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1 Are really Nature-Based Solutions sustainable solutions to design future cities in
 2 a context of global change? Discussion about the vulnerability of these new
 3 solutions and their probable unsustainable implementation.

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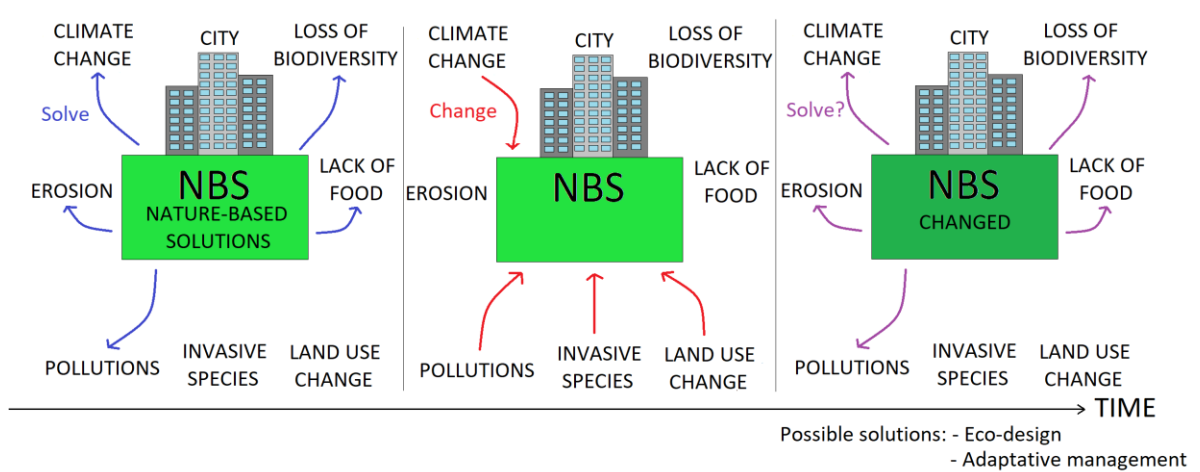
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14 **Highlights**

- 15 • Nature-Based Solutions (NBS) in cities solve problems like floods, heat, etc.
- 16 • But NBS can be threatened by disturbances like global change, pollution, etc.
- 17 • In fact, these disturbances could notably alter services provide by NBS.
- 18 • To avoid this, NBS should be designed by considering socio-eco-evolution.
- 19 • It would also be good to diversify urban NBS, so that some survive disturbances.

21 **Graphical abstract**



23 Abstract

24 The urban ecosystem is a very challenging environment that faces many problems such as
25 various pollutions, higher temperatures than its surroundings or flooding risks due to soil
26 sealing. Nature-based solutions (NBS) seem to be good option to address these problems,
27 while simultaneously offering benefits for facing climate change and the biodiversity crisis.
28 Despite their potential, NBS can be threatened by various urban disturbance, namely: land use
29 change, pollution, or invasive species. These disturbances can have multiple consequences on
30 urban NBS, such as causing changes in plant characteristics/traits, altering the services they
31 provide, and even make certain plant populations disappear, etc. In turn, these consequences
32 may even jeopardize the solutions themselves, which then may no longer solve the problems
33 they originally targeted. To avoid this, NBS should be eco-designed, i.e. designed in function
34 of their environment. Their management should be adaptive and should also take into
35 consideration the evolution of climatic and anthropogenic factors. The choice of species
36 should not be left to chance or random: In this sense, is it better to plant native species for
37 biodiversity conservation or exotic species that are more likely to resist global changes? Is it
38 better to find resistant or ruderal species that have proven themselves in the face of certain
39 disturbances? In any case, it would be good to diversify any NBS to have a better chance of
40 survival in the face of global changes.

41 **Keywords:** Urban, biodiversity, ecosystem service, disturbance, sustainability

42

43 1. Introduction

44 The urban environment is a highly complex environment with substantial pressures on
45 biodiversity. The five major urban pressures on wildlife are the presence of buildings,
46 underground infrastructure, communication systems, industries, and urban population (Trojan,

47 1981). Moreover, the occurrence of hydro-meteorological hazards adds another layer of
48 disturbances. In this vein, cities could be particularly hot during summer, with temperatures
49 up to 10°C higher than those of surrounding areas (Kim, 1992). This phenomenon, called
50 urban heat island, is due to a large heat excess from the rapidly heating urban surfaces that
51 often consist of buildings, asphalt, bare soil and short grasses (Grimm et al., 2008). According
52 to IPCC climate experts, the severity of heat waves and their frequency will increase in cities
53 due to global warming and ongoing urbanization (IPCC, 2021). Cities are also highly
54 susceptible to flooding risks, as ground surfaces in cities are often impervious, hence with low
55 water infiltration rates in contrast to higher runoff values (Kalantari and Sörensen, 2019).
56 Despite its characteristics, the urban environment is characterized with a particular
57 biodiversity (Kowarik, 2011). For example, a study in Germany showed that some plants in
58 heavily urbanized environments are being increasingly dispersed by humans and animals, and
59 have become more nitrogen and heat tolerant (Knapp et al., 2010).

60 Nature-Based Solutions (NBS) are the most recent entry to the panel of expected solutions for
61 cities. NBS is a new concept used in research and practice (Nesshöver et al., 2017). There are
62 many definitions of this concept, but the best known are those of the International Union for
63 Conservation of Nature (IUCN) and the European Commission (EC). The IUCN defines NBS
64 as: *“actions to protect, sustainably manage and restore natural or modified ecosystems that*
65 *address societal challenges effectively and adaptively, simultaneously providing human well-*
66 *being and biodiversity benefits”* (IUCN, 2020a). The EC gives another definition that has
67 been updated in 2020: *“Solutions that are inspired and supported by nature, which are cost-*
68 *effective, simultaneously provide environmental, social and economic benefits and help build*
69 *resilience. Such solutions bring more, and more diverse, nature and natural features and*
70 *processes into cities, landscapes and seascapes, through locally adapted, resource-efficient*
71 *and systemic interventions.”* (European Commission, 2020a). This concept can be connected

72 to other concepts such as Ecological Engineering, Catchment Systems Engineering, Green
73 and Blue Infrastructure, Ecosystem Approach, Ecosystem-based Adaptation/Mitigation,
74 Ecosystem Services Approach/Framework, or Natural Capital. (Nesshöver et al., 2017).
75 Urban NBS are also likely to provide answers to the circularity challenges of a city (i.e.
76 circular resource management), especially with regard to the water cycle and the treatment,
77 recovery and reuse of water and waste (Langergraber et al., 2021 a).

78 The purpose of this opinion article is to warn that urban NBS and the services they provide
79 may be threatened by the various disturbances present in the city, and to provide suggestions
80 for remedying them. Indeed, the sustainability of these NBS (used to make the city
81 sustainable!) in the face of disturbances is not sufficiently taken into consideration. This paper
82 therefore aims to and expose and discuss this possible paradox. As the disturbances and
83 challenges of the urban realm will only be compounded with climate change, numerous
84 questions arise: Faced with these numerous drivers of change, is the sustainability/durability
85 of these NBS assured? Is there a risk of failure or of reduced performances in the face of the
86 problem they are supposed to address? Should nature be left to its own means, even if the
87 ecological trajectories will inevitably be disrupted, or should it be assisted to facilitate its
88 adaptation? This article aims to address these questions and attempts to provide some
89 recommendations for a sustainable implementation of urban NBS.

90

91 2. Methodology

92 This article is based on bibliographic work and logical reasoning. The first part will discuss
93 nature-based solutions and ecosystem services in cities.

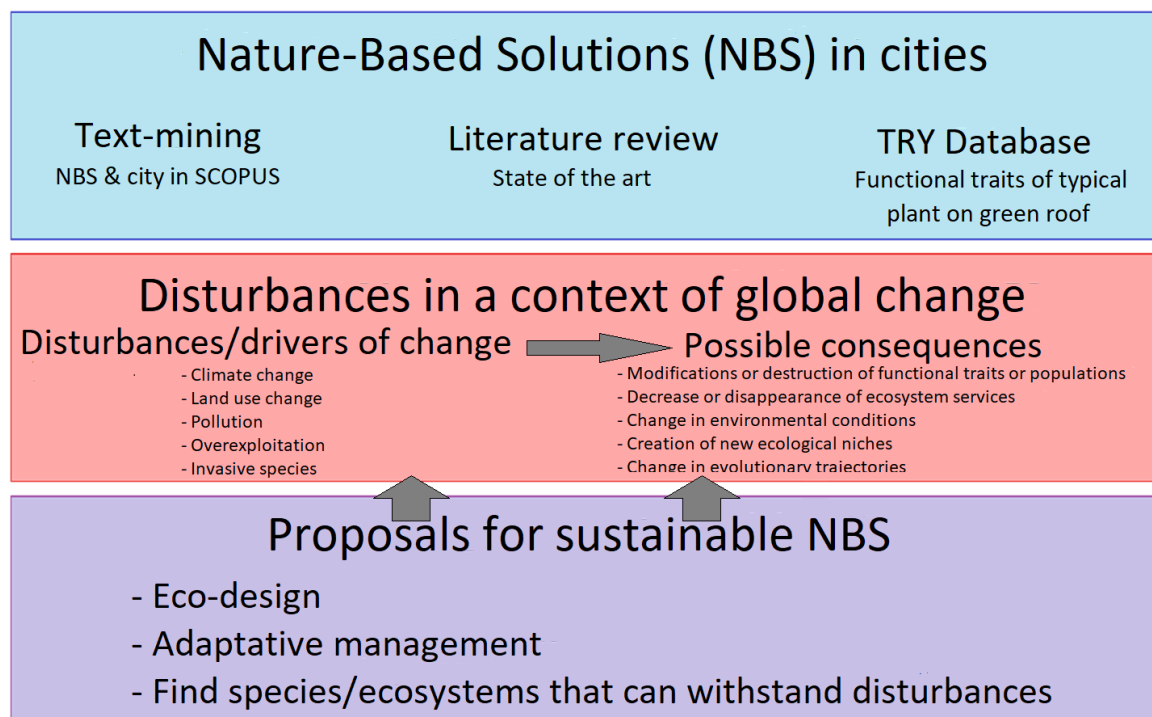
94 To account for forms of urban NBS in the scientific literature, a text-mining analysis was
95 conducted to study the current NBS in urban environments. Carried out using the SCOPUS

96 database for peer-reviewed literature, the occurrence of some keywords used in publications
97 on urban NBS from the appearance of the concept in 2016 until December 13, 2021 was
98 studied. The keywords used for this search were: *nature-based* AND *solution* AND *city*. The
99 analysis was then carried out for the titles, abstracts and keywords of the studied corpus (453
100 documents). Only the keywords appearing at least 8 times were conserved.

101 This first part will also present a particular study devoted to green roofs. Green roofs and their
102 plants were chosen because the scientific literature on this type of NBS is extensive and
103 exhaustive inventories of their plants exist. An individual analysis of several papers dedicated
104 to green roofs was carried out (Köhler, 2006; Lundholm et al., 2010; Rochefort et al., 2016;
105 Catalano et al., 2017; Riviere, 2019). These documents were retained because they provided
106 an exhaustive list of used/studied species with their relative quantities. After analysing the
107 different kind of species implemented on the roofs, the most commonly represented species
108 have been identified. As a result, a list of 27 dominant (planted and spontaneous) plant species
109 used on green roofs in temperate environments (Germany, Belgium, Canada and Switzerland)
110 was obtained. Six plant functional traits (lifespan, pollination, root system, persistence of
111 leaves, leaf surface per plant, stomatal conductance per leaf area) which seem essential for
112 ecological functions (water retention, evapotranspiration, gas exchange, particle trapping,
113 pollen transfer) and ecosystem services (regulation of hydrological cycles, flood risks and
114 climate regulation, air and water quality regulation, pollination and support of biodiversity)
115 were selected for our study. Then, the TRY plant traits database (<https://www.try-db.org>;
116 Kattge et al., 2020) was used to quantify and qualify the 6 functional traits of the 27 dominant
117 selected plants. Thanks to the richness of the TRY database, almost all the traits could be
118 quantified/qualified for these 27 inventoried species. Based on these results, a composite
119 portrait of a typical plant has been created (by averaging the numerical variables, and
120 retaining the most common value for the qualitative variables; Table 1). As this analysis was

121 carried out on a relatively limited sample, it would be interesting to do further research on a
 122 larger sample of rooftops or even with other types of NBS present in the city.

123 The second part will deal with disruptions in the urban environment and their consequences
 124 on NBS and their associated plants. Finally, the last part will focus on the ways to overcome
 125 these disruptions and their consequences by proposing some possible solutions. The rationale
 126 behind this approach is to provide a detailed representation of NBS challenges and potential
 127 solutions to ensure the continuity of these solutions in the cities of tomorrow. The work done
 128 for this paper is illustrated in Figure 1.



129

130 Figure 1: Illustration of the methodology and content of the article.

131

132

133

134

135 3. Nature-based solutions in the city

136 3.1 Nature-based solutions and ecosystem services in cities

137 Here, we focus on NBS in the urban environment. In this environment, NBS can take various
138 forms (Dorst et al., 2019) such as urban forests (Tomao et al., 2017; Yao et al., 2017), green
139 roofs and facades (Xing et al., 2017; Frantzeskaki, 2019), parks and street trees (Giannakis et
140 al., 2016; Santiago Fink, 2016), ecological corridors (Giannakis et al., 2016), ponds, natural
141 water retention areas or vegetated swales (Scott et al., 2016; Xing et al., 2017), pervious
142 pavements (Fini et al., 2017), urban gardens (Cabral et al., 2017; Van der Jagt et al., 2017)
143 including rain gardens (Scott et al., 2016), or urban agriculture (Artmann and Sartison, 2018).
144 These forms of NBS are often aimed at flood prevention, urban heat islands mitigation,
145 biodiversity conservation, recreation, food production, erosion prevention, or pollution
146 reduction (Frantzeskaki, 2019; Hobbie and Grimm, 2020). Today, NBS are being used as tool
147 for local adaptation and for short-term results, as part of pragmatic responses to manage
148 emergencies. They are a direct answer to climate change and landscape fragmentation as they
149 restore the vegetated area in the city. The benefits they provide, such as flood prevention,
150 microclimate regulation or air quality regulation, are called ecosystem services. Ecosystem
151 services are usually classified into four categories: supporting (providing habitats for species,
152 and maintaining genetic diversity), provisioning (provision of food, freshwater and raw
153 material), regulating (air quality regulation, microclimate regulation, noise reduction, and
154 water drainage/purification) and cultural services (physical-mental health, moral well-being,
155 ecotourism and recreation). These services are of particular interest in urban environments
156 (Bolund and Hunhammar, 1999; Maas et al., 2006; Tzoulas et al., 2007), because the majority
157 of human beings live in cities (La Banque Mondiale i.e. World Bank, 2020). By their
158 multifunctionality and potential use to address multiple ecosystem services simultaneously,
159 NBS are recognized as efficient tools to improve ecosystem services in urban areas (Raymond

160 et al., 2017; Castellar et al., 2021). For this reason, several policy initiatives promoting NBS
161 measures in cities have recently raised (European Commission, 2020b; IUCN, 2020b).
162 Therefor NBS and their associated ecosystem services play vital roles in addressing urban
163 challenges and in enabling planning towards sustainable and resilient cities (Andersson et al.,
164 2014; Almenar et al., 2021). Ecosystem services (an anthropocentric concept) can be seen as
165 the result of ecological functions (a concept centred on ecosystems and their components)
166 provided by living beings and/or abiotic components/conditions. In this article, only biotic
167 components (living beings) especially plants are considered. A definition of ecological
168 function is the interaction of species or through their ecological role where a species or group
169 of species maintain a biogeochemical flux or pool, and/or support ecosystem productivity
170 (Brodie et al., 2018). In turn, these functions are influenced by individual characteristics often
171 referred to as functional traits. For instance, in the case of a plant these would be its leaf shape
172 or persistence, type of pollination or dispersal means (Knapp et al., 2010). As such, the air
173 quality regulation as an ecosystem service is linked to the ecological function of particle
174 trapping, which in turn depends on the functional trait of the leaf surface [larger leaf area
175 gives a greater particle capture potential] (Commissariat Général au Développement Durable,
176 2010; Chen et al., 2015).

177

178 3.2 Finding: How are NBS present in cities today?

179 The integration of NBS in cities raises many questions on the species that are usually used,
180 the way they are managed and on the practices that are used for their maintenance. As already
181 described, NBS in the city can take many forms. Consequently, practices vary accordingly:
182 human interventions on a site can range from very limited modifications to major ones, such
183 as the creation of ecosystems (Gómez Martín et al., 2020). NBS requiring greater

184 management efforts are usually implemented in the downtown areas of cities, while in the
185 peripheries, NBS that require less management are often present (Krauze and Wagner, 2019).

186 The analysis of urban NBS forms in the literature showed that the most publishing journals on
187 this topic were found to be: Sustainability (MDPI), Urban Forestry and Urban Greening
188 (Elsevier), Environmental Research (Elsevier), Science of The Total Environment (Elsevier)
189 and Water (MDPI). Accordingly, the main types of NBS described in literature were found to
190 be: green spaces (82), urban forests (81), trees (25), green roofs (22), urban agriculture (19),
191 recreational parks (18) and wetlands (8).

192 The typical plant of green roofs made from the list of 27 dominant species is an important
193 result, but it is not a panacea. The plant species are rather small and lack heterogeneity.
194 Pollination of this typical plant is dependent on insects, especially bees, which makes it more
195 vulnerable to disturbance that can be drivers of pollinator loss (Potts et al., 2010). The
196 modelled plant has a rather long leaf persistence time and average leaf surface and stomatal
197 conductance. These trait values allow an important performance of water retention,
198 evapotranspiration, gas exchange and particle trapping (among other ecological functions)
199 that are related to the services of the hydrological cycle and water flow regulation,
200 (micro)climate regulation, water and air quality regulation. However, these functions and
201 services can be influenced by the many disturbances that characterize the urban environment.

202

203 4. Nature-based solutions necessarily disrupted?

204 4.1 Many disruptions, especially in the city

205 Often ecosystems, especially urban ones, are hyper-disturbed. Even when ecosystems are left
206 to self-organize, there are always drivers of change such as climate change, land-use change,

207 pollution, overexploitation and invasive alien species (Pereira et al., 2012). In the urban
208 environment, disturbances are even more numerous than in the surroundings, given the strong
209 anthropogenic influence. Indeed, the world's urban population is steadily increasing; 34% of
210 humans lived in cities in 1960 and have increased to 56% in 2020 (La Banque Mondiale i.e.
211 World Bank, 2020). Horticultural plants, which are very present in cities, are often the source
212 of invasive plant spreading (Reichard and White, 2001). Human-induced drivers of change
213 can then affect evolutionary trajectories (Palumbi, 2001). For example, heavy metal exposures
214 have caused changes in the evolutionary properties of (resistance) plants living in
215 contaminated sites (Wu and Kruckeberg, 1985). Another example is that in habitats disturbed
216 by humans, plants have a lower level of outcrossing than in an undisturbed environment
217 (Eckert et al., 2010) which could be due to reduction of outcrossed pollen receipt (Eckert et
218 al., 2010). Indeed, even if humans do not directly act on an ecosystem, they still have an
219 indirect impact via climate change or various pollution sources.

220 However, disruptions are not always sudden. Some of them can occur continuously like
221 climate change. As already mentioned, the IPCC reports that “*Cities intensify human-induced*
222 *warming locally, and further urbanization together with more frequent hot extremes will*
223 *increase the severity of heatwaves*” and “*Urbanization also increases mean and heavy*
224 *precipitation over and/or downwind of cities*” (IPCC, 2021). The increase of extreme events
225 (drought, rainfall) in terms of intensity and frequency can clearly have consequences on
226 vegetation (Zhang et al., 2021). Therefore, the selection of plants species that can survive
227 water-deficits, especially on dry soil as green roof substrates is crucial (see Du et al., 2019).
228 The consequences of climate change can also be temporary positive as global warming can
229 advance the phenological phases of leaf development and delay the phenological phases of
230 leaf senescence (Wohlfahrt et al, 2019).

231

232 4.2 Possible consequences of disturbances on NBS

233 The multitude of disturbances present in the city (climate change, land-use change, pollution,
234 overexploitation and invasive alien species) can have multiple consequences on urban NBS,
235 ranging from simple modifications of functional traits and/or populations of living beings to
236 their destruction. Indeed, disturbances also called drivers of change can modify the functional
237 traits of plants, create new ones or eliminate them. Some of these traits named “keystones” are
238 very important for humans, as they interfere with many ecosystem services (Hevia et al.,
239 2017). The modification or disappearance of such traits can therefore mean the decrease or the
240 disappearance of many of their related services. The leaf surface of a plant is one of these
241 "keystones" traits, as it is linked to many services such as the regulation of hydrological
242 cycles, flood risk, microclimate and air quality. This trait appears to be most affected by land
243 use change (Hevia et al., 2017).

244 The above-mentioned drivers of change (climate change, land-use change, pollution,
245 overexploitation and invasive alien species) can lead to the selection of plants that have
246 certain functional traits. For example, urbanization can lead to the selection plants that are
247 more tolerant to nitrogen and heat (Knapp et al., 2010). Human disturbances can also destroy
248 parts of plant population or even the whole, even the specimen present on a site, thus reducing
249 site-biodiversity. Indeed, a study on a Chinese island showed that the direct factors making
250 small plant populations susceptible to extinction were human disturbances (Chen et al., 2014).
251 According to Köhler (2006), floristic diversity of green roofs is mainly influenced by weather
252 conditions (temperature and rainfall), so climate change can have a serious impact on this
253 diversity in the future. The change of land use in the environment of a given NBS can alter the
254 necessary conditions necessary for solutions’ life cycle or for the delivery of its purposes,
255 according to the complementary land use concept of Colding (2007). This concept is built “*on*
256 *the idea that land uses in urban green areas could synergistically interact to support*

257 *biodiversity when clustered together in different combinations*” (Colding, 2007). For
258 example, private gardens adjacent to urban public parks would enhance bird diversity through
259 the landscape complementation functions provided by native tree cover, berry bushes, ponds,
260 or freshwater springs, which increase the likelihood of attracting species (Blair, 1996; Melles
261 et al., 2003).

262 Destruction of populations and/or changes in environmental conditions can lead to the
263 creation of new ecological niches, and thus the colonization of a NBS by new species. It can
264 also change the dominant species that are most likely to provide ecosystem services. Indeed,
265 according to Xie et al. (2018), the functional characteristics of dominant plant species on
266 green roofs are important to provide several services. Drivers of change can therefore destroy
267 natural equilibrium and can also change evolutionary trajectories through adaptation.
268 Accordingly, the question of impoverishing the evolutionary trajectories of the species present
269 can be raised. It would also be important to refocus human/non-human relationships on
270 maintaining evolutionary potential (Lecomte and Sarrazin, 2016). Therefore, the risk of
271 reducing or losing ecological functions and ecosystem services of urban NBS through human
272 disturbances exists. This phenomenon has already been observed in non-urban environments,
273 land use intensification was linked to the loss of functional traits (such as thin bark and large
274 size for trees in Brown et al., 2013) and the reduction of several ecosystem services (such as
275 the harvest of fuel wood and construction timber in Brown et al., 2013; Laliberté et al., 2010;
276 García-Llorente et al., 2015). In urban environments, this raises the question of whether the
277 targeted ecosystem services are still being provided, and whether the original problems are
278 still being solved despite the anthropogenic disturbances present in the city and their
279 consequences. Accordingly, one can also question if we are still dealing with nature-based
280 solutions at this level.

281

282 5. How to deal with these disturbances and their consequences?

283 5.1 Eco-design and adaptive management to overcome disruptions in the city

284 The previous section raised the question of how to deal with these disruptions and their
285 consequences for NBS in the city. It can also relate to the question of ensuring the
286 sustainability of the sought solutions. Therefore, it could be interesting to have ecosystems
287 that are well-maintained over time and which are autonomous with planted and spontaneous
288 species that reappear from one year to another or reproduce on site. Eventually, new
289 colonisations that replace plants that have disappeared from the ecosystem can appear.
290 However, the question of how to achieve this sustainability is raised. The idea is to work on
291 the long term, to tap the full potential of the species' life cycles, and to anticipate the drivers
292 of change and their consequences. For this purpose, urban NBS could be eco-designed, hence
293 accommodating for life cycles and natural adaptation. Eco-design is based on the fact that:
294 *“the environment helps to define the direction of design decisions and the environment*
295 *becomes a co-pilot in product [here the NBS] development”* (Brezet, 1997). The design
296 process also requires collaboration between different sectors in order to use the full potential
297 of NBS to address multiple urban challenges simultaneously (Langergraber et al., 2021 b).
298 There is also the question of NBS-derived ecosystem service sustainability. But, is there a will
299 to maintain all of these services as much as possible on the long term? Or target one or more
300 in particular? The purpose is to move towards a dynamic ecological balance that provides
301 ecosystem services, hence maintaining the durability of the designed/implemented NBS.

302 Regarding the management of NBS in cities for coping with disruptions, a legitimate question
303 arises: do we let “nature” take over or do we accompany it? It would be probably a good idea
304 to let nature take over more often in urban NBS, without direct human intervention or just the
305 bare minimum, such as an annual maintenance of green roofs, the removal of invasive plants,

306 etc. This type of *let it happen* management encourages the development of spontaneous
307 species that are important for the functioning of ecosystems (Couvét and Ducarme, 2018) and
308 allows ecosystems to become somewhat self-organized. Ecosystems are thus closer to a
309 functional natural state. It also reduces the financial, labour and time costs associated with
310 NBS maintenance. Nesshöver et al (2017) stress the fact that NBS governance must be
311 adaptive. Indeed, management must respond to the “reality of the field” and react to
312 unexpected events. Lambert and Donihue (2020) go further to stress that evolving urban
313 biodiversity requires incorporating evolutionary perspectives into management for these
314 efforts to succeed given the dynamic nature of the urban environment. It is also important to
315 take into consideration the landscape’s heterogeneity, the ecological dynamics and the
316 evolutionary consequences on biodiversity, i.e. to have an evo-centric approach (Lecomte and
317 Sarrazin, 2016). Thus, solid progress towards socio-eco-evolution in the city is needed (Des
318 Roches et al., 2021). Accordingly, human societies, non-human living beings and their
319 ecology and evolution, as well as their interactions should be better accounted for. Whether in
320 eco-design or management, it could be interesting to mimic nature and its ecosystems in an
321 effort to understand their behaviour in the face of various disturbances.

322

323 5.2 Finding species and ecosystems that can withstand urban disturbances

324 One of the objectives of NBS is to provide environmental benefits (see IUCN and European
325 Commission definitions). In this context, one of the main goals is the conservation of
326 biodiversity. For this purpose, it may be a good idea to use local plant species, with species
327 already present in the city where the NBS is implemented. As a result, vegetation populations
328 will be larger and therefore more viable. This is important as small and range-restricted
329 populations are highly vulnerable to extinction (Terborgh and Winter, 1980; Gilpin, 1986).
330 The establishment of NBS in the city can also be an opportunity to introduce species that were

331 not initially present in the urban environment, but in its surroundings, hence increasing
332 biodiversity in the city. There are already initiatives that promote and facilitate the use of
333 local wild species such as the French label “Végétal local” (Végétal local;
334 <https://www.vegetal-local.fr/>). However, will these local species be able to cope with
335 disturbances like global warming? Perhaps it would be better to plant exotic (non-invasive)
336 species that can withstand droughts for example or rising temperatures? In support of this
337 argument, one study showed that in North America, the phenology of exotic species adapted
338 better to climate change than native species (Wolkovich et al., 2013).

339 Another solution is to find and install plant species that can cope with the disturbances present
340 in the city, such as “resistant” or ruderal species, or species that have been proven to work in a
341 given context in the face of a given disturbance. The rationale behind this approach is the
342 concepts of ecological resilience, which is the ability of a living system to recover the
343 structures and functions of its baseline state after a disturbance (Holling, 1973), and
344 resistance, which is the ability of a system to remain fundamentally unchanged when
345 subjected to a disturbance (Grimm and Wissel, 1997). The idea is to return to the initial
346 trajectories, before disturbances (or new favourable ones). However, this aspirational target is
347 not always guaranteed. In the case of new evolutionary trajectories, one can speak about
348 transformability, which is the ability to create a fundamentally new system when ecological,
349 economic, or social structures make the existing system unsustainable (Walker et al., 2004).
350 In this sense, anticipating changes in eco-evolutionary trajectories by experimenting or
351 studying correlations in urban environments could be an interesting platform to explore.

352

353

354

355 5.3 Issues of scale and risk of failure

356 It could also be necessary to think about the challenges of urban spatial scales (e.g. building,
357 allotment, district, city, agglomeration, or megalopolis). Hutchins et al. (2021) have already
358 addressed this issue for optimizing NBS for resilient cities. According to the Authors, this
359 requires the development of a tools that take into consideration the optimization of ecosystem
360 services and environmental quality indicators. It may also be interesting to study the
361 connectivity of existing and future NBS. Indeed, the resulting ecosystem services do not only
362 depend on the scale of implementation, but also on the network linking them at a larger scale.
363 To provide ecosystem services at large scales, NBS have to be widely implemented. As
364 demonstrated by Versini et al. (2020) for green roofs in European conurbations, fractal
365 analysis can used as an innovative multi-scalar tool to provide information on the
366 heterogeneity of green roofs spatial distribution and to optimize their deployment scenarios
367 depending on the targeted impact(s).

368 There is a need for collective awareness on the risks of failure of any NBS. This includes the
369 fact that the *let it happen* is very likely to be disrupted by factors such as climate change.
370 Additional failure risks can also result from the current implementations of urban NBS that
371 may have disappointing results (such as disservices related to safety, aesthetics or health for
372 instance, see Gómez-Baggethun and Barton, 2013). Therefore, it could be useful to go to
373 diversify choices, and “not to place all eggs in the same basket”. In an unknown future, the
374 more potential solutions emerge, the more likely some of them will resist disruptions. The
375 distribution and the diversity of these solutions will echo to the land use concept developed by
376 Colding (2007).

377

378

379

380 6. Conclusion

381 Urban environments are very complex and challenging ecosystems. Drivers of change
382 influencing this particular context are numerous. On one hand, the increase of urban
383 populations and the resulting intensifications of urban cover can modify the water cycle (by
384 inducing imperviousness and heat storage), facilitate invasive species spreads and create
385 various types of pollution. On the other, climate change can intensify the occurrence of
386 extreme events like flooding or heat waves.

387 The use of NBS is therefore one of the main means to help cities adapt to these constraints
388 and to make them more resilient. For this reason, NBS for climate change adaptation are
389 starting to gain prominence in scientific discourses.

390 Through the (re)introduction of nature, NBS also represent a good solution for biodiversity
391 and for its effective return to the city. However, if the constraints of global changes on
392 societies are now obvious and well documented, the same is probably also true for the non-
393 human living world. Nevertheless, the latter's response to these constraints remains uncertain.
394 To our knowledge, scientific literature has rarely addressed this question. Thus, the use of
395 NBS for mitigation or adaptation purposes in cities has to be examined with great caution.
396 NBS are usually implemented to mitigate or to adapt the environment to the current situation,
397 often leaving aside the need to forecast the evolution of future constraints and how NBS will
398 respond to them. This stationary point of view has obviously some limitations.

399 Indeed, resistance to strong constraints also has its limits for city biodiversity. Accordingly, it
400 is difficult to predict whether introduced or local species will survive extreme conditions
401 which they may face. It is also unclear whether this newly introduced nature will be able to

402 provide the ecosystem services for which it was initially planned for. Climatic hazards, such
403 as various types of pollution, can indeed alter some of these "keystones" traits.

404 This clearly questions the way of approaching the introduction of biodiversity in cities. The
405 time has come to question whether Nature-Based Solutions should be considered as a way to
406 rethink our cities in their entirety. A paradigm shift is surely necessary to move from
407 business-as-usual approach "adapting to what?" all the time, to rather "adapting what to
408 what?", taking into account the possibilities of the territory and its limits.

409 This approach requires the adoption of a systemic and dynamic approach that gives the
410 diversity, complementarity and renewal of species an important role to ensure services, their
411 sustainability and their adaptability. A stronger involvement of ecologists is required to
412 question these points at scales that go beyond that of the infrastructure on which NBS are
413 often installed. It is about understanding better understanding how a particular NBS fits its
414 surrounding environment, and how its complementarity with the whole system can benefit
415 everyone.

416 In addition, a more global reflection integrating local authorities, engineering design offices
417 and urban planners could be beneficial. The objective is to link aspects of biodiversity with
418 planning, public policies, and climate, in order to share the knowledge with more technical
419 and decision-making organizations. This framework should allow a more successful and
420 cautious reintroduction of nature into cities hence avoiding "greenwashing"

421

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427

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