Biophilia: Nature-based solutions for sustainable cities

Alessio Russo[1*], Maria Ignatieva[2], Giuseppe T. Cirella[3,4], Luca Belelli Marchesini[5,6], Pavel Krestov[7], Evgeny Korzhov[8], Vitaly Kalita[9], Vladimir Pavlovsky[10], Francisco J. Escobedo[11]

[1]Laboratory of Urban and Landscape Design, School of Arts, Culture and Sports, Far Eastern Federal University, Vladivostok, Russia
[2]Swedish University of Agricultural Sciences, Uppsala, Sweden
[3]Institute of Earth Sciences, Department of Regional Policy and Political Geography, Saint Petersburg State University, Saint Petersburg, Russia
[4]Polo Centre of Sustainability, Imperia, Italy
[5]School of Natural Sciences, Far Eastern Federal University, Vladivostok, Russia
[6]Department of Earth Sciences, VU University, Amsterdam, The Netherlands
[7]Botanical Garden-Institute FEB RAS, Vladivostok, Russia
[8]Department of Graphic Design, School of Arts, Culture and Sports, Far Eastern Federal University, Vladivostok
[9]School of Humanities, Far Eastern Federal University, Vladivostok, Russia
[10]School of Arts, Culture and Sports, Far Eastern Federal University, Vladivostok, Russia
[11]Functional and Ecosystem Ecology Unit, Biology Program, Faculty of Natural Sciences and Mathematics, Universidad del Rosario, Bogotб DC, Colombia

[*]Corresponding author: alessio.landscape@gmail.com, russo.a@dvfu.ru

Introduction

More than half the world's population now live in cities. After decades of massive urban migration and unplanned sustainable urban development, cities are facing unprecedented environmental, health and social problems. According to the World Health Organization, urban air pollution is associated with the death of around 1.2 million people globally every year, mainly due to cardiovascular and respiratory diseases (WHO 2010). In combination, the availability of unhealthy food choices and several urban factors (e.g. overcrowding, high-volume traffic, heavy use of motorised transportation, poor air quality and lack of safe public spaces and recreation and sports facilities)have discouraged physical activity and promoted unhealthy food consumption, directly affecting lifestyle, health and life expectancy(WHO 2010). Furthermore, unnatural urban settings may increase vulnerability to maladaptive neurobiological functions and associated emergence of psychiatric illness (e.g. depression) (Lambert et al. 2015).In response to climate change, a rapidly growing global population and associated environmental, health and social problems, we need to find innovative approaches (e.g. Biophilia, Ecopolis, EcoCity, Nature-Based Solutions (NBS)) to design more liveable, healthy, sustainable and resilient cities.

The idea for biophilic cities is inspired by Wilson's(1986)concept of 'biophilia'(i.e. the human need to have connections with nature) and provides a theoretical basis with potential to explain and enhance health and wellbeing. Such benefits within the urban nature paradigm have the potential to substantially improve the liveability of dense and polluted urban areas(Russo & Cirella 2017; Reeve et al. 2015; Kellert 2016; Beatley & Newman 2013). In our opinion, biophilia is an extension of a cleaner urbanisation strategy and promotes future-based ideas in which sound human-nature living conditions are encouraged. More recently, the analogous concept of NBS has emerged as a way to operationalise an ecosystem services approach within spatial planning policies and practices. Whenapplied at the urban scale, NBS emphasises multi-functionality in terms of services and functions, including drainage management, habitat provision, ecological connectivity, health and wellbeing, recreational space, energy reduction and, in particular, climate change, mitigation and adaptation(Scott et al. 2016; Cohen-Shacham et al. 2016).

Biophilic cities and NBS can thus deliver considerable health benefits at individual and family level. For example, the sight of natural elements such as urban forests or individual trees within a city can deliver important positive impacts on mood, reduction of fatigue and enhanced individual resilience and health (Beatley & Newman 2013).In particular, NBS measures such as green walls, roof gardens, street trees and vegetated drainage basins have the potential to contribute to reducing pollutant concentrations in cities(Cohen-Shacham et al. 2016; Janhдll 2015; Escobedo et al. 2011). These novel ideas reflect augmented forms of NBS implementation in terms of living and research capacity. Research shows that living in areas with walkable green spaces can e.g. positively influence the longevity of urban senior citizens (Takano et al. 2002). A study by Shanahan et al. (2016) in Australia showed that people who made long visits to green spaces had lower rates of depression and lower blood pressure and frequently had greater social cohesion within the community. Green spaces and NBS in urban areas, through the provision of carbon storage and sequestration, carbon offsetting, cooler microclimates and reduced surface water runoff, can help adapt cities for climate change (Gill et al. 2007; Russo et al. 2015).However, NBS, biophilic cities and urban green infrastructure have been studied in only a few Russian cities (Nilsson et al. 2007; Dushkova et al. 2016;Kazakova and Beloshenkova, 2015; Kerimova, 2015; Ignatieva et al., 2009). Interestingly, the pioneering interdisciplinary concept of Ecopolis was developed between 1980-2000 by Moscow State University, with the goal of designing a new type of human settlement that safeguarded development between the biosphere and processes of urbanisation (Agavelov et al., 1985; Ignatieva, 2000). This paper presents cutting-edge, exploratory NBS, biophilic and urban green infrastructure research within the scope of a Russian metropolitan area. It expands upon a conceptual framework for NBS indicators and a biophilic planning approach, with a description of the methodology and related-coupled approaches.

Methods

The study area is the city of Vladivostok, which is largely an industrial city located in Far Eastern Russia, with a population of 633,414 inhabitants, covering an area of 331.16 km^2 (Fig. 1).The air pollution from industrial enterprises and intensive metropolitan traffic has been identified as the cause of asthma morbidity in the resident population(Veremchuk et al. 2016).The aim of the present study was to characterise the city by quantifying and mapping its 'biophilic indicators' (i.e. percentage of the population with access to a green space or park within a few hundred metres; percentage of urban land area covered by vegetation of different types; number of alternative ecologically driven design features (e.g. green rooftops, green walls and rain gardens); useof inspiration from nature (e.g. forms, colours and textures) in architecture and landscape design; and extent of flora and fauna (e.g. species) found within the city. Our vision of 'biophilic indicators 'was adapted from Beatley (2011) and Beatley and Newman (2013)(Table 1).

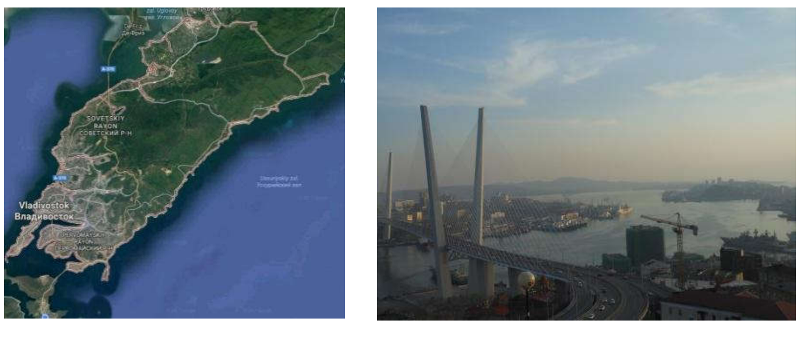

Fig. 1.The study area of Vladivostok (Source: Google Maps).

Furthermore, using an interdisciplinary approach, we identified a range of tools for assessment of ecosystem services and benefits provided by NBS in Vladivostok. In particular, we aim to measure, model and quantify air pollution removal from green elements, carbon storage and CO_2sequestration by integrating NBS into the Vladivostok context. We will also assess the social, psychological and wellbeing benefits provided by a biophilic planning approach. In addition, using a 'research by design method', we aim to develop several urban design scenarios for a concrete neighbourhood. The design brief was to develop a systematic method for deciding how the actual urban ecosystem should be modified to enhance ecosystem services and psychological wellbeing. For example, we sought to identify where rain gardens or green roofs should be located, and what species composition, design feature and appropriate management practices could be suggested.

Results

From a literature review, we identified biophilic indicators (Table 1) and several NBS indicators, methods and approaches to quantify urban ecosystem services (Table 2).The formatting and results from Table 1 are indicative of biophilic city indicators and were compiled to best describe the initial step to building an indicator-based dataset. In terms of framework development, Table 2 breaks NBS indicators down into: categories, indicators, units, method and source.We related these indicators to a given spatial scale to allow the conversion from absolute number to density (n/km^2, n/capita) which would apply both for green design features and for the building-integrated vegetation (with different cover fractions of the building). For the building-integrated vegetation, we also considered the overall green surface cover in terms of both the horizontal and vertical dimensions.

Table 1.Biophilic city indicators (adapted from Beatley 2011; Beatley & Newman 2013)

KEY PARAMETERS	INDICATORS
Biophilic conditions and infrastructure	Percentage of population living within a few hundred metres of a park or green space Percentage of city land area covered by trees or other vegetation Number of green design features (e.g. green rooftops, green walls, rain gardens) Percentage of building-integrated vegetation (BIV) Extent of natural images, shapes, forms employed in architecture and seen in the city Consistency of flora and fauna (e.g. species) found within the city
Biophilic behaviours, patterns, practices and lifestyles	Average proportion of the day spent outside Visit rates for city parks Percentage of trips made on foot Extent of membership and participation in local nature clubs and organisations
Biophilic attitudes and knowledge	Percentage of residents expressing care and concern for nature Percentage of residents who can identify common species of flora and fauna
Biophilic institutions and governance	Priority given to nature conservation by local government; percentage of municipal budget dedicated to biophilic programmes Existence of design and planning regulations that promote biophilic conditions (e.g. mandatory green rooftop requirement, bird-friendly building design guidelines) Presence and importance of institutions, from aquaria to natural history museums, that promote education and awareness of nature Number/extent of educational programmes in local schools aimed at teaching about nature Number of nature organisations and clubs of various sorts in the city, from advocacy to social groups

Table 2. A framework for measuringNature-Based Solution (NBS) indicatorsin Vladivostok, Russia

CATEGORIES	INDICATORS	UNITS	METHOD	SOURCE
Regulating services	Air quality improvement 1) Amount of pollutants (NO_2, O_3, SO_2, CO and particulates) removed by NBS 2) Dry deposition rate	1) kg/year 2) cm/s	Field data and modelling approach (e.g. EMEP MSC-W model, i-Tree Eco V6/UFORE model, ENVI-met V4 model) andresearch by design method(e.g. different design scenarios with green roofs vs conventional roofs). Measurements of air pollutant levels using dry deposition passive samplers placed under tree canopies.	Janhäll 2015; Guidolotti et al. 2016; Yli-Pelkonen et al. 2017
	Potential of NBS to mitigate urban CO_2 emissions (CO_2 storage and sequestration by NBS) 1) CO_2 sequestration 2)Carbon stocks in vegetation and soil	1) kg CO_2 $m^{-2}y^{-1}$ 2)ton C /ha	Biomass estimates byallometric equations and growth rate predictions using tree core analysis. Soil CO_2 effluxes directly measured with chamber systems. Eddy covariance technique.	Russo et al. 2015; Weissert et al. 2014; Liu et al. 2012; Crawford & Christen 2015
	Maintenance of a healthy urban forest (Diversity Index)	%	Identification of urban trees.	Dobbs et al. 2014
	Runoff mitigation 1)Impervious and permeable surface 2) Canopy interception	1) % sealed surface relative to permeable surface (ha) 2)Interception % of precipitation	Mapping urban impervious surfaces using aerial images. Tree rainfall interception model.	Xiao et al. 2000
Supporting services	Habitat provision	%	Ratio of native trees	Dobbs et al. 2014
Provisioning services	Food production and medicinal plants 1)Total area of EGI 2) Harvested crops 3) Medicinal plants 4)Potential food production	1)ha 2)ton/ha 3) no. of species/ha 4)ton/ha	Identification of different edible green infrastructure typologies (e.g. botanical gardens, school gardens, allotment gardens, domestic garden) Assessing crop yields using GIS and field work. Potential food production using multiple land use scenarios. Identification of medicinal plants	Haberman et al. 2014; Da Rocha et al. 2015 Russo et al. 2017
Cultural services	Maintenance of natural heritage	%	Identification of native species	Dobbs et al. 2014

	Recreation 1) Land suitable for outdoor recreation 2) Open space per habitant 3) Number of recreation sites 4)Playgrounds for children 5)Area of park per inhabitant 6)Access to public recreation sites	1) % 2) m^2 per capita 3) number 4) m^2 5) ha/inhabitant 6)Inhabitants within 1 km from a public park	Spatial data of open spaces, field work	Dobbs et al. 2014; Da Rocha et al. 2015; La Rosa et al. 2016; WHO, 2016
Biodiversity, health and human wellbeing	1)Shannon diversity index (H) 2)Presence/abundance of selected species 3)Psychological wellbeing and perceived species richness	1) Adimensional 2) Percentage cover 3)Depression, anxiety and stress scale, blood pressure	Floristic and habitat surveys. Questionnaires to urban green spaces users in different locations (e.g. with high and low biodiversity level; urban and peri-urban). Physiological recovery in different virtual environments (research by design method)	Carrus et al. 2015; Fuller et al. 2007; Shanahan et al. 2016; Annerstedt et al. 2013

Discussion

We propose an interdisciplinary approach based on mixed quantitative and qualitative methodology and tools to assess ecosystem services and human wellbeing by different NBS interventions in Vladivostok. However, using multiple approaches and tools to assess multiple ecosystem services can lead to different results. In order to allow comparisons across sampled cities, standardisation of the various approaches and methodologies is needed. Our indicator 'Percentage of population living within a few hundred metres of a park or green space' can be used to establish green space accessibility standards at national or city level. In other countries, e.g. the UK, city residents should have access to a natural green space of minimum 2 ha within a distance of 300 m from home, within a walking distance of no more than 5 minutes, while the European Common Indicators suggest this distance to approximate a 15 minute walk (WHO, 2016).

The results of the biophilic indicators used in this study might be suitable for comparison with the Global Biophilic Cities Network (see http://biophiliccities.org/the-biophilic-cities-project/).

Our NBS indicators can be used to predict and simulate future situations and performances and to develop city benchmarking, which consists of comparing NBS indicators within and across cities to establish how well an area or city is performing vis-a-vis other locations (e.g. Russian cities) or against a best practice benchmark(Kitchin et al. 2015).

Conclusions and Recommendations

The expected outcomes of this research will help city planners and community members of Vladivostok, Russia, with possible extension to other towns or cities in Russia and the Asia-Pacific Region, to better understand ecosystem services and the benefits associated with a NBS approach. It will extend understanding of how an existing city can improve natural systems between buildings and on their rooftops and may highlight the importance of restoring degraded urban ecosystems. Enhancing NBS in Vladivostok through its new master plan can stimulate economic growth and improve the wellbeing and the landscape aesthetic in urban areas. Furthermore, landscape architects and urban planners will amplify their knowledge base and view for a sustainable planning framework and design of future Russian cities and beyond.

References

Agavelov, V., Brudny, A., Bozhukova, E., Kavtaradze, D., Orlova, E., Rusinl, Yanitsky, O.& Zubakin, V. 1985. Ecopolis Programme. The International Exposition, Tsukuba, Japan. 1985.

Annerstedt, M. et al. 2013. Inducing physiological stress recovery with sounds of nature in a virtual reality forest — Results from a pilot study. *Physiology & Behavior* 118, 240-250.

Beatley, T., 2011. *Biophilic Cities*, Washington, DC: Island Press/Center for Resource Economics.

Beatley, T. & Newman, P. 2013. Biophilic Cities are sustainable, resilient cities. *Sustainability*, 5(8), pp.3328–3345.

Carrus, G. et al., 2015. Go greener, feel better? The positive effects of biodiversity on the well-being of individuals visiting urban and peri-urban green areas. *Landscape and Urban Planning* 134, 221-228.

Cohen-Shacham, E. et al. 2016. *Nature-Based Solutions to Address Societal Challenges*, Gland, Switzerland: IUCN.

Crawford, B. & Christen, A. 2016. Spatial source attribution of measured urban eddy covariance CO2 fluxes. *Theor Appl Climatol.* 119, 733-755.

Da Rocha, S. et al. 2015. *Mapping and assessment of urban ecosystems and their services*, Available at: http://publications.jrc.ec.europa.eu/repository/handle/JRC100016.

Dobbs, C., Kendal, D. & Nitschke, C.R. 2014. Multiple ecosystem services and disservices of the urban forest establishing their connections with landscape structure and sociodemographics. *Ecological Indicators*, 43, pp.44–55.

Dushkova, D., Haase, D. & Haase, A. 2016. Urban green space in transition : Historical parks and Soviet heritage in Arkhangelsk, Russia. *Critical Housing Analysis* 3(2), 61-70.

Escobedo, F.J., Kroeger, T. & Wagner, J.E. 2011. Urban forests and pollution mitigation: analyzing ecosystem services and disservices. *Environmental pollution* 159(8-9), 2078–87.

Fuller, R.A. et al. 2007. Psychological benefits of greenspace increase with biodiversity. *Biology Letters* 3(4), 390–394.

Gill, S. et al., 2007. Adapting cities for climate change: the role of the green infrastructure. *Built Environment*, 33, pp.115–133.

Guidolotti, G., Salviato, M. & Calfapietra, C. 2016. Comparing estimates of EMEP MSC-W and UFORE models in air pollutant reduction by urban trees. *Environmental Science and Pollution Research* 23(19), 19541–19550.

Haberman, D. et al. 2014. The Potential of Urban Agriculture in Montrйal: A Quantitative Assessment. *ISPRS International Journal of Geo-Information* 3(3),1101–1117.

Ignatieva M., Konechnaya G. and G. Stewart. St.Petersburg in Plants and Habitats of European Cities.2011. *Vegetation and Plants of European Cities.*Kelcey, J. and Muller, N. (eds.). Springer-Verlag, pp.407-452

Ignatieva, M. 2000. Ecopolis-towards the total holistic city: lessons in integration from throughout the world. In: *Proceedings of Urban biodiversity and ecology as a basis for holistic planning and design Workshop, Stewart, G. and Ignatieva, M (Ed)*, pp. 102-105.

Janhäll, S. 2015. Review on urban vegetation and particle air pollution – Deposition and dispersion. *Atmospheric Environment* 105, 130–137.

Kazakova,M., Beloshenkova, A. 2015. Historical and modern green areas of Ryazan. *In: M.Ignatieva, N. Thorne, E.Golosova, P. Berg., P. Hedfors, T. Eriksson, D. Menzies (eds). History of the Future. 52nd World Congress of the International Federation of Landscape Architects Congress proceedings. 10– 12 June 2015. Saint-Petersburg, Russia. Peter the Great Saint-Petersburg State Polytechnic University Polytechnic University Publishing House, St. Petersbur*g, p.70

Kellert, S. 2016. Biophilic urbanism: the potential to transform. *Smart and Sustainable Built Environment* 5(1), 4-8.

Kerimova., N. 2015. A systemic approach for creating green-blue infrastructure in the post-industrial area of the Viborgskaya embankment, Saint Petersburg. In: *M.Ignatieva, N. Thorne, E.Golosova, P. Berg., P. Hedfors, T. Eriksson, D. Menzies (eds). History of the Future. 52nd World Congress of the International Federation of Landscape Architects Congress proceedings. 10– 12 June 2015. Saint-Petersburg, Russia. Peter the Great Saint-Petersburg State Polytechnic University Polytechnic University Publishing House, St. Petersburg*, p.71

Kitchin, R., Lauriault, T.P. & McArdle, G. 2015. Knowing and governing cities through urban indicators, city benchmarking and real-time dashboards. *Regional Studies, Regional Science* 2(1), 6–28.

La Rosa, D., Spyra, M. & Inostroza, L. 2016. Indicators of cultural ecosystem services for urban planning: A review. *Ecological Indicators* 61, 74–89.

Lambert, K.G. et al. 2015. Brains in the city: Neurobiological effects of urbanization. *Neuroscience & Biobehavioral Reviews* 58, 107–122.

Liu H. Z., Feng J.W., Järvi L.&Vesala, T. 2012. Four-year (2006–2009) eddy covariance measurements of CO_2 flux over an urban area in Beijing. *Atmos. Chem. Phys*. 12, 7881–7892.

Nilsson, K. et al. 2007. Implementing urban greening aid projects – The case of St. Petersburg, Russia. *Urban Forestry & Urban Greening* 6(2), 93–101.

Reeve, A.C. et al. 2015. Biophilic urbanism: contributions to holistic urban greening for urban renewal. *Smart and Sustainable Built Environment* 4(2), 215-233.

Russo, A. et al. 2015. Transportation carbon dioxide emission offsets by public urban trees: A case study in Bolzano, Italy. *Urban Forestry & Urban Greening* 14(2), 398–403.

Russo, A. & Cirella, G.T. 2017. Biophilic Cities: Planning for sustainable and smart urban environments. In R. Aijaz, ed. *Smart Cities Movement in BRICS*. Observer Research Foundation and Global Policy Journal, 153–159.

Russo, A. et al. 2017. Edible green infrastructure: An approach and review of provisioning ecosystem services and disservices in urban environments.*Agriculture, Ecosystems and Environment*242, 53–66.

Scott, M. et al. 2016. Nature-based solutions for the contemporary city/Re-naturing the city/Reflections on urban landscapes, ecosystems services and nature-based solutions in cities/Multifunctional green infrastructure and climate change adaptation: brownfield greening as an a. *Planning Theory & Practice* 17(2), 267-300.

Shanahan, D.F. et al. 2016. Health Benefits from nature experiences depend on dose. *Scientific Reports* 6(1), 28551.

Takano, T., Nakamura, K. & Watanabe, M. 2002. Urban residential environments and senior citizens' longevity in megacity areas: the importance of walkable green spaces. *Journal of Epidemiology and Community Health* 56(12),913–918.

Veremchuk, L.V. et al. 2016. Urban air pollution, climate and its impact on asthma morbidity. *Asian Pacific Journal of Tropical Biomedicine* 6(1), 76–79.

Weissert, L.F., Salmond, J.A. & Schwendenmann, L. 2014. A review of the current progress in quantifying the potential of urban forests to mitigate urban CO2 emissions. *Urban Climate* 8, 100–125.

WHO, 2010. Urbanization and health. *Bulletin of the World Health Organization*, 88(4), pp.245–246. Available at: http://www.who.int/bulletin/volumes/88/4/10-010410.pdf.

WHO, 2016. Urban green spaces and health: a review of the evidence, Copenhagen. Available at: http://www.euro.who.int/__data/assets/pdf_file/0005/321971/Urban-green-spaces-and-health-review-evidence.pdf?ua=1.

Wilson, E.O. 1986. *Biophilia*, Cambridge: Harvard University Press.

Xiao, Q. et al. 2000. A new approach to modeling tree rainfall interception. *Journal of Geophysical Research: Atmospheres* 105(D23),29173–29188.

Yli-Pelkonen, V., Setдlд, H. & Viippola, V, 2017. Urban forests near roads do not reduce gaseous air pollutant concentrations but have an impact on particles levels. *Landscape and Urban Planning* 158(2), 39–47.