluxes of urban polluted soils...)?
	What role can play soil fauna in the creation of substrates for green roofs and urban agriculture and for waste recycling?

### **Functioning of aquatic ecosystems**

Do urban aquatic ecosystems have a different functioning from their non-urban equivalents?	Can we manage urban aquatic ecosystems to provide more ecosystem services?
What is the impact of urban environment on the functioning of aquatic ecosystems?	
How does the urban environment impact the mineral nutrient and dissolved organic matter contents of urban aquatic systems?	How can the sanitary quality of urban aquatic systems be improved?
How do human activities impact the sanitary quality of urban aquatic systems?	Can ecological engineering help improving the sanitary quality of urban aquatic systems?
What is the accumulation of xenobiotic substances and trace elements along the food webs of urban aquatic ecosystems?	

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536 **Table 3**

537 List of questions on the coupled functioning of urban ecological systems and human  
 538 societies

<b>Fundamental issues</b>	<b>Applied issues</b>
<b>Perception of Nature in urban areas</b>	
<b>What is the perception of urban Nature and biodiversity by city-dwellers?</b>	<b>Why and how can the awareness of city-dwellers to Nature and biodiversity be increased?</b>
What is the perception of green spaces (including lakes and rivers)?	Can the increase of city-dweller awareness to Nature help changing their relation to Nature in general?
What is the perception of soils?	Can the increase of city-dweller awareness to Nature help linking rural and urban people?
What is the perception of street trees?	How can be various audiences (age, socio-professional category) be targeted by these efforts to increase awareness?
What is the perception of ordinary biodiversity?	
Is the provision of services recognized? How is it perceived?	
Is Nature accepted in towns? Has this changed with time?	
How do these perceptions depend on sex, age, socio-professional category, size of the town, the level of development of the country?	
Can citizen sciences or urban agriculture help changing the perception of Nature and biodiversity in towns?	
<b>Governance and public policies</b>	
What are the places / government authorities for the governance of urban Nature and biodiversity at the town scale or at larger scales?	How can citizens be associated to the governance of urban Nature and biodiversity?
Can the governance of Nature and biodiversity in towns serve as a model of governance for human-nature relations in general?	How can public policies and private activities be linked for the governance of urban biodiversity?
What are the differences in the governance of Nature between towns of different continents and countries with different levels of economic development?	What are the institutional, economic and legal obstacles to the development of urban Nature and biodiversity?
What is the impact of the features of the governance of urban Nature on urban biodiversity?	What fiscal and economic levers could favour the development of urban Nature and biodiversity?
Are there specific legislations for urban biodiversity and ecosystems?	What levers could favour the development of innovative green infrastructures?

How does the legislation impact urban ecosystems and biodiversity?	How can the management of urban biodiversity over various spatial scales be improved while these scales depend on different administrative divisions and types of administrative divisions?
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### **Ecosystem services**

#### **How can ecosystem services be assessed in urban areas?**

How can the services and disservices linked to human health be assessed?

How can the services linked to psychological well-being be assessed?

How can cultural services be assessed?

Can the costs avoided thanks to urban ecosystems be assessed?

What is the demand for ecosystem services in urban areas?

#### **How can the assessment of ecosystem services in urban areas be used?**

Can the assessment of urban ecosystem services be used to guide the governance of towns?

What role can the assessment of ecosystem services and the optimization of their provision play in the design of sustainable cities?

Are there trade-offs between services (e.g. between aesthetic, cultural and regulation services?)

Is it possible to optimize the provision of ecosystem services by urban areas in a multi-functional approach?

Are there differences in the access to urban Nature and ecosystem services between socio-professional categories?

Can urban and peri-urban agricultures play a significant role in the provision of food?

Can the assessment of ecosystem services be used to increase the health of city dwellers?

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543 **Fig. 1.** Number of publications in urban ecology and their percentage relatively to the  
544 total number of publications in ecology from 1980 to 2015. The Web of Science (Web  
545 of Science Core Collection) was used to search for articles mentioning “urban” AND  
546 “ecology” in the topics (i.e. in the title, abstract and keywords) to assess the number

547 of articles in urban ecology while the total number of articles in ecology was  
548 assessed searching the same data base for “ecology” in the topics.

549

550 **Fig. 2.** General organization of the collective work used to build the research agenda.

551

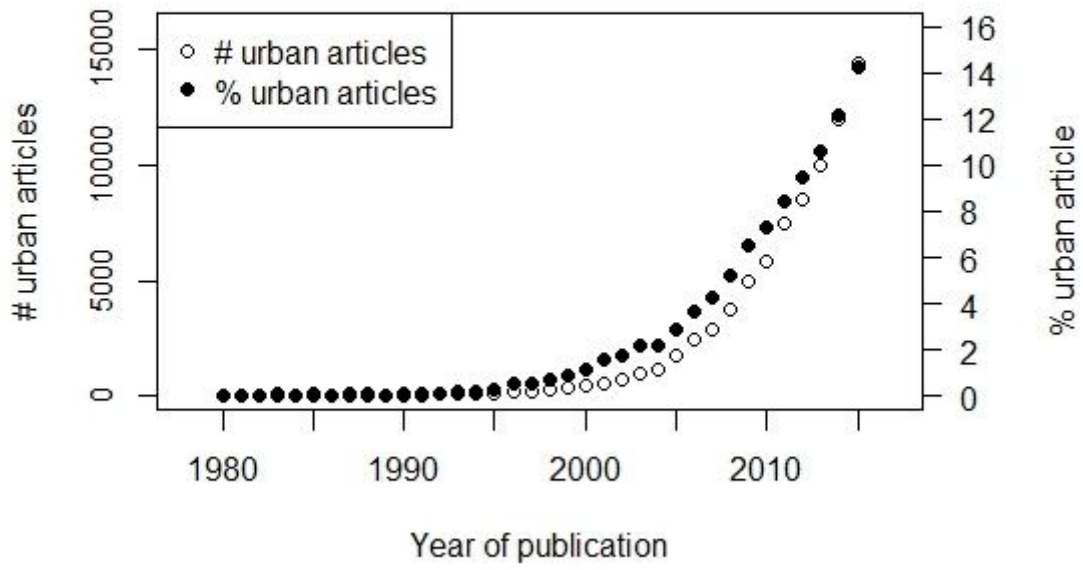
552 **Fig. 3.** Diagram describing interactions between humans, biodiversity and ecosystem  
553 functioning in urban environments and displaying accordingly the organization of the  
554 research agenda (See Tables 1 to 3) in three broad types of question and in  
555 fundamental (understanding) and applied (managing) issues.

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558 Fig. 1

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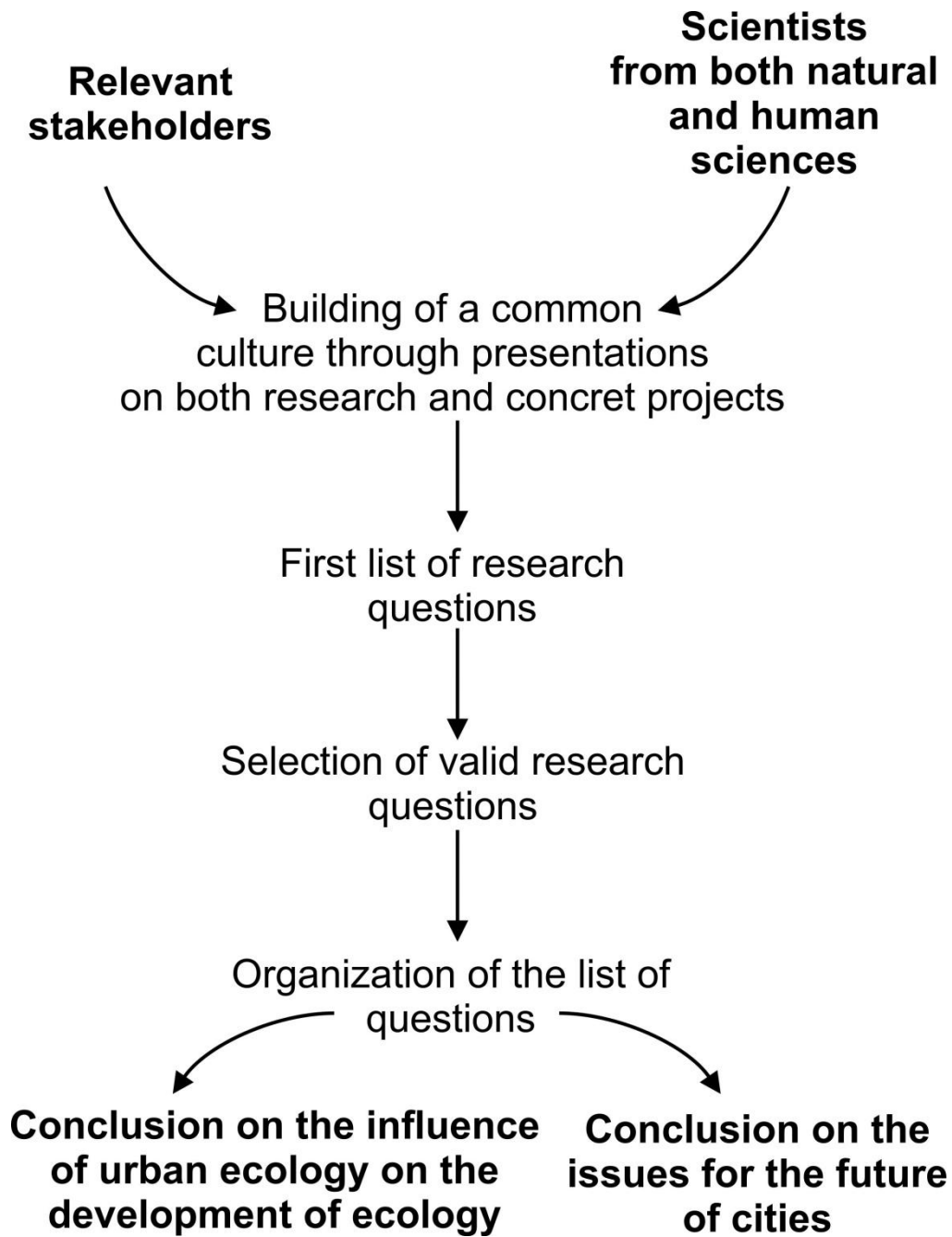
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563 Fig. 2

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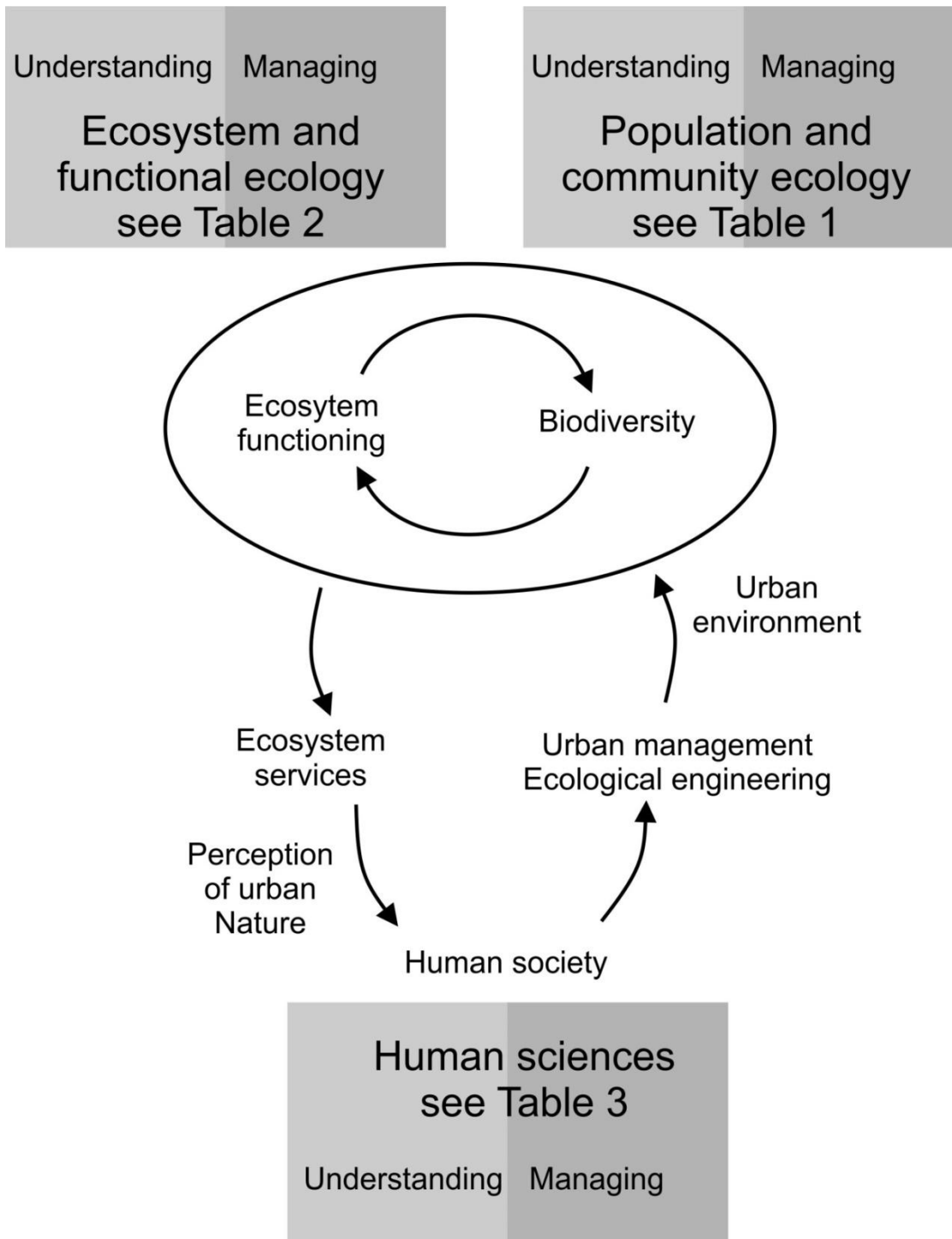
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567 Fig. 3

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- 574 Alberti, M. 2007. *Advances in urban ecology*: Springer.
- 575 Alberti, M., 2015. Eco-evolutionary dynamics in an urbanizing planet. *Trends Ecol.*  
576 *Evol.* 30 (2), 114-126.
- 577 Alberti, M., Marzluff, J.M., Shulenberger, E., Bradley, G., Ryan, C., Zumbrunnen, C.,  
578 2003. Integrating humans into ecology: opportunities and challenges for  
579 studying urban ecosystems. *BioScience.* 53 (12), 1169-1179.
- 580 Andersson, E., Tengö, M., McPhearson, T., Kremer, P., 2015. Cultural ecosystem  
581 services as a gateway for improving urban sustainability. *Ecos. Serv.* 12, 165-  
582 168.
- 583 Barot, S., Abbadie, A., Couvet, D., Hobbs, R.J., Lavorel, S., Mace, G.M., et al., 2015.  
584 Evolving away from the linear model of research: a response to Courchamp et  
585 al. *Trends Ecol. Evol.* 30 (7), 368–370.
- 586 Barot, S., Lata, J.-C., Lacroix, G., 2012. Meeting the relational challenge of ecological  
587 engineering. *Ecol. Eng.* 45, 13-23.
- 588 Barot, S., Yé, L., Abbadie, L., Blouin, L., Frascaria, N., 2017. Ecosystem services  
589 must tackle anthropized ecosystems and ecological engineering. *Ecol. Engin.*  
590 99, 486-495.
- 591 Batty, M., Axhausen, K.W., Giannotti, F., Pozdnoukhov, A., Bazzani, A., Wachowicz,  
592 M., et al., 2012. Smart cities of the future. *Europ. Phys. J. Spec. Top.* 214 (1),  
593 481-518.
- 594 Begon, M., Colin, R.T., Harper, J.L. 2005. *Ecology: From Individuals to Ecosystems*:  
595 John Wiley & Sons.
- 596 Berkes, F., 2009. Evolution of co-management: role of knowledge generation,  
597 bridging organizations and social learning. *J. Environ. Manage.* 90 (5), 1692-  
598 702.
- 599 Breuste, J., Niemelä, J., Snep, R.P.H., 2008. Applying landscape ecological  
600 principles in urban environments. *Landscape Ecol.* 23 (10), 1139-1142.
- 601 Caragliu, A., Del Bo, C., Nijkamp, P., 2011. Smart Cities in Europe. *J. Urban Tech.*  
602 18 (2), 65-82.
- 603 Clergeau, P., Jokimäki, J., Snep, R., 2006. Using hierarchical levels for urban  
604 ecology. *Trends Ecol. Evol.* 21 (12), 660-661.
- 605 Clergeau, P., Jokimäki, S., Savard, J.-P., 2001. Are urban bird communities  
606 influenced by the bird diversity of adjacent landscapes? *J. Appl. Ecol.* 28 (5),  
607 1122–1134.
- 608 Clergeau, P., Savard, J.-P.L., Mennechez, G., Falardeau, G., 1998. Bird abundance  
609 and diversity along an urban-rural gradient: a comparative study between two  
610 cities on different continents. *The Condor.* 100 (3), 413-425.
- 611 Collins, J.P., Kinzig, A., Grimm, N.B., Fagan, W.F., Hope, D., Jianguo Wu, J., et al.,  
612 2000. A new urban ecology. *Am. Scientist.* 88, 416-425.
- 613 David, A.A.J., Boura, A., Lata, J.-C., Rankovic, A., Kraepiel, Y., Charlot, C., et al.,  
614 2018. Street trees in Paris are sensitive to spring and autumn precipitation and  
615 recent climate changes. *Urban Ecosystems.* 21 (1), 133-145.
- 616 Dusza, Y., Barot, S., Kraepiel, Y., Lata, J.-C., Abbadie, L., Raynaud, X., 2017.  
617 Multifunctionality is affected by interactions between green roof plant species,  
618 substrate depth and substrate type. *Ecol. Evol.* 7 (7), 2357–2369.
- 619 Elmqvist, T., Fragkias, M., Goodness, J., Güneralp, B., Marcotullio, P.J., McDonald,  
620 R.I., et al. 2013. Stewardship of the biosphere in the urban era. In: Elmqvist T,  
621 Fragkias M, Goodness J, Güneralp B, Marcotullio PI, McDonald RI, et al.,

622 editors. *Urbanization, biodiversity and ecosystem services: challenges and*  
623 *opportunities*. Springer, Dordrecht, pp. 719-746.

624 Forman, R.T.T., 1995. Some general principles of landscape and regional ecology  
625 *Landscape Ecol.* 10 (3), 133-142.

626 Foti, L., Dubs, F., Gignoux, J., Lata, J.-C., Lerch, T.Z., Mathieu, J., et al., 2017. Trace  
627 element concentrations along a gradient of urban pressure in forest and lawn  
628 soils of the Paris region (France). *Sci. Tot. Envir.* 598, 938-948.

629 Francis, R.A., Lorimer, J., 2011. Urban reconciliation ecology: the potential of living  
630 roofs and walls. *J. Environ. Manage.* 92 (6), 1429-37.

631 Gómez-Baggethun, E., Barton, D.N., 2013. Classifying and valuing ecosystem  
632 services for urban planning. *Ecol. Econ.* 86, 235-245.

633 Gómez-Baggethun, E., Gren, Å., Barton, D.N., Langemeyer, J., McPhearson, T.,  
634 O'Farrell, P., et al. 2013. Urban ecosystem services. In: Elmqvist T, Fragkias  
635 M, Goodness J, Güneralp B, Marcotullio PI, McDonald RI, et al., editors.  
636 *Urbanization, biodiversity and ecosystem services: challenges and*  
637 *opportunities*. Springer, Dordrecht, pp. 629-664.

638 Hamer, A.J., McDonnell, M.J., 2008. Amphibian ecology and conservation in the  
639 urbanising world: A review. *Biol. Cons.* 141 (10), 2432-2449.

640 Heynen, N., Perkins, H.A., Roy, P., 2006. The Impact of political economy on race  
641 and ethnicity in producing environmental inequality in Milwaukee. *Urban*  
642 *Affairs Review.* 42 (1), 3-25.

643 Kobori, H., Dickinson, J.L., Washitani, I., Sakurai, R., Amano, T., Komatsu, N., et al.,  
644 2015. Citizen science: a new approach to advance ecology, education, and  
645 conservation. *Ecol. Res.* 31 (1), 1-19.

646 Kowarik, I., 2011. Novel urban ecosystems, biodiversity, and conservation. *Environ.*  
647 *Pollut.* 159 (8-9), 1974-83.

648 Laurans, Y., Rankovic, A., Billet, R., Pirard, R., Mermet, L., 2013. Use of ecosystem  
649 services economic valuation for decision making: questioning a literature  
650 blindspot. *J Environ. Manag.* 119, 208-19.

651 Lo, A.Y.H., Jim, C.Y., 2010. Differential community effects on perception and use of  
652 urban greenspaces. *Cities.* 27 (6), 430-442.

653 Lo, A.Y.H., Jim, C.Y., 2012. Citizen attitude and expectation towards greenspace  
654 provision in compact urban milieu. *Land Use Policy.* 29 (3), 577-586.

655 Luederitz, C., Brink, E., Gralla, F., Hermelingmeier, V., Meyer, M., Niven, L., et al.,  
656 2015. A review of urban ecosystem services: six key challenges for future  
657 research. *Ecosystem Services.* 14, 98-112.

658 Lundholm, J.T., Cadotte, M., 2015. Green roof plant species diversity improves  
659 ecosystem multifunctionality. *J. Appl. Ecol.* 52 (3), 726-734.

660 Madre, F., Vergnes, A., Machon, N., Clergeau, P., 2013. A comparison of 3 types of  
661 green roof as habitats for arthropods. *Ecol. Engin.* 57, 109-117.

662 Mc Donnell, M.J., Pickett, S.T.A., 1990. Ecosystem structure and function along  
663 urban-rural gradients: an unexploited opportunity for ecology. *Ecology.* 71 (4),  
664 1232-1237.

665 McHale, M.R., Bunn, D.N., Pickett, S.T., Twine, W., 2013. Urban ecology in a  
666 developing world: why advanced socioecological theory needs Africa. *Front.*  
667 *Ecol. Environ.* 11 (10), 556-564.

668 Miller, J.R., 2005. Biodiversity conservation and the extinction of experience. *Trends*  
669 *Ecol. Evol.* 20 (8), 430-4.

670 Mitsch, W.J., Jørgensen, S.E., 2003. Ecological engineering: a field whose time has  
671 come. *Ecol. Eng.* 20, 363-377.

672 Mullaney, J., Lucke, T., Trueman, S.J., 2015. A review of benefits and challenges in  
673 growing street trees in paved urban environments. *Land. Urban Plan.* 134,  
674 157-166.

675 Niemelä, J., 1999. Is there a need for a theory of urban ecology? *Urban Ecos.* 3 (1),  
676 57-65.

677 Phillipson, J., Lowe, P., Proctor, A., Ruto, E., 2012. Stakeholder engagement and  
678 knowledge exchange in environmental research. *J. Environ. Manage.* 95 (1),  
679 56-65.

680 Pickett, S.T.A., Cadenasso, M.L., Grove, J.M., Groffman, P.M., Band, L.E., Boone,  
681 C.G., et al., 2008. Beyond urban legends: An emerging framework of urban  
682 ecology, as illustrated by the Baltimore Ecosystem Study. *Bioscience.* 58 (2),  
683 139-150.

684 Ramalho, C.E., Hobbs, R.J., 2012. Time for a change: dynamic urban ecology.  
685 *Trends Ecol. Evol.* 27 (3), 179-88.

686 Ramirez, K.S., Leff, J.W., Barberan, A., Bates, S.T., Betley, J., Crowther, T.W., et al.,  
687 2014. Biogeographic patterns in below-ground diversity in New York City's  
688 Central Park are similar to those observed globally. *Proc. Royal. Soc. B* 281  
689 (1795).

690 Schwartz, M.W., Thorne, J.H., Viers, J.H., 2006. Biotic homogenization of the  
691 California flora in urban and urbanizing regions. *Biol. Cons.* 127 (3), 282-291.

692 Seto, K.C., Fragkias, M., Güneralp, B., Reilly, M.K., 2011. A meta-analysis of global  
693 urban land expansion. *Plos ONE*, e23777.

694 Seto, K.C., Güneralp, B., Hutyrá, L.R., 2012. Global forecasts of urban expansion to  
695 2030 and direct impacts on biodiversity and carbon pools. *Proc. Natl. Acad.*  
696 *Sci. USA.* 109 (40), 16083-16088.

697 Shwartz, A., Turbé, A., Simon, L., Julliard, R., 2014. Enhancing urban biodiversity  
698 and its influence on city-dwellers: an experiment. *Biol. Cons.* 171, 82-90.

699 Standish, R.J., Hobbs, R.J., Miller, J.R., 2013. Improving city life: options for  
700 ecological restoration in urban landscapes and how these might influence  
701 interactions between people and nature. *Land. Ecol.* 28 (6), 1213-1221.

702 Steffen, W., Richardson, K., Rockstrom, J., Cornell, S.E., Fetzer, I., Bennett, E.M., et  
703 al., 2015. Sustainability. planetary boundaries: guiding human development on  
704 a changing planet. *Science.* 347 (6223), 1259855.

705 Sutherland, W.J., Freckleton, R.P., Godfray, H.C.J., Beissinger, S.R., Benton, T.,  
706 Cameron, D.D., et al., 2013. Identification of 100 fundamental ecological  
707 questions. *J. Ecol.* 101 (1), 58-67.

708 Vergnes, A., Blouin, M., Muratet, A., Lerch, T.Z., Mendez-Millan, M., Rouelle-Castrec,  
709 M., et al., 2017. Initial conditions during technosol implementation shape  
710 earthworms and ants diversity. *Land. Urban Plan.* 159, 32-41.

711 Vergnes, A., Kerbiriou, C., Clergeau, P., 2013. Ecological corridors also operate in an  
712 urban matrix: A test case with garden shrews. *Urban Ecos.* 16 (3), 511-525.

713 Wilkinson, C., Sendstad, M., Parnell, S., Schewenius, M. 2013. Urban governance of  
714 biodiversity and ecosystem services. In: Elmqvist T, Fragkias M, Goodness J,  
715 Güneralp B, Marcotullio PJ, McDonald RI, et al., editors. *Urbanization,  
716 Biodiversity and Ecosystem Services: Challenges and Opportunities: A Global  
717 Assessment.* Springer Netherlands, Dordrecht, pp. 539-587.

718 Zhao, S., Liu, S., Zhou, D., 2016. Prevalent vegetation growth enhancement in urban  
719 environment. *Proc. Natl. Acad. Sci. USA.* 113 (22), 6313-8.

720  
721