Chapter 3

Dynamics of an Urban Forest in Response to Urban Development and Management Initiatives — Case of Bukit Timah Nature Reserve

Kalyani Chatterjea

Additional information is available at the end of the chapter

http://dx.doi.org/10.5772/61233

Abstract

Singapore, a tropical island of only 716 km², has substantial land under forest. But rapid urbanisation coupled with the scarcity of land has also resulted in extensive land clearance. Though highly urbanised, Singapore has managed to retain 4.5% of the land area under nature conservation, and 2.9% under closed forest. Out of four protected areas, two of these, the Central Water Catchment Forest (CWC forest) and Bukit Timah Nature Reserve (BTNR), are protected under the Parks and Trees Act of 2005 with a total area of 3,043 ha. Though originally connected, these two forests were separated from each other by a major highway, leaving BTNR, the smaller of the two, with a total land area of 163 hectares, surrounded by not just the highways, but also by a fast developing urban residential area. The forest boundaries have seen dense urban development as close as only 50 m from the forest edge. As a result, micro-climatic parameters such as atmospheric temperature, relative humidity, soil surface temperature, light conditions, wind velocity, all have seen significant changes over time and the gradient of such changes are drastic and steep along most forest verges. Currently some ameliorating steps are being taken by the forest management to counter the ill effects of too much encroachment and fragmentation.

Keywords: Fragmented forest, edge effect, edge forest, urban forest, forest degradation, forest micro-climate

1. Introduction

Situated in the tropics between 1º09′N and 1º29′N and longitudes 103º38′E and 104º06′E, Singapore comprises one main island and several small islets and covers an area of 710.2 km². Originally a lowland tropical forested island with mangrove vegetation and mudflats at the coastal verges, Singapore was mainly a fishing island, with little disturbance to the original dense forested land. Since British colonial times in the 19th century, however, inland forests retreated in the wake of clearances made for human habitation and the high rates of deforestation and land clearances continued even after independence, giving in to high demand for a fast growing economy. The thickly forested Bukit Timah Hill, the highest on the island, was recognised as a landmark by European settlers in the 19th century. However, it was rarely visited due to its inhospitable terrain, and was inhabited only by gambier farmers. Its role changed when a main road (Bukit Timah Road) was built to reach it by 1840 and another road linking Bukit Timah to Kranji was built in 1845 [1]. In 1843, a road cutting through the reserve was built from the foot of the hill to its summit. During colonial times, Singapore had its first forest reserve at Bukit Timah in 1883, when the conservation aimed to preserve flora and fauna of the forest. In 1951, under the Nature Reserves Act, Singapore had five nature reserves, Bukit Timah, Pandan, Labrador, and the Catchment Area, when some unique nature reserves were set aside, but without much focused planning and objective [2, 3]. Subsequently, however, even as economic development and demand for space spearheaded large-scale forest clearance, the post-independence period from 1965 actually also saw serious engagement in nature area conservation. The National Parks Board was set up in 1990 to specifically manage the parks and greenery and conserve all nature reserves with legal protection under the Parks and Trees Act of 2005. The National Parks Board was given the responsibility to take charge of not just the many new green spaces created under the greening schemes of Singapore, but also to actively conserve the few naturally green areas that still remained. The city state of Singapore managed to retain 4.5% of the land area under nature conservation and 2.9% under closed forest, in spite of being highly urbanised and in severe demand for land space. Currently, there are a total of four protected nature reserves in Singapore, which enjoy total protection, even in the face of aggressive urban expansion. Tracts of primary and secondary rainforests in the Bukit Timah and Central Catchment Nature Reserves, as well as mangroves and mudflats in Sungei Buloh Wetland Reserve are examples of such nature areas protected even under intense pressure on the already scarce land and in spite of heavy demand for development. Out of these, the Central Water Catchment Forest (CWC forest) and Bukit Timah Nature Reserve (BTNR), with a total area of 3,043 ha, are protected under the Parks and Trees Act of 2005 for the protection and propagation of the native biodiversity.

In spite of these sincere conservation efforts, land scarcity and pressure on the economic front has put forward great demands of land acquisition and development around Bukit Timah and the forest peripheries have seen significant changes. The intense development around the forests in Singapore has opened up new landscapes and altered existing ones. This has created wide zones of non-forested landcover around the originally forested areas. In particular, BTNR and its surrounding areas have seen large-scale and continued change in the environment, making it one of the most impacted locations in Singapore. The most visible impact of similar

http://dx.doi.org/10.5772/61233

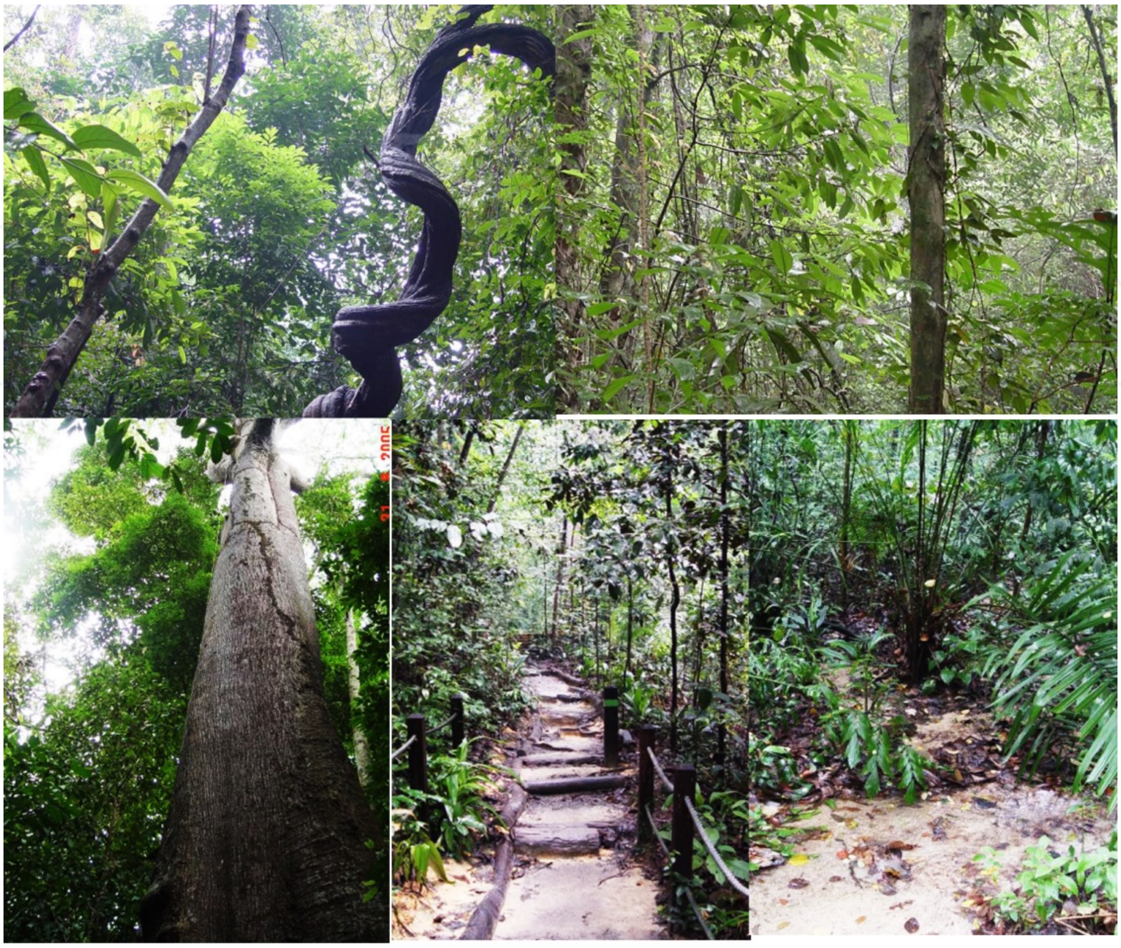
landuse changes close to forest boundaries is the edge effect. Edge effects occur where forested areas come in direct contact with non-forested environments and have been found to extend from 40 m [4] to 500 m [5, 6] into forest interiors. Zheng and Chen [7] agreed that generally the sharper the contrast between two adjacent patches, the stronger the edge effect. In the case of BTNR, the contrast between the forested and the surrounding non-forested environment is drastic, with major highways and roads running along the forest boundaries. Isolation of forests due to landuse change and land conversions is considered to be the biggest threat to biodiversity and have been documented as being the key reason for loss of native species, invasion of exotic species, pronounced soil erosion, and decreased water quality, and collectively, severely affects the integrity of ecological systems [8–12]. In addition to being fragmented, when a forest becomes the centre of urban development as well as a major natural attraction, the pressure of providing eco-system services are increased, as mentioned by Tobias [13]; such demands lead to higher demand for land and amenities such as easy access and proximity to infrastructure, all in turn put excessive pressure on the forest. One direct result of this will be urban sprawl, which is listed as a major impact factor in biodiversity degradation by Gayton [14].

This chapter looks specifically at BTNR in Singapore to follow the pattern of urban expansion around the area and to examine the spatial changes in the surrounding locations. The forest boundaries have seen dense urban residential development that goes as close as only 300 m from the forest boundaries. This not only allows the encroachment of non-forested microclimatic environment to get too close to the forest buffering the interior closed forest, but also allows easy access for people who visit it in large numbers for various recreational, educational, and social purposes. The chapter takes a look at the longitudinal changes the forest boundaries have undergone. It also looks at the various ameliorating steps being taken by the forest management to counter the ill effects of too much encroachment, fragmentation, and overuse.

2. Bukit Timah: The forest

BTNR has some secondary and some primary forest, with a core closed forested area of about 75 ha. Though small, it houses a very high density of flora and fauna and has been documented as having more than 1,000 species of flowering plants, 10,000 species of beetles, and many other organisms indigenous to tropical rainforests [15].

BTNR is situated on the highest hill in Singapore, a steep grano-dioritic batholith (163 m), with a rugged topography and slopes often exceeding 35 degrees. While the fringes of the core forest were disturbed in the past, giving way to scattered forests and some small-scale fruit tree cultivation, much of the interior of the closed forest at BTNR still retains the authentic ‘feel’ of a primeval rainforest. The dense evergreen tropical forest cover is known to house more species of trees than in the whole of North America [15]. Trees as tall as 35–37 m, loaded with epiphytic growth; and in places dense canopy cover retain, in the large part, a typical tropical rainforest environment, complete with little under-growth, dark and moist forest interior, extending lianas, dense but shallow surface root systems, and buttressed trunks (Figure 1).



Source: Author

Figure 1. Inside Bukit Timah Nature Reserve.

The rugged topography in some places leads to irregularities in the main canopy, largely consisting of Dipterocarpaceae. Common species are Seraya (Shorea curtisii), Meranti Tembaga (Shorea leprosula), Meranti Sarang Punai (S. parvifolia), Nemesu (S. pauciflora), and Melantai (S. macroptera). Dipterocarpaceae are by far the most important constituents of the main canopy of BTNR [15]. Another important family of main canopy and occasionally, emergent trees is the Leguminosae, represented by Kempas (Koompassia malaccensis), Sepetir (Sindora wallichii), Petai (Parkia speciosa), and Kerangi (Dialium spp.) [15].

The sub-canopy layer in BTNR grows in light-deficient, micro-climatically constant environment, with little wind movement, constantly moist, and heavily shaded conditions. Most of the vegetation here are simply juveniles, going through the growing stage. Some important species are Euphorbiaceae (Rubber tree family), Rubiaceae (Ixora family), and Annonaceae (Custard apple family).

The 'shrub' layer is the lowest layer of woody plants. Various types of palms are important elements of the undergrowth flora in BTNR, most common being the young rattans (climbing palms).

http://dx.doi.org/10.5772/61233

The ground layer in BTNR is not so conspicuous or abundant, mostly consisting of seedlings. Herbaceous plants are commonest along paths where some light penetrates. Some ferns (*Tectaria singaporeana*) and wild ginger (*Zingiberaceae*) are important ground vegetation in BTNR.

Bukit Timah forest also has an abundance of climbers, some woody lianas, and some herbaceous climbers that grow in shade. Epiphytes are common as well, both on the main canopy as well as under shade. Especially common and characteristic are the fig species, referred to as 'stranglers', which start off as epiphytes and then extend roots to the ground. These roots often coalesce to surround the host tree, often strangling them to form a freestanding fig tree.

3. Bukit Timah: The fast changing landscape

While parts of BTNR still hold a near-original forest condition, it has, over the years, undergone some structural changes brought about gradually by the various changes to the forest interior as well as the forest fringes. The very first such large-scale change was initiated by the construction of the six-lane highway in 1985 through the heart of the forest in the centre of the island, causing divisive fragmentation and separating the smaller Bukit Timah forest from its larger counterpart, the forests of the Central Catchment (Figure 2).

Source: Author

Figure 2. Bukit Timah Expressway (BKE) running through the forest, fragmenting BKE from CWC.

This north-south running highway cut through the central granite country, exposing not just the core of the batholith, but also exposing the core of the forest to the exterior open environment like never before. Suddenly, the usual daily migration routes of the small land animals were interrupted by fast-running traffic. Though no records of animal mortality were kept, numerous experiences of animals stranded along the highway have been related in informal discussions. Although these accounts cannot be verified quantitatively, this is an expected outcome of truncating a forest teeming with small fauna such as the long-tailed macaque, pangolin, civet cats, etc.

The highway development came at a time when economic development and the necessity of fast and efficient transport link between the north and south of the island drove landuse planning. During the 90s, major relocation of original light industries of this area was carried out, clearing land around Bukit Timah hill for high-density, high-rise urban residential development. This left BTNR, the smaller of the two forests, with a total land area of 163 hectares, surrounded by not just the highways, but also by a fast developing urban residential area. Beyond the forest boundaries, BTNR is surrounded by non-forested environments all around and such breaks in the forested landscape include other multiple-lane highways, major roadways, a water pipeline with open service areas, a railway line and vast areas of high-density, high-rise residential developments, and tarmacked car parks. Although the recently expanded surrounding urban landscape also includes a number of green spaces and parks, the manicured greenery have little semblance to the original tropical rainforests that retreated and got truncated because of the urban invasion. Being the highest hill on the island, the forest is not only seen as a much-desired place to live nearby, but also as a place for recreation and outdoor activities by the rising urban population living just a short walk away from it. As a result of the combined effect of rapid urban growth around the forest peripheries and the increasing interest in nature-based recreation among the urban population, the forest is undergoing inevitable changes, both at the boundaries and in the interior. From this perspective Bukit Timah represents the constant dynamic balance between demands of modern urban expansion and sincere conservation efforts to retain it both as a pristine forest as well as the 'Peoples' forest'.

4. Methodology

Inevitable pressure from growing urban development in a land-hungry country puts increasing pressure on the existing forest. Past development initiatives to make way for efficient infrastructure and functionality has had unintended effects on the very forest that has always been at the centre of conservation efforts. But some strategies are being taken to re-establish some of the previous environmental conditions, though many gaps exist. This chapter tries to methodically record the direct impacts of changes over time and also looks at the possibilities of improvements aimed at reinstating some of the original conditions.

To establish the current status and also to examine the dynamic changes the forest has been undergoing, several types of field data have been collected from boundary and interior forest areas over a period of four years and also developments in the surrounding areas and some environmental phenomena have been traced since the 1950s till present to (1) determine changes in landuse at and near the boundaries of the forest, (2) record changes in micro-climate over time in response to landuse changes, (3) record changes in the forest interior surface conditions due to over-use by visitors, and discuss the current ameliorating steps being taken to reinstate and reinvigorate forest trail conditions in the interiors.

http://dx.doi.org/10.5772/61233

Landuse changes were followed through using landuse maps, topographic maps, as well as by ground surveys. Environmental data such as atmospheric temperature, relative humidity, soil surface temperature, light intensity, and wind velocity were measured in the forest interiors as well as at the forest boundaries, urban landuse at the fringe areas, along roads and railway line along the boundary of the forest, over six phases in four years for comparison of the changing values. Data obtained were plotted using GIS (Geographic Information Systems) to establish spatial patterns of the observed environmental factors over time. This is done to establish the changing responses of the forest interior and exteriors to the altered landscapes.

Forest interiors were also examined to quantify impact on the forest floor due to overuse by visitors. To quantify the impact of hiking and jogging activities on the forest trails a post-impact sampling framework was used and compared with undisturbed sections of the forest (as controls), to establish the degree of impact such excessive use has resulted in over time. Changes to bulk density and surface penetration resistance of forest floor and trail surfaces were measured and status of organic matter content on the same surfaces was determined using the LOI (Loss on ignition) method. These data are aimed at establishing the degree of changes forest interior environment has undergone, specifically due to heavy usage by residents from nearby residential areas.

The study also looked at the current initiatives that are being taken by BTNR forest management to correct some of the problems created due to past urban infrastructure development. The establishment of an eco-link is seen as a major initiative to re-establish the lost connectivity between BTNR and the CWC forest. The eco-link was opened in 2013. Vegetation along the link is still in a state of growth and faces the challenge of being re-established after a period of about 30 years of separation. But management initiatives are set to reinstate indigenous vegetation to facilitate connectivity between the two severed forests. The study will also look at the latest initiative of closing the very popular BTNR from public access to repair and reinstate the forest interior conditions. The closure, repair, and revitalisation of the forest interior conditions will take about two years when the trails will be repaired, improved to reduce visitor impact and increase safety, and in general allow the forest to recover from the prolonged and excessive exposure. The initiatives are seen as direct proactive step taken to ensure sustainability of BTNR as a functioning tropical rainforest, even as it serves as the much-needed nature retreat to the thousands of urban populace living nearby.

5. Data on changes around BTNR

5.1. Landuse change

The Bukit Timah forest prior to independence was part of the central forested zone, with some mixed scattered forests and small-scale orchards surrounding the main forest area [16]. Residential areas were mainly some low-rise bungalows and one single line railway line ran along one of the boundaries. The greatest impacting landuse were the granite quarries around the hill. But these, apart from the areas of actual extraction, did not have much impact on the main forest boundaries or the interiors. All this changed when the Bukit Timah Expressway (BKE) was constructed right through the heart of the central forest, creating a wide divisive landuse interruption. Several other roadworks followed in the wake of more development around the forest. In the 90s, the surrounding areas were cleared of the then-existing light food industries to give way to high-rise condominiums and public housing. A long water pipeline was already in place and with the new roads and buildings, the fragmented BTNR become an island forest, severed from the main forested zone. Figure 3 shows the pattern of landuse changes over time and also the current road and residential developments around BTNR. Though some peripheral areas were added to BTNR to create a buffer around the core forest of 75 ha, some segments of the forest still lie alarmingly close to main roads with heavy traffic, concrete covered surfaces of car parks and the entire forest of BTNR has become a small fragmented tropical rainforest island separated by a 'sea' of inhospitable non-forested landscape, unsuitable for many rainforest organisms. Truncation from the larger counterpart will have obvious effects of lack of migration of species and many more. The full effect of the fragmentation usually takes many decades to unfold, as the existing main canopy trees usually take long time to show the full impact. But when forest interiors are exposed to external ambient conditions, changes to the forest environment can be readily observed.

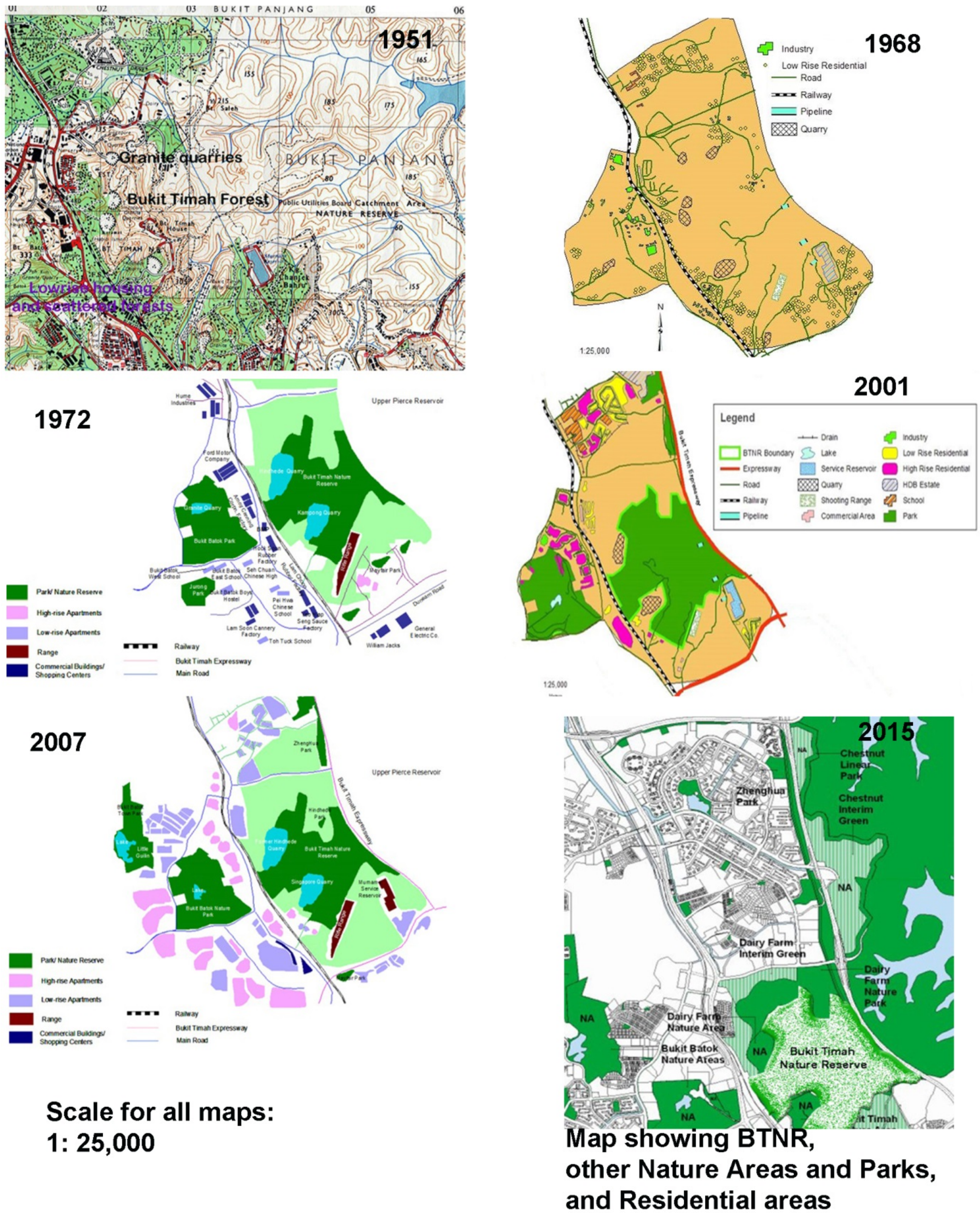
5.2. Environmental change

The forest interior and peripheral atmospheric conditions were monitored between 2011 and 2014. Data of atmospheric temperature and relative humidity were taken several times during this period from various locations within and outside the forest. Each data set was developed from data collected on the same day and same time frame (between 8 am and 9 am on the same day by several groups working simultaneously at different locations). The objective was to record the existing environmental condition, so that the differences between interior and exterior locations can be fairly compared. This was done to establish the environmental differences resulted from exposing former forested locations to non-forested landscapes. Environmental data were obtained from a total of 1,130 locations over the study period. Measurements for all environmental parameters were taken in six phases between February 2011 and June 2014, with December and February months coinciding with the slightly cooler and wetter months, while March and May corresponding to marginally drier and slightly warmer months. The actual number of measurement stations for all data are given in Table 1.

Year and month of measurement	Forest	Exterior	Total
February, 2011	47	35	82
February, 2012	100	100	200
May, 2012	200	240	440
March, 2013	52	50	102
December, 2013	190	21	211
June, 2014	35	60	95
Total	624	506	1130

Source: Author

Table 1. Number of measurement sites for each observation period.



Source: Adapted from various sources and field surveys and created by Author

Figure 3. Landuse changes around BTNR from 1951–2015.

Table 2 shows the changes in the mean temperature records from a total of 1,130 locations within the study sites during the various phases of data collection.

	Year and month of measurement	Minimum		Maximum	
		Forest	Exterior	Forest	Exterior
Atmospheric Temperature (°C)	February, 2011	25.1	30.9	27.0	34.1
	February, 2012	26.6	28.8	29.5	35.5
	May, 2012	24.5	28.0	29.2	37.8
	March, 2013	25.7	29.0	29.7	34.7
	December, 2013	24.5	30.0	29.6	37.8
	June, 2014	26.5	31.5	27.0	34.1
	Mean	25.5	29.7	28.7	35.7

Source: Author

Table 2. Temperatures (°C) measured for forested and exterior locations.

Apart from atmospheric temperature, relative humidity was also measured from the same locations for both forested and exposed sections. Table 3 shows the values obtained from 1,130 study locations.

	Year and month of measurement	Minimum		Maximum	
		Forest	Exterior	Forest	Exterior
Relative Humidity (%)	February, 2011	88.0	74.2	96.3	89.5
	February, 2012	65.3	52.6	98.2	85.1
	May, 2012	70.7	57.0	94.1	88.5
	March, 2013	65.3	58.0	91.7	78.3
	December, 2013	88.9	78.0	95.6	87.1
	June, 2014	91.4	63.4	99.3	85.7
	Mean	78.2	63.9	95.9	85.7

Source: Author

Table 3. Relative humidity (%) for forested and exterior locations.

Soil temperature measurements were very much in line with the atmospheric temperature distributions across forested and non-forested sites and Table 4 gives the details of the values recorded over the five phases of monitoring.

While forest interiors are generally in shaded conditions, the forest fringes are exposed to too much sunlight, especially in tropical Singapore where days are long and sunshine is generally strong. Light conditions were recorded both inside the forest as well as in exterior zones with

http://dx.doi.org/10.5772/61233

	Year and month of measurement	Minimum		Maximum	
		Forest	Exterior	Forest	Exterior
Soil Temperature (°C)	February, 2011	24.3	27.0	26.8	31.1
	February, 2012	23.9	28.0	28.0	34.1
	May, 2012	23.6	32.5	27.0	34.0
	March, 2013	23.9	26.0	29.0	34.0
	December, 2013	23.5	26.4	27.5	33.5
	June, 2014	22.0	28.0	27.0	34.2
	Mean	23.5	27.98	27.6	33.5

Source: Author

Table 4. Surface soil temperature (°C) recorded at forested and exterior locations.

varying characteristics during the May 2012 and December 2013 surveys. Table 5 gives the results obtained from 651 locations and shows the differences observed.

Classification of Landcover	Locations of Measurement Sites	Light Intensity (Lux)
Forest interior	Forest trails	59–3,088
Fringe forest area	Old scattered forest buffer	322–1,113
	Jalan Asas (scattered forest with old fruit trees)	322–7,811
	Rifle Range Road (through forest cover)	1,113–14,332
Along roads and highways	Along minor roads: Rifle Range Road (open area)	1,398–105,770
	Along major roads: Dairy Farm Road	3,012–104,479
	Major highway (BKE)	104,479–135,710
Open car parks and condominiums	Open car parks	12,696–121,695
	Condominiums	3,433–110,074

Source: Author

Table 5. Light intensities (Lux) recorded inside BTNR and the peripheral areas.

Wind velocities recorded during the study did not reveal dramatic results, mainly as wind is usually an insignificant phenomenon in the humid tropics, except during storms. Most days are sultry, with little or no wind movement at all. In fact, many of the locations recorded less that 1 m/s wind velocity. However, the recorded wind velocity data shows spatial differences that coincide with exposed landscapes, with highest wind velocities recorded along open, major highways at the forest peripheries, as shown in Table 6.

Classification of Landcover	Locations of Measurement Sites	Maximum Recorded Wind Velocity (m/s) Taken on Sultry Days
Forest interior	Forest trails	0–1.8
Fringe forest area	Old scattered forest buffer	2.3
	Jalan Asas (scattered forest with old fruit trees)	2.5
	Rifle Range Road - through forest cover	2.3
Along roads and highways	Along minor roads: Rifle Range Road (open area)	3.0
	Along major roads: Dairy Farm Road	5.7
	Major highway (BKE)	5.3
Open car parks and condominiums	Open car parks	4.8
	Condominiums	3.6

Source: Author

Table 6. Wind velocities recorded at different locations in and around BTNR.

6. Date analysis

6.1. Landuse change

There has been significant change in the landuse around BTNR since Singapore became independent. Figure 3 shows the landuse in 1951, with BTNR surrounded by scattered pineapple plantation, sundry minor cultivation, tall grass, and small rustic housing. There were a few food processing industries around the neighbouring areas, as well as five granite quarries at the boundary areas belonging to Singapore Granite Quarries and Hindhede Quarry. The Malayan Railway ran at the western verge of the forest. But overall, the peripheries were a low-density rural residential area with low impact on the neighboring forest, providing the buffer protection, with no large-scale disruption of the actual forest environment. Bukit Timah forest was, at that time, a part of the much bigger Central forest. After the 1990 demarcation of the area as a high-rise residential zone, the landscape was altered drastically. New roads, major highways, and cleared land for high density urban development changed the low impact quiet vicinity to one with heavy traffic, large-scale land clearance (Figure 4), and rapid construction work.

This large-scale development made the forest fringe retreat, moved heavy volumes of sediments, and generally established a wide area of non-forested landscape in the surrounding areas of BTNR, now a truncated forest from the larger hinterland forest of the CWC forest. With new residential buildings, new roads and car parks became a part of the landscape. Previously shaded scattered forest zones ceased to exist and the fringe areas now lie juxtaposed with the dense forests of BTNR. Bukit Timah forest lost its effective buffer zone. Some land

Source: Author

Figure 4. Large-scale land clearance and heavy construction work at the forest periphery. BTNR in the background.

was regained as the new buffer, creating a total area of 163 ha, though the interiors were only about 75 ha (Figure 3). The tussle between development and conservation of the forest drove high-density and high-cost land development at the edge of the forest where condominiums were constructed just next to the deep forest, providing much natural solace to the urban residents, but, introducing an invasive, intruding, and often interrupting influence on the forest characteristics (Figure 5).

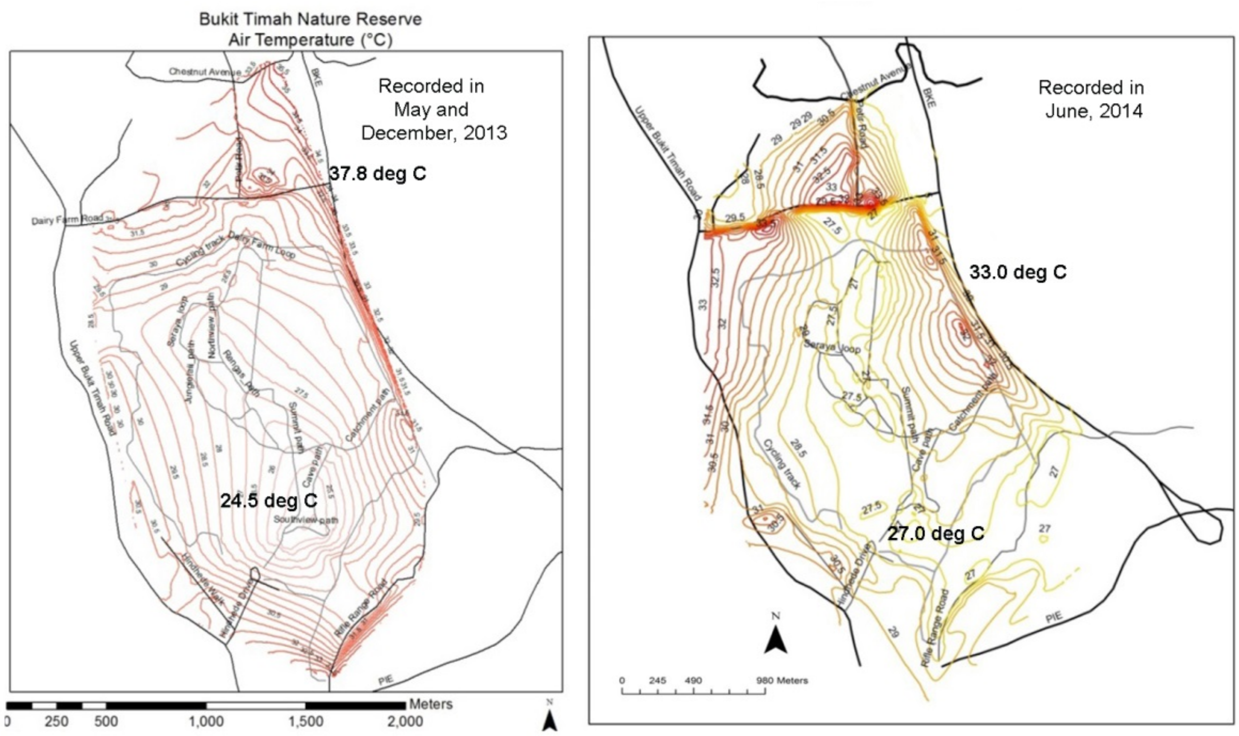
Source: Author

Figure 5. Residential and Infrastructural development less than 50-100m from the forest edge

By the 2000s, the area around BTNR changed permanently, with granite quarries no longer in operation, the railway shut down and given to a green corridor with naturally regenerating vegetation and replaced by clusters of high-rise buildings, car parks, wide roads all around, some less than 100 from the forest fringe. The areas around as well as the forest environment changed permanently. In 2015, there are 81 listed condominiums within a radius of 1–2 km from the forest edge and some new ones are coming up, less than 200 m from the Dairy Farm Road edge of the forest.

6.2. Temperature changes: Temperature distribution

Such large-scale alteration of landuse resulted in changes in the environmental conditions of the forest edge. Atmospheric conditions monitored, such as atmospheric temperature, relative humidity, and soil surface temperatures recorded over four years since the development established permanently, show distinguishable changes in all parameters. Figure 6 shows 8–12°C temperature differences between forest interiors and the peripheries, within a distance of only 1,000–1,500m from the road edges into the forest.



Source: Author

Figure 6. Temperature distribution in and around BTNR, as recorded in 2013 and June2014 (Minimum 24.5°C and Maximum 37.8°C)

Though temperature records were taken on discreet days, since there is only minor variation in monthly temperatures, it is significant to note that in all the six study periods, spanning different months of the year, the temperature of the forest interior and exterior areas maintained similar differences. The 2011 records showed a 9°C difference between the two, while overall, such ranges in temperature varied from 9–13°C, with mean differences of 10.3°C between the coolest and the warmest locations. Alarmingly, this temperature differences occur within distances of less than 300 m and in all records the highest temperatures are recorded along the verge of the forest skirting the main roads and highways (Figure 6). The worst rates of change in temperature are recorded at >4°C within 100 m at the BKE/BTNR, Dairy Farm/ BTNR, and Rifle Range Road/BTNR interfaces. The figure below (Figure 7) shows the pattern of temperature changes from the forest interior to the forest verge. The 300 m at the edge of the forest seem to experience the most drastic change in temperature, making this the 'edge forest' zone, and thus the most impacted belt.

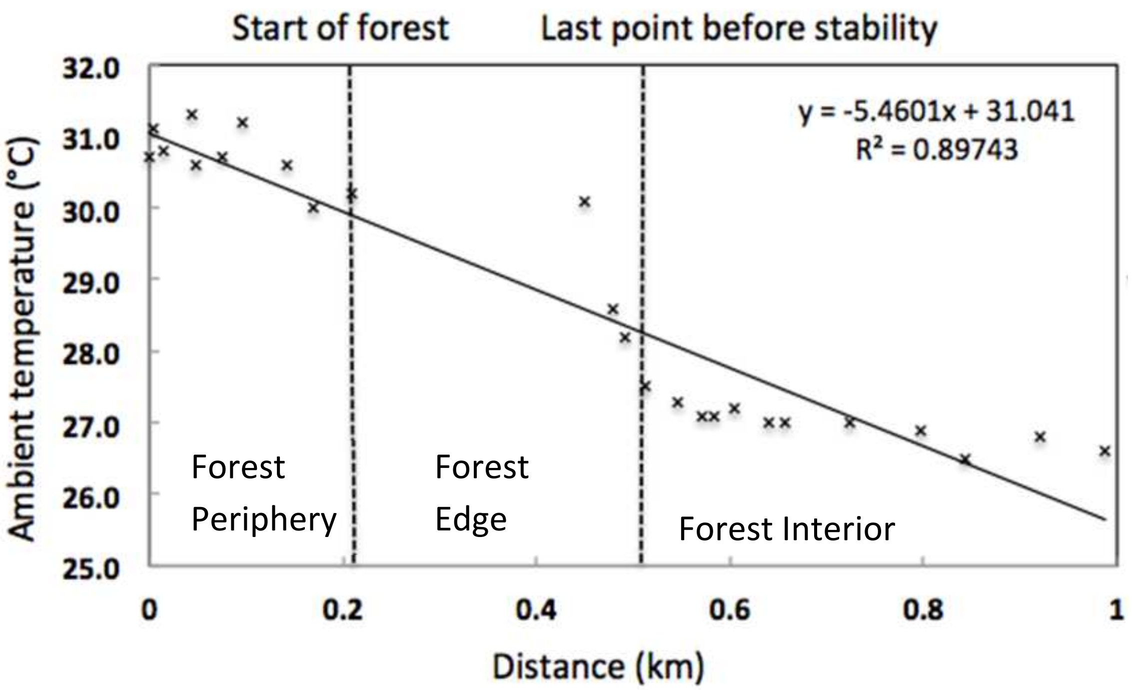


Figure 7. Pattern of temperature change from forest interior to forest periphery.

The temperature distribution recorded over four years around BTNR reveals that urban landscapes, such as major roads, highways, and the car parks adjacent to this major roads have the highest ambient temperatures, with some sites measuring more than 13°C higher than those of the forest interior. Temperature gradients at the forest buffer zones close to roads are considerably steeper. This is in line with previous research that showed that the road width is a significant factor in determining microclimate given the variance in road edge effect [17].

Table 7 shows the temperatures observed and the changes recorded along selected transects drawn across forested to open, exterior boundary areas. There is a mean increase in air temperature of 7.3°C from inside to outside the forest boundaries. Table 7 gives the rates of change along certain locations and it is evident that the sharpest change occurs along the boundary of the forest with the major highway (BKE), while rates of change are negligible across the interior forest sections. This exemplifies the drastic environmental gradients faced by forest peripheral areas when such drastic alterations are made due to urbanisation so close to forest boundaries.

	Forest Interior (FI) n=413	Forest Buffer (FB) n=211	Exterior (E) n=506	Transect I	Transect II	Transect III	Transect IV	Transect V
Maximum temperature (°C)	28	28.1	37.8	33.5	34	37.8	33.5	28
Minimum temperature (°C)	24.5	31	32.2	29.5	29	29	28.5	24.5
Range (°C)	Mean from IF to E = 7.3° C			4	5	8.8	5	3.5

Maximum, minimum, and range of temperature recorded across forest interior, forest buffer, and exterior locations.

Source: Author

Table 7. Temperature changes at the various BTNR study sites in forested and exterior locations.

Description								
Temperature								
	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean Lower Bound	95% Confidence Interval for Mean Upper Bound	Minimum	Maximum
FI	107	26.0850	0.92255	0.08919	25.9082	26.2619	24.50	27.50
FB	107	29.0299	0.64064	0.06193	28.9071	29.1527	28.10	31.00
E	107	33.2776	1.00511	0.09717	33.0849	33.4702	32.20	37.80
Total	321	29.4642	3.08158	0.17200	29.1258	29.8026	24.50	37.80

ANOVA					
Temperature					
	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	2,797.951	2	1,398.976	1,847.434	0.000
Within Groups	240.807	318	0.757		
Total	3,038.758	320			

Source: Author

Table 8. ANOVA for temperatures recorded in the three categories of landcover: Forest Interior (FI), Forest Buffer (FB), and Exterior areas (E).

The highest temperature range of 4°C within a space of only 62 m is recorded across Transect I. The same trend is recorded along all road margins, indicating that steep environmental gradients are characteristic of areas exposed to highways and open concrete covered surfaces. Specifically, highways/wider roads and car park surfaces demonstrated significantly higher temperature gradients than narrower roads, and this is in line with previous research that showed that the road width is a significant factor in determining microclimate given the variance in road edge effect (Nyandwi, 2008).

Based on data recorded across the all types of landcovers, e.g., forest interior areas (FI), forest boundary buffer vegetated areas (FB), and the open exterior concrete-covered/metalled areas (OE), ANOVA tests are done and the results show very clearly that there is statistically significant difference (F=<.0005) among the three types of landcover in terms of temperatures recorded (Table 8). This is evident in raw data as well, as the highest temperatures recorded on car parks, construction sites, and roads show an increase of 9.3°C from the forest interiors and such increases are consistent around the entire forest boundary.

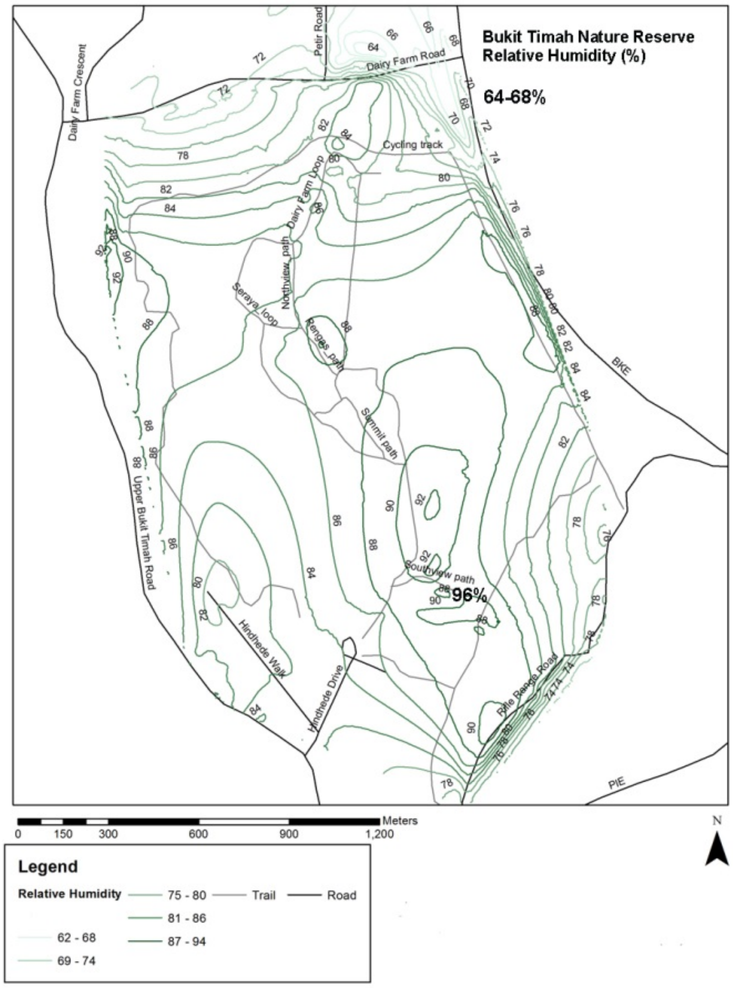
6.3. Relative humidity changes: Relative humidity distribution

Relative humidity (RH) values both inside and at the forest boundary areas were recorded at the same locations where atmospheric temperatures were measured. Figure 8 shows the isohume map of the BTNR area. Similar to the isotherm distribution, the isohume map also shows the forest interiors having the highest RH values (mean of 95.9%), while it dips to lows of 52.6% on some exterior sections of the study area, along expressways.

Similar to the patterns of temperature change, RH distribution in and around BTNR also clearly shows impact of landuse change. Rates of change are high along major roads, along the same sections that recorded high gradients of change in temperature. Along the more vegetated forest verges, such as along Jalan Asas, however, RH variations are gentle, indicating that even when not under characteristic forest cover, denser vegetation does provide adequate protection from desiccation from exposed direct sunlight.

6.4. Soil temperature changes: Soil temperature distribution

Soil surface temperatures recorded at the same sites as atmospheric temperatures and RH show close similarity in distribution pattern. Over the four years and six phases of recordings, forest interiors consistently returned low soil surface temperatures from the heavily shaded, damp forested interiors, with minimum temperatures going as low as 22°C, with a maximum of 27.6°C, while the exposed forest peripheries recorded soil temperatures as high as 33.5°C along open major roadsides along outside boundaries (Table 9). Figure 9 shows the distribution of soil temperatures that follow similar patterns as the distribution of atmospheric temperature. Although Pohlman [18] did not record a significant change in soil temperature with distance from the forest edge, the present study recorded a significant rise of more than 8°C from forest interior to the open forest edge (Table 4).



Source: Author

Figure 8. Distribution of RH in BTNR and surrounding areas

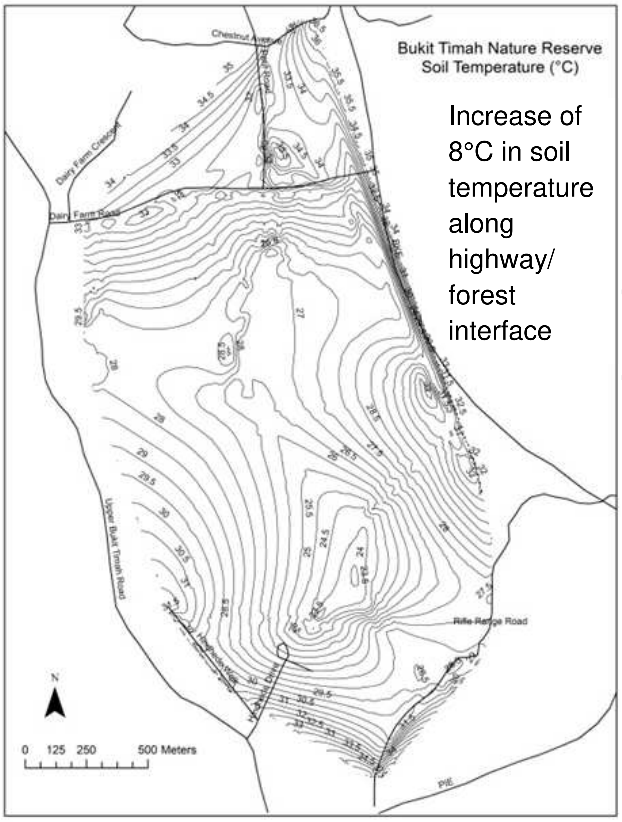
	Forest Interior (FI)	Forest Buffer (FB)	Exterior Areas (E)
Maximum Soil Temp (°C)	28.0	29	34.2
Minimum Soil Temp (°C)	22	26	26.0
Mean Soil Temp (°C)	25.5	27.9	30.7

Source: Author

Table 9. Soil temperatures (°C) recorded from various categories of landcover.

The steepest gradient of soil temperature change is seen along the open stretch of the BTNR boundary with the BKE. The rate of change of the soil surface temperature at this stretch of

http://dx.doi.org/10.5772/61233



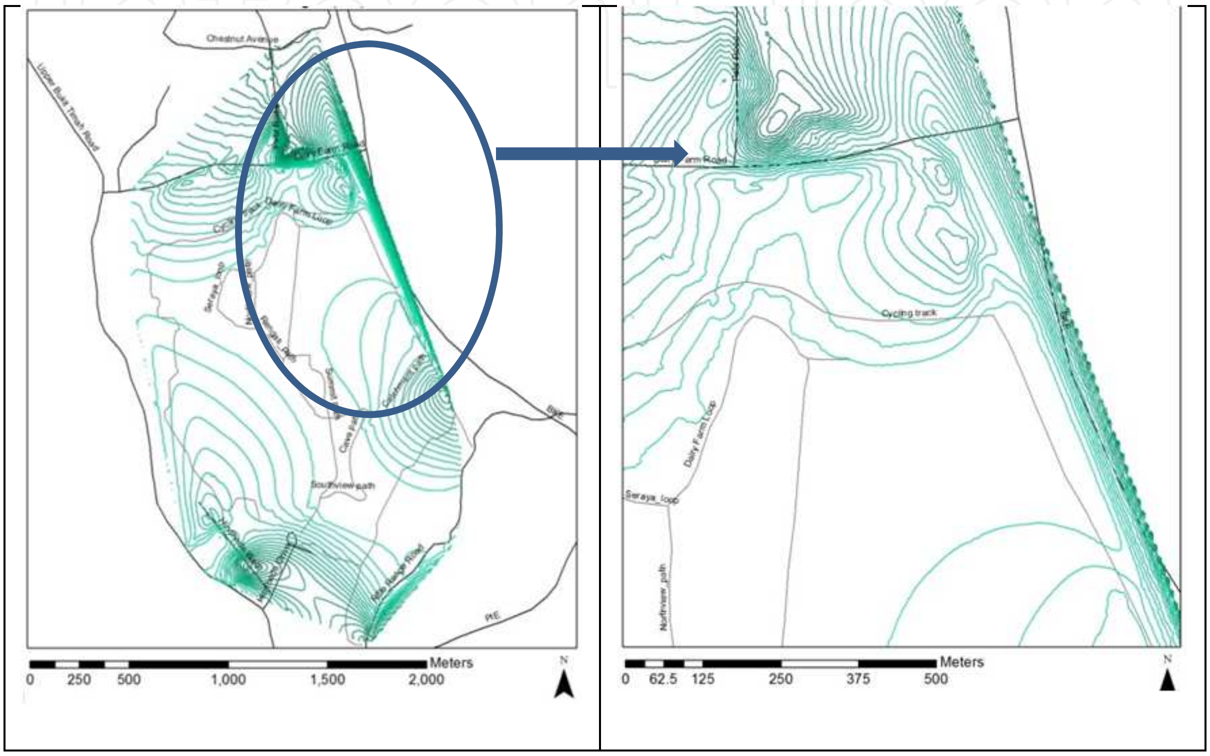
Source: Author

Figure 9. Distribution of soil temperature in and around BTNR.

open ground is 8°C within a distance of only 70 m, where the forest edge sharply interfaces with the open grasscover of the water pipeline service area, next to the highway. Records also show that the surface soil records slightly higher levels, even when full forest cover is not removed. The buffer forest areas showed slight increase in the soil temperatures, perhaps due to the thinner vegetation covers and higher exposure to sunlight.

6.5. Light intensity distribution

The interior sections of BTNR are characteristically in deep shaded conditions, with parts such as the Fern Valley and Jungle Fall in the southwest part of the deep forest being in perpetual dark and humid conditions. Small gaps do exist due to occasional treefalls, particularly on steep slopes [19], allowing some sunlight in. But on the whole, forest interiors exhibit low light conditions. Measurement of light intensities have yielded figures as low as 59 lux, with other parts of the forest recording a little over 1,000 lux (Figure 10). But the situation changes drastically at the highway verges of the forest, with readings as high as 135,710 lux, in full tropical overhead sunlight conditions. The map shows how the high light intensity zones are all along major roads, which is not unexpected. But the gradient of change from low to extremely high light exposures is very steep, with readings changing from a low of around 1,000 lux to the full extent of 120,000 lux occurs within a span of merely 100 m. This sudden change and the resultant exposure of forest vegetation are due to the open highways running too close to the forest peripheries. What is more interesting is that certain sections of the forest periphery, that have some scattered vegetation cover (e.g., Jalan Asas boundary at the western end) recorded low light intensity, merely because of the dense secondary vegetation cover that grew once the forest fringe was cleared. The gradient of change in this location is, therefore, not as steep, providing the inner forest enough protection from exposure.



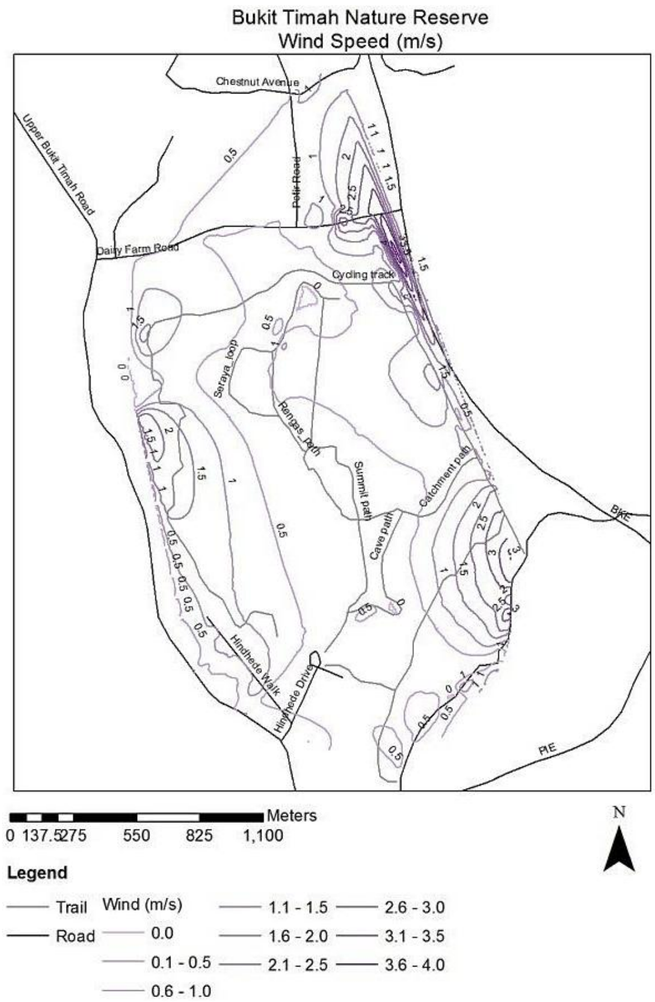
Source: Author

Figure 10. Distribution of light intensities in and around BTNR.

6.6. Wind velocity distribution

While atmospheric temperature, RH, and soil temperature variations showed consistent patterns of distribution across the different landcovers, wind velocities recorded in and around forest areas did not return consistent results. Figure 11 shows the wind velocity distributions in and around BTNR.

Tropical rainforest areas characteristically do not show significant variations in wind velocities under normal conditions, except during sudden thunderstorms. So wind velocity measurements did not yield any consistent data. However, even in the low wind conditions of a normal sultry day, open stretches of major roads and highways along the forest verge, open car parks, and condominium sites at the periphery recorded wind velocities of 3.6–5.7 m/s. While such measurements are not significantly high, it shows how the forest segments along these exposed locations may be vulnerable to treefalls during frequent thunderstorms.



Source: Author

Figure 11. Distribution of wind velocity in and around BTNR

When all parametric values, except the irregular wind conditions, are compared, it becomes clear that the boundaries of BTNR skirting the major roads and highways are impacted heavily in all aspects, making the edge effects very significant.

Table 10 shows the drastic changes in temperature, RH, soil temperature, as well as light intensities within very short distances and the rates are alarming as this sudden change in such essential environmental conditions are bound to have long-term effects on the forest conditions.

It is significant to note that while changes are drastic along major disruptions, locations that have low impact development and some vegetation cover serve as buffer (Jalan Asas area shown below, Figure 12) record milder degrees of change.

This can be an important factor to note as future management of edge effects of the forest can perhaps be rolled out around such findings and buffer areas can be invigorated to provide adequate protection to the BTNR interiors.

Transect Locations	Rates of Changes Observed (Change per 100 m Distance Across Transect)				Landuse Type
	Temperature (°C)	RH (%)	Soil Temperature (°C)	Light Intensity (Lux)	
At FI to BKE boundary	6.5	33	8.88	>160,000	Exterior (E)
At FI to Dairy Farm Road boundary	3.0	25	2.4	47,800	Exterior (E)
At Dairy Farm Road to paved carpark, construction site boundary	3.0	22.5	2.29	>160,000	Exterior (E)
At FI to Rifle Range Road boundary	3.0	7.5	2.1	21,800	Exterior (E)
At FI to Jalan Asas (vegetated) boundary	0.12	0	0.34	114	Forest Buffer (FB)
Inside Forest	0.02	0	0.1	100	Forest Interior (FI)

Source: Author

Table 10. Rates of change in environmental parameters at forest edges.

Source: Author

Figure 12. Vegetation cover in the buffer areas

6.7. Impact of visitors on forest surface conditions

Apart from the physical impacts of rapid growth of urban landscape around the forest, residential developments close to the forest boundaries also provide a heavy visitor base to the forest. This sudden rise in the visitorship to the formerly unknown forest has resulted in significant changes to the original forest surface conditions. Changes to the forest interior have been documented by Chatterjea [2, 3, 20].

The forest at BTNR sees more than 400,000 visitors in any normal year, who visit the forest for 1–2 hours and who usually go there for exercise and relaxation. The visitors go through the many laid out forest trails, most of which have natural surfaces and steep slopes (Figure 13).

Source: Author

Figure 13. Visitors and the steep slopes inside BTNR

The systematic degradation of these trails and the resultant impact on the forest conditions due to overuse have been discussed in detail by Chatterjea [20, 21]. The main outcome of such degradation to the interior of the forest is the altered surface condition along the trails, which, due to the severe impact of the pounding by joggers, have become severely compacted. Surface penetration resistances have been measured along all trail surfaces over time and results are shown in Table 11. When compared with undisturbed forested slopes, trails show a staggering 3–15 times higher compaction.

Surface Penetration Resistance (from 600 locations)	Forest	Trail	Trail-side
Maximum Resistance (kPa)	965 .3	2,137.4	2,068.4
Minimum Resistance (kPa)	68.9	1,037.9	68.9
Mean Resistance (kPa)	419.2	1,238.8	912.0

Source: Author

Table 11. Surface penetration resistance, showing compaction of forest and trail sections.

Bulk density figures obtained from a total of 54 trails, trail-side, and forest surfaces along six trails inside BTNR show comparable results and these are shown in Table 12.

Surface type	Bulk Density (g/cm³)	
Forest (n=18)	Maximum:	1.16
	Minimum:	0.60
Trail-side (n=18)	Maximum:	1.45
	Minimum:	1.24
Trail (n=18)	Maximum:	2.38
	Minimum:	1.78

Source: Author

Table 12. Bulk density measured along undisturbed forest, trail-side, and trail slopes.

Bulk density data showing a two to three times increase in density on forest trail soils support the findings of the surface resistance values obtained from similar surface classes, indicating that the trails are several magnitudes higher in surface compaction. As a result of such heavy compaction, trail surfaces often generate surfacewash during the many rainstorm events, generating fast-flowing flows that are potentially erosive. Chatterjea [19, 22] mentioned that such generated surfacewash, though at places restricted by the surface roughness, can be highly damaging to the forest environment, washing off much important soil nutrients and thus negatively impacting the forest biological environment. Figure 14 shows some examples of heavily degraded trails that recorded extreme penetration resistance and thus heavy compaction.

Due to excessive compaction, as shown in the surface penetration data, many trails go beyond repair, disallowing any root penetration even after being left unused for some length of time. It is alarming to record increasing penetration resistance values on trail-sides. These tracts running along the designated trails are initially covered often with indigenous ground vegetation, young saplings, and fresh leaf litter, a major source of nutrients to the forest vegetation. With very high human traffic on the trails, visitors tend to go beyond the designated trails, compacting what was originally beyond the designated trail surfaces. This problem is exaggerated during heavy rains when the trails, with their compacted surfaces, are sites of

Source: Author

Figure 14. One of the many heavily compacted trails inside BTNR

heavy surfacewash. Top surfaces get muddy and subsequently the slippery surfaces are avoided by the joggers who tend to use the trailsides, thus impacting these the same way (Figure 15).

Source: Author

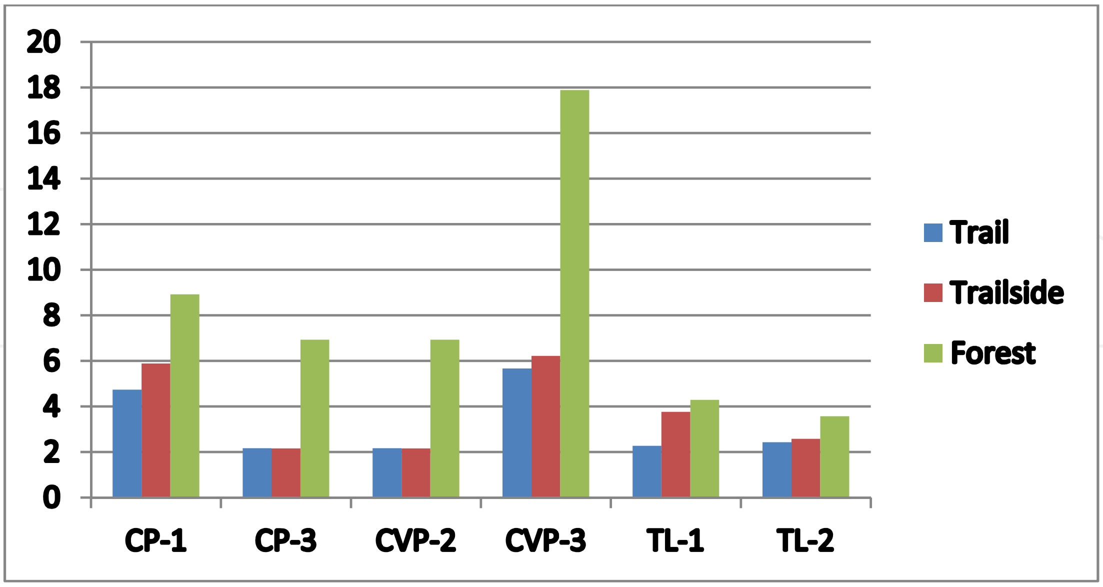
Figure 15. Trail conditions during heavy storms, with bike marks and surface wash (Note the surface wash on the left)

This leads to the widening of the existing trails. Generation of strong surfacewash during rainstorms washes off the much-precious top soil. Figure 16 shows how surfacewash results in topsoil loss, which can affect vegetation regeneration as the soil nutrients are lost, thus affecting growth of forest vegetation.

Source: Author

Figure 16. Trail sections with top soil removed through erosion

The amount of organic matter in soils from undisturbed forested slopes, as well as from trail surfaces was measured using the LOI method. Figure 17 shows that organic matter is reduced significantly in soils on trails. This can be attributed to loss by surfacewash, as well as reduced micro-organism activity within the highly compacted trail soil.



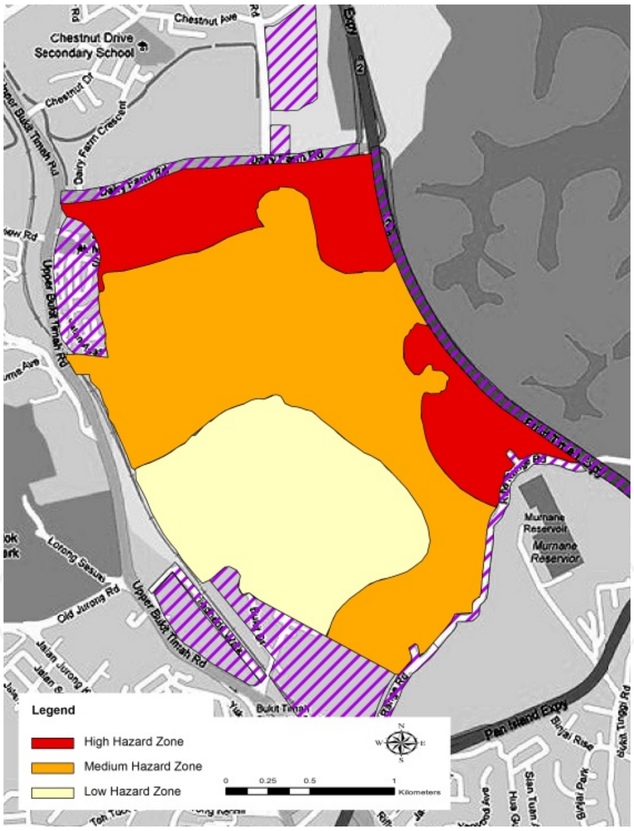
Source: Author

Figure 17. Percent organic matter in surface soils along trails, trail-sides, and on undisturbed forest slopes (CP, CVP, TL are trail names).

http://dx.doi.org/10.5772/61233

7. Management of current conditions at BTNR

During the early years of BTNR as a reserve forest, it was hardly known to the public. There was no formal entrance, no car park or any other amenities to cater to people as it hardly had visitors, except a few researchers and some avid nature lovers. But the situation changed with the landuse alterations in the surrounding areas and with the growing resident population in the many condominiums around. Today, BTNR is a favourite destination for the nearby residents, mostly as the steep slopes provide a rugged topography for outdoor exercise in trying conditions. Surveys done by Chatterjea [2] revealed that 89% of the people went there for exercise, while only 11% went for nature watch. Most went to the trails, which is reflected in the soil compaction results. Degraded trails, as reported by Chatterjea [3], a general thinning of BTNR vegetation [15], the transport disruption by construction of BKE leading to fragmentation of BTNR, the fast-growing residential development around BTNR were some of the many concerns that had counter-effect on the forest that was tagged as Singapore's most prominent conservation icon.

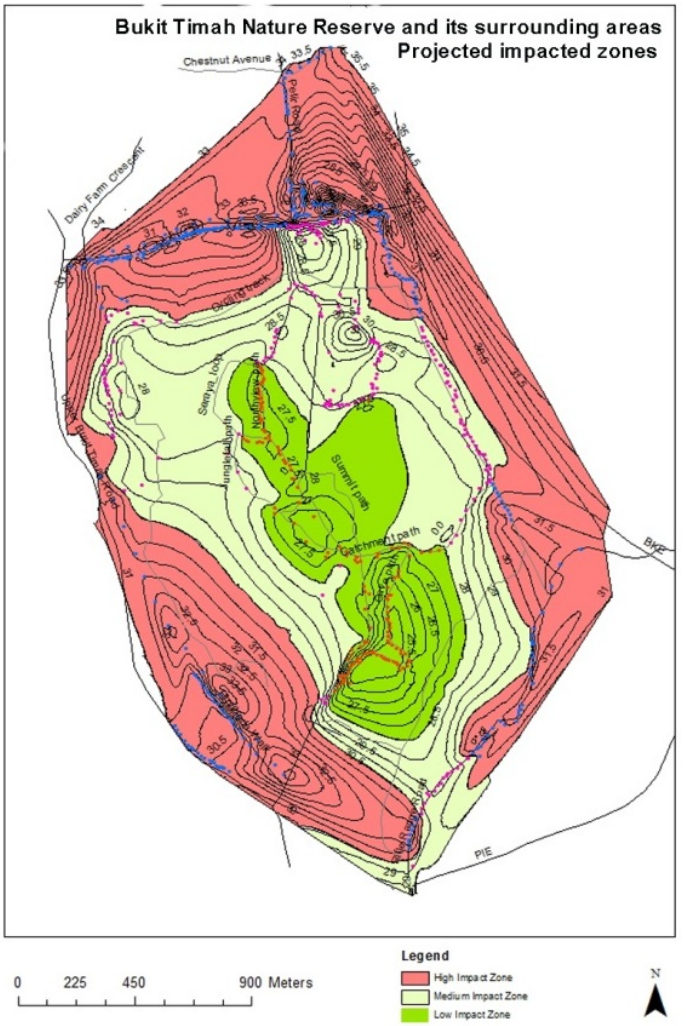


Source: Author

Figure 18. Map showing impacted areas in and around BTNR

If data on atmospheric and soil temperature increase and RH decreases along the forest peripheries are taken into account and superimposed, certain areas can be clearly demarcated as being the most impacted. These will all be along major highways (BKE and Dairy Farm Road). Based on the steep gradients of temperature change along these locations, a spatial zoning can be suggested, indicating the most impacted, and thus the most hazardous areas in the BTNR forest. Figure 18 shows such areas of high hazard, medium hazard and low/no hazard areas.

If the collected field information can be used to draw a possible scenerio for the future trends of forest condition at BTNR, locations of significant edge effects that might have high impact on the forest interior conditions can be demarcated, making these boundary areas hazardous for the sustainability of the forest. Figure 19, based on range of changes of all parameters, shows that the outer boundaries may be extending beyond mere 100 meters, well into the forest. This will, in time have negative impact on the forest interiors, posing concens for the sustainability of the forest, unless some measures are taken to enhance the buffer effect of the boundary areas.



Source: Adapted from Chatterjea [16]

Figure 19. Map showing combined effect of all environmental changes and possible impacted areas within BTNR forest interior

http://dx.doi.org/10.5772/61233

Some initiatives have been taken since 2000 to provide a buffer zone to the forest interior and land was added to the original 75 ha forest to provide some buffer against encroaching urban landuse. But the problem still remained with BKE posing a threat to any possible migration of species across from BTNR to the CWC forest. The increasing number of visitors was the other problem plaguing the forest interiors. In response to these multifaceted problems, the National Parks Board put up a two-pronged management initiative. The first initiative was to construct an eco-corridor across the BKE in an effort to re-establish an eco-link between BTNR and the larger forest at CWC, hoping to re-establish some faunal and eventually some floral establishment between the two initially connected, but subsequently separated forested landscape (Figure 20).

(Photos by courtesy of National Parks Board, Singapore)

Figure 20. The Eco-Link @ BTNR, showing gradual establishment of vegetation cover

The Eco-Link @BTNR was designed to make a safe and easy passageway for ground-moving animals such as pangolins, civet cats among others, and also the long-tailed macaques. The link was established in 2013 and is now in the process of being vegetated with indigenous species to provide natural protection to the resident animals. Figure 20 shows the Eco-Link in two phases, signifying an effort to correct the environmental mistake that had earlier fragmented BTNR. It is not easy to establish if this effort will have any sustainable, positive effect on the forest conditions or whether BTNR will be in a better state because of this corridor. But surely, it shows the conservation efforts and also the zeal to correct past environmental mistakes.

The second initiative, however, is aimed at more definite outcomes, to re-invigorate the forest interior, to re-establish much of the lost forest conditions, while keeping the streams of people satisfied with their daily dose of exposure to BTNR's rugged environment. The forest trails, in their highly degraded conditions, had become dangerously hazardous. So the forest management closed the forest for two years, starting September 2014, to correct the slope disturbances, construct boardwalks over badly damaged trails, reorganising trail locations on gentler slopes, creating trail protection, particularly at the sides, to avoid trail extension, constructing wooden steps over exposed roots to reduce or stop damage to forest vegetation, and generally reestablishing a natural condition that will, in the future, reduce impact on the forest while complying with the heavy demand by the urban visitors. It is expected that with no trampling of the trails in these two years, some of the trails will revive some vegetation cover and regain the soil structure of a characteristic forest surface. If the number of visitors can be controlled and if some of the peripheral forest areas opened for public use can ease the pressure on BTNR, it will help in creating a more sustainable condition for BTNR.

8. Conclusion

Judging from the records shown in Table 10, the heavily impacted locations can be managed with proactive management to reduce the impacts, as found in Jalan Asas boundary. That will provide effective buffer protection to the forest interiors, at least to retain the forest interior environmental conditions. Thus, it might be wise to establish a legally protected buffer zone to effectively protect the forest interiors, without compromising too much on development.

Urban greening is not unknown to Singapore and already there is an active initiative in creating urban forest tracts around both BTNR and CWC, to provide the urban population places for recreation under forest cover. Examples of such are Bukit Batok Nature Park, Hindhede Nature Park, and the new and upcoming Windsor Green Park, where areas surrounding the BTNR and the CWC forests are being deliberately developed and tended to provide forest environment for the increasing appetite of people for outdoor activities. The recently decommissioned railway line running along one edge of BTNR and demarcating that linear land as a green corridor is a positive action towards creating a green buffer and keeping development at bay at the strategic boundary zone. All these initiatives are in line with the requirements that may save the forest at BTNR from being overexposed and overused. Currently, the forest is closed to visitors for about two years. This time will be given for the forest interiors to get revived, with no trampling of trail surfaces. Once the forest is reopened, trails that were marked as heavily impacted and thus hazardous [3] will have boardwalks on some difficult sections so that future trampling will not pose as serious a threat as before.

Bukit Timah forest, being the only surviving primary rainforest in Singapore, is a very important part of the greenscape of Singapore. Due to the conservation efforts, it has been possible to retain some of its natural richness, though it is increasingly under threat. But the current emphasis on its conservation through positive steps at ameliorating some problems is in the right direction to protect this natural heritage of Singapore.

Acknowledgements

The research is part of a project funded under NIE AcRF no. RI 1/12 KC. Many of the field data were collected with the help of research assistants and students. Some information as well the as photographs of the Eco-Link @BTNR are provided by NParks officers at Bukit Timah Nature Reserve and their contribution is acknowledged.

Author details

Kalyani Chatterjea

Address all correspondence to: kalyani.c@nie.edu.sg

National Institute of Education, Nanyang Technological University, Singapore

References

[1] Lum S, Sharp I, editors. A view from the summit: The story of Bukit Timah Forest, Singapore. Singapore: Nanyang Technological University and National University of Singapore; 1996. 141 p.

[2] Chatterjea K. Public use of urban forest, its impact, and related conservation issues: The Singapore experience. In: Wong TC, Shaw BJ, Goh KC, editors. Changing sustainability: Urban development and change in Southeast Asia. Singapore: Marshall Cavendish; 2006. p. 53-79.

[3] Chatterjea K. Development and environment: A constant battle. In: Ooi GL, Chatterjea K, Chang CH, Lim KYT, editors. Geographies of a changing world: Global issues in the early 21st century. Singapore: Prentice Hall; 2007. p. 585-607.

[4] Davies-Colley RJ, Payne GW, van Elswijk M. Microclimate gradients across a forest edge. New Zealand Journal of Ecology. 2000;24:111-121.

[5] Lawrence WF. Hyper-disturbed parks: Edge effects and the ecology of isolated rainforest reserves in tropical Australia. In: Lawrence WF, Bierregaard RO, editors. Tropical forest remnants, ecology, management, and conservation of fragmented communities. Chicago: The University of Chicago Publishers; 1997. p. 71-82.

[6] Laurance WF, Goosem M. Impacts of habitat fragmentation and linear clearings on Australian Rainforest Biota. In: Stork N, Turton S, editors. Living in a dynamic forest landscape. Wiley-Blackwell; 2008. p. 295-306.

[7] Zhang D, Chen J. Edge effects in fragmented landscapes: A generic model for delineating area of edge influence. Ecological Modelling. 2000;132:175-190.

[8] Collinge SK. Ecological consequences of habitat fragmentation: Implications for landscape architecture and planning. Landscape and Urban Planning. 1996;36:59-77.

[9] Harris LD. The fragmented forest: Island biogeography. Theory and the Preservation of Biotic Diversity. Chicago: University of Chicago Press; 1984. 230 p.

[10] Wilcove DS, McLellan CH, Dobson AP. Habitat fragmentation in the temperate zone. In: Soul ME, editor. Conservation Biology: The science of scarcity and diversity. Massachusetts: Sinauer Associates; 1986. p. 237-256.

[11] Hunter ML Jr. Wildlife, forests, and forestry. New Jersey: Prentice-Hall; 1990. 370 p.

[12] Bierregaard RO Jr., Lovejoy TE, Kapos V, Augusto DSA, Hutchings RW. The biological dynamics of tropical rainforest fragments. Bioscience. 1992;42:859-866.

[13] Tobias S. Preserving ecosystem services in urban regions: Challenges for planning and best practice examples from Switzerland. Integrated Environmental Assessment and Management. 2013;9(2):243-251.

[14] Biodiversity British Columbia Technical Sub-committee. Major impacts to biodiversity in British Columbia a report to the conservation planning tools committee [Internet]. May 2007. Available from: http://www.biodiversitybc.org [Accessed: January 7, 2015].

[15] Wee YC, Corlett R. The city and the forest. Singapore: Singapore University Press; 1986. 186 p.

[16] Chatterjea K. Edge effects and exterior influences on Bukit Timah Nature Reserve, Singapore. European Journal of Geography. 2014;5(1):8-31.

[17] Nyandwi E. Road edge effect on forest canopy structure and epiphyte biodiversity in a tropical mountain rainforest, Nyungwe National Park, Rwanda. Enschede, Netherlands: Institute for Geo-Information Science and Earth Observation; 2008. 73 p.

[18] Pohlman CL, Turton SM, Goosem M. Edge effects of linear canopy openings on tropical rainforest understorey microclimate. Biotropica. 2007;39(1):62-71.

[19] Chatterjea K. Surface Wash: The dominant geomorphic process in the surviving rainforest of Singapore. Singapore Journal of Tropical Geography. 1990;10(2):95-109.

[20] Chatterjea K. Sustainability of an urban forest: Bukit Timah Nature Reserve. In: Diez J.J., editor. Sustainable Forest Management. Rijeka: InTech; 2012. p. 143-160.

[21] Chatterjea K. Assessment and demarcation of trail degradation in a nature reserve, Using GIS: Case of Bukit Timah Nature Reserve. Land Degradation and Development. 2007;18(5):500-518.

[22] Chatterjea K. Dynamics of fluvial and slope processes in the changing geomorphic environment of Singapore. Earth Surface Processes and Landforms. 1994;19(7): 585-607.

[23] [Double click to insert bibliographysource here]

IntechOpen