Metamorfosa:Journal of Biological Sciences 8(2): 202-209 (September 2021)
DOI: 10.24843/metamorfosa.2021.v08.i02.p03
https://ojs.unud.ac.id/index.php/metamorfosa/article/view/63378

JURNAL METAMORFOSA
Journal of Biological Sciences
eISSN: 2655-8122
http://ojs.unud.ac.id/index.php/metamorfosa

The Role of City Forest: Study of Malang Urban Forest Contribution in Sequestrating Carbondioxide Emition

Peran Hutan Kota : Studi Kontribusi Hutan Kota Malang Dalam Penyerapan Emisi Karbondioksida

Roimil Latifa, Diani Fatmawati*, Ahmad Fauzi

Department of Biology Education, Faculty of Teacher Training and Education, Universitas Muhammadiyah Malang, Jl. Raya Tlogomas 246 Malang 65144
**Email: dianifatmawati87@gmail.com*

ABSTRACT

Malabar, as an urban forest has a potential in CO_2 sequestration which was not documented yet. This quantitative descriptive research aimed to describe the contribution of Malabar urban forest in CO_2 emission mitigation through calculating the amount of CO_2 absorbed by the forest. The data collection used was non-destructive in which the indicators measured were DBH and the height of the trees with DBH more than 20 cm. The data gained then were analyzed using Alometric Chave formula to obtain the amount of plant biomass, carbon values, and CO_2 values. The results showed that the potential of Malabar urban forest is not optimized yet as the low amount of carbon stored in this forest (37.004 ton/ha per year). Thus, it is suggested to enrich the forest with the trees which are able to sequestrate the great amount of CO_2.

Kata kunci: Alometric Chave, CO_2 sequestration, Malabar urban forest.

INTRODUCTION

Urban forest is one of public services which is commonly found in most of big cities. Not only as the identity of the cities where they are placed, but forests also benefit the citizen's live in the cities. Some of the advantages possibly gained are the urban forest capacity in reducing noises (Samara & Tsitsoni, 2011; Uletika *et al.*, 2016), the shading created from the trees grow in forests (Bowler *et al.*, 2010; Livesley *et al.*, 2016) and beautiful scenery (Dobbs et al., 2014; McPherson *et al.*, 2017; Zhou & Rana, 2012). These have placed urban forest as one of alternatives to reduce citizen stress level. Furthermore, the ecological advantage such as birds habitat (Lerman *et al.*, 2014; Sulaiman *et al.*, 2013), water conservation (Livesley *et al.*, 2016), and germ plasm conservation (de Oliveira *et al.*, 2011) are also presented by the existence of urban forests.

As the positive effects brought by urban forest, its presence has been considered as a must in providing green city area to decrease disadvantage gasses in the air. This has not only been popular alternative in reducing pollutant (Remina *et al.*, 2019; Velasco *et al.*, 2016) in a certain area, but this is also expected to minimize the harmful compound produced from urban citizen activities (Kanniah *et al.*, 2014). Moreover, a health structure of urban forest has significant role in creating a more livable city as considerable as more capable to adapt with uncertain climate changes phenomena (Livesley *et al.*, 2016). The presence of trees in city has been the enhancer of carbon dioxide (CO_2) absorption rapidity through photosynthetic process (Febriani *et al.*, 2018; Marchi *et al.*, 2017).

Even though CO_2 is categorized as a middle-toxic level compound, in some certain conditions, it can be altered to be strongly hazardous material (McIntush *et al.*, 2011). As the increase of transportation uses as well as industrial activities, the higher level of CO_2 content in the atmosphere occurs (Andrlík, 2014; Elosta *et al.*, 2013). Yet, CO_2 has been addressed as the main gas causing greenhouse effect which leads to the nowadays global warming phenomena (Khan, 2017). This, in turn, gives negative impacts to living organism and the environment in the same time such as health issue (Ioan & Amelitta, 2015), the sea level rise (Kaintura & Gusain, 2016), and global climate changes (Ansarizadeh *et al.*, 2015; Nwankwoala, 2015). Due to its significant role in climate changes, the upsurge of CO_2 amount in the atmosphere has been an interesting topic in various scientific discussions and investigations (Ansarizadeh *et al.*, 2015).

In general, one of promising method in reducing CO_2 emission in the atmosphere is by saving the carbon in the non-atmosphere possible mediums (Toochi, 2018). Almost of green plants possess the ability in storing CO_2 (Kristiyanti, 2021) through photosynthetic process (Hopkins & Huner, 2009; Toochi, 2018). For approximately a half of carbon assimilated in photosynthesis are released to the air through respiration (Mackey, 2014). Therefore, the higher number of trees in urban forests the greater amount of CO_2 to be adsorbed. This also promote daytime urban heat mitigation and improve residents' well-being (Ziter *et al.*, 2019). However, somehow, it is important to be noted that not all species of plants are able to sequestrate pollutants optimally (Livesley *et al.*, 2016; Mercy *et al.*, 2018; Rane *et al.*, 2017; Vogt *et al.*, 2017). Some of them, even, can contribute in increasing the amount of pollutant (Livesley *et al.*, 2016). Thus, the studies which address the ability of urban forest in adsorbing CO_2 is crucial to be conducted in various cities and countries.

The analysis of urban forest ability in adsorbing carbon has been done in many countries such as China (Liu & Li, 2012), United State (Nowak *et al.*, 2013), and Spain (Baró *et al.*, 2014). The similar studies were also conducted in various cities in Indonesia such as Semarang (Febriani *et al.*, 2018), Surabaya (Sukmawati *et al.*, 2015), and Palangka Raya (Fidayanti & Palangkaraya, 2016). Likewise, some urban forests are found in Malang in which Malabar is the largest one (Subandi & Prastiwi, 2017). It was also reported that Malabar Forest produce the greater oxygen amount compared to the other forests in Malang (Sesanti *et al.*, 2011). Furthermore, the plant species in this forest are more divers (Isnaini *et al.*, 2015). The characteristic of this forest is the absent of vegetation plantation pattern. The vegetation spread in the whole forest area as well as the random pattern of plant space (Alfian & Kurniawan, 2010).

There were some previous researches done in Malabar Forest. These research focuses were also divers such as insect diversity (Kartikasari *et al.*, 2015), type and vegetation pattern (Alfian & Kurniawan, 2010; Isnaini *et al.*, 2015), and oxygen production of Malabar Forest (Sesanti *et al.*, 2011). Thus, this study was focused on the capability of Malabar Forest in absorbing carbon in Malang. Through this research, it is expected to gain the description of Malabar contribution in dealing with CO_2 emission mitigation.

MATERIALS AND METHODS

This quantitative descriptive research aimed to calculate the amount of CO_2 absorbed in Malang urban forest, Malabar (Figure 1), and was conducted on April 2017. The population were the all tree types found in Malabar Forest in which the sample were the trees with trunk diameter more than 20 cm and the diameter at breast height (DBH) more than 1.3 m.

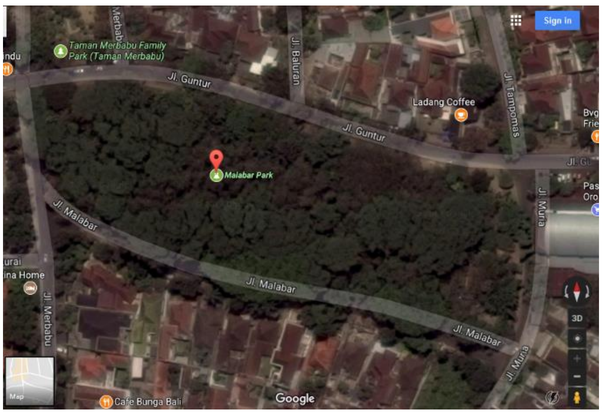

Figure 1. The location of Malabar Forest in Malang (source: GoogleMap)

Data Collection

Non-destructive method was chosen in this research. The data were collected in seven plots with 0.3 Ha for each. It was constructed two-layer subplot in each plot, namely subplot A (10 × 10 m) and subplot B (5 × 5 m) (Figure 2). In subplot A, the measurements of DBH and height of the trees with DBH more than 20 cm were done. Meanwhile, in subplot B, the same procedure was done to the DBH of the trees as well as the height of the trees with DBH between five and 20 cm.

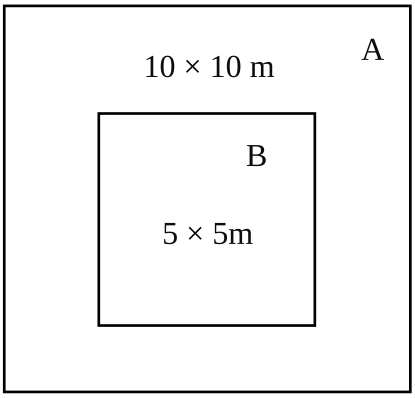

Figure 2. Plot design which comprised of two-layer subplot

Data Analysis

The measurement of plant biomass

The DBH value obtained from subplots A and B were then calculated by using Alometric Chave et al. within rahardjanto (2015) (see formula (1)).

$$Y = 0.059 \text{ X } \rho \text{ X } DBH^2 \text{ X } T \text{..........................} (1)$$

where Y is total of biomass (kg); DBH is the Diamater at Breast Height (m); T is plant height; and ρ is specific weight of wood, 0.68 g/cm^3 for natural forest and 0.61 g/cm^3 for plantation forest (Rahardjanto, 2015)

The Measurement of Carbon Value

Carbon value was calculated using Formula (2) with the conversion factor of 0.5.

$$C = B + 0.5 \text{ ....} (2)$$

where C is the amount of carbon stock (ton/ha); B is the total biomass of calculated tree stand (ton/ha).

The Measurement of CO_2 Value

The CO_2 value was obtained by using Brown formula (3).

$$CO_2 \text{ Sequestration (ton/ha)} = \left(\frac{bmrCO_2}{bmrC}\right) \text{ X C Value................... } (3)$$

where bmr CO_2 is the relative molecular weight of CO_2 (i.e. 44); and bmr C is the relative molecular weight of C (i.e.12)

RESULTS AND DISCUSSION

The calculation summary of biomass, carbon value, and CO_2 value resulted are served in Table 1. It can be seen from the table that the total amount of biomass in Malabar Forest as high as 3.544 ton/ha per year, while carbon value was 37.004 ton/ha per year, and CO_2 sequestration was 135.77 ton/ha per year.

Table 1. The summary of biomass, carbon value, and CO_2 sequestration by trees in Malabar Forest, Malang city

No	Location	Plot	Biomass (ton/ha per year)	C Value (ton/ha per year)	CO_2 Sequestration (ton/ha per year)

1	A	A	0.94	6.44	23.67
		B	0.02	2.52	9.24
2	B	A	0.37	2.84	10.4
		B	0.014	5.01	18.39
3	C	A	0.96	3.46	12.67
		B	0.011	3.01	11.04
4	D	A	0.37	1.87	6.86
		B	0.004	0.504	1.85
5	E	A	0.35	2.85	10.46
		B	0.012	2.01	7.38
6	F	A	0.26	2.76	10.12
		B	0.013	1.51	5.55
7	G	A	0.2	0.7	2.57
		B	0.02	1.52	5.57
TOTAL			3.544	37.004	135.77

Urban forest has the ability in reducing CO_2 emission in urban area. This ability related to the capability of forest trees which naturally need CO_2 in their life survival. The atmospheric CO_2 will be assimilated by every tree as the way to produce their own food through photosynthetic process (Toochi, 2018). However, every urban forest possesses different CO_2 sequestration level, thus the contribution in reducing CO_2 emission is also various.

One of the main factors determine the sequestration level is tree types grow in urban forest (Livesley *et al.*, 2016; Mercy et al., 2018; Rane *et al.*, 2017; Vogt *et al.*, 2017). The results of this research showed that Albizia chinensis was the highest number of the trees grow in Malabar Forest. There were 31 trees of *A. chinensis* found in the research sampling plots. This domination was followed by *Polyalthia longifolia* (14 trees), *Pithecellobium dulce* (5 trees), *Gmelina arborea* (5), *Chrysophyllum cainito* (4), *Chamaedorea sp*. (4), and the lowest number was possessed by *Averrhoa belimbi*, *Elais guinensis*, *Ficus maclelandii*, and *Mimusoph elengi* in which there only one tree found for each species.

Notwithstanding that *A. chinensis* was the highest number of trees dominate the forest, however, this species is not categorized as the tree with the high CO_2 sequestration capability. The research done in Maros reported that *Samanea saman* dan *Cerbera odollam* were the species with the highest sequestration capability (Mercy *et al.*, 2018). The cultivation of *S. saman* was recommended in the other research due to its high capability in sequestrating CO_2 (Das & Mukherjee, 2015; Hafids *et al.*, 2018; Suwanmontri *et al.*, 2013). However, on the other hands, no report suggests *A. chinesis* as the species addressed to absorb CO_2 in urban area. This indicates that the existence of the plantations in Malabar Forest has not been optimized yet.

The findings of this research were in line with some previous researches. A research conducted in Barcelona reported that the carbon absorption by city forest was too low compared to the total emission of greenhouse gases resulted from those urban activities (Baró *et al.*, 2014). Likewise the research in Chuncheon, Korea, revealed that city forest cannot absorb the whole CO_2 emission produced in that city (Lee *et al.*, 2014). Therefore, these researches recommended the expansion of green area in the cities to diminish CO_2.

The endeavors in reducing carbon emission have been becoming global challenge and addressed to be comprehended by scientists (Di Vita *et al.*, 2017). As the massive proliferation of the vehicle uses, industrial machinery, as considerable as the household activities have up surged the carbon emission in the atmosphere (Andrlík, 2014; Kanniah *et al.*, 2014; Zhao *et al.*, 2010). Thus, to minimize the activities which worsen the condition as well as enlarge green area are the main way enable human to cope with the nowadays global warming issue. Consequently, to construct a green area in the city is the most frequent alternative chosen to solve global warming issue (Kanniah *et al.*, 2014; Livesley *et al.*, 2016; Velasco *et al.*, 2016).

The results of this research indicate that Malabar Forest possesses the fair level of CO_2 sequestration. As the largest city forest in Malang, Malabar is expected to be the main carbon storage in Malang City. Besides holding the role as oxygen factory, Malabar Forest is projected to be able to deal with the rapid increase of carbon emission occurring these days. Nevertheless, if this effort does not meet the expectation, the other global warming mitigation methods are crucial to be arranged in Malang. Some of the methods are expansion of green area, reforestation effort by planting some certain plant species which have high ability in absorbing carbon, as considerable as legalizing policies related to the use of vehicles in Malang.

CONCLUSION

The potential of Malabar Forest in global warming mitigation is still low in which the total amount of biomass in Malabar Forest was 3.544 ton/ha per year, while carbon value was 37.004 ton/ha per year, and CO_2 sequestration was 135.77 ton/ha per year. Thus, the alternative optimation effort possibly done is by enriching the diversity of trees planted, mostly those which has the ability in absorbing a great amount of CO_2 in the environment.

ACKNOWLEDGEMENT

A great appreciation is devoted to The Rector of University of Muhammadiyah Malang (UMM) for granting the research funding, also the Director and staff of Directorate of Research and Community Service UMM for managing this research proposal and report. Deep gratitude is also directed to Head of Environmental Services of Malang Regency Government for providing official permission in sample collection. The last but not the least, appreciation is also sent to the Head of Biology Laboratory UMM for providing equipment to conduct this research.

REFERENCES

Alfian, R., and H. Kurniawan. 2010. Identifikasi bentuk, struktur dan peranna hutan Kota Malabar Malang. *Buana Sains*, 10(2), 195–201.

Andrlík, B. 2014. Carbon dioxide emissions as an indicator of reduction of negative externalities related to road motor vehicle operation. *Acta Universitatis Agriculturae et Silviculturae Mendelianae Brunensis*, 62(4), 613–621.

Ansarizadeh, M., K. Dodds, O. Gurpinar, L. J. Pekot, U. Kalfa, S. Sahin, S. Uysal, T. S. Ramakrishanan, N. Sacuta, and S. Whittaker. 2015. Carbon dioxide — Challenges and opportunities. *Oilfield Review*, 27(2), 36–50.

Baró, F., L. Chaparro, E. Gómez-Baggethun, J. Langemeyer, D. J. Nowak, and J. Terradas. 2014. Contribution of ecosystem services to air quality and climate change mitigation policies: The case of urban forests in Barcelona, Spain. *Ambio*, 43(4), 466–479.

Bowler, D. E., L. Buyung-Ali, T. M. Knight, and Pullin, A. S. 2010. Urban greening to cool towns and cities: A systematic review of the empirical evidence. *Landscape and Urban Planning*, 97(3), 147–155.

Das, M., and A. Mukherjee. 2015. Carbon sequestration potential, its correlation with height and girth of selected trees in the Golapbag Campus, Burdwan, West Bengal (India). *Indian Journal of Scientific Research*, 10(1), 53–57.

de Oliveira, J. A. P., O. Balaban, C. N. H. Doll, R. Moreno-Peñaranda, A. Gasparatos, D. Iossifova, and A. Suwa. 2011. Cities and biodiversity: Perspectives and governance challenges for implementing the convention on biological diversity (CBD) at the city level. *Biological Conservation*, 144(5), 1302–1313.

Di Vita, G., M. Pilato, B. Pecorino, F. Brun, and M. D'Amico. 2017. A review of the role of vegetal ecosystems in CO2 capture. *Sustainability (Switzerland)*, 9(10), 1–10.

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

Elosta, A. B., A. S. Leksono, and M. Purnomo. 2013. People knowledge and perceptions about carbon dioxide (CO_2) air pollution in Malang caused by motor vehicles. *International Refereed Journal of Engineering and Science (IRJES)*, 2(9), 46–51.

Febriani, A. P., T. R. Soeprobowati, and M. Maryono. 2018. Analysis of urban forest needs as anthropogenic (CO_2) gas absorbent in Semarang City. *E3S Web of Conferences*, 31, 1–5.

Fidayanti, N., and U. Palangkaraya. 2016. Analisis serapan karbondioksida berdasarkan tutupan lahan di kota Palangka Raya. *Jurnal Matematika, Saint, dan Teknologi*, 17(2), 77–85.

Hafids, A., N. Dwi, R. Wildan, F. P. Arinda, A. Janna, and A. Fauzi. 2018. Daya perkecambahan biji trembesi (Samanea saman) yang direndam oleh hormon giberellin. Prosiding Seminar Nasional IV 2018: Peran Biologi dan Pendidikan Biologi Dalam Revolusi Industri 4.0 dan Mendukung Pencapaian Sustainability Development Goals (SDG's), hal. 137–144.

Hopkins, W. G., & Huner, N. P. A. 2009. Introduction to plant physiology, US: John Wiley & Sons, Inc.

Ioan, B., and L. Amelitta. 2015. Carbon dioxide –Significant emission sources and decreasing solutions. *Procedia - Social and Behavioral Sciences*, 180(November 2014), 1122–1128.

Isnaini, R., Sukarsono, and R. E. Susetyarini. 2015. Keanekaragaman jenis pohon di beberapa arela hutan Kota Malang. Prosiding Seminar Nasional Pendidikan Biologi 2015, Prodi Pendidikan Biologi, FKIP, Universitas Muhammadiyah Malang, pp. 630–635.

Kaintura, A., and M. Gusain. 2016. Carbon dioxide: Present scenario, future trends and techniques to reduce CO_2 concentration in air. *International Journal of Scientific and Research Publications*, 6(2), 158–162.

Kanniah, K. D., N. Muhamad, and C. S. Kang. 2014. Remote sensing assessment of carbon storage by urban forest. IOP Conference Series: Earth and Environmental *Science*, 18(1), pp. 1-5.

Kartikasari, H., Y. B. S. Heddy, and K. P. Wicaksono. 2015. Analisis biodiversitas serangga di hutan kota Malabar sebagai urban ecosystem services Kota Malang pada musim pancaroba. *Jurnal Produksi Tanaman*, 3(8), 623–631.

Khan, Z. A. 2017. Causes and consequences of greenhouse effect & its catastrophic problems for earth. *International Journal of Sustainability Management and Information Technologies*, 3(4), 34.

Kristiyanti, N. N. E., I. K. Ginantra, and I. A. Astarini. 2021. Composition, vegetation structure, and carbon absorption potential of Mangrove Forests in Ngurah Rai Forest Park, Denpasar. *Metamorfosa: Journal of Biological Sciences*, 8(1), 1–17.

Lee, J., G. Lee, and J. Kim. 2014. Calculating total urban forest volume considering the carbon cycle in an urban area - focusing on the city of Chuncheon in South Korea. Forest Science and Technology, 10(2), 80–88.

Lerman, S. B., K. H. Nislow, D. J. Nowak, S. DeStefano, D. I. King, and D. T. Jones-Farrand. 2014. Using urban forest assessment tools to model bird habitat potential. *Landscape and Urban Planning*, 122, 29–40.

Liu, C., and X. Li. 2012. Carbon storage and sequestration by urban forests in Shenyang, China. *Urban Forestry and Urban Greening*, 11(2), 121–128.

Livesley, S. J., G. M. McPherson, and C. Calfapietra. 2016. The urban forest and ecosystem services: Impacts on urban water, heat, and pollution cycles at the tree, street, and city scale. *Journal of Environment Quality*, 45(1), 119.

Mackey, B. 2014. Counting trees, carbon and climate change. *Significance*, 11(1), 19–23.

Marchi, M., V. Niccolucci, R. M. Pulselli, and N. Marchettini. 2017. Urban sustainability: CO2 uptake by green areas in the historic centre of siena. *International Journal of Design and Nature and Ecodynamics*, 12(4), 407–417.

McIntush, K. E., J. E. Lundeen, K. S. Fisher, and C. A. M. Beitler. 2011. When CO_2 is more hazardous than H_2S. *Brimstone Sulfur Symposium*, September, 44–45.

McPherson, E. G., Q. Xiao, N. S. van Doorn, J. de Goede, J. Bjorkman, A. Hollander, R. M. Boynton, J. F. Quinn, and J. H. Thorne. 2017. The structure, function and value of urban forests in California communities. *Urban Forestry and Urban Greening*, 28(September), 43–53.

Mercy, A., B. Hamzah, and D. Rahim. 2018. An analysis of the adequacy of green lane vegetation in absorbing The carbon monoxide (CO) of transportation activities. *International Journal of Engineering Science Invention (IJESI)*, 7(5), 59–64.

Nowak, D. J., E. J. Greenfield, R. E. Hoehn, and E. Lapoint. 2013. Carbon storage and sequestration by trees in urban and community areas of the United States. *Environmental Pollution*, July 2013, 229-236.

Nwankwoala, H. N. L. 2015. Causes of climate and environmental changes: The need for environmental-friendly education policy in Nigeria. *Journal of Education and Practice*, 6(30), 224–234.

Rane, A. D., S. S. Narkhede, S. G. Bhave, and M. M. Burondkar. 2017. Quantification of CO2 absorption rates of few tropical trees of Konkan Region of Maharashtra. *Advanced Agricultural Research & Technology Journal*, I(I), 19–23.

Remina, D., C. Chairul, and N. Nurainas. 2019. Analysis of vegetation and the estimation of carbon stock in indigenous protected Forest Ghimbo Bonca Lida Kampar Riau. *Metamorfosa: Journal Of Biological Sciences*, 6(1), 19–24.

Samara, T., and T. Tsitsoni. 2011. The effects of vegetation on reducing traffic noise from a city ring road. *Noise Control Engineering Journal*, 59(1), 68.

Sesanti, N., E. B. Kurniawan, and M. Anggraeni. 2011. Optimasi hutan sebagai penghasil oksigen Kota Malang. *Jurnal Tata Kota dan Daerah*, 3(1), 65–74.

Subandi, H. B. H., and J. H. Prastiwi. 2017. Jejak kuasa atas tata ruang (Studi kasus kebijakan revitalisasi hutan Kota Malabar). *Jurnal Wacana Politik*, 2(2), 113–127.

Sukmawati, T., H. Fitrihidajati, and N. K. Indah. 2015. Penyerapan karbon dioksida pada tanaman hutan kota di Surabaya. *Lentera Bio*, 4(1), 108–111.

Sulaiman, S., N. H. N. Mohamad, and S. Idilfitri. 2013. Contribution of vegetation in urban parks as habitat for selective bird community. *Procedia - Social and Behavioral Sciences*, 85, 267–281.

Suwanmontri, C., C. Kositanont, and N. Panich. (2013). Carbon dioxide absorption of common trees in chulalongkorn university. *Modern Applied Science*, 7(3), 1–7.

Toochi, E. C. 2018. Carbon sequestration: How much can forestry sequester CO2? Forestry Research and Engineering: *International Journal*, 2(3), 148–150.

Uletika, N. S., P. Hardini, and A. Darmawan. 2016. Noise reduction in industrial environment: Case study in cement factory cilacap, Indonesia. *International Journal of Innovation and Applied Studies*, 18(2), 2028–9324.

Velasco, E., M. Roth, L. Norford, and L. T. Molina. 2016. Does urban vegetation enhance carbon sequestration? *Landscape and Urban Planning*, 148, 99–107.

Vogt, J., S. Gillner, M. Hofmann, A. Tharang, S. Dettmann, T. Gerstenberg, C. Schmidt, H. Gebauer, K. Van de Riet, U. Berger, and A. Roloff. 2017. Citree: A database supporting tree selection for urban areas in temperate climate. *Landscape and Urban Planning*, 157, 14–25.

Zhao, M., Z. hong. Kong, F. J. Escobedo, and J. Gao. 2010. Impacts of urban forests on offsetting carbon emissions from industrial energy use in Hangzhou, China. *Journal of Environmental Management*, 91(4), 807–813.

Zhou, X., and M. M. P. Rana. 2012. Social benefits of urban green space: A conceptual framework of valuation and accessibility measurements. *Management of Environmental Quality*, 23(2), 173–189.

Ziter, C. D., E. J. Pedersen, C. J. Kucharik, and M. G. Turner, 2019. Results suggest strategies for managing urban land-cover patterns to enhance resilience of cities to climate warming. *Proceedings of the National Academy of Sciences of the United States of America*, pp. 7575–7580.