Scale of measurement	District to region scale
Data source	
Required data	Total native bird species detected in built areas. The count census numbers can be obtained from city council archives or bird watch organizations.
Data input type	Quantitative or semi-quantitative
Data collection frequency	Annually
Level of expertise required	Low to Moderate – for the identification of the taxonomic groups
Synergies with other indicators	Related to *Reclamation of contaminated land* and *Ratio of open spaces to built form* indicators
Connection with SDGs	SDG 11 Sustainable cities and communities, SDG 13 Climate action, SDG 15 Life on land
Opportunities for participatory data collection	Participatory data collection is feasible via citizen science with appropriate training of the volunteers
Additional information	
References	Chan, L., Hillel, O., Elmqvist, T., Werner, P., Holman, N., Mader, A., & Calcaterra, E. (2014). User's Manual on the Singapore Index on Cities' Biodiversity (also known as the City Biodiversity Index). Singapore: National Parks Board, Singapore.

10.19 Species diversity – general

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Species diversity - general	**Biodiversity**
Description and justification	It is important to foster research and monitoring of biodiversity to determine the best assemblages of species to achieve the most efficient NBS, including the optimization of multiple economic, ecological and social benefits and exploration of trade-offs created by NBS. This can be achieved

	by collection of new data in the field and the use of remote sensing to gather comprehensive data on additional benefits, to complement existing data and observation. Species diversity refers to the number of individual species per area. It can be useful in detecting colonisation of a given area or response of species to a given management action. Counts for species or groups of species can provide an intuitive biodiversity metric which also has public resonance and the data can be used to populate indicators and measure progress towards conservation policy targets. Whilst survey of individual target conservation species and/or umbrella species can be of value in relation to specific conservation objectives, quantification of biodiversity indices can also have value in providing a more holistic insight into overall biodiversity and greater representation of a range of taxa. Key drivers for such biodiversity monitoring include: - Assisting local authorities to evaluate their progress in urban biodiversity conservation (for example against Aichi/national/local biodiversity targets); - Ensuring NBS contribute positively to biodiversity conservation; - Creating a foundation for development of Local Biodiversity Strategies/Action Plans (see example of Lisbon, Portugal in MAES reference below) Serving as a public platform upon which biodiversity awareness raising exercises can be launched.
Definition	Changes in overall number of species/species diversity/biodiversity indices within area affected by NBS.
Strengths and weaknesses	+ Count of species is relatively easy to monitor - Sensitive to area and site specific – extrapolation to larger area overestimates species density due to the non-even species distribution. Mobile species counts require taking into consideration their different relation to the studied habitat/area (e.g., migrants, breeding – resting species). **Applied methods:** Strength of indicator depends of the quality of the data used and the representativeness of the index selected to overall biodiversity patterns. Raw data can characterise species spatial and temporal distributions but are generally limited because of the time/costs involved in the detailed level of data collection needed to accurately detect change.

	Earth observation / Remote sensing methods: Remote sensing has been increasingly contributing to timely, accurate, and cost-effective assessment of biodiversity-related characteristics and functions during the last years. Various studies have demonstrated how satellite remote sensing can be used to infer species richness. However, most relevant studies constitute individual research efforts, rarely related with the extraction of widely adopted Convention on Biological Diversity (CBD) biodiversity indicators (Petrou et al., 2015). Furthermore, systematic operational use of remote sensing data by managing authorities remains limited. The monitoring with CBD related indicators can be facilitated by remote sensing. Numerous studies using RS data to measure biodiversity-related properties are presented in the literature, covering a broad range of applications, study areas, data and methods. However, most studies are rarely explicitly connected to any widely adopted biodiversity indicator that could be extracted through them directly or indirectly. Instead, various indicators have been used by individual studies, resulting in numerous incompatible monitoring systems (Feld et al. 2009). Furthermore, despite the increasing availability of RS data, the connection between variables measured by RS and indicators required by the biodiversity and policy-making community is still poor (Secades et al. 2014). Thus, a link of RS approaches to a common set of indicators would be highly beneficial.
Measurement procedure and tool	A variety of methods exist from applied/public participation techniques through to earth observation/remote sensing approaches. **Applied / Participatory Methods**: Use species or groups of species count methods (e.g., plot (quadrat) count, point count and line transect methods) to calculate species density expressed in units of species per specified area. The City Biodiversity Index (CBI) (Chan et al 2014), was proposed to engage cities in the implementation of the Convention on Biodiversity's strategic plan for biodiversity. The CBI was intended to provide a benchmark of biodiversity conservation efforts of cities, it provides a self-assessment tool to monitor the progress of biodiversity conservation efforts against a city's baseline. The first part of the framework involves a profile of the city, then 23 indicators are proposed that comprise 3 core

	components: 1) native biodiversity, 2) ES provided by biodiversity, and 3) governance and management of biodiversity. This framework could be used to undertake a full CBI self-assessment. Alternatively, those indicators that directly measure biodiversity could be used, for example Indicator 3: native biodiversity in built-up areas (bird species), or Indicators 4-8 which include three 'core indicator' groups that are most surveyed worldwide – plants, birds and butterflies. Cities can select two additional taxonomic groups (for instance those where data is already held or target groups of local importance/conservation interest). The data from the first year of implementing the Index provides the baseline for future monitoring. It is recommended that application of the Index take place every 3 years to allow sufficient time for the results of biodiversity conservation efforts (e.g., NBS implementation) to materialise. Example units of calculation are: number/abundance of native bird species per hectare. The net change in number of native species from the previous survey to the most recent survey is calculated as: total increase in number of species (as a result of re-introduction or restoration efforts, new species found, etc.) minus number of species that have gone extinct. Possible sources of data include agencies in charge of nature conservation/biodiversity (Wildlife Trusts, etc), city municipalities and urban planning agencies, biological records centres, nature groups, universities, etc. The Urban Biodiversity Inventory Framework (UBIF 2017) offers an alternative 3 track methodology to collect species diversity information as follows: Track 1 - collating data from partners/stakeholders; Track 2 - presence/absence of surrogate species; Track 3 - relative abundance estimates of surrogate species. Track 1 requires the least additional resources but with limited scope for summary statistics, whereas Tracks 2 and 3 require increasing resources but generate increasingly detailed data e.g., comparing changes at a site over time. The CBD agreed a set of 26 specific biodiversity indicators (2010 Biodiversity Indicators Partnership 2010), some of which reflect measures in the CBI (above) and others that could be extrapolated for use under this indicator: • Trends in the abundance/distribution of selected species (e.g., birds/butterflies) • Change in status of threatened and/or protected species (Red List species/species of European interest) • Change in extent of habitats (e.g., vulnerable habitats/habitats of conservation importance)

	• Coverage of protected areas (loss/gain of nationally/locally designated areas/sites) Additional specific examples of general biodiversity measures typically undertaken by professional ecologists include: The Defra Biodiversity Metric 0.2 (Natural England 2018) was developed to as a means of assessing changes in biodiversity value as a consequence of development or land-use change, primarily with the aim of quantifying biodiversity net-gain. It uses habitat as a proxy to measure biodiversity which is converted into measurable ‘biodiversity units’ according to the area of each habitat type. The metrics score different habitat types (e.g., woodland, grassland) according to their relative biodiversity value and adjusts this according to the condition and location of the habitat. Where new habitat is created or existing habitat is enhanced, then the associated risks of doing so are factored into the metric. It can be used to calculate losses and gains in biodiversity from actions. The metric sites within the ‘mitigation hierarchy’. To apply the metric a site should be surveyed, mapped and divided into parcels of distinct habitat types present using a recognised habitat classification system. The biodiversity ‘value’ of a habitat parcel is evaluated on the basis of its area and the relative ‘quality’ of its habitat (distinctiveness, condition, strategic significance, habitat connectivity). The calculation uses the scores and the area of the habitat to give a number of biodiversity units that represent the biodiversity value of that habitat parcel. The relative value in biodiversity units ‘post development’ is then deducted from the ‘baseline’ to give a value for the extent of change e.g., ‘Net Gain’. Net loss would require improvement to development proposal to improve the number of biodiversity units obtained or, if there is no scope for additional on-site compensation or enhancement, off-site measures will need to be considered. BREEAM UK Strategic Ecology Framework (SEF) is a new framework for evaluating, protecting and enhancing ecology in the built environment (Yates, Abdul & Buchanan, 2016). BREEAM credits for ecology (BREEAM 2014) provides a scoring system for assessing the ecological value of a site before and after development (Land Use and Ecology LE01 – LE06). Both protocols start with a Preliminary Ecological Appraisal (PEA) and evaluate and monitor how proposed schemes will benefit biodiversity. The credit system awards high scores to schemes that deliver ecological enhancement. **Earth Observation / Remote Sensing**:

	There are a number of recent remote sensing approaches able to extract related properties that exist for each headline indicator. Methods cover a wide range of fields, including: habitat extent and condition monitoring; species distribution; pressures from unsustainable management, pollution and climate change; ecosystem service monitoring; and conservation status assessment of protected areas. There are some advantages and limitations of different remote sensing data and algorithms. By virtue of the large spatial coverage, information-rich character, and high temporal resolution, remote sensing technology has been widely used in UGS research (Chen et al., 2018). At the end of the 20th century, low/medium spatial resolution remote sensing products began to be applied to the identification of vegetation types (Mucina, 2010). Recent developments in remote sensors offer an excellent opportunity to explore various aspects of different vegetation types. With the many advantages of new remote sensors, combining the advantages of different sensors optimized for vegetation features has attracted a significant amount of research interest and has enabled researchers to propose many promising new techniques for the identification of various vegetation types. For example, using high temporal resolution remote sensing images together with vegetation phenological features can achieve more accurate identification of vegetation types (Yan et al. 2018; Senf et al. 2015). Utilizing the 3D structures provided by LiDAR imagery in combination with the hundreds of narrow spectral bands provided by hyperspectral (HS) imagery can enable the identification of more vegetation types (Xia et al. 2018; Alonzo et al. 2014) However, although there has been much research that involved combining multi-source data sets or adopting better classification methods, these are still unable to identify different social function types of UGS. For further details on measurement tools and metrics, including those adopted by past and current EU research and innovation projects see the Connecting Nature Environmental Indicator Metrics Review Report.
Scale of measurement	**Applied methods:** Can be used to measure change over a range of scales from city level down to a borough/neighbourhood/site/plot/defined habitat level. **Earth observation/Remote sensing methods:** at various geographical scales. Satellite remote sensing technology in the last decade has empowered interdisciplinary research at regional and local scale with high temporal resolution in order to provide information about changes in species distribution, habitat degradation and fine-scale disturbances of forests.

Data source	
Required data	Typically, total species/group count detected in the area. However, required data will depend on selected methods, for further details see applied and earth observation/remote sensing metrics reviews in: Connecting Nature Environmental Indicator Metrics Review Report
Data input type	Typically Quantitative, However, data input types will depend on selected methods, for further details see applied or earth observation/remote sensing metrics reviews in: Connecting Nature Environmental Indicator Metrics Review Report
Data collection frequency	Annually is a good frequency target. However, data collection frequency will depend on selected methods, for further details see applied or earth observation/remote sensing metrics reviews in: Connecting Nature Environmental Indicator Metrics Review Report
Level of expertise required	Medium to high: **Applied methods**: Expertise needed for accurate monitoring of some species groups. Relatively straightforward data analysis based on the CBI calculation for example. **Earth observation/Remote sensing methods**: Expertise in mapping and interrogation of data using GIS software is typically required. Level of expertise required is greater with increasing complexity of software processing. Typical "multi-spectral" sensors with 4 to 20 carefully selected and well-calibrated bands provide a great deal of information, and adding more bands can help with specific issues. "Hyperspectral" sensors can have more than 200 bands and can provide a wealth of information to help, for example, identify specific species. Processing such datasets requires special expertise and satellite-based hyperspectral sensors are not yet common. Other sensor types include radar and lidar which actively emit electromagnetic energy and measure the amount that is reflected—these sensors are useful for measuring surface height as well as tree canopy characteristics and surface roughness. Lidar is generally more precise than radar and ideal for measuring tree height. Radar is particularly useful where cloud cover is a problem (for instance, in the biodiversity-rich tropical rainforests) because it penetrates clouds.
Synergies with other indicators	The significance of urban land-system synergies and spatial governance are increasingly emerging towards sustainable targets (also regarding the biodiversity conservation) and liveable environments in cities. Satellite remote sensing, process-based models and big data are playing pivotal roles for obtaining spatially explicit knowledge for the purpose of biodiversity conservation and better planning for managing

	cities. Thus, synergy will be provided through the integration of governance with remote sensing, modelling and big data. Direct measures of supporting/increasing biodiversity could have synergies with landuse change, greenspace area and accessibility to greenspace (wildlife areas).
Connection with SDGs	All SDGs except 1 and 5: Biodiversity underpins food production; Links between biodiversity and health & wellbeing benefits; Links to environmental education; Links between biodiversity and water quality; Links between biodveristy and clean energy (biosolar, biofuel); Job creation; Improved green infrastructure and industry associated with biodiversity (potential disservices also); Social equality in relation to access to nature; Sustainable urban development; Biodiversity a good indicator of responsible consumption; Climate change adaptation; Potential co-benefits related to more sustainable water management; Biodiversity benefits; Environmental Justice in relation to biodiversity; Opportunities for collaborative working.
Opportunities for participatory data collection	**Applied methods** Data capture could include public participation and citizen science data collection. Such practices are widespread including using volunteer recording groups for particular species groups. **Earth observation / Remote sensing methods**: It is today possible to integrate remote sensing data and in situ observations to monitor several essential biodiversity variables such as habitat structure and phenology. In this context, municipalities should explore the possibilities of launching citizen science projects and consider the possibility in general that within cities, local knowledge on biodiversity and ecosystem services may reside in many different groups within civic society. Here, we can face the challenges related to scaling, boundaries, locally adapted indicators and scoring which can be met by each municipality developing their interpretation of what scale and what boundary is the most appropriate, what definitions to use, and what set of sub-indicators may best reflect the local ecological and cultural context. However, there are some challenges that are not easily addressed at the municipal level and need input from the research community.
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