



Bangkok's existing mixed fruit orchards are tree diversity hotspots for city greening

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Abstract

Bangkok's Inner Orchard (BIO), located in the west peri-urban area of the city, provides both fresh products and ecological benefits to its inhabitants. Although this unique forest-like cultivation of mixed fruit trees growing on dikes has the potential to become an urban forest, it has never been thoroughly investigated. Urban expansion is a threat to this orchard. Sustainable cities must maintain a balance between development and the environment. In this study, six orchards were surveyed by collecting data on tree species, plant height, crown width, and location and analyzed to identify the orchard areas covered by forest canopy and clarify the forest structure and tree species diversity in the orchards. Overall, 98.64% of the forest canopy within the orchard area was evaluated using cover analysis. Analysis of the forest structure of the BIO revealed that the average tree height was greater than that of common orchard trees. Tree diversity analysis showed an average Shannon index value of 2.53, indicating mid-range diversity. Older orchards showed a greater diversity of fruit tree species, whereas newer orchards, replanted after major flood and drought events, showed a lesser diversity of fruit tree species. In order to protect BIO on the long-term, it is essential to identify and apply appropriate conservation strategies. Including BIO areas in the Bangkok greening scheme would cause rapid increases in the green area per capita ratio. Both urban food forest and urban agriculture concepts could be applied to existing BIO orchards, which represent new urban green area types. BIO thus has the potential to act as an urban forest and tree diversity hotspot for Bangkok.

Keywords Bangkok's Inner Orchard · Geographic information system · Tree diversity · Urban agriculture · Urban forest

Introduction

Urban green areas

The world population has shown a trend for the movement of populations from rural to urban areas, with more than half of the global population already settled in cities (Debnath et al. 2014; Anguluri and Narayanan 2017). The United Nations (UN) estimated that 68% of the world's population would live in urban areas by 2050 (Department of Economic and Social Affairs, United Nations 2018). Some members of the urban population live in crowded compact cities, whereas the remaining live in vast urban sprawls. As a consequence,

the urban environment is strongly affected by various forms of urbanization, and the sustainable development of urban areas is challenging. Therefore, Goal 11—sustainable cities and communities—is included in the sustainable development goals of the UN (Division for Sustainable Development Goals, Department of Economic and Social Affairs, United Nations 2015).

Urban greening is one of the strategies used to maintain and improve the urban environment, which affects humans to large extent. A lack of green areas in the urban environment has become a major problem that influences the quality of living, health, and well-being of urban dwellers (Bolund and Hunhammar 1999; De la Barrera et al. 2016; Wolch et al. 2014; Arifwidodo and Chandrasiri 2021; Arifwidodo et al. 2022). Green areas provide ecosystem services such as the mitigation of air pollution, capture of particulate matter (PM 2.5 and 10), microclimate regulation, urban cooling, noise reduction, and runoff mitigation, which aid in coping with the environmental problems resulting from urbanization (Bolund and Hunhammar 1999; Arifwidodo 2014).

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Green areas help people relax and maintain good health by engaging in physical activity and recreation (Cohen et al. 2007; De Jong et al. 2012; Pietilä et al. 2015; Wang et al. 2019; Arifwidodo and Chandrasiri 2020). Urban agriculture as well as urban food forest in green areas also provide food and various materials, thus they are an essential part of the urban food system (Tsuchiya et al. 2015; Opitz et al. 2016; Nogueira-McRae et al. 2018; Park et al. 2019).

Bangkok, the capital city of Thailand, is one of the fastest-growing cities in the world (Lo et al. 1996). Over the past four decades, the urbanized area of Bangkok has expanded to its surrounding provinces, forming a metropolitan region called the Bangkok Metropolitan Region (BMR). New urban fringe development, in the form of built-up housing areas, commercial facilities, offices, factories, and warehouses, has taken the place of the green areas of former agricultural lands, while in the center of the city, real estate developers invested in former open green areas in central business districts to develop high-density high-rise condominiums, hotels, offices, and shopping malls (Intasen et al. 2017). The Bangkok Metropolitan Administration (BMA) is concerned about the lack of green areas in the city and aims to increase such areas to 10 m²/person by building more new urban public parks in the Green Bangkok 2030 campaign (C40 Cities 2020; Bangkok Metropolitan Administration 2021). The goals of this campaign also include increasing the urban tree canopy cover in Bangkok from 8.6 to 30% (Intasen et al. 2017). However, the expansion of green areas by building new public parks is a slow process, and the rate of greening will be insufficient to reach this goal, particularly because both urban expansion and the urban population are increasing at an extremely high rate due to birth and migration.

The conventional design of urban public parks in Bangkok, as in many developing cities, is primarily focused on the growing of ornamental plants and lawns (Richards et al. 2017). However, diverse types of green areas should be included in the planning. Vegetation in existing semi-natural green areas aids in improving the urban environment and ecology, providing ecosystem services that are necessary for a livable city (Richards et al. 2017). Green areas of agricultural lands already exist in the BMR, but thorough investigation on the potential of existing fruit forest patches for urban greening is still lacking.

Surrounding agricultural lands

Cities are the primary economic organ of most countries (Jacobs 1970) and are usually surrounded by agricultural land, which tends to be fertile, with high-quality soils (Bryant et al. 1982). The spatial relationships between urban and agricultural lands are described in Von Thünen's Isolated

State Model (Rodrigue 2020). Different types of agricultural land are located in the form of rings at specific distances from a city, with the distance based on the perishability and heaviness of the goods. For instance, perishable products from market gardens and dairy farms are produced in close proximity to the city to prevent decay during long periods of transportation. Firewood and lumber production areas are located further away from the center in the next ring, but they remain close to the city for easy transportation of these heavy products (Rodrigue 2020).

Various types of agricultural lands—rice paddy fields, aquaculture farms, vegetable gardens, and fruit orchards—are located around Bangkok. Even before the establishment of Bangkok as the capital city of Thailand, the primary function of these agricultural lands has been the provision of food. Bangkok originated as a small agricultural village with fertile deltaic soil, growing various tropical fruits and vegetables to serve Ayudhaya, the former capital city. Although the urbanization of Bangkok led to a lack of green areas, the existing agricultural land may have good potential to become a multi-functional urban agricultural land, bringing additional benefits to the urban environment and population.

Urban forest as a green area in Bangkok

Urban forest is collectively defined as an urban ecosystem that consists of forest patches, trees, plants, and associated animals located in and around the city where people live, work, and play (Nilsson et al. 2001; Weirsum and Sands 2013; Vogt 2020). From this inclusive urban forest definition, forest patches, wooded areas, and tree-dominated parks can be counted as urban forests in the same as trees planted along roads and in gardens (Weirsum and Sands 2013). To define a forest, the tree canopy cover was a key index used for forest area identified by the Global Forest Resources Assessments (FRA) of the Food and Agriculture Organization (FAO) and the United Nations Framework Convention on Climate Change (UNFCCC).

Urban forests became a global phenomenon that is the backbone of cities' green infrastructure. They were used as bridges and buffers between rural and urban areas in various cities (FAO 2017). Urban forests enhanced the environmental cities' footprint which is necessary for urbanites' well-being (Weirsum and Sands 2013).

In Thailand, forest clearing was previously the main form of land exploitation. The legislature gave property rights to the individual who cleared and utilized wildlands. This concept is still rooted in the existing laws. Therefore, most of former Bangkok's natural forests have been cut down over time, giving way to agriculture and urban development (Tejajati et al. 1999; Delang 2005; Asanok et

al. 2017). However, mixed fruit trees were planted instead of natural forests along the Chao Phraya River, forming a series of multi-storied, forest-like orchards, jointly called Bangkok's Inner Orchard (BIO) (Chankrajang and Vechbanyongratana 2020). These mixed fruit orchards, a typical traditional cultivation system in Southeast Asia, could act as an urban green area, with the potential to become an urban forest (Sritongchuay et al. 2019).

Urban forests are urban green areas that contribute to urban ecology by enhancing the biodiversity in urban regions (Korhonen et al. 2021). Tree diversity is a key driver of overall forest-associated biodiversity (Ampoorter et al. 2020). A wide array of ecosystem services is supported by tree species diversity which is necessary for urban ecosystem adaptability and resilience to disturbance (Morgenroth et al. 2016; Cordonnier et al. 2018). Lack of biodiversity, reflected in a low diversity of tree species, is an essential problem associated with deterioration of the urban environment caused by the widening of urban areas (Mirski 2020; Berthon et al. 2021). This study aims to understand the potential of BIO as tree diversity hotspots. The objectives of the study were (1) to identify the orchard areas covered by forest canopy and (2) to explore forest structure and tree species diversity. The findings from this study can be used by the local government to evaluate their potential to be integrated into green space planning policies in Bangkok.

Methods

Study area

The study area was focused on the BIO located in the western part of the BMR. The area was selected because it had the most extensive land use changes due to urbanization but at the same time, it also had the biggest patch area identified as the BIO. We obtained land-use maps from 1959 to 2000 with aerial photographs in 2022 retrieved from the Royal Thai Survey Department to understand the overall spatial patterns of BIO at the macro scale. A total area of 230 km² was identified as the BIO at the western part of BMR.

We then conducted a pre-survey of all areas categorized as the BIO to select the microscale study areas based on three criteria: (1) it was still operational, (2) it had clear boundaries, (3) it was possible to identify the owner of the orchard (because we needed the owner's permission to survey the orchards). Using a snowballing sampling method, six orchards were selected for the study. We could not expand the number of orchards in the study due to time constraints and budget limitations. Although the number of orchards used for the study was small, they had a good

spatial distribution, spreading from the northern to the southern part of the whole BIO (Fig. 1).

Orchards that are still operational include both old continuing orchards (OC) and newly planted orchards (NP). The selected orchards were: (1) Orchard A, a NP orchard, located in the Muang district, Nonthaburi province; (2) Orchard B, an OC orchard, located in the Talingchan district, Bangkok; (3) Orchard C, an OC orchard, located in the Bangkoknoi district, Bangkok; (4) Orchard D, an OC orchard, located in the Bangkoknoi district, Bangkok; (5) Orchard E, an OC orchard, located in the Chom Thong district, Bangkok; and (6) Orchard F, an OC orchard, located in the Phra Pradaeng district, Samut Prakarn province. More detailed information on orchard characteristics can be found in Table 1.

Landscape and vegetation survey

Because the study area was located in the urban fringe area of Bangkok where rapid urbanization of the former orchard area is continuously happening, pre-surveys were conducted on-ground across the entire orchard region based on maps and documented studies to obtain a clear picture of the current status of the orchards. Urban development encroached upon the existing fruit orchard area, forming intermixed urban–rural parcels. As a consequence of this type of urbanization, the following three types of orchards were found: (1) old continuing (OC), (2) newly planted (NP), and (3) abandoned orchards (AO).

An on-ground survey was conducted on the six selected orchards. Physical information on these orchards was collected, focusing on landscape and vegetation because the BIO landscape combines natural and human-made systems for growing fruit trees on low-lying land near the Chao Phraya River. The land has been rearranged into ditches and dikes, which provide a higher ground level for growing fruit trees and a lower ground level for irrigation ditches. The orchard size and landform of each orchard were measured with the orchard owners' guidance for the land boundary. These measured spatial data were mapped in a geographic information system (GIS) database using ArcGIS 10.4 (Environmental Systems Research Institute, Redlands, CA, USA).

Five graduate students majoring in forestry were recruited for the field survey. We conducted a three-days training for the surveyors in identifying tree species and measuring tree dimensions. The following parameters were collected during the survey: tree location, tree height, crown width, and species. A handheld global positioning system device (GPSMAP 62sc; Garmin Ltd.; Olathe, KS, USA) was used to acquire the exact location of each tree. A laser measuring tool (Leica Disto D2; Leica Geosystems Ltd., Heerbrugg,

Fig. 1 Location of the six study orchards in the BMR

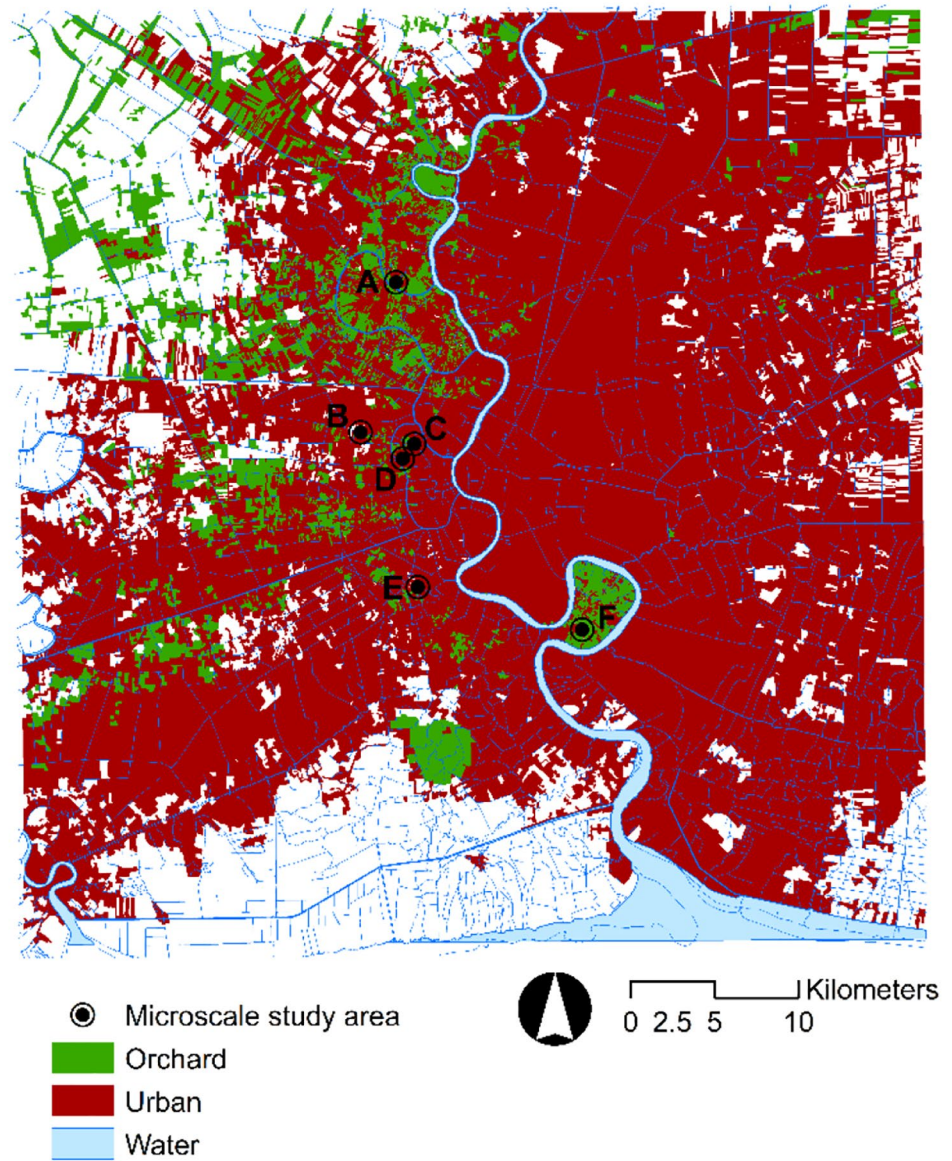


Table 1 Comparison of orchard size, type, average tree canopy cover, average tree height, average tree canopy diameter, and Shannon diversity index in six orchards

Orchard	Orchard Size (m ²)	Type	Average Tree Canopy Cover (%)	Average Tree Height (m)	Average Tree Canopy Diameter (m)	Shannon Index
A	12,000	NP	61.37	4.27	3.44	1.62
B	3,680	OC	57.35	4.46	3.06	2.75
C	4,320	OC	62.35	5.69	3.78	2.57
D	2,176	OC	44.93	4.66	2.70	1.99
E	11,200	OC	58.27	4.37	3.28	3.51
F	1,712	OC	50.66	4.18	2.92	2.73

Orchard types: Old continuing (OC), Newly planted (NP), Abandoned orchard (AO)

Switzerland) was used for measuring tree dimensions. Tree guidebooks were consulted to correctly identify tree species (Veesommai and Jenjittikul 2006; Gardner et al. 2007; Veesommai and Kaewduangtien 2009). When necessary, leaves and flowers were collected along with photographs, and submitted to domain experts for the identification of tree species. The collected tree information was entered into a GIS map for further analysis.

Data analyses

Data from the landscape and vegetation surveys were analyzed (1) to identify the orchard areas covered by forest canopy, and (2) to explore the forest tree structure and tree diversity in the orchards.

Identification of orchard areas covered by forest canopy

Tree canopy cover is a metric widely used to evaluate urban forests (Barron et al. 2016). To estimate the urban afforestation, we adopted the definition of a forest from FRA and UNFCCC to appropriately measure forest areas in the orchard scale. The afforestation scale, tree height, and tree canopy cover were used to determine the forest attributes. For FRA, forest is a land area of more than 0.5 ha, with a tree canopy cover of more than 10% of which was covered by a canopy of trees at least 3 m high (UNEP 2009). For UNFCCC, forest is a land area of 0.01–0.1 ha, with 10–30% minimum tree canopy cover of 2–5 m tree height (UNEP 2009). In this study, an orchard area of 10 × 10 m, over 10% of which was covered by a canopy of trees at least 2 m high was considered to be a forest area.

The tree datasets, including tree height, average tree crown width, and tree location, were used for spatial analysis to identify orchard areas covered by forest canopy. ArcGIS 10.4 was used for data preparation. Data from trees at least 2 m high were used for further analysis. The crown area of each tree was generated in a circular shape using ArcGIS based on the collected average crown width data. The average crown width data came from measurements of each tree's crown width in 4 directions from its stem—north, south, east, and west. These data were used to create a canopy cover layer map, which was superimposed on a 10 × 10 m fishnet grid layer map. The percentage of tree canopy cover in each cell was analyzed using the zonal statistics tool in ArcGIS 10.4.

Forest structure and tree diversity analysis

Forest structure The structure of a forest is vital to its biodiversity (Pan et al. 2018). The data collected on tree species, height, and crown width from six orchards were used for

forest structure analysis. Trees at least 2 m high from the field survey data were included for the analysis. The average tree height and crown width per orchard were calculated and compared. The maximum and minimum tree height and crown width were also included in the comparisons. Scaled forest transects were drawn on-site to create a forest profile for each orchard, including the tree canopy layers. Tree profile diagrams were drawn at the sides of each orchard.

Tree diversity analysis Data on tree species were used for tree diversity analysis by employing the Shannon diversity index. Only trees with a minimum height of 2 m were included in this analysis.

The Shannon index (H') scores species diversity from 0 to 5, with a higher score indicating a higher diversity. The Shannon index was computed according to the following formula:

$$H' = - \sum_{i=1}^S Pi \ln Pi$$

where H' is the Shannon index, Pi is the proportion of individual trees found in i species, S is the total number of species, and $\sum_{i=1}^S Pi$ is the sum of Pi of tree species 1 to S .

Values of the Shannon index were compared among the six orchards.

Results

Identification of orchard areas covered by forest canopy

Analysis of the forest canopy based on a 10 × 10 m grid layer map revealed that nearly all orchard areas were covered by forest canopy. Out of 147 squares from six studied orchards, 145 were evaluated as forest areas.

Tree canopy covered 8,496.6 m² of the 14,700 m² (57.80%) covered by all study orchards. However, some variation in the tree canopy cover ratio was recorded in each orchard. The highest average tree canopy cover ratio (62.35%) was observed in Orchard C (max = 99.67%, min = 30.15%), followed by that in Orchard A, which was 61.37% (max = 84.4%, min = 14.27%). The average tree canopy cover ratio was the third highest in Orchard E at 58.27% (max = 95.54%, min = 17.88%), followed by Orchard B at 57.35% (max = 91.21%, min = 1.67%), Orchard F at 50.66% (max = 85.54%, min = 15.02%), and Orchard D with 44.93% (max = 63.18%, min = 19.82%) (Figs. 2 and 3) (Table 1).

Fig. 2 Map of tree canopy coverage ratio in each of the 10×10m cells of the Orchard D area

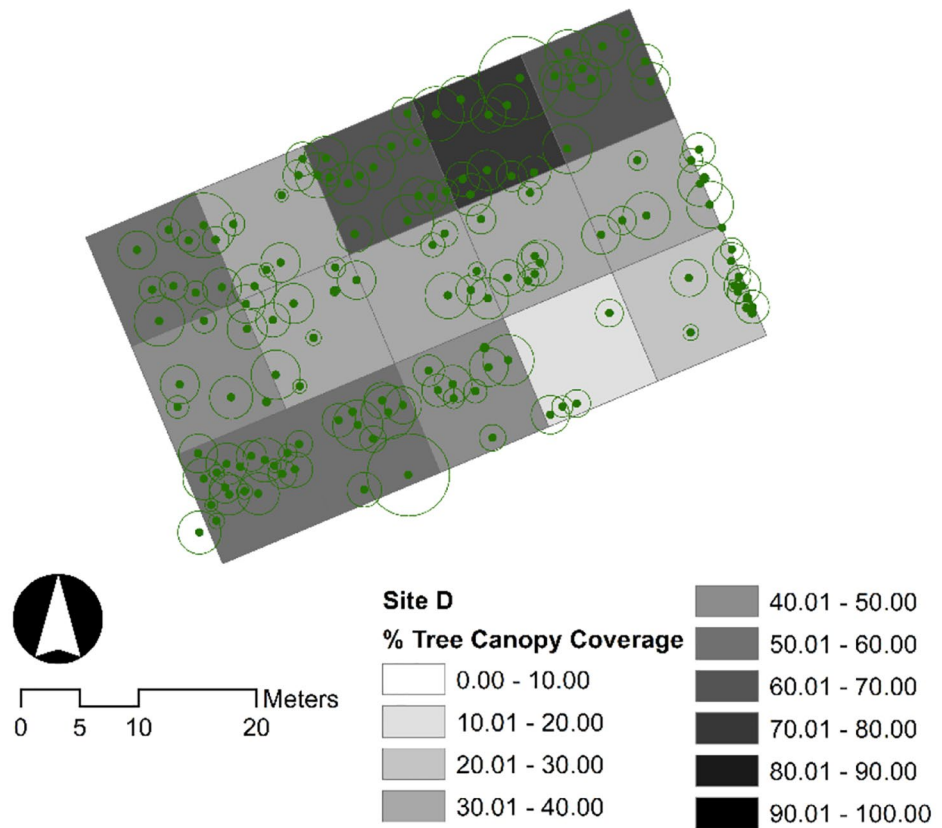
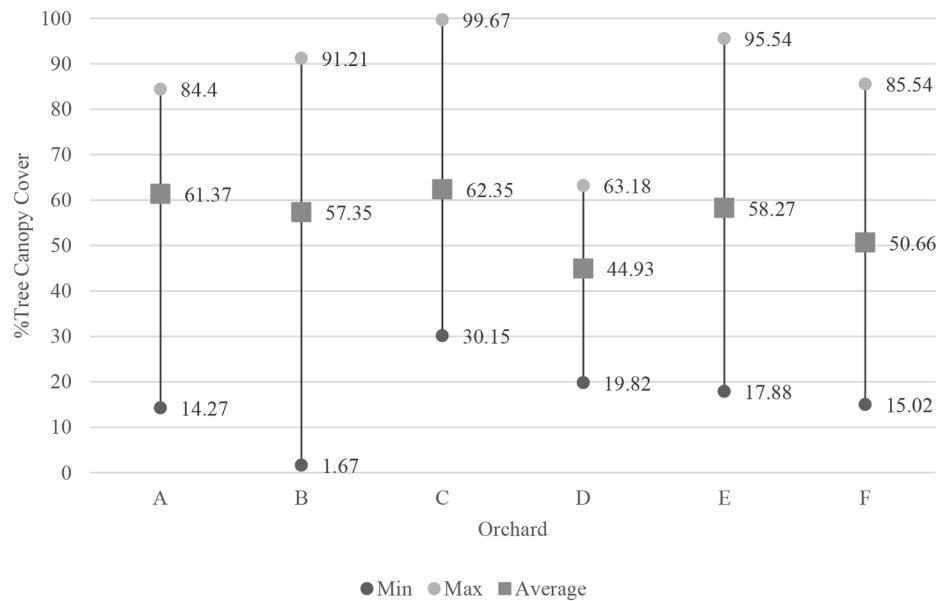


Fig. 3 Comparison of tree canopy cover ratio in 10×10m cells among six orchards



Forest structure and tree diversity analysis

Forest structure analysis

The tree heights from six orchards were measured and compared. The average tree height in Orchard C was 5.69 m (max=19.40 m, min=2 m), followed by Orchard D with 4.66 m (max=13.10 m, min=2 m). The third highest value was noted in Orchard B, which had an average tree height of 4.46 m (max=14 m, min=2 m), followed by Orchard E with 4.37 m (max=13.20 m, min=2 m), Orchard A with 4.27 m (max=12 m, min=2 m), and Orchard F with 4.18 m (max=12 m, min=2 m) (Figs. 4 and 5) (Table 1).

The canopy diameters of trees from six orchards were measured and compared. Orchard C had the largest average tree canopy diameter at 3.78 m (max=12 m, min=0.60 m), followed by Orchard A with 3.44 m (max=8.60 m, min=1 m). The third was Orchard E, whose average tree canopy diameter was 3.28 m (max=11.60 m, min=0.60 m), followed by Orchard B having an average tree canopy diameter of 3.06 m (max=8 m, min=0.46 m), Orchard F with 2.92 m (max=7.8 m, min=0.6 m), and Orchard D with 2.70 m (max=7.10 m, min=0.34 m) (Figs. 4 and 5) (Table 1).

Tree diversity analysis

The diversity of the trees in the six orchards was analyzed using the Shannon index. Orchard E was the richest in terms of species, with a Shannon index of 3.51. There were 292 trees of 58 species in this orchard. The majority were *Litchi chinensis* Sonn. (31 plants), *Musa balbisiana* Colla (24), and *Artocarpus heterophyllus* Lam. (20). Orchard B had the second highest tree diversity, with a Shannon index of

2.75 for 36 species within 159 trees. Most of them were *Syzygium malaccense* (L.) Merr. & L.M.Perry (36 plants), *Musa × paradisiaca* L. (27), *Carica papaya* L. (15), and *Syzygium samarangense* (Blume) Merr. & L.M.Perry (15). Orchard F had the third highest tree diversity, with a Shannon index score of 2.73 for 29 species within 134 plants. Most of them were *Cocos nucifera* L. (21 plants), *Leucaena leucocephala* (Lam.) de Wit (19), and *Senna siamea* (Lam.) H.S.Irwin & Barneby (19). Orchard C had the third highest tree diversity, with a Shannon index score of 2.57 for 39 species within 420 trees. The most prevalent species were *Mangifera indica* L. (85 plants), *Artocarpus heterophyllus* (78), and *Cocos nucifera* (77). The fifth was Orchard D with a Shannon index score of 1.99 for 19 species within 142 trees. Most of them were *Musa × paradisiaca* (47 plants), *Azadirachta indica* A.Juss. (29), *Mangifera indica* (20), and *S. malaccense* (20). The lowest tree diversity was found in Orchard A, which had a Shannon index score of 1.62. There were 18 species within 208 trees and most were *Musa × paradisiaca* (62 plants), *Erythrina fusca* Lour. (52), and *Durio zibethinus* Moon (45) (Tables 1 and 2).

Discussion and conclusions

Our results revealed that the BIO had the potential to be an urban forest as a part of the Bangkok greening scheme. This BIO green area is composed of large trees that provide tree canopy cover and tree species diversity.

Fig. 4 Comparison of tree height and tree canopy diameter in six orchards

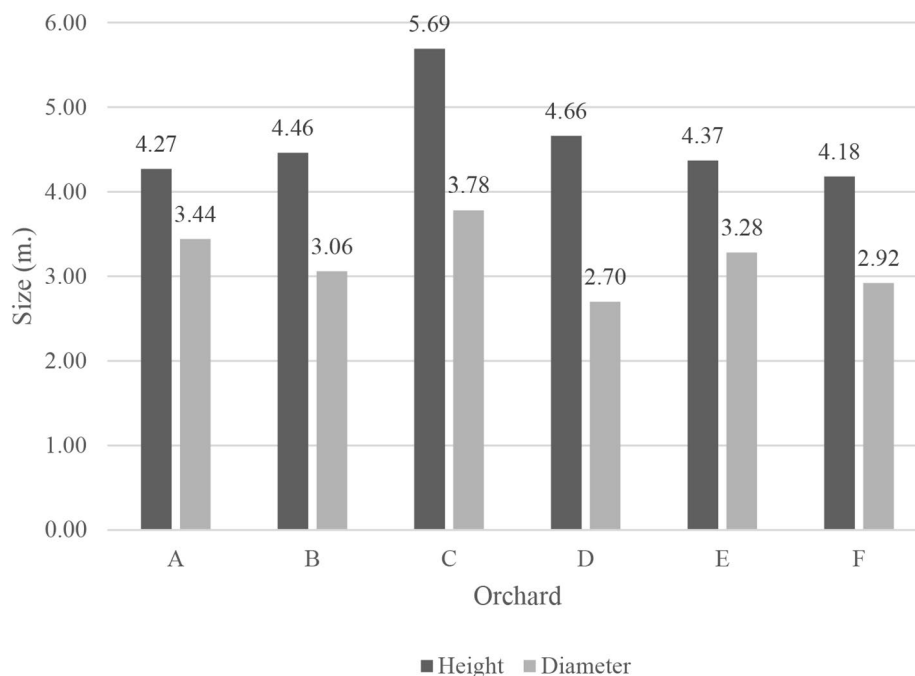




Fig. 5 Tree profile and photos of Orchard D

Orchard areas covered by forest canopy

The intermixing of rural and urban areas in Asian cities has aided their greening evolution from agricultural lands to a large extent (McGee 1972). Our results revealed that the existing mixed fruit orchards in Bangkok, the BIO, can be categorized as urban forests. Based on the FRA and UNFCCC criteria, most of the study orchard areas (14,500 m² from a total 14,700 m² (98.64%)) were regarded as forests based on analysis of the tree canopy cover ratio.

An increase in urban tree canopy (UTC) cover is one of the indices that the BMA aims to pursue. UTC is a basic but important index for green space management in cities worldwide (Parmehr et al. 2016). UTC values in some major cities in the US are: New York City 20.9%, Philadelphia 15.7%, and Chicago 11%, and in other continents: London 20%, Tokyo 19%, and Beijing 24% (Nowak and Dwyer 2007; Endreny et al. 2017). For Bangkok, a study conducted in 2013 estimated that the urban tree cover was 8.6%, which was relatively low (Intasen et al. 2017). However, agricultural areas were excluded from this study. A tree cover analysis of BIO revealed that the mixed fruit tree canopy covered a relatively large area: 57.8% of the orchards studied. Therefore, inclusion of the BIO as an urban green area will increase the UTC of both Bangkok and the BMR.

Forest structure and tree diversity

Forest structure

Forest structure, particularly tree height, is important to forest biodiversity (Martins et al. 2017; Pan et al. 2018). Tree height has a strong relationship with tree species richness (Marks et al. 2016). Our analysis revealed that the average tree height in the BIO was greater than that of common orchard trees. Tree height in rural areas is usually as low as 1.5–2.25 m because farmers need to trim tree branches to facilitate harvesting and the distribution of sunlight (Mika 1992; Wagenmakers and Callesen 1995). However, the tree height recorded in the field survey in the BIO was greater. The average tree height in each orchard ranged from 4.18 to 5.69 m. The tallest tree (19.4 m) was *Cocos nucifera*, in Orchard C. *Mangifera indica* was the tallest tree in Orchard D (13.1 m), *Erythrina fusca* (12 m) was the tallest in Orchard A, *Cocos nucifera* (12 m) in Orchard F, and *Artocarpus altilis* (Parkinson) Fosberg and *Litchi chinensis* (13.2 m) in Orchard E.

Fruit growing in the BIO followed the traditional style of agricultural practice on small subsistence farms (Khaokhrueamuang 2014). Various fruit trees occurring here imitate a natural forest structure with canopy layers at different heights. These allowed suitable sunlight conditions for different kinds of fruit trees, vegetables, and herbs that can grow together naturally in a compact area. Tree branch trimming to lower the height of fruit trees is not a common practice in the BIO. In a previous study, Sommeechai et al.

Table 2 List of plant species found in six orchards

Plant Species	Common Name	Number of Plants in Orchard					
		A	B	C	D	E	F
<i>Acacia pennata</i>	Climbing wattle	0	0	2	0	3	0
<i>Aegle marmelos</i>	Bael	0	2	0	0	0	0
<i>Alocasia sandieriana</i>	Sander's alocasia	0	1	0	0	0	0
<i>Alpinia galanga</i>	Galanga	0	1	0	2	0	0
<i>Annona muricata</i>	Soursop	0	2	0	0	0	0
<i>Annona squamosa</i>	Sugar apple	3	1	1	0	0	0
<i>Antidesma thwaitesianum</i>	Mao fruit	0	2	0	0	0	0
<i>Ardisia polycephala</i>	Duck's eyes	0	0	0	0	0	3
<i>Areca catechu</i>	Areca palm	18	0	2	0	12	3
<i>Artocarpus altilis</i>	Breadfruit	1	1	8	0	2	1
<i>Artocarpus heterophyllus</i>	Jackfruit	0	4	78	1	20	1
<i>Averrhoa bilimbi</i>	Bilimbi	0	2	0	0	12	1
<i>Averrhoa carambola</i>	Carambola	0	0	1	0	0	0
<i>Azadirachta indica</i>	Siamese neem tree	1	1	10	29	5	7
<i>Baccaurea ramiflora</i>	Rambeh Bambi	0	2	1	0	1	0
<i>Bambusa bambos</i>	Bamboo	0	0	0	1	0	0
<i>Bambusa multiplex</i>	Hedge bamboo	0	0	6	0	0	0
<i>Barringtonia acutangula</i>	Indian oak	0	0	0	0	9	0
<i>Barringtonia racemosa</i>	Powderpuff tree	0	0	1	0	0	0
<i>Bauhinia acuminata</i>	Snowy orchid tree	0	1	0	0	0	0
<i>Bouea macrophylla</i>	Marian plum	0	3	2	1	2	0
<i>Broussonetia papyrifera</i>	Paper mulberry	0	0	0	0	0	2
<i>Canna indica</i>	Canna lily	0	0	0	0	6	0
<i>Carallia brachiata</i>	Corkwood	0	0	0	0	1	0
<i>Carica papaya</i>	Papaya	1	15	2	2	3	1
<i>Caryota mitis</i>	Fishtail palm	0	0	0	0	1	2
<i>Cerbera odollam</i>	Pong pong	3	0	0	0	0	0
<i>Citrus aurantifolia</i>	Key lime	4	1	0	0	12	0
<i>Citrus hystrix</i>	Kiffir lime	0	2	2	1	0	0
<i>Citrus maxima</i>	Pomelo	1	0	0	1	2	0
<i>Citrus reticulata</i>	Tangerine	13	0	0	0	1	0
<i>Citrus sinensis</i>	Sweet orange	1	0	0	0	1	0
<i>Clerodendrum fragrans</i>	Glory bower	0	0	0	0	1	0
<i>Cocos nucifera</i>	Coconut	0	10	77	0	5	21
<i>Dalbergia cochinchinensis</i>	Siamese rosewood	0	0	0	0	1	0
<i>Dillenia indica</i>	Elephant apple	0	0	0	0	1	0
<i>Diospyros rhodocalyx</i>	Ebony	0	0	1	0	0	0
<i>Dolichandrone serrulata</i>	Trumpet tree	0	0	0	0	0	1
<i>Duranta erecta</i>	Golden dewdrop	0	0	0	0	1	0
<i>Elaeocarpus hygrophilus</i>	Ma Kok Nam	0	0	0	0	2	0
<i>Erythrina fusca</i>	Coral tree	0	0	1	0	12	3
<i>Etlingera eliator</i>	Torch ginger	0	0	0	0	2	0
<i>Fagraea fragrans</i>	Tembusu	0	0	0	0	1	0
<i>Ficus maciellandii</i>	Banana leaf fig	0	0	0	0	2	0
<i>Ficus racemosa</i>	Cluster fig	0	0	6	0	1	0
<i>Garcinia cowa</i>	Cowa	0	0	0	0	2	0
<i>Garcinia mangostana</i>	Mangosteen	1	0	0	0	0	0
<i>Garcinia schomburgkiana</i>	Madan	0	3	1	0	1	1
<i>Graptophyllum pictum</i>	Caricature plant	0	1	0	0	0	0
<i>Gymnanthemum extensum</i>	Bitterleaf tree	0	1	0	2	0	0
<i>Heliconia psittacorum</i>	Heliconia	0	0	0	0	1	0
<i>Hibiscus rosa-sinensis</i>	Hibiscus	0	0	0	0	0	1

Table 2 (continued)

Plant Species	Common Name	Number of Plants in Orchard					
		A	B	C	D	E	F
<i>Hylocercus undatus</i>	Dragon fruit	0	0	1	0	0	0
<i>Lagerstroemia speciosa</i>	Queen's flower	0	0	0	0	5	0
<i>Lansium domesticum</i>	Langsat	0	1	0	0	0	0
<i>Lasia spinosa</i>	Spiny Lasia	0	0	1	0	0	0
<i>Lepisanthes fruticosa</i>	Luna nut	0	2	0	0	0	0
<i>Lepisanthes rubiginosa</i>	Mertajam	0	0	0	0	0	2
<i>Leucaena leucocephala</i>	River tamarind	0	0	3	0	15	19
<i>Litchi chinensis</i>	Lychee	1	0	4	0	31	0
<i>Livistona speciosa</i>	Mountain serdang	0	0	0	0	0	1
<i>Malpighia glabra</i>	Barbados cherry	0	1	0	0	0	0
<i>Mangifera indica</i>	Mango	3	9	85	20	14	3
<i>Manilkara zapota</i>	Sapodilla	0	0	1	0	0	0
<i>Mimusops elengi</i>	Asian bulletwood	0	0	0	0	2	0
<i>Morinda citrifolia</i>	Noni	0	0	2	8	9	12
<i>Moringa oleifera</i>	Moringa	4	0	0	0	0	0
<i>Morus alba</i>	Mulberry	0	0	1	0	1	0
<i>Muntingia calabura</i>	Jamaican cherry	0	0	2	0	0	1
<i>Musa balbisiana</i>	Banana	2	0	14	1	24	0
<i>Musa sapientum</i>	Banana	54	27	22	47	8	15
<i>Oroxylum indicum</i>	Broken bones tree	0	0	0	0	6	0
<i>Pandanus amaryllifolius</i>	Pandanus palm	0	0	0	0	1	0
<i>Persicaria odorata</i>	Vietnamese coriander	0	0	0	0	1	0
<i>Phyllanthus acidus</i>	Star gooseberry	0	2	2	0	2	2
<i>Phyllocarpus septentrionalis</i>	Monkey flower tree	0	0	0	0	1	0
<i>Phyllostachys sulphurea</i>	Yellow running bamboo	0	0	0	0	6	0
<i>Pithecellobium dulce</i>	Manila tamarind	0	0	0	0	0	2
<i>Pseuderanthemum atropurpureum</i>	Purple false Eranthemum	0	1	0	0	0	0
<i>Psidium guajava</i>	Guava	0	0	1	2	4	0
<i>Pterocarpus indicus</i>	Burmese rosewood	0	0	0	0	0	1
<i>Ptychesperma macarthurii</i>	MacArthur palm	0	1	0	0	0	0
<i>Punica granatum</i>	Pomegranate	0	0	0	0	0	1
<i>Saccharum officinarum</i>	Sugar cane	0	0	0	1	1	0
<i>Sandoricum koetjape</i>	Santol	0	0	23	1	0	0
<i>Senna siamea</i>	Cassod tree	0	1	0	0	0	19
<i>Sesbania javanica</i>	Sesbania	0	2	0	0	0	0
<i>Solanum ferox</i>	Solanum	0	0	0	0	2	0
<i>Solanum torvum</i>	Turkey berry	0	1	0	0	0	0
<i>Solanum xanthocarpum</i>	Yellow berried night shade	0	0	1	0	0	0
<i>Spathodea campanulata</i>	African tulip tree	0	1	0	0	0	0
<i>Spondias pinnata</i>	Hog plum	0	0	0	0	3	0
<i>Streblus asper</i>	Siamese rough bush	0	2	13	0	2	1
<i>Syzygium jambos</i>	Rose apple	0	0	2	0	0	0
<i>Syzygium malaccense</i>	Malay apple	0	36	26	20	4	0
<i>Syzygium samarangense</i>	Java apple	0	15	11	0	2	0
<i>Tabebuia argentea</i>	Silver trumpet tree	0	0	0	0	1	0
<i>Tabebuia rosea</i>	Pink trumpet tree	0	0	0	0	0	1
<i>Tabernaemontana divaricata</i>	Crepe jasmine	0	0	0	1	0	0
<i>Tamarindus indica</i>	Tamarind	0	0	2	0	1	6
<i>Tecoma stans</i>	Yellow elder	0	0	0	0	1	0
<i>Tectona grandis</i>	Teak	0	0	0	0	11	0
<i>Terminalia catappa</i>	Bengal almond	0	0	1	0	0	0
<i>Theobroma cacao</i>	Cocoa	0	1	0	0	0	0

Table 2 (continued)

Plant Species	Common Name	Number of Plants in Orchard					
		A	B	C	D	E	F
<i>Thevetia peruviana</i>	Yellow oleander	0	0	0	0	2	0
<i>Thyrsostachys siamensis</i>	Bamboo	0	0	0	0	4	0
<i>Wrightia religiosa</i>	Water jasmine	0	0	0	0	2	0

(2018) identified three layers of tree canopy, whereas Sampanpanish and Lamroenprucksa (1994) identified four layers in these mixed fruit tree orchards. Because the tree canopies formed in the six studied orchards were continuous, the identification of tree canopy layers varied depending on the methods employed in previous studies (Sampanpanish and Lamroenprucksa 1994).

Tree diversity

The Shannon index measures species abundance and tree evenness (Magurran 2004). In the BIO, the Shannon index score ranged from 1.5 to 3.5. This scoring range is a typical value in most ecological studies (Kirkhoff 2010). The average Shannon index calculated from the six studied orchards was 2.53, which falls in the medium range of diversity. The highest score recorded in Orchard E was 3.51, a relatively high diversity value. The lowest score recorded in Orchard A was 1.62, which is considered a low diversity value. However, the present study excluded vegetation having a height lower than 2 m—shrubs and ground cover—from the analysis. Therefore, a Shannon index value including all vegetation present in the orchards should be included in future studies.

Old continuing orchards, represented by Orchards B, C, D, E, and F, consisted of relatively diverse fruit tree species. In contrast, the new Orchard A, replanted after a major flood in 2011 and a drought in the following year, had a lower diversity of fruit tree species.

To further investigate tree diversity, we randomly selected three case studies investigating natural tropical forests in Thailand and compared the diversity indices obtained in these studies. The first study was a tree diversity study of a mountain evergreen forest in the Chiang Dao Wildlife Sanctuary in the Chiang Mai province. The Shannon index scores from four study plots ranged from 1.32 to 2.10. The average diversity score was 2.06 (Kambai et al. 2016). The second study assessed the tree diversity of a forest complex in the Kui Buri National Park, Prachuap Khiri Khan province. This study shows that the Shannon index score depended on the type of the forest: mixed deciduous forest (1.20–2.60), secondary forest (0.43–1.85), or agricultural area (0–1.85) (Temchai et al. 2016). The third study was an assessment of the tree diversity of the Phu Khiao-Nam

Nao forest corridor in the Phitsanulok province. The Shannon index score of dry evergreen forest trees was 2.4, that of mountain coniferous forest trees was 2.36, that of deciduous forest trees was 1.15, and that of deciduous dipterocarp forest trees was 2.04 (Suksawang et al. 2012). Tree diversity in the BIO was in the same range as that assessed in natural forests, and higher than that in agricultural lands.

The BIO urban forests can be considered as multifunctional agricultural land that provides ecosystem services to the city. The BIO areas also play an essential role as an urban food forest, producing fresh tropical fruits such as durians, mangos, mangosteens, rose apples, jackfruits, litchis, coconuts, bananas, etc., and local herbs. The species diversity of fruit trees found in these traditional mixed-fruit orchards reflected a large variety of fruits and herbs that can be produced from the BIO. They also provide regulating services that improve the urban environment. Large trees located in urban forests are a sink for CO₂ and can help in offsetting carbon emissions from urban areas through photosynthesis (Pasher et al. 2014; Schafer et al. 2019).

A collection of large trees in the BIO is thus a valuable resource for improving Bangkok's urban environment, especially in expanding suburban residential areas. Large trees provide shade, and fresh air by significantly reducing air temperature and air pollution (Nowak and Heisler 2010; Krul 2015). New residents enjoy the lush green atmosphere of neighboring orchards by utilizing them as parks for recreation and exercise. The orchards have been encroached upon by new housing estates built by various real estate development companies. These new housing estates pose as a threat to the surrounding green areas of the BIO while clearing large amounts of large trees on their own land. Nevertheless, the presence of trees in urbanized areas increases a property's real estate value because the quality of life is enriched by tree diversity, which provides both aesthetic appeal and microclimate improvement (Singh et al. 2018).

Taking all these problems into consideration, we suggest that it is important to conserve the BIO using appropriate strategies because the ongoing development of civil engineering affects the area to a large extent. Protection of this semi-natural green space at an early stage of urban development is essential because it is difficult to regenerate this land in the future (Richards et al. 2017). In terms of planning, these agricultural lands could also act as buffer zones

to help avoid conflict between the urban environment and natural forests (Zhou and Wang 2011). Despite the fact that suitable greening policies are essential for the sustainability of urban development (Zhou and Wang 2011), the green areas of Bangkok are currently only defined as public parks, according to an open-space plan developed by the BMA (Taylor and Hochuli 2017). Including these BIO areas in the Bangkok greening scheme would be a powerful strategy to improve the green area per capita ratio. Urban food forest and urban agriculture share concepts of improving the sustainability and resilience of urban communities by the use of food-producing trees and agricultural produce to create urban edible landscapes (Bailkey and Nasr 2000; Clark and Nicholas 2013). Both urban food forest and urban agriculture concepts could be applied in this greening scheme as new types of urban green areas in the BIO for long-term community benefits (Kowalski et al. 2019).

Effective green urban planning and management that includes urban forests could provide many benefits to urban dwellers. The urban forests of the BIO are located primarily on private properties. However, Clark et al. (1997) suggested that urban forests on both public and private lands should be included in planning and management with the aim of addressing the association between the benefits and disadvantages of urban forest management (Dwyer et al. 1992). Therefore, accurate and quantitative assessment of data pertaining to these urban forests are vital to determine the value of services provided and to assess appropriate management strategies (Pirnat and Hladnik 2016).

At present, many BIO orchards have been negatively affected by urbanization, and an effective conservation plan does not exist. However, many farmers continue farming using traditional approaches. Some orchards have been adapted to urbanization by turning them into semi-public spaces in which people can hike and undertake various other activities. These orchards are an example of how conservation and utilization of agricultural land can co-exist in urban areas. However, all community members should be responsible for the management of these urban tree resources (Kenney et al. 2011).

This study revealed that the BIO had the potential to be an urban forest and tree diversity hotspot for Bangkok. The six study areas showed that the tree height was greater than the common orchard trees. The average value of the Shannon index was 2.53, indicating that they had similar tree species diversity to natural forests in Thailand. These findings indicated that the BIO could play an important role in Bangkok's urban greening policies as an urban forest. This study has limitations. Hence, future studies are required. Explorations on how to measure and identify BIO using a more sophisticated method are required to understand how the BIO can benefit urban areas.

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Data Availability The datasets generated and/or analysed during the study are available from the corresponding author upon request.

Declarations

Ethics approval Not applicable.

Competing interests The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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