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RESEARCH PAPER

Rapid Ecological Resilience Assessment of Urban Forest Parks: An alternative approach

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Abstract
Rising threats, such as climate change, have thus far resulted in disruptions to ecosystems. Therefore, ecological resilience (eco-resilience) to absorb such distractions and maintain the capacity of ecosystems has been the focal point of numerous studies. In most cases, the characteristics of ecosystems are considered as indicators shaping this type of resilience. In this study, an alternative approach was adopted to examine the performance and outcomes of an ecosystem instead of reflecting on affective factors. Therefore, the resilience index (RI) of an urban forest park was assessed using eco-functional indicators, such as eco-volume (V_{eco}), eco-height (H_{eco}), bio-volume (V_{bio}), and eco-volume (V_{eco}). At first, the forest park zoning was done. Then, each of the introduced indicators was calculated based on its specific parameters. Finally, the RI of the urban forest park was premeditated. The results showed that each zone with more effective Veco, Heco, and Veco gained a higher score in terms of resilience. The obtained score for RI was thus the function of the current ecological state of each zone. The study conclusions also confirmed that the outputs of the applied framework could embody the main indicators of resilience assessments (viz. thresholds, adaptive capacity, and self-organization). The application of this model on a larger scale required further studies.
Keywords: Adaptive Capacity, Thresholds, Ecosystem, Resilience Indicators

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INTRODUCTION

Ecological resilience (eco-resilience), as defined by Holling (1973), refers to the capability of an ecological system to respond and adapt to disturbance, and then shift to new balance, once the system passes from a *steady-state* equilibrium point, while engineering resilience is sustaining the integrity of a designated system. Therefore, it confers safety management in order to cope with complexity (Patriarca, Bergström, Di Gravio, & Costantino, 2018). Socio-ecological resilience also assumes it as an interconnected system. Accordingly, it concentrates on the ability of the community to deal with a disturbance, caused by external factors, and reorganize socio-ecological systems following a disturbance (Holling, 1996; Neil Adger, Arnell, & Tompkins, 2005). Eco-resilience addresses the increasing capacity of ecosystems to maintain desirable services in exposure to environmental fluctuations and human exploitations (Folke, Hahn, Olsson, & Norberg, 2005). The main goal of eco-

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resilience is to enhance the capability of ecosystems to absorb distractions and preserve the feedback, processes, as well as required natural structures with ecosystems. Resilience also interprets as the ability of ecosystems to cope with threats, absorb impacts, and even recover and adapt following persistent stresses or disruptive events (Marchese, Dayton, et al.2018). One of the first definitions in this sense describes resilience as jumping or restoring to the primary state (Holling, 1973). Of note, resilience is not always returning to the primary balance, but this can be the probability of adaption and transformation at the present state as well as survival rates and changes in the future (Folke et al., 2010). These descriptions show resilience as perceived in different manners due to its disciplinary background (Bone, Moseley, Vinyeta, & Bixler, 2016). Moreover, flexibility and thresholds are two critical dimensions of resilience (Gunderson, 2000; Nikinmaa et al., 2020).

This ability discloses three fundamentals' tenets, i.e., resistance (namely, thresholds), recovery or reorganization, and adaptive capacity (Boyd & Folke, 2011; Elmqvist et al., 2003; Folke, 2006; Folke et al., 2010). Each tenet also refers to thoughtful realities, that is, resistance embraces thresholds that ecosystems can resist against disturbances, recovery or reorganization introduces the alternative regimes after disturbances(Baho et al., 2017; Carpenter, Walker, Anderies, & Abel, 2001; Ferro-Azcona et al., 2019; Folke et al., 2004; Gunderson & Allen, 2010; Gunderson, Allen, & Holling, 2010), and adaptive capacity denotes the ability of ecosystems to resist, depending on their diversity and complexity as well as a learning mechanism(David G. Angeler & Allen, 2016; David G Angeler et al., 2019; Ferro-Azcona et al., 2019; Gunderson & Allen, 2010; Gunderson, Allen, & Holling, 2010).

Forest resilience is thus a developing concept that covers a wide variety of subjects. For example, Arianoutsou et al. (2011) assessed forest resilience after fires using the geographic information system (GIS) software and multiple criteria to analyze biological and geographic indices in Keep Union National Park in Greece and then ranked the high-risk ones affecting the loss of resilience (Arianoutsou, Koukoulas, & Kazanis, 2011). As well, Seidle et al. (2014) studied a perspective in the United States to investigate how effective the residual parts of trees (as an important class of biological heritage from fires) were in forest ecosystem-disturbance resilience. They also suggested that tree heritage was an important part of disturbance flexibility, which could highlight the forest-preserving potentials to deal with challenges facing ecosystem management challenges (Seidl, Rammer, & Spies, 2014). Besides, Hale et al. (2015) designated an approach based on a system with several dependencies, co-increments, and tensions, which allowed for tree resilience management in forest parks. They further pointed out the particular weaknesses, and identified urban forest resilience and accessible functional capabilities (Hale et al., 2015). Moreover, Siedl et al. (2016) examined the relationship between resilience and ecosystem-associated services and concluded that ecological disturbance had a potential impact on such services and resilience could act as a powerful approach to address the existing changes and the impact of disturbance regimes (Seidl, Spies, Peterson, Stephens, & Hicke, 2016).

Baho et al. (2017) also quantified eco-resilience based on some main attributes, including adaptive capacity, scales, alternative regimes, and thresholds. They even provided theoretical bases, which needed to be practically examined. Another study, assessing the resilience of spruce forests in Norway was similarly an attempt to quantify forest resilience, in which the correlation between climatic parameters and resilience had been investigated, describing that resilience was strongly context-dependent and thus precipitation could play a critical role in this respect (Seidl, Vigl, Rössler, Neumann, & Rammer, 2017). Bowditch et al. (2019) further considered forest resilience through public perceptions and used mixed methods for spatial resilience mapping purposes. In this sense, some factors such as carbon marketing and forest development could have significant effects on public perceptions. Investments in public partnerships could also foster forest resilience. Likewise, Albrich et al. (2020) reviewed forest-resilience simulation models and found that little research had considered resilience processes and further development of the applied models was necessary.

According to Ovenden et al. (2021), the relationship between growth resilience and extreme drought had followed nonlinear trajectories, which could have some effects on the post-recovery growth of trees (Ovenden, Perks, Clarke, Mencuccini, & Jump, 2021). In a similar study, Perez-Luque et al. (2021) had examined the resilience of forest trees to water stress gradients and unfolded that the resilience had not followed a homogeneous pattern due to discrepancy in ecological conditions (Pérez-Luque, Gea-Izquierdo, & Zamora, 2021). Additionally, Mina et al. (2021) had assumed landscapes as functional networks to assess resilience, and had concluded that the resilience indicators of forests had been negatively influenced by climate change as well as reduced forest capacity to adapt to global changes (Mina, Messier, Duveneck, Fortin, & Aquilué, 2021).

Numerous studies have been also conducted on eco-resilience, as Baho et al. (2017) reported that the implementation of practical quantitative resilience measurements was a challenge and the lack of operational frameworks was a gap between science and action (Gunderson et al., 2020; Baho et al., 2017). Furthermore, most of the current research have focused on merely evaluating a selection of resilience attributes. As a result, such assessments fail to represent the resilience of the whole system. Nevertheless, there is an alternative approach, in which the outcomes of ecosystems are measured instead of evaluating the parameters shaping resilience. This approach also relies on the presumption that if an ecosystem is resilient, its reflection is evident in its outcomes. Therefore, this approach applies a holistic framework instead of putting emphasis on partial parameters, which increase uncertainties.

Resilience is also calculated through five main parameters, which form the core of the alternative approach, namely, eco-volume (Veco), eco-height (Heco), eco-climax (Ceco), basal area (BA), and bio-volume (Vbio) (Torrico & Janssens, 2010). In this respect, Veco measures three main attributes, i.e., the ecological function of an ecosystem as a whole, the quality of natural systems, and the interactions of biotic and abiotic components of an ecosystem. It also has its deep root in the Planet competition over limited resources(Janssens, Pohlan, Keutgen, & Torrico, 2009; Janssens & Torrico, 2004; Torrico Albino & Carlos, 2006; Torrico & Janssens, 2010). As well, Heco is the typical plant weight gained over time for each plant community, and includes the height of canopy onward in the dominant plants (Janssens, Keutgen, & Pohlan, 2009; Sonwa, Weise, Nkongmeneck, Tchatat, & Janssens, 2017; Torrico Albino & Carlos, 2006; Torrico & Janssens, 2010). Vbio further refers to the overall capacity of biomass in a given specific place. In forest parks, the diameter and the height of tree species are equal to Vbio (M. Janssens et al., 2009; Pandya, Salvi, Chahar, & Vaghela, 2013; Sonwa et al., 2017; Torrico Albino & Carlos, 2006). As defined in Torrico et al. (2006), Ceco is assumed as the stabilized state of an ecosystem that had reached equilibrium. As a result, the potential of Veco achieves the highest rate. At this stage of the succession, an ecosystem experiences relative stability and it contains the highest amount of information in the form of net productivity biomass and symbiotic (Odum, 1969). .

The alternative approach concerned has been thus far examined in natural and agricultural ecosystems. It also has the potential to be exploited in different ecosystems such as urban forest parks while facing less uncertainty. Consequently, the present study was an attempt to adapt the mentioned framework to evaluate urban forest park resilience. Hereupon, the proposed approach was applied in a case study located in the city of Tehran (Iran) and the outcomes were compared with the reality of the area concerned.

MATERIALS AND METHODS

This study was focused on an urban forest park called Lavizan, in District 4 in the city of Tehran (Iran). In terms of its geographic coordinate, this park is located on longitude 51°29' to 51°34'15" equal to 544,000 to 551,500 Universal Transverse Mercator (UTM) and altitude 35◦44'20" to 35◦46'45" equal to 3,956,500 to 3,969,600 UTM (Figure 1). The minimum park elevation is 1,390 m and the maximum elevation is 1,590 m of the sea level with diverse roughness and mostly hills. The initial

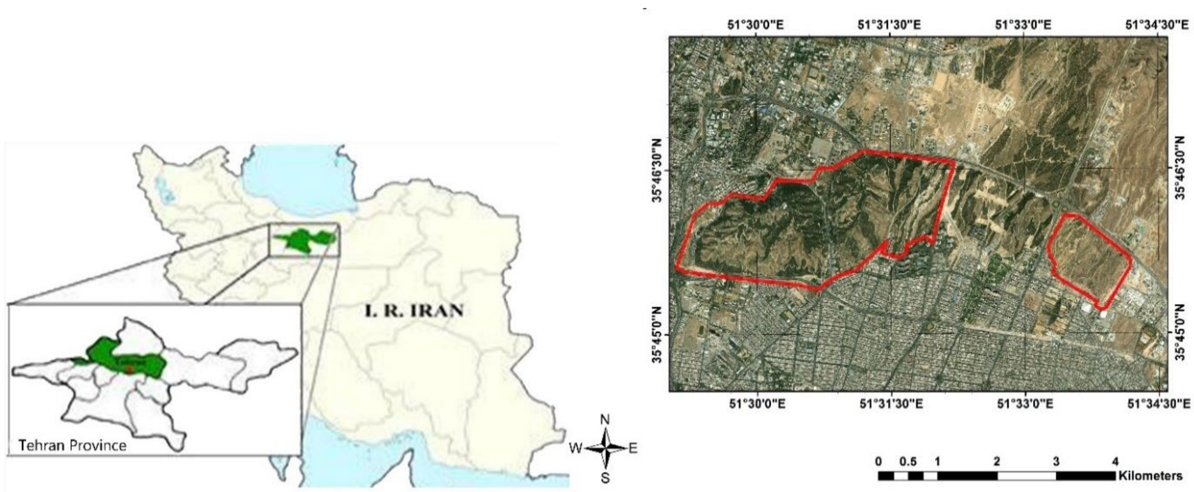

Fig 1. Lavizan forest park geographical location

area of Lavizan Forest Park is about 1075.6 hectares, but it currently reaches 762 hectares. It is also surrounded by urban fabric, and constantly threatened by urban development. Initially, the park was built as an urban green space, but it was gradually placed inside the city of Tehran with further urban development (Darabi, Ehsani, & Kafi, 2018). This park has significant plant species and its natural structure has been maintained (Peel, Finlayson, & McMahon, 2007). The climate in this area is semi-arid with a cold winter, based on the Amberg Climate Classification. The soil texture is mainly clay- or loamy-sandy (Abdollahzadeh, et al. 2003), whose average PH is 7.74 (Yousefi, et al., 2018).

To assess the level of eco-resilience in Lavizan Forest Park, the quick assessment technique was used, as proposed by Terrico et al. (2010) to calculate the level of resilience in natural and agricultural systems. This technique was based on V_{eco}, H_{eco}, effective V_{eco}, and potential volume (V_{pot}) in forest ecosystems. Based on Figure 2, the technique utilized in this research included four sections:

1. Zoning based on the overall characteristic of the area, including landform, hydrologic characteristics, soil, vegetation cover, vegetation diversity, and access paths
2. Determining dominant plant species in each zone
3. Calculating resilience assessment parameters in each zone (viz. V_{eco}, H_{eco}, C_{eco}, BA, and V_{bio}
4. Establishing resilient and non-resilient zones

Fig. 2. Resilience calculation flowchart. See the table 1 for parameters calculation.

Eco-resilience assessment also requires the measurement of five main parameters, including V_{eco}, H_{eco}, C_{eco}, BA, and V_{bio}. First, each parameter is explained, and then the assessment equation is presented in Table 1.

The V_{pot} is the complete maturation state of a forest, which is sometimes called the climax. This level is a structural performance unit in balance with energy and material flow among the constituting elements and refers to the maximum interaction between organisms (viz. plants, animals, and other living creatures) and biological community or bio-isolation, which is along with the biotope as a limited concept. Therefore:

$$Vpot = Vloss + Veco$$

V_{loss} is also equal to V_{pot}-V_{eco} and indicates the ecosystem regression in terms of V_{eco}. In this respect, higher V_{eco} leads to increased ecosystem loss in terms of quality, performance, and services. The flexibility index (namely, RI) also represents the resistance against systems measured by comparing V_{bio} with V_{pot}. As well, the V_{bio} indicates the present state of the ecosystem and V_{pot} shows its steady state.

The accurate evaluation of the parameters also necessitated field data. For this purpose, the survey parcels of 200 m * 200 m were designed. Then, a systematic random sampling model was implemented, wherein the wood species were determined and the related data for the dominant species were recorded (Table 3). At the next step, the dominant trees were identified in each zone (Figure 3 and Table 2). Applying the proposed framework additionally required a field

Table 1. Variables and measured parameters

Indices	Definitions
$\mathbf{Eco-volume/Veco = Heco \times Area\ [m^3]}$	A specific level of a system which is defined by bio-height. Eco-volume is expressed in term of hectare, generally (m3ha-1). In fact, eco-volume is the product of occupied area by vegetation and surrounding environment.
Veco = land area × eco-height	This is a measurable space or volume above the ground that is bounded by a uniform vegetation and its height.
$\mathbf{Eco-height/(Heco)\ [m^3]}$	Eco-height is the mean weight and weight coefficient over time and throughout different plants society sections. Eco-height includes the height from the peak of coverage to the end in dominant plants (higher layer).
$\mathbf{Bio-volume/Vbio = Basal\ Stem\ Area \times Heco[m^3]}$	This parameter is the overall plant volume (trees, bushes, grasses) occupying a particular space. Hence, bio-volume of a plant is its fresh biomass divided by its specific weight. This concept is determined based on the dominant plant in term of m3ha-1.
$\mathbf{Evo-volume\ Efficiency/Ve = Yield/Vloss}$ $\mathbf{Ve = Yield/(Vpot - Veco)}$	This parameter indicates the money or energy efficiency of the lost units.
Resilience index/Ri	The system resilience is calculated by comparing the Vbio and Vpot. The bio-volume indicates the present state of system and Vpot indicates the steady-state of ecosystems. The resilience index is defined as the ecosystems resistance to tolerate changes, distortions and stresses as well as the system capability to self-rehabilitation to reach the steady-state in which the system would be capable to provide goods and services.

Adopted from:(Torrico & Janssens, 2010)

Table 2. The main characteristics of parcels

Parcel name	Zone No.	Dominant tree	Scientific name	Area (ha)
Parcel (A)	1	Robinia	Robinia Orientaris	13
1-1	2	Fraxinus Rotundifolia	Fraxinus Rotundifolia	11.1
Parcel (B)	3	Cedar	Cupress	78.3
2-1	4	Fraxinus Rotundifolia	Fraxinus Rotundifolia	32.2
	5	Pine	Pinus Eldarica	41.2
	6	Pine	Pinus Eldarica	77.6
	7	Robinia	Robinia Orientaris	66.5
Parcel (C)	8	Pine	Pinus Eldarica	41.8
	9	Fraxinus Rotundifolia	Fraxinus Rotundifolia	27.7
	10	Pine	Pinus Eldarica	47
	11	Tagouk	Celtis Australis	21.1
	12	Robinia	Robinia Orientaris	76.4
Parcel (D)	13	Pine	Pinus Eldarica	32.7
	14	Cedar	Cupress	24.7
	15	Robinia	Robinia Orientaris	26.9
Parcel (E)	16	Ailanthus	Ailanthus altissima	22.5
	17	Cedar	Cupress	59.8
	18	Tagouk	Celtis Australis	26.5
	19	Berry tree	Morus Alba	17.2

Table 3. Effective factors on resilience

Zone Number	The dominant tree	Mean Stem diameter (cm)	Mean height (m)	Mean Slope	Mean Height
1	Robinia Orientaris	72.6	18.3	19.8	1451.5
2	Fraxinus Rotundifolia	46.6	12	22.5	1452.8
3	Cupress	45.3	19	15.0	1523.9
4	Fraxinus Rotundifolia	34.33	9.5	17.9	1494.2
5	Pinus Eldarica	58.33	24.3	18.9	1459.2
6	Pinus Eldarica	53.6	31	16.7	1510.9
7	Robinia Orientaris	68.66	17.3	15.1	1462.9
8	Pinus Eldarica	63	27.3	15.1	1548.0
9	Fraxinus Rotundifolia	41.6	7.6	15.6	1514.1
10	Pinus Eldarica	42.3	23.3	12.0	1482.0
11	Celtis Australis	74.66	22.3	11.7	1544.6
12	Robinia Orientaris	71	14.6	14.0	1532.4
13	Pinus Eldarica	64.6	30.6	11.8	1546.9
14	Cupress	48	26	11.1	1501.9
15	Robinia Orientaris	32.3	16.3	12.5	1523.6
16	Ailanthus altissima	34.66	16.6	11.3	1560.2
17	Cupress	40	16.3	9.6	1542.4
18	Celtis Australis	66	26	11.4	1566.5
19	Morus Alba	36	13.6	7.6	1539.8

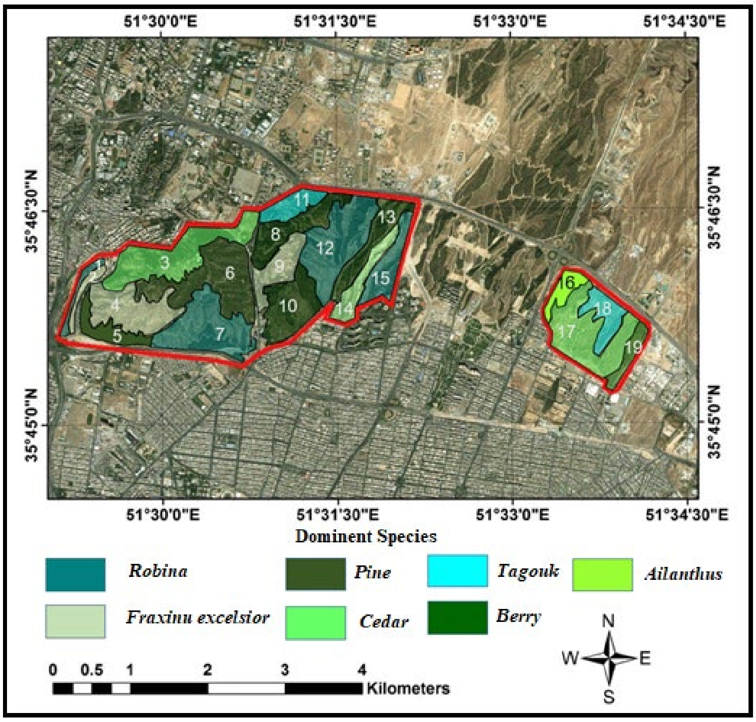

Fig. 3. Lavizan forest park zoning map. Zone properties are cited in Table 2.

survey. Thus, a small area (that is, 19 parcels) was considered as the base survey area to increase accuracy and help in more appropriate field data collection.

The output of the calculation accordingly reflects the resilience of systems, which normally is from zero up to 0.5. Here, zero denotes a lack of resilience, and 0.5 represents the climax status of the ecosystem or complete resilience. Therefore, based on the obtained index, the state of the ecosystem can be classified into high resilience, relative resilience, resilient, low resilience, and lack of resilience.

RESULTS AND DISCUSSIONS

In order to assess resilience, it was necessary to zone the study area. Therefore, Lavizan Forest Park was zoned based on biotic and abiotic characteristics. Accordingly, the most important factor was plant species in each area. With regard to the zoning outcomes, five main areas and 19 parcels were identified. In these parcels, environmental quality and dominant species could play critical roles.

Resilience measurement additionally required some variables, such as V_{eco}, V_{pot}, H_{eco}, and V_{bio}, obtained using the values and the formula proposed in Table 1. Finally, RI was calculated by comparing V_{bio} and V_{pot}, whose values are depicted in Table 4 and Figure 4.

According to the field survey and calculations, each zone gained an RI score. The RI had been also affected by the environmental condition of each parcel. As well, the RI outcomes could be grouped into four categories as follows: (1) high resilience (RI>0.2), (2) resilience (RI>0.1 and ≤0.2, (3) relative resilience (RI >0.06 and ≤0.1), and (4) low resilience (RI≤0.06). Based on the mentioned classification, zones no. 1, 11, and 12 were categorized as ones having high resilience, and zones no. 2, 5, 6, 13, 14, 16, and 18 were characterized as ones with resilience. Moreover, zones no. 3, 7, 10, 15, and 19 were identified as one having relative resilience, and eventually, zones no. 4, 9, and 17 were specified as ones with low resilience.

Table 4. The effective factors on resilience

Zone	The dominant tree	Mass volume (silo)	Annual growth (Silo)	Veco	Heco	Vbio	Vpot	Ri
1	Robinia Orientaris	25.1	0.3	25.1	7.6	5.17	19.62	0.26
2	Fraxinus Rotundifolia	10.5	0.15	10.5	12	2.26	18.84	0.11
3	Cupress	274.1	4.1	274.1	19	3.57	39.56	0.09
4	Fraxinus Rotundifolia	30.47	0.45	30.47	9.5	0.59	18.84	0.03
5	Pinus Eldarica	1809	27.1	1809	24.3	6.1	46.15	0.13
6	Pinus Eldarica	3409	51.1	3409	31	5.84	46.15	0.12
7	Robinia Orientaris	128.7	1.9	128.7	5.4	5.9	19.62	0.3
8	Pinus Eldarica	1836	27.5	1836	27.3	7.71	46.15	0.16
9	Fraxinus Rotundifolia	26.2	0.3	26.2	7.6	0.9	18.84	0.05
10	Pinus Eldarica	2064	30.9	2064	23.3	2.92	46.15	0.06
11	Celtis Australis	4.34	0.06	4.34	22.3	9.1	28.6	0.31
12	Robinia Orientaris	147.8	2.21	147.8	14.6	5.5	19.62	0.28
13	Pinus Eldarica	1436	21.54	1436	3.6	4.8	46.15	0.1
14	Cupress	86.4	1.29	86.4	26	4.08	39.56	0.1
15	Robinia Orientaris	52.07	0.78	52.07	5.3	1.31	19.62	0.06
16	Ailanthus altissima	4.5	0.06	373.5	16.6	5.7	33.84	0.16
17	Cupress	209.3	3.14	209.3	3	2.04	39.56	0.05
18	Celtis Australis	5.4	0.08	5.4	26	8.16	28.6	0.2
19	Morus Alba	3.2	0.04	233.9	13.6	1.28	20.34	0.06

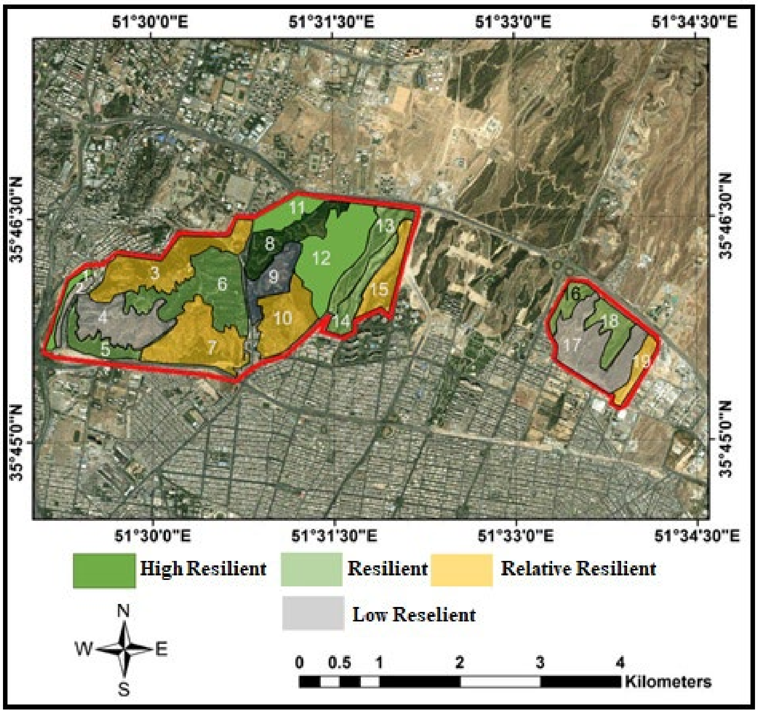

Fig. 4. Map of rezoning based on resilience index

The zones with high resilience were also located in the northern part of the site. This area benefited from lower evaporation and high humidity. As well, the dominant species were relatively floriferous with a high mean diameter of the stem.

In parcel C, the trees were positioned mainly on the eastern and northern parts of the site. The species with high quality had been also established alongside Hangam and Shahid Babaie highways. The rate of growth was further reflected in the thickness of the stem diameter in this area. The quality of the trees had reduced by distance from the highway strip. The dispersion of cedar was mostly observed throughout parcel E, particularly in the eastern and western parts. Cedar species had not also gained desirable quality due to human interventions, and they had been partially dried in some parts. In parcels A and B, the species had not experienced a suitable state in terms of quality. These areas suffered severe slopes. A compact hydrographic network had further developed and the significant mortality rate of the trees was visible. Moreover, a number of the trees had been dried and some of them had been cut down to prevent the dispersion of the city longhorn beetle and fungal pests.

In contrast, the parcels in appropriate environmental circumstances were more resilient. Factors such as the diversity of vegetation and animal species were also perceptible. Organic material enrichment alongside deep soil had further enhanced this suitability. In addition, the hydrologic network had been distributed properly. All these characteristics had thus increased RI in comparison with other parcels.

Resilience relies on the ability of system dynamics, which provides an opportunity to adapt an ecological system to new circumstances after a disturbance through complex adaptive strategies (Norberg, 2004; Beisner et al., 2003). Of note, resilience is a function of several factors such as flexibility, adaptation, resistance capability against input pressures, as well as reorganization after any disruptions (Gunderson, Allen, and Holling., 2010; Gunderson & Allen, 2010; Nikinmaa et al., 2020). All such factors must be reflected in resilient ecosystems. The applied assessment method, instead of reflecting on the affected factors during resilience, examined the outcomes of the system. This meant that if an ecosystem was resilient, it had a highly effective Veco, Heco, and Vbio. In other words, if the results of assessing these indicators in an ecosystem reflected a somewhat suitable situation, it meant the ecosystem was resilient.

To determine the accuracy of the method, the RI of the zones in the study area were compared. The outputs needed to be consistent with the existing environmental facts of each zone and the variation could be meaningful among the zones and in line with the overall ecosystem property as explained by Holling (1973) and Allen et al., (2016). Therefore, if RI had two characteristics, then the results could be valid. First, if RI showed the function of the entity of each zone, then it varied in agreement with ecosystem variation between the zones. Second, the RI of the index could follow the current ecosystem property of the site.

According to the first point and Table 4, RI reflected the differences among the zones appropriately. For example, in zone no. 17, which did not have a suitable planting pattern, the area was facing poor soil and there was less diversity in plant species, so it showed the lowest RI, while zones no. 7 and 11, which had suitable environmental conditions with higher planting diversity, had more resilience. The results in Figure 5 profoundly illustrate the consistency of the zones in this method and have an acceptable correspondence with reality. With reference to the second point, the study results showed that zones no. 11, 7, 12, and 1 had proper ecological conditions so that the existing trees (particularly, their growth and quality) seemed to be in an optimal condition. The opposite side of this issue could be further observed in zones no. 17 and 9. Hence, this index characterized the present conditions.

Moreover, what this method evaluates relies on the existing conditions of the site, which are the consequence of the ecological structure performance over time continuum. Using this method should be thus consistent with other resilience assessments in terms of three fundamental tenets, namely, thresholds, adaptive capacity, and self-organization following disruptions.

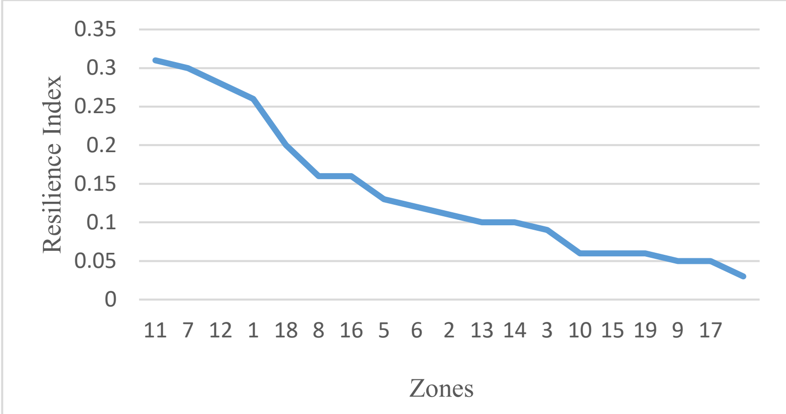

Fig. 5. Comparison of RI between different zone of study

In the case of thresholds, the current ecological condition refers to the continuum of the forest park experiencing sustainable growth at certain thresholds. The Heco also determines the growth quality of a plant community over time. In addition, Ceco, which assesses the ecosystem equilibrium, depicts whether it is resilient to appropriate thresholds or not (Nikinmaa et al., 2020). As a result, the assessment of the determining factors embodies the thresholds. It means that environmental parameters (viz. maximum and minimum rates) are monitored over a long period (since the construction of forest parks). Consequently, the thresholds are measured indirectly. In this case study, several environmental factors were investigated, such as temperature and precipitation (over 60 years). The lowest temperature in this area reached -15 degrees Celsius in January 1969, with the highest rainfall by 77 mm in 24 hours, and the maximum temperature was 43 degrees Celsius in 1975 (Meteorological Organization of Iran, 2021). Therefore, some parts of climatic fluctuations could be understood and evaluated as the thresholds of climate resilience. These data represented steadiness in the given forest park. However, the resilience threshold was not limited to just temperature changes or precipitation, and other data needed to be considered.

In terms of adaptive capacity and flexibility, various indicators were also discussed (Dardonville, Bockstaller, & Therond, 2020), in which the diversity and complexity of the ecosystem was the most important element (Beller et al., 2019). The calculated RI had been thus affected by the diversity of plant species. Accordingly, the Pearson correlation coefficient was applied to unfold the impact of diversity and complexity on RI. The correlation between Vbio and RI was correspondingly estimated at about 0.77 (p-value=0.0001), revealing the relationship between the ecological function, the quality of natural systems, and the interactions between biotic and abiotic components of the ecosystems and RI. As stated in Torrico et al. (2010), increasing Veco could lead to a surge in biomass and more biodiversity. For example, zone no. 11 had the highest rate of species diversity, so it had optimal conditions in terms of resilience. On the other hand, the diversity of the plant species, including herbaceous plants, shrubs, and trees, could not only bring higher diversity in an ecosystem cycle but also attract more animals, birds, and other biotic organisms, which could subsequently provide complexity.

Considering the relationship between vegetation density and ecological resilience, it is estimated that the areas with better resilience have the highest vegetation density. These areas consist of trees that are high in terms of planting area. For example, the pine, cypress, and acacia species, which have the highest planting area in the forest park, are mainly located in areas with high RI in the region. Based on the diversity of biotic and abiotic components and the quality of the ecosystem function, it was expected that zones with high scores could embody diversity and complexity. Hence, it seems that a percentage of the dominant plants, in comparison with the remaining ones, would be a good indicator to calculate in further studies.

Moreover, Vbio, referring to the overall capacity of biomass, was a reflection of diversity and complexity. The function of the ecosystem also depended on species diversity, which was significantly correlated with resilience (Anderegg et al., 2018; Elmqvist et al., 2003; Reinmoeller & Van Baardwijk, 2005; Schmitt et al., 2020; Wolf, Hoppe, & Rost, 2018). In this study, the statistical analyses indicated a significant correlation of 0.95% confidence level. The results were also consistent with the findings reported by Torrico et al. (2010). Consequently, it was inferred that adaptive capacity could be measured indirectly. The self-organization index was further the result of combining the previous two indicators, namely, adaptive capacity and thresholds.

It is expected that an overall image of resilience is obtained through measuring the proposed indicators although a challenge will remain unreciprocated, that is if future changes go beyond the historical thresholds that the ecosystem has experienced so far and it will be still resilient or not. Naturally, each method is associated with a degree of uncertainty, which can be soothed by extensive research in various domains and eliminating effective factors in this respect. Therefore, using this method requires critical evaluations in different domains and scales.

In the end, the pressure due to climate change is going to intensify on natural ecosystems. Urban forest parks also suffer from additional anthropogenic tensions due to being adjacent to cities. Therefore, they need more support to increase their adaptive capacity. Extending the capability of urban forest parks is also unavoidable. As stated in McWethy et al., (2019) focus on the basic concept of resilience is not the appropriate response to the rapid changes and thus urban forest parks should gain new transformative ability in response to such changes.

It should be noted that the resilience of urban forests is a multidimensional and socio-ecological subject. Therefore, its management and aesthetic characteristics should be also considered in addition to ecological issues. From a managerial perspective, issues such as the selection of tree species, problems with tree root growth (Hasan et al. 2017a; Hasan et al. 2017b), shading, resistance against wind, appropriate response to urban pollutants, fertilizer needs, pest and disease management, economic costs, resistance against extreme climatic phenomena (Darabi and Saeedi 2019), in addition to forestry requirements should be addressed (Afrianto et al., 2021). From an aesthetic point of view, a well-proportioned appearance, such as a beautiful canopy, leaves and flowers, alongside the restorative functions, such as reduced anxiety and stress, should be taken into the account (Afrianto and Tamnge 2015; Husti et al. 2015; Hall and Knuth 2019). As Garmestani, et al., (2020) indicates deal with complex systems by simple regulation standards will lead to inverse consequences. All together, these issues imply that the resilience of urban forest parks is merely a socio-ecological subject than an ecological one.

CONCLUSION

This study aimed to assess eco-resilience based on ecological outcomes. The applied framework was also an alternative approach focused on the outcomes of ecosystems instead of evaluating the effective indicators of resilience. This evaluation was conducted in a forest park located in the city of Tehran (Iran). The study results further disclosed that the alternative approach while measuring the effective indicators of resilience such as thresholds, adaptive capacity, and self-organizing, was a holistic method to properly measure the resilience of an ecosystem. This work faced restrictions in terms of access to detailed ecological data; therefore, there would be much certainty if accurate ecological information were added. However, in order to ensure the results and evaluate the degree of certainty, the application of the framework utilized in this study in different ecosystems seems necessary.

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CONFLICT OF INTEREST

The authors declare that there is not any conflict of interests regarding the publication of this manuscript. In addition, the ethical issues, including plagiarism, informed consent, misconduct, data fabrication and/ or falsification, double publication and/or submission, and redundancy has been completely observed by the authors.

LIFE SCIENCE REPORTING

No life science threat was practiced in this research.

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