Beyond the Red Meranti

Fresh Perspectives on Malaysia’s Pasoh Forest Reserve and Climate Change

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Congratulations to Forest Research Institute Malaysia (FRIM) and authors of “Beyond the Red Meranti”, for working diligently to come up with a book that has succeeded in translating the research and science that goes into a better understanding of the impacts of climate change. But what makes this book different from the other books on climate change is that the research and science to which this book is based upon, was conducted in none other than FRIM’s earliest research station at the Pasoh Forest Research in Negeri Sembilan.

We often heard of rising temperatures, heat waves, massive floods and extreme hurricanes as prevalent occurrence around us. These are changes that do not occur overnight. Our planet has always been a “brewing pot” just waiting for the “boiling point” when we, the inhabitants, finally take notice that our environment is changing.

While climatic changes are partly nature’s doing, we have also succeeded in amplifying and hastening the process in the rush for modernization. It is without a doubt that global issues such as climate change affects us all individuals. And, because of this, it is absolutely important for us to understand what climate change is all about.

A quick browse through your local bookstores or online publishers will help you provide a list of books that catered to help children, students, parents, teachers, scientists, shop owners, parking attendants, and just about anyone, understand climate change. As climate change is an evolving occurrence, so should our understanding of the matter. Hence, in my opinion, we can never have enough publications, articles and books to help us enrich ourselves with knowledge for a better understanding on climate change.

This book also serves as a testimony to the forward thinking of FRIM’s past and current researchers for placing science as the backbone of our everyday lifestyle. Finally, I hope you find this book as engaging and as informative as I do.
Since its establishment in 1985, the Forest Research Institute Malaysia has always been at the forefront of scientific research and development relevant to the demands and needs of today’s society. Over the decades, FRIM has promoted, facilitated and led research in various fields from wood products, medicinal plants and drug discoveries, forestry management and improved techniques, without forgetting fundamental yet crucial forest ecology exploration (flora, fauna and its interactions). The Pasoh FRIM Research Station, maintained and managed by FRIM since 1977 was established for continuous research on long term ecological studies to provide better understanding on complex ecological processes of lowland tropical rain forests. Ecological studies in Pasoh began as early as in 1964 and with time, the forest biological richness and its accessibility naturally garnered the interest of many local and foreign scientists and researchers. Today, there are at least ten long-term ecological research projects being conducted in Pasoh with more than 400 publications produced making the Pasoh Forest Reserve, one of the most extensively studied lowland tropical forests in Southeast Asia.

I am very delighted with the production of this book as it serves as a landmark to understanding the impact of climate change on the productivity and integrity of lowland tropical forest ecosystems using local information. The book was made possible with the collection of numerous data and information gathered through years of research conducted at the reserve.

I must say that the production of this book is timely as people from various backgrounds are trying to grasp the issue of climate change and anticipate its impact. It is my sincere hope that the contents of this book will help you get a better understanding of how climate change will impact our forests and that this will result in more attention and efforts given to the conservation of our natural resources as a mitigation measure to reduce the impacts of climate change.

Last but not least I would like to express my sincere thanks and gratitude to the team of authors, comprising Dr Christine Fletcher, Dr Shamsudin Ibrahim, Dr Samsudin Musa, Dr Abd Rahman Kassim and Dr Marc Abrams for their commendable efforts in writing this book. It took a lot of effort to digest a vast array of research data and information for our understanding, but with dedication and team spirit, I am glad that it came through.
Another book on climate change?

Yes, but this is different. Different because here we attempted to understand a global issue using local information gathered at one of FRIM’s oldest research station and plot in the Pasoh Forest Reserve in Negeri Sembilan. Well known amongst ecologists but lesser amongst the general public, the Pasoh FRIM Research Station is host to an amazing rich history of scientific information on forest ecology since the late 1960s. Chapter 1 of this book introduces you the history and intrinsic values of the Pasoh Forest Reserve. In Chapter 2, we slowly reel you in on how forests play an ecological important role other than as a natural resource for timber, food and medicinal plants. In fact, forests have a much bigger unseen role in balancing the planet’s ecosystem, which includes regulating climate.

The underlying causes of climate change are but many and thus so are the impacts as presented in Chapter 3. However, this book focuses on how Malaysia’s tropical forests are responding to the changing climate by using various historical ecological data.

Basically, this book aims to gather and use this historical information gathered over more than three decades at Pasoh FR to help us understand a current and pertinent global issue, climate change, and how it affects us. This was the biggest challenge we faced in writing Chapter 4 – to translate and condense research findings from various individual climate-change-related studies built upon the vast amount of environmental data, into something that we can relate to. Although these studies were designed for individual purposes, not necessarily to understand the impacts of climate change, but we felt that indirectly, it contributed in one way or another to give us a fresh perspective on forest and climate change.

In the concluding chapter, we made deductions on the possible impacts of climate change on our forests and environment based on the trends shown by the research conducted in Pasoh FR. It is our hope that the general public and policy makers determining the fate of our forests, gain a new perspective on the role of forest in mitigating climate change, as well as the need for sound scientific information for better decision making. Indirectly, we hope this book makes you feel like packing your bags and head for Pasoh FR to embark on new and exciting research projects, or to just simply appreciate nature.
Chapter 1

A Place Called Pasoh
Located just 140 km southeast of Malaysia’s bustling capital city, Kuala Lumpur, is a quiet lowland tropical rainforest. The Pasoh Forest Reserve in the state of Negeri Sembilan (Malay for the ‘ninth state’) is located at 2° 98' 20 N, 102° 31' 30 E.

Biogeographically, this forest patch is considered an island forest as it has been isolated from the main peninsular Malaysian forest range, also known as the Central Forest Spine (CFS). Surrounding the reserve is agriculture, oil palm plantations and other developed land.

Consisting of mainly dipterocarp trees (tropical tree chiefly with two-winged fruits, hence the name ‘dipterocarp’, di = two, pteron = wing, karpos = fruit), this forest island covers an area of 139 km², six times the size of the island country, Tuvalu or one fifth of the Republic of Singapore. The forest area is relatively flat with undulating hills to the northeast, and reaches an altitude of 600 m above sea level. This reserve is under the custodian of the State Forestry Department of Negeri Sembilan. In 1977, it was designated as a forest reserve to function for a variety of purposes, including production forestry (sustainable timber harvesting) and the protection of flora and fauna (conservation and research).
Within this reserve is an area of 18.4 km² set aside for research purposes. The core area of about 4 km² consists of pristine forests, while the remaining areas are regenerating forests harvested for timber in the 1950s. The main soil type consists of alluvium (in the lowland) and shale (on the hill slopes), with smaller areas of laterite (red, iron rich) soil on the hill summit. The alluvium soil contains more water as it is in the wet, swampy areas of the reserve, while the shale is more variable in texture. This provides a variety of habitat platform for a diversity of trees to establish in the reserve.

Holloway & Intachat 2003
Logged-over forests comprise the research component of Pasoh FR. The number in brackets indicate the year it was logged.

Pasoh FR covers 139 km² including 18.4 km² of forest (in box) gazetted as Research Forest where the Pasoh 50-ha permanent plot and Pasoh FRIM Research Station is located.
Since 1977, the Forest Research Institute Malaysia (FRIM) was given the mandate to manage this forest area and facilities for research purposes. Previously, it was under the management of Malaysia’s first university, Universiti Malaya, which was conducting pioneer research work with researchers from the United Kingdom under the International Biology Programme with UNESCO and the Man and Biosphere (MAB) Programme. Since FRIM took over its management, the forest research area has gained an international reputation as an ideal field laboratory for tropical forest ecological studies.

Cool and dry

Negeri Sembilan is relatively drier (lower rainfall) than other states in Peninsular Malaysia. It receives an annual average of 1842 mm of rain (between 1974–1996) ranging from 1700–3200 mm and the temperature ranges between 21–33 °C with an average of 25.4 °C. Above canopy temperatures are similar averaging 25.7 °C between 1992–1999. It is generally dry throughout the year with a minor wet season between March – May and a distinct wet season between October – December.

Home of the Red Meranti

The plant life in Pasoh Forest Reserve is amongst the most studied in Southeast Asia. This is mainly due to the establishment and monitoring of a 50-hectare permanent forest dynamic plot within the pristine core area of the research forest. Established in 1985 together with the Centre for Tropical Forest Science (CTFS) under the Arnold Arboretum and Harvard University, all stems (trees and plants) 1 cm at diameter breast height (dbh) and above is censused every five years. From the 2005 census exercise, more than 310,000 trees have been tagged, mapped and monitored for growth and mortality. This consists of over 800 species, 21 of which were species new to science.
Fletcher, C.  
Well-defined trail to the 50-hectare demographic plot in Pasoh FR
Forest structure and species composition in this reserve is typical of the lowland forest of Peninsular Malaysia; a complex architecture provided by trees and plants of many species and sizes. The most prominent feature is the emergent trees whereby the crown of the trees grow out of the main forest canopy. The emergent trees in this reserve are mainly dipterocarp trees from the family Dipterocarpaceae (Shorea spp. – Meranti, Dipterocarpus spp. - Keruing and Neobalanocarpus heimii – Chengal) and the legume family, Leguminosae (Koompasia malaccensis – Kempas tree and Intsia palembanica – Merbau) among others. These trees can grow to impressive heights of over 60 m tall and girth of over 2 m. The biggest tree recorded within the Pasoh 50 ha demography permanent ecology plot is a Chengal tree measuring 231.2 cm dbh.

Source: Iida, Y.
Forest structure of Pasoh Forest Reserve
Lianas climb trees to claim light atop the canopy.

Saplings sprout from the forest floor especially when there is sunlight.

Resin is produced by Dipterocarp trees to 'patch' up cuts and wounds on its bark.

Fine flowers from large trees carpet the forest floor.
Beneath this emergent layer is the main canopy and lower-storey trees consisting of more general and commonly distributed tree families such as Myrtaceae (Kelat), Guttiferae (Mangosteen), Sapindaceae (Rambutan) and Anacardiaceae (Mango). Many of these trees produce edible fruits. The ground vegetation consists of smaller plants like gingers, palms, ferns and herbaceous plants.

Apart from trees and plants, the Pasoh forest is also inhabited by a variety of fungi (mushrooms). Unlike plants, it does not have chlorophyll, hence is usually in colours other than green. There are several edible mushroom species that grow in Pasoh. Some species of mushrooms can be seen throughout the year while some are more abundant or more obviously seen during the wetter seasons. Among the more commonly seen species is the Microporus species which usually grow on branches and twigs. In this regard, it can be considered an epiphyte or air plant and it not rooted in the ground.

Typically tropical rain forests experience mass flowering, followed by mast fruiting that occurs at irregular intervals ranging from 2 to 10 years. Phenological observations of trees within the 50 ha permanent forest study area indicate that mass flowering (also known as ‘general flowering’) occurred in late 2001–early 2002 and again in early 2004–late 2005. It is also during this time that non-dipterocarp families will flower. Flowers of Shorea section mutica spp. (Red Meranti group) is exceptionally more abundant.
Wild and free

Since the first survey conducted in the reserve in 1964, a total of 540 vertebrate species (animals with a backbone i.e. birds, squirrels, primates, frogs) have been recorded. This total also includes reptiles and amphibians, collectively known as herpetofauna (70 species), small mammals including squirrels, tree shrews, rats, bats, primates and carnivores (70 species) and birds (233 species). Big game animals such as tigers and elephants are not presently found in this reserve, and the last recorded sighting was in the late 1980s. However, tapir, sun bears and panthers are still being recorded in the reserve, although this is an extremely rare event.

Most of the other animals are not readily seen on a daily basis as they prefer to be in the shade and protection of the forest and hide from humans. However, the White-handed gibbon (Hylobates lar) can usually be heard calling in late mornings while the shy dusky-leaf monkey (Presbytis obscurus) can sometimes be seen leaping from tree to tree at the sub-canopy layer. Long-tailed (Macaca fascicularis) and short-tailed (Macaca nemestrina) macaques are relatively common below the canopies, often coming down to the ground in search of food. Also common on the forest floor is the wild boar (Sus scrofus) and the water monitor lizard (Varanus salvator) especially in the swamplike area.

In the canopy level, various bird species can be spotted especially at dawn and dusk when it is most active. Among the more common bird species in this reserve is the tree babblers (family Timaliidae), woodpeckers (family Picidae), and the sunbirds and spiderhunters (family Nectarinidae). Although less-frequent, the loud calls of the great argus (Argusianus argus) can sometimes be heard deep in the forest but rarely seen.
Beyond the Red Meranti

The following pictures are courtesy of the TEAM network. Images were captured using camera traps.

Water monitor lizard (*Varanus salvator*)

Short-tailed or pig-tailed macaque (*Macaca nemestrina*)

Grey-bellied squirrel (*Callosciurus caniceps*)

Malayan porcupine (*Hystrix brachyura*)

Blue-winged pitta (*Pitta moluccensis*)

Jungle fowl (*Gallus gallus*)
The following pictures are courtesy of the TEAM network. Images were captured using camera traps.

A scavenging wild boar (Sus scrofa) 

Wild boars (Sus scrofa) 

Tapir (Tapirus indicus) 

Barking deer (Muntiacus muntjak) 

Argus pheasant (Argusianus argus) 

Green-winged pigeon (Chalcophaps indica)
At night, there is usually a lively chorus of cicadas while the bats and frogs are most active, alongside with other nocturnal animals such as the lesser mousedeer (*Tragulus javanicus*), common palm civet (*Paradoxurus hermaphroditus*) and the large porcupine (*Hysterix brachyura*).

Insect diversity in the Pasoh Forest Reserve is also bountiful with over 400 moth species, 10% of which are new records, previously known to have only occurred in Borneo, 57 species of termites and 9 species of stingless bees, an important pollinator of forest trees. Other exciting finds include the giant millipede and giant forest ant (*Camponotus gigas*) in addition to over 20 identified colourful butterfly species.

**Life abundant**

The Pasoh Forest Reserve is not only rich in history, but also in the biodiversity of flora, fauna and all other living organisms.
Twenty-five percent of all tree species recorded in Peninsular Malaysia can be found here, as with a quarter of all palm species and 56% of mammal species. The rich diversity of trees and plant life can be attributed to the variety of soil types of alluvial to laterite from the lowland to the hills. The comfortable temperature and rainfall in this tropical region also provides a conducive growing environment for a diversity of trees and plant life. With this comes the associated animal diversity; from large and small vertebrates to insects.

The history of Pasoh Forest Reserve which came to be so well studied for its diversity is largely due to the conservation and research consciousness of various parties; both locally and internationally, making the Pasoh Forest Reserve a haven for researchers and nature enthusiasts. Much of Pasoh is being protected for the sake of preservation and this will likely lead to further increases in biodiversity in the future. In addition, Pasoh will serve as an excellent model system for the study of the impacts of future climate change on tropical rainforests in southeast Asia. Previous studies conducted at Pasoh, including those reviewed in the chapter, will serve as a baseline for quantifying impacts on the forest environment induced by climate change.
Chapter 2

Bellwether for Climate Change
The world is currently facing a climate crisis which is real, human induced and urgent. Increasing greenhouse gas (GHG) emissions from anthropogenic activities mainly from the burning of fossil fuels has caused the rise of global temperatures resulting in changes in the global climate system. This changing global climate has been identified as the most serious threat to mankind today and effective global efforts are needed to mitigate its impacts. Climate change impacts threaten food security, biodiversity, natural habitats, health and peoples quality of life. These impacts arise from rising temperatures, extreme weather events, rise in sea levels and spread of diseases. It is not only a major driver of global environmental change but climate change also influences complex and intertwined tropical forest ecosystems that rest in a delicate balance.

### Forests and climate change

As globally important storehouses of carbon, tropical forests play a critical role in influencing the earth’s climate. Forest plants and soils drive the global carbon cycle by sequestering carbon dioxide through photosynthesis and releasing it through respiration and decomposition. Yet, in many parts of the world, forests are being rapidly cleared for agriculture or pasture, destructively logged and mined, and degraded by human-set fires. When forests are degraded or cleared, their stored carbon is released back to the atmosphere during harvest and burning, thus these forests are becoming net contributors of carbon to the atmosphere. The IPCC 2007 Report also projected that 20 to 30% of global biodiversity will face extinction if the global temperatures increase between 1.5 to 2.5 °C. The report highlighted a projected loss of 20 - 80% of the Amazon rainforest and biodiversity and Australia may lose about 50% of the rainforest in Queensland.

Globally, we noticed weather patterns are changing and this in turn has greater impacts on food production and species migration. Fresh water scarcity risks are becoming even more acute in drought-stricken countries and flooding may increasingly threaten our coastal communities and directly impact hundreds of thousands of people each year. Solutions are needed now. Our ecosystems must be able to adapt to these changes so that they can retain productivity, continue to buffer extreme weather events and provide fresh water and a myriad of other services

<table>
<thead>
<tr>
<th>Phenomenon and direction of trend</th>
<th>Likelihood of future trends based on projections for 21st century</th>
</tr>
</thead>
<tbody>
<tr>
<td>Warmer and fewer cold days and nights over most land areas</td>
<td>Virtually certain</td>
</tr>
<tr>
<td>Warmer and more frequent hot days and nights over most land areas</td>
<td>Virtually certain</td>
</tr>
<tr>
<td>Warm spells/heat waves. Frequency increases over most land areas</td>
<td>Very likely</td>
</tr>
<tr>
<td>Heavy precipitation events. Frequency (or proportion of total rainfall from heavy falls) increases over most areas</td>
<td>Very likely</td>
</tr>
<tr>
<td>Area affected by droughts increases</td>
<td>Likely</td>
</tr>
<tr>
<td>Intense tropical cyclone activity increases</td>
<td>Likely</td>
</tr>
<tr>
<td>Increased incidence of extreme high sea level (excludes tsunamis)</td>
<td>Likely</td>
</tr>
</tbody>
</table>

for all life on earth. In addition, human communities need the knowledge and tools to effectively adapt to the impacts of climate change.

Next to the burning of fossil fuels are activities related to land use, primarily tropical deforestation and forest fires. Currently, the carbon dioxide emissions from human activity are estimated to be 7.5 billion tonnes of carbon annually, of which 1.5 to 1.8 billion tonnes comes from forest-related sources. GHG from deforestation are mostly carbon dioxide with lesser amounts of methane and carbon monoxide. This tropical deforestation is one of the most critical environmental problems facing the developing countries today in terms of its long-term catastrophic impacts on biodiversity, economic opportunities lost, social problems, and contribution to global climate change.
Forests, giving life

Forest ecosystems continue to deliver a wide array of products and services to society. Perhaps the most important product from the forest is wood, which also has a diversity of applications and purposes, such as construction purposes, furniture and fuel. However, there are also a large number of non-timber forest products coming from the forest, like medicinal plants, honey, fruits and other food plants. The availability, the use and the importance of these products varies by region and by culture. In developing countries a significant number of people are still dependent directly upon these products for their subsistence especially local communities who live adjacent to forest areas.

Ficus, a keystone species has a significant impact on diversity in its vicinity

Ahmad Fitri, Z.
One of the many medicinal plants commonly found in Malaysia, Goniothalamus ridleyi

Some fruits of rattan trees are edible

Ahmad Fitri, Z.
Apart from visible products, forests also deliver a variety of ecosystem services. Forests play an important role in the global and local water cycle. The specific role very much depends on the local circumstances and conditions and also on the forest type itself. Forests are known to regulate rainfall and water flows. In steep areas forest cover helps to protect the soil against erosion.

From a biodiversity viewpoint, forests are also extremely valuable. The tropical rainforest has the largest biodiversity of all biomes. Many iconic animal species such as tigers, elephants, rhinoceros and primates uses forest habitats for their population growth. However, ecosystems in general have changed significantly over the past 50 years, more than in any other period of human history and the impact of such changes to ecosystems including forest ecosystem are enormous. This has resulted in a big and often irreversible loss of diversity of life on earth where 1000 times more species of both flora and fauna became extinct in the last century compared to the previous century. At this moment 10 to 30 % of mammal, bird and amphibian species are threatened with extinction. Interventions are required to reduce deforestation, forest fragmentation and forest degradation that could undermine the integrity of ecosystem functioning. This is now being linked to the more complex issue of climate change.
Forests provide ecosystem services such as ensuring a steady supply of clean water.
Forests can also influence local climate. Tropical forests have a net cooling effect through evapotranspiration. On a global level, forests stabilize climate by regulating energy and water cycles. Rainwater that is generated by the tropical forest enables agriculture and agroforestry production, which are of great importance to the economy of the countries involved. Deforestation in Southeast Asia can have consequences on rainfall patterns in Southern Europe and the Northwest coastal area of the United States by changing weather patterns and ocean currents.

**The need to conserve**
Malaysia, as many other countries, recognises that forests play an important role in ameliorating the adverse impacts of climate change. Consequently, Malaysia has taken positive steps towards managing the valuable resource on a sustainable basis to ensure that the nation continues to enjoy the myriad of benefits including its roles in maintaining a stable climate. A sustainable forest management can generate forest biomass as a renewable resource. Some of this biomass can be substituted for fossil fuels. This approach has a greater long-term potential for reducing net emissions than does growing trees to store carbon. Establishing forests on degraded or non-forested lands adds to the amount of carbon stored in trees and soils.

Measures to protect, restore, and sustainably manage forests offer significant climate change mitigation potentials. Furthermore, forest-based measures can be an effective complement to abatement options focused on fossil fuel emissions.

**Forest-based mitigation of global warming can occur by three strategies:**

1. **Conservation of existing forests** - to avoid emissions associated with forest degradation or clearing.

2. **Sequestration by increasing forest carbon absorption capacity** - occurring primarily by planting trees or facilitating the natural regeneration of forests, especially on marginal land and by making changes in forest management to increase biomass.

3. **Substitution of sustainably produced biological products** - substituting wood products for materials requiring energy-intensive production, such as aluminum or concrete, and substituting woody biomass for fossil fuels as an energy source.
Beyond the Red Meranti

Deep green

Despite annual logging activities, Malaysia is able to maintain a relatively large part of its land in natural forests. Total forest cover was estimated at 18.3 million ha or 56% of the total land area. The major forest types consist of 16 million ha of dry inland forest, 1.36 million of swamp forest, 0.58 million ha of mangrove forest, and 0.4 million ha of forest plantation, where the proportion of forest areas is much higher in Sabah and Sarawak than in Peninsular Malaysia.

The forest habitats of Malaysia are home to a wide array of plants, animals and micro-organisms. A good example is the high diversity of plants found in a 50-ha plot of lowland dipterocarp forest in Pasoh Forest Reserve with 814 tree species from 290 genera and 78 families. The species number constituted almost one third of the total number of tree species in Peninsular Malaysia. The flora also showed high level of unique species found nowhere else (endemism) and 746 species (26%) out the 2830 tree species are endemic to Peninsular Malaysia. Endemism is reported to be even higher among the herbs, ranging between 87% to 96% in some of the large families.

### Species diversity in Peninsular Malaysia

<table>
<thead>
<tr>
<th>Plant/animal Group</th>
<th>Number of Species</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flowering Plants</td>
<td>8,000</td>
</tr>
<tr>
<td>Ferns</td>
<td>500</td>
</tr>
<tr>
<td>Fungi</td>
<td>300</td>
</tr>
<tr>
<td>Mammals</td>
<td>203</td>
</tr>
<tr>
<td>Birds</td>
<td>616</td>
</tr>
<tr>
<td>Snakes</td>
<td>141</td>
</tr>
<tr>
<td>Frogs</td>
<td>93</td>
</tr>
<tr>
<td>Lizards</td>
<td>&gt; 80</td>
</tr>
<tr>
<td>Butterflies</td>
<td>1,022</td>
</tr>
<tr>
<td>Moths</td>
<td>&gt; 5,000*</td>
</tr>
<tr>
<td>Other insects</td>
<td>&gt; 20,000*</td>
</tr>
<tr>
<td>Other invertebrates</td>
<td>&gt; 10,000*</td>
</tr>
</tbody>
</table>

Note: * denotes estimates
Source: Cranbrook 1988

Fletcher, C.

With its palette of colours and variety of shapes, a forest canopy is a sight to behold.
It has been reported that Peninsular Malaysia’s forest is an extremely complex ecosystem and are richer in tree species than in similar area of Africa and South America. They are in fact the most species rich communities known anywhere in the world.

Malaysia has a National Forestry Policy for the establishment of a Permanent Forest Estate (Permanent Reserved Forests), including Pasoh FR, to be classified and managed under four major functions, namely, Protection Forest, Production Forest, Amenity Forest, and Research and Education Forest. The policy recognises the role of forests in regulating climatic and physical conditions of the country, safeguarding water supplies, ensuring environmental stability and the protection of biological diversity. The Pasoh Forest Reserve is a primary example of these important functions of forest ecosystems.
Chapter 3

The Long View
The amount of energy impacting the earth’s climate is the balance between incoming and outgoing solar radiation. About 30 percent of solar radiation that reaches Earth is reflected back into space; another 20 percent is absorbed by the atmosphere and the remaining 50% of the solar radiation is absorbed by the earth’s surface. Much of this energy is released back to the atmosphere and then trapped by naturally occurring and anthropogenic greenhouse gases, mainly carbon dioxide (CO₂), methane (CH₄), nitrous oxide (N₂O) and fluorinated gases. This trapped energy contributes to global warming in a reaction called the greenhouse effect. As we increase anthropogenic greenhouse gases into the atmosphere (mostly through the burning of fossil fuels) we increase the greenhouse effect and, in theory, increase global warming.

**On the rise**

Natural levels of greenhouse gases are (and have been) vital to maintaining the earth’s temperature at a comfortable level for all life forms. Without these gases, the world’s temperature would be 33 °C cooler than they are today, and would not support life as we know it. The problem arises when greenhouse gases go way beyond their “normal” level or range, as we are experiencing today. Greenhouse gases have increased since the start of...
the Industrial Revolution about 200 years ago, at first rather slowly and then more rapidly, again mainly from the increasing rates of burning fossil fuels and industrial activities. For example, carbon dioxide has increased from 280 parts per million (ppm) at the start of the industrial revolution to 390 ppm at present day. Most scientists believe this increase is causing the trapping and retaining of more of the sun’s energy leading to increased temperatures here on earth. Over the last 100 years, global temperatures have increased about 1.0 °C.

The 2007 United Nations Intergovernmental Panel on Climate Change (IPCC) Fourth Assessment Report states that, “Most of the observed increase in globally averaged temperatures since the mid-20th century is very likely due to the observed increase in anthropogenic greenhouse gas concentrations”. Many of the warmest

annual temperatures have been recorded over the last decade. Average global temperatures are predicted to increase from 2.0 to 5.0 °C by 2099.

The Intergovernmental Panel on Climate Change in 2007 outlined the following impacts on plants and animals if CO2 levels continue to rise as expected:

- Increased maximum and minimum temperatures resulting in heat stress on people, livestock and wildlife. Increase growth of some plants, declines in others.
- Increased intense precipitation resulting in increased flooding and soil erosion.
- Increased summer drying over mid-latitude continental interiors resulting in increased droughts, impaired water resources, decreased crop and forests yields.
- Increase in tropical cyclone intensity resulting in increased danger to human life, increased coastal erosion, and damage to coastal and forest ecosystems.
- Intensified drought and flooding associated with El Niño and La Nina events
- Increased Asian summer monsoon variability resulting in increased flood and drought magnitude in temperate and tropical Asia.
- Rising sea levels by several meters over a few centuries if the Greenland ice sheet melts significantly.

Source: http://www.ncdc.noaa.gov/cmb-faq/anomalies.php. Global temperatures from over a century show a rising trend from 1980 onwards, with dips between 1880-1910, a period referred to as The Little Ice Age.
The flip side

However, there are some positive aspects of increased CO₂ in the atmosphere. Because CO₂ uptake and fixation is the primary function of plant photosynthesis, increasing amounts of this gas has a fertilizing, stimulatory effect on tree physiology and growth. In a review of this subject, there have reports that elevated CO₂ levels have enhanced a wide range of forest ecosystem and tree physiological processes, including above- and below-ground growth, carbon sequestration, nutrient cycling, water relations, wood quality, phenology, stress tolerance, interactions with air pollutants, heterotrophic interactions, and ecosystem functioning. However, it has been reported that trees may be CO₂ saturated and that further increases in atmospheric CO₂ will not lead to further enhancements in photosynthesis and tree growth.

Over the last century, the forest macro- and micro-environment has changed dramatically in most parts of the world. The growing season has been extended by about 10–20 days in temperate regions. Precipitation chemistry has become more acidic but richer in nitrogen from the burning of fossil fuels. Some regions are now receiving more precipitation while other areas are receiving less. Widespread forest cutting and subsequent wildfires have replaced old-growth forests with younger, faster growing forests. The over-all stimulatory effect of these factors is present in many tree physiology and forest growth studies.

The 1°C increase in average global temperatures since in the middle-late 19th century have received much scientific and media attention. Nevertheless, it is important for all environmental scientists to understand that temperatures have increased or decreased by 1–3 °C many times during the Holocene, including several instances when the rise in temperature was as rapid, or nearly as rapid (referred to as abrupt climate change), as that during the present day temperatures are still in the middle of the Holocene range and still below past peaks experienced between 3400 and 8000 years ago.
last 100 years. Present-day temperatures are still well below previous temperature peaks between 3000-8000 years BP (referred to as the Holocene thermal maximum) and below the Holocene mean temperature.

Thus, we are still well within the natural range of climate variation for the last 10,000 years for most parts of the world. One probably reason why some forest tree species are responding favorably to warming temperatures with increased photosynthesis and growth is because their ancestors have experienced them in the past. With that said, we need to be concerned that further increases in greenhouse gases will cause temperature to rise to near or above the past peaks of the Holocene.

**Hot and cold**

The tropics play a very important role in moderating the cold temperatures of the Arctic and Antarctic regions. Ocean currents are warmed in Southern Pacific (passing through Malaysia) and Indian Oceans and make their way across the southern tips of South America and Africa.

The warm currents originating in the tropics also travel to the Gulf of Mexico and then northward to the north Atlantic providing relatively temperate climate to countries such as England, Iceland and Greenland.
Pasoh FR’s canopy walkway allows phenological observations and microclimate measurements at various levels, from the forest ground to its canopy.
Scientists are worried that a continuation of melting of glacial (mainly from Greenland) and the polar ice caps will drastically dilute the North Atlantic Ocean and “break” what is known as the “Great ocean conveyor belt”. This will cause an even more drastic change in the earth’s climate.

No one knows with certainty what unknown or unforeseen factors, or chance events, and/or may alter climate (subtly or abruptly) or what role abrupt, natural climate natural (non-anthropogenic) variation in climate will play over the next few centuries. For example, the rate of global warming from 2000–2010 did not increase from the previous decade, despite the increase in CO₂ concentrations from 370 to 390 ppm. This is attributed to an unexpected decline in water vapour in the upper atmosphere. This does not mean that the rate of temperature increases won’t resume in the future, but that many unforeseen things happen in complex systems.

**Trees speak**

The recent warming is clearly impacting tree physiology and nearly all other forest ecosystem processes, including the expansion of tree ranges to higher latitudes and elevations. But care must be taken to not overstate the uniqueness of these occurrences because they are most likely a “repeat” of what happened during previous warming during the Holocene.

While computer models provide a “best estimate” of future warming climate scenarios (2–5°C over the next century), these outcomes may be altered by a suite of environmental factors other than greenhouse gases. Also, the results from climate models are simply predictions. Therefore, environmental scientists need to take a much longer view of climate change when they assess the impacts of the recent warming trend, realize that we are still within the natural range of climate variation for the Holocene, that there have been some positive global change impacts to date on forest trees, and that future climate may or may not follow recent predictions.

Within this context, long-term research in forest ecosystems can be invaluable. With more than three decades of scientific research, and as one of Asia’s most studied areas on forest ecology, the Pasoh Forest reserve offers a ready pool of knowledge and a new perspective to create greater understanding of the long-term effects of climate change.
Chapter 4

Pasoh Revisited
In the 1970s, research in Pasoh FR slowly evolved from fundamental, explorative environmental studies like understanding soil properties and distribution, rainfall and runoff, light intensity at different vertical levels, vegetation type and distribution. Having laid the foundation on the existing environmental and physical conditions of Pasoh, research in the 1980s progressed to exploring the living organisms it harboured. Harvested forests adjacent to Pasoh further provided an excellent opportunity for comparative studies and an understanding on the impacts of land-use changes on the residual flora and fauna. It was also in this decade, in 1985, that a large permanent plot was established by the Centre for Tropical Forest Science (CTFS) and Arnold Arboretum at Harvard University. The 50 ha plot was the second of such plots established under the CTFS network which now hosts over 40 plots in tropical and temperate forests worldwide. As with all plots within this network, the main goal of having such a plot is to assist researchers in understanding the natural dynamics and ecology particularly in tropical forests.

Technology advancement in the 1990s and the early second millennium paved ways for more sophisticated assessments and monitoring activities such as microclimatic changes, soil respiration, gas emissions from soil and remote sensing and geographic information systems in understanding tree distribution. In 1992, the National Institute for Environmental Studies (NIES), Japan erected a three-tower-canopy-walkway structure made of aluminium alloy. At a height of 30 m above ground, the tower and walkway system enabled research to be conducted at different heights of the forest from the ground to the tree canopy level. Two years later, one of the towers was extended to 52 m in height for the placement of microclimatic sensors to measure temperature and gas exchanges, among others, beyond the forest canopy.

The combination of useful baseline information collected since the 1970s, advancing technology and equipment, topped with a well established large permanent plot and a tall research tower facility, resulted in meaningful scientific information which was relevant then and even more so today. The following are a glimpse of how these studies contribute to a better understanding of today’s environmental issues such as climate change.

Equation of change

In the last 50 years, Malaysia has undergone a period of rapid development. This has resulted in land use and land cover changes associated with the intense development. In addition, the expansion of larger cities has contributed to the warming trend in the last half century. In Peninsular Malaysia, temperatures increased at rates between 2.7–4.0°C over the last century.

Dr Ahmad Makmom Hj Abdullah, a lecturer at Universiti Putra Malaysia (UPM) and his team had noticed that the watershed
Selective timber extraction in production forest areas within the Pasoh FR

A variety of land use changes marks the periphery of Pasoh FR
ecosystems in Pasoh FR have been negatively impacted by deforestation and other forms of vegetation removal, construction of the logging roads, extraction trails and landings results in soil erosion and subsequently affect the watershed ecosystem. The total forested and regenerating forest areas declined from 66% to 29% of the total area, a rate of deforestation which was higher than that in any other parts of Southeast Asia from 1981 to 1990. However, it must be cautioned that this percentage was calculated based on a relatively smaller land area in Pasoh compared to larger-scaled land use changes in other Southeast Asian countries. In addition, these changes occurred in stateland forests (outside of the forest reserve boundary) resulting from planned land development schemes. Much of the land cover had changed from native forest to oil palm and rubber tree plantations in 2003 and 2004. Secondary vegetation at Pasoh increased during this time, probably from forest regeneration after logging. These results are illustrated in the following figure.

The researchers concluded that urbanization and other forms of economic activity are responsible for the land cover change across the states and localities throughout Peninsular Malaysia, including Pasoh FR. This resulted in micro-climate changes at Pasoh FR, with increased averaged surface temperatures. Deforestation increased the maximum day temperature by about 1°C in the study area. Loss of high vegetation cover and conversion to bare land has greater impacts to the surface temperature compared with the conversion of high vegetation to light vegetation such as agriculture activities (e.g. rubber and oil palm). This study also showed that the changes of land cover affected the temperature of areas adjacent to Pasoh FR and was very useful in assessing the impacts of land cover changes and predicting the associated micro-climate

Source: Makmom et al. 2010. Land cover 28 April 2003 (a) and about a year later, on 22 April 2004 (b).
changes. This study also provides important baseline data for land-use patterns in the Pasoh region under present-day climate conditions.

Counting the cost
Supporting this study on land use changes and its effect on micro-climatic changes in more detail, is a simulation study by a team of local and international researchers, headed by Dr Minaco Adachi from the National Institute for Environmental Studies (NIES), Japan. The team took into account rapid emissions from carbon pools as well as gradual decomposition of coarse woody debris on the forest floor in estimating the carbon budget of Pasoh FR. In this process, the change in vegetation structure (e.g., biomass and canopy leaf amount), plant eco-physiological properties (e.g., photosynthetic capacity and turnover), and soil properties (e.g., soil texture, moisture content, respiration, temperature and water content) were important factors considered. Using a biogeochemical model called VISIT (Vegetation Integrative Simulator for Trace gases) and data derived from a reanalysis global climate dataset produced by the U.S. National Center for Environmental Prediction and the U.S. National Center for Atmospheric Research over the last 60 years indicated that air temperature at Pasoh FR could have increased about 1°C, while precipitation has increased on average by about 750 mm per year.

It was also observed that soil surface became warmer and dryer after a clearcut event, because it received more direct solar radiation. An evaluation of the total carbon emissions caused by deforestation and land-use change found that 40% of harvested carbon was released to the atmosphere within ten years. A large decrease in aboveground and belowground biomass, litter and humus
associated with the logging event in 1976 at Pasoh FR. Low levels of carbon in plants and soils remained in place for about twelve years after logging. After 1988, increases in above and below ground biomass are apparent, but many more decades are needed before these components return to the pre-logging levels. The researchers also concluded that biomass production was positively associated with increases in precipitation at Pasoh.

The total carbon emission induced by land use change in Malaysia was estimated at 1.47 million tons of carbon during the decade of 1995 to 2004. This means that when forests are cleared for economic development, large quantities of carbon go into the atmosphere and contribute to elevated CO\textsubscript{2} and potentially global warming. The results of this study provide valuable information for REDD (Reduce Emissions from Deforestation and forest Degradation) initiatives. These results also indicated that adequate forest management, included reforestation, is important for reducing carbon emission from soil, and carbon budget at each ecosystem needs to be evaluated over a long-term to further evaluate the impacts of climate change and land-use impacts.

**Forests from the trees**

Forest ecosystems world-wide vary greatly in biomass due to anthropogenic and natural disturbance regimes, or even the lack of disturbances. Tropical rainforests (such as Pasoh FR) represent one extreme of high biomass, while deserts represent the other extreme of low biomass. It is thought that the high biomass of tropical rainforests is due to high rainfall and warm temperatures. In contrast, deserts are very dry and can be excessively hot. It can be expected that a more favourable rainfall distribution would increase productivity and old-growth forest biomass.

Forest biomass and carbon stocks have recently been the focus of several important studies due to the fact that deforestation releases large amounts of CO\textsubscript{2} into the atmosphere contributing to the greenhouse effect. However, global change may be altering carbon emissions and uptake even in undisturbed natural forests, which may have either a positive or negative influence on the greenhouse effect. Researchers, Drs. Larjavaara and Muller-Landau from the Centre for Tropical Forest Sciences (CTFS) plotted biomass data from 141 plots around the world, including the Pasoh FR. What they found was a relationship between annual temperature average and ranges, and forest biomass. Tropical plots with high temperatures and low variation in temperatures have intermediate above-ground biomass. In contrast, boreal plots with low average temperatures and high variation in temperatures have low aboveground biomass.

A related study conducted at Pasoh FR reported that 58-95% of the trees at Pasoh are experiencing decelerating growth. Reduced growth was associated with increases in mean daily minimum temperature. Therefore, increased
temperatures in the tropics are over-riding the fertilizing effect of elevated CO$_2$ on tree growth. This just goes to prove that understanding the current global biomass variation as reported in these studies is a key to understanding potential changes due to changing climate.

How does the forest grow
To further help in understanding the impact of climate change on the tropical forest, the growth, mortality and distribution pattern of trees in Pasoh FR was examined based on tree census periods taken between 1985–1990, 1990–1995, and 1995–2000. Researchers have compared these tree information with average annual temperature collected from a nearby climate station, where there was a general trend of increasing temperature over the period between 1985 and 2000.

Gathering tree information from a 50-ha primary forest was a mammoth task which

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Source: Larjavaara and Muller-Landau 2010.
Old-growth forest biomass in relation to climate shows that a bubble diameter proportionate to above-ground biomass.
took place in 1987, 1990, 1995, 2000, 2005 and 2010. All free-standing trees greater than 10 mm dbh (diameter at breast height) were measured at 1.3 m above ground and identified to species level. A detailed study of the soil properties of the area was carried out by Adzmi et al. (1996) and was used to complement results from the tree census.

The study area can be broadly classified into four major habitats based on these soils; (1) wet alluvial, (2) dry alluvial, (3) shale, and (4) laterite. Alluvial soils are deposited by stream flooding events, whereas laterite is an old, red-colored, nutrient-poor tropical soil rich in iron and aluminium.

Results indicated that the annual tree diameter growth rate decreased over the census period at 1.45 mm/year (1st census in 1985), 0.79 mm/year (2nd census in 1990) to 0.56 mm/year (3rd census in 1995). The highest annual growth rate was recorded at the wet alluvial site at 1.54 mm/year for the first census period. Wet alluvial and dry alluvial sites showed the two highest increments for first and second period. In third census period, dry alluvial and shale sites shared the highest growth at 0.56 mm/year. Despite the differences observed among the sites, the annual growth rate declined at all sites in the later census periods.

Larger trees experienced better annual growth rate (dbh) than trees in the smaller size classes. However, regardless of the dbh category, the annual diameter growth rate showed consistent declines across the study periods. Alarmingly, the annual mortality rate showed an increase over census period at 1.17% (1st census), 1.48% (2nd census) to 2.0% (3rd census). Mortality rate, like the decline in growth rate, was negatively impacted over the study period in all four habitats with the increase in mean annual temperature of 0.05 °C per year from 1985 until 2000.

This observation is also consistent with reports of decreases in relative growth rates for tropical tree species at Pasoh and in Panama hence indicated the negative impacts of global climate change on tropical forests of southeast Asia. This contrasts with temperate forests where tree growth has been stimulated by climate change factors such as warmer temperature (in a temperature limited region), longer growing season and increased CO₂ levels, which enhance photosynthesis (see Chapter 3). The studies reviewed in this chapter suggest that the forests at Pasoh are being negatively impacted by climate change in terms of decreased tree growth and increased tree mortality. Therefore, further increases in global temperatures, as scientists predict, may have additional negative effects on the trees at Pasoh FR.

**Its in the roots**

Land cover changes may give us an indication of modifications occurring in above ground vegetation, but carbon is also stored and released from below ground, in tree roots, soil and other organic matter. Therefore to better understand the
Niiyama, K.

Soil profiling to assess the biomass of soil and roots at different depths.

Roots and soil are sorted by hand.
dynamics in tropical rain forests, estimations of root biomass are important. However, most of the previous studies of biomass estimation of tropical rain forests in South-East Asia have assessed only above ground biomass. Thus Dr. Kaoru Niiyama from the Forest and Forest Products Research Institute in Japan and his colleagues had spent considerable time in Pasoh FR unearthing such information.

They reported a decreasing pattern in the vertical distribution of root biomass in soil pits, where 80 to 90% of root biomass was concentrated on the upper 50 cm soil layer. In contrast, the lowest layer, 150–200 cm, contained only a small amount of roots. Remarkably, roots were distributed to a depth of 4 m or more in the soil profile. In general, the main function of roots located near the soil surface is the uptake of nutrients, whereas deep roots in the soil profile function to anchor and support large trees as well as the uptake of water that tends to increase in deeper soil. Nutrient concentrations are higher in the upper surface because of the accumulation following plant biomass decomposition.

The reporting of root biomass in this study contributes nicely to increasing the data pool and filling data gaps that exists for root biomass estimates in tropical rainforests. This study also provides important baseline data for root biomass and distribution in the tropics under present-day climate conditions.
One for the other
Chapters 2 and 3 highlighted the importance of carbon uptake (sequestration) by forest trees in maintaining atmospheric carbon and climatic balance. Tropical rainforests play a very important role in regulating world climate. To understand the primary importance of the role of gas exchange in the global climate, scientists must research the physiology of tropical rainforests. The actual range of tree carbon and water gas exchange is influenced by climate variability. Studies, such as this, are needed to clarify the influence of environmental factors and their future changes on gas exchange processes of tropical forests.

To support this claim, a team of researchers led by Yoshiko Kosugi (Kyoto University, Japan) under the NIES/FRIM/UPM project investigated carbon dioxide (CO₂), water (H₂O), and heat exchanges of the tropical rainforest during a seven-year period in Pasoh FR. Measurements at the canopy level (30–52 m above ground) was made possible by a tall tower erected in 1992 that allowed researchers to work in and above the forest canopy. They used the Eddy Covariance method involving gas exchange measurements above the forest canopy which includes measurements of photosynthesis (involving CO₂) at the leaf surface and transpiration (involving water vapour).
Results from this study recorded that the annual rainfall averaged at 1,865 mm per year and fluctuated between 1,451–2,235 mm during the seven year study (from 2003–2009). The study site had a constant rainy period in November and December, and mild dry periods between January to March and July to October. However, the intensity of these dry periods varied annually, and 2009 was a dry year that was affected by an El Nino weather event caused by changes in the temperature of ocean currents passing by Malaysia. Air temperature, vapour pressure deficit and radiation decreased during the wet periods in November and December of every year. Most of the rainfall occurred in the evening and at night.

Evapotranspiration (ET) is the total amount of water that evaporates from plant leaves, soil surface and open water (lakes and streams). The researchers of this study reported that ET did not decline significantly during dry periods (which are normally expected) because water was supplied to the trees from soil layers deeper than 0.5m. This phenomenon coincided well with the observed root distribution at this site as reported in the study by Kaoru Niiyama described earlier in this chapter. This serves as an important example of two studies at Pasoh complimenting one another.

The researchers concluded that the seasonal variability in tree physiology at Pasoh FR is affected by the variation in rainfall pattern. They detected a relationship of evapotranspiration (water loss) with available energy and high atmospheric demand for moisture. However, there was no dependence of evapotranspiration on the amount of rainfall or soil water content, which is a very interesting result. Trees controlled water loss on dry days to prevent
excessive water loss regardless of soil water content.

In contrast, tree photosynthesis and forest respiration was impacted by soil water content, but not variation in sunlight. Therefore, the reduction in radiation caused by factors such as fog and haze events does not cause a significant change in canopy CO₂ exchange. A decrease in rainfall resulting in soil drought would, however, cause a decrease in both photosynthesis and respiration.

The results and implications of this study are very important in relation to predicting the impacts of climate change of tropical tree physiology and growth. The authors used natural variation in climate over a seven-year period that included wet versus dry, warm versus hot, and cloudy versus sunny conditions to monitor the variation in forest responses. This information is vital to our understanding of how tropical rainforests in southeast Asia will respond to future changes in climate. Future comparison with results from other tower sites in the tropics, coupled with a larger data set with wider variation in micro-meteorological conditions, will be valuable for evaluating the response of tropical rainforests to climate change.
Chapter 5

Going Beyond the Red Meranti
As a result of global climate change, higher temperatures have occurred in Peninsular Malaysia, with the western Peninsular Malaysia region experiencing the highest increase as reported in the Malaysian Meteorological Department Scientific Report January in 2009. The frequency of relatively drier years has also increased for Peninsular Malaysia since 1970. Additionally, most of the El Niño events have resulted in relatively drier years for the region.

Monsoons are a common occurrence in Peninsular Malaysia with an intensity index that is closely related to the tropical Pacific sea surface temperature. Its prevailing north-easterly winds over the South China Sea are associated to annual flooding mainly in eastern states of the Peninsular. Thus, skillful seasonal climate outlook is essential for better management of resources and for mitigation purposes. However, the greater uncertainty in the rainfall-monsoon relationship due to the changing climate is expected to pose greater challenges in forecasting the seasonal rainfall anomalies over the region. As temperatures continue to increase with global climate change, a corresponding change increase in the strength of the monsoon is anticipated.

**Living the change**

With shifting global climate patterns, the environment will also experience the impacts of these changes. Studies on Pasoh FR have documented the nature of these impacts on tropical forests.

- Average annual surface temperatures in the region increased by 0.5-1.1 °C during the period 1901-2005. Climate model indicate that average annual temperatures are likely to increase across the region by approximately 1°C through 2030, and they will keep increasing through the remainder of the 21st century. We anticipate that a continuation of warming will have a negative effect on the Pasoh forest in terms of decreased tree growth, increased tree mortality, and increased decomposition and depletion of soil organic matter. As such there will be gradual degradation of the forest in terms of tree density as well as biodiversity.

- Precipitation patterns are changing regionally, with increases in some locations and decreases in others. Climate model simulations suggest that net precipitation rates will increase across the region in the next 20 years, but decreases probably will vary geographically and temporally. Over the last 60 years, average annual precipitation has increased at Pasoh FR. If this trend continues, it will help mitigate the negative impacts of increased warming, meaning that a reduction in tree growth and increased in tree mortality may be less than if warming is coupled with decreased precipitation. However, increased precipitation and warming together will stimulate even higher rates of organic matter decomposition and more rapidly deplete soil carbon. This in turn can eventually negatively impact tree growth.
Both of the above changes (increase in temperature and/or precipitation) imply that the productivity of forest is expected to decrease in the long run which in turn will have significant ecological and economic implications. Since forestry is an important economic sector in Malaysia, poorer yields from the forest will lower financial returns from the forests to state coffers.

Observations and data collected over at least 25 years in Pasoh FR has shown us is that watershed ecosystems as in Pasoh FR have been negatively impacted by deforestation and other forms of vegetation removal, construction of the logging roads, extraction trails and landings results in soil erosion. In addition, the reporting of root biomass at Pasoh FR represents important new information for tropical rainforests in Southeast Asia. The study provides important baseline data for root biomass and distribution under present-day climate conditions, which can then be compared to data collected in the future to assess changes in root biomass as influenced by climate change.

Seasonal climate at Pasoh FR is affected by the variation in rainfall pattern. The physiology of trees at Pasoh respond to climate change to enhance tree growth. While tree growth may show a future decline as the planet continues to warm, trees do their best to keep growing. Over
the last 60 years, air temperature at Pasoh has increased about 1°C, while precipitation has increased on average by about 750 mm per year. Soil surface became warmer and drier after a clear-cut event (1976), because it receives more direct solar radiation. Deforestation and land-use change causes 40% of harvested carbon to be released to the atmosphere within 10 years. A large decrease in aboveground and belowground biomass, litter and humus was associated with the logging event in 1976 at Pasoh.

Depressed levels of plant and soil carbon remained in place for more than a decade after logging. Above-ground biomass varied strongly with average annual temperature and temperature range. Tropical plots with high temperatures and low temperature variation have intermediate above-ground biomass. Forest plots with the highest above ground biomass were located in regions with average annual temperature of 8–15°C and with annual temperature range of less than 15°C.

Research at Pasoh FR has also discovered that flowering is impacted by changes in climate. For example, a study by Sakai and colleagues in 2006 reported that mass flowering (over a 10 year period) was triggered by drought years that are typically associated with the transition from La Nina to El Nino climate events. Therefore, future changes to the frequency and magnitude of La Nina-El Nino climate may impact mass flowering at Pasoh. This may have implication on the regeneration process and recovery of the forest.
The IPCC report in 2007 had highlighted some potential adverse impacts on tropical forest which may also pose as a potential threat to Pasoh FR due to climate change. Among those expected are:

1. Nearby agricultural and agro-forestry production will change water and nutrient (including excess fertilizer runoff) regimes to natural forests.

2. Water shortages may ensue, changes in water table and water cycles.

3. More extreme weather and an increased frequency of severe and catastrophic storms.

4. Increased insect and disease may impact native flora and fauna (including wildlife).

5. Increased plant and animal deaths from heat waves.

6. Increased extinctions of native species of animals and plants.

7. Changes to animal and plant habitats.

8. Increase invasion of introduced and exotic species that negatively impact natural habitats.

9. A change will occur in phenology plants, including leafing out, flowering and seed production.

10. Habitat loss and destruction from landslides.

11. Cultural or heritage sites destroyed faster due to increased weather extremes.
Climate studies also suggest that tropical rainforests and associated vegetation may experience episodes of dieback as a result of a warming and drier climate. Climate change may also alter disturbance regimes within some forests, including the frequency and intensity of insect and disease outbreaks. Climate change is also expected to bring hotter, drier conditions during the dry season, which is likely to make tropical forest more vulnerable resulting in increase in the extent and incidence of forest fires in the region. In recent decades Southeast Asia has suffered some of the world’s worst forest and peatland fires. These fires contribute to increased greenhouse gas emissions and blanket of smoky air over the region called “haze”.

The future conservation of Pasoh will serve as an excellent example of how to lessen or mitigate some of the deleterious impacts of climate change, including wildfire outbreaks. Immediate threats such as landuse changes for agricultural development will have to be addressed. Forest management plans should ensure that forest lands are protected and well managed on a sustainable basis to mitigate climate change impacts.

Tropical forests are important reservoirs and sinks of carbon. Healthy trees and forests, such as those at Pasoh FR, absorb carbon dioxide and therefore help to mitigate climate change. The Pasoh forest also provides many ecosystem services such as food resources, watershed
protection, purification of water and air, recreational services, spiritual inspiration and scientific discovery.

**Pasoh for today**

While Pasoh research forest covers some 1,840 hectares, it has a 600 hectare core area which contains pristine forest. This core is surrounded by forests logged between the fifties and seventies. Since its gazettement in 1977 as a research and education forest by the Forestry Department of Negeri Sembilan, no other development has taken place within the confines of the reserve, making it one of the few tropical lowland forests left in its natural state for more than three decades. Most remaining intact lowland forests are either recreational forests, national parks or wildlife sanctuaries.

Along the periphery of the reserve, cultivated stretches of land intermingle with small communities. Such a setting offers and opportunity for study into the impacts of land-use changes on forest dynamics and natural forest regeneration and recolonisation of wildlife.

While there is great potential for new and future studies to be conducted within this area, the body of knowledge acquired since the sixties is also an important source of baseline information. Studies focusing on an extensive range of topics have auded the expansion of more contemporary studies on climate change, biodiversity and forest ecosystems.

For example between the 1970s and 1980s, early studies on wildlife diversity and soil types subsequently provided a ready canvas for applied studies of the 1990s on ecological interactions between flora and fauna like seed dispersal and pollination, changes in forest dynamics/structure such as tree growth, mortality and recruitment rates and interactions between biotic and abiotic factors.

While little known, Pasoh and its existing breadth and depth of knowledge accrued over more than three decades remains an invaluable place not merely for researchers but for society at large as the world continues to deal with more demanding environmental issues such as climate change.

**Here and beyond**

Forest ecosystems in Malaysia, such as the Pasoh FR, represent a key asset contributing to the ecology of the region. A long history of scientific investigation at Pasoh FR has provided invaluable information regarding the composition, structure, function, physiology and growth of tropical ecosystems in a changing world.

The studies conducted at Pasoh over the the last three decades will provide a treasure-trove of baseline data which future studies can be used to access the impacts of climate change, land-use impacts and natural and anthropogenic disturbance factors on tropical forests in the region, Southeast Asia and Neotropics.
In addition, we suggest that the scope of research at Pasoh FR be expanded to fill other knowledge gaps, such as the impacts of climate change on the fauna, including major wildlife species, and other flora besides trees. Future climate change will produce some resident winners and losers at Pasoh FR, those species that may benefit or be harmed, respectively. One way to mitigate the harmful effects of climate is to utilize the microsite and microclimate variation that exists at Pasoh FR and propagate species on cooler microsites. Minimizing future logging will also help maintain cool (shaded) and moist sites with high vegetation at Pasoh FR. Other forms of active forest management that promote the regeneration and growth of native trees species and eliminates invasive species will also contribute to over-all forest health at Pasoh FR.

Pasoh Forest Reserve has served as a premier example of lowland tropical rainforest for scientific investigation, education, and a natural resource to be enjoyed by visitors. Together with close cooperation and support from the Forestry Department of Negeri Sembilan and relevant state authorities, the Forest Research Institute Malaysia (FRIM) offers various facilities for research, education and aesthetic appreciation at the reserve. The national and global recognition received at the reserve would not have been possible without the commitment by the state forestry department to gazette the reserve since 1977 for long-term ecological research. It is our hope that it will continue to be protected, well managed and utilized for these purposes long into the future.
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Above-ground biomass (AGB)
All biomass of living vegetation, both woody and herbaceous, above the soil including stems, stumps, branches, bark, seeds and foliage. It is normally expressed as tones of biomass or carbon per hectare. AGB is given the highest importance in carbon inventory and most mitigation projects related to forest land and agroforestry.

Anthropogenic
Made by people or resulting from human activities. Usually used in the context of emissions that are produced as a result of human activities.

Atmosphere
The gaseous envelope surrounding the Earth. The dry atmosphere consists almost entirely of nitrogen (78.1% volume mixing ratio) and oxygen (20.9% volume mixing ratio), together with a number of trace gases, such as argon (0.93% volume mixing ratio), helium, radiatively active greenhouse gases such as carbon dioxide (0.035% volume mixing ratio), and ozone.

Biomass
Total dry weight of all living organisms that can be supported at each tropic level in a food chain. Also, materials that are biological in origin, including organic material (both living and dead) from above and below ground, for example, trees, crops, grasses, tree litter, roots, and animals and animal waste.

Carbon Dioxide
A naturally occurring gas, and also a by-product of burning fossil fuels and biomass, as well as land-use changes and other industrial processes. It is the principal anthropogenic greenhouse gas that affects the Earth’s radiative balance. It is the reference gas against which other greenhouse gases are measured and therefore has a Global Warming Potential.

Carbon Sequestration
The uptake and storage of carbon. Trees and plants, for example, absorb carbon dioxide, release the oxygen and store the carbon. Fossil fuels were at one time biomass and continue to store the carbon until burned.

Climate Change
Climate change refers to any significant change in measures of climate (such as temperature, precipitation, or wind) lasting for an extended period (decades or longer). Climate change may result from:

• natural factors, such as changes in the sun’s intensity or slow changes in the Earth’s orbit around the sun;
• natural processes within the climate system (e.g. changes in ocean circulation);
• human activities that change the atmosphere’s composition (e.g. through burning fossil fuels) and the land surface (e.g. deforestation, reforestation, urbanization, desertification, etc.)
Beyond the Red Meranti

Deforestation
Those practices or processes that result in the conversion of forested lands for non-forest uses. This is often cited as one of the major causes of the enhanced greenhouse effect for two reasons: 1) the burning or decomposition of the wood releases carbon dioxide; and 2) trees that once removed carbon dioxide from the atmosphere in the process of photosynthesis are no longer present.

Ecosystem
Any natural unit or entity including living and non-living parts that interact to produce a stable system through cyclic exchange of materials.

El Niña
La Niña is an ocean-atmosphere event that follows El Niño years. During La Niña, the sea surface temperature in the equatorial Pacific Ocean will be lower by 3–5 °C. The name La Niña means “little girl,” in Spanish. Significant changes in climate and the occurrence of fire are often associated with La Nina events around the world.

El Niño - Southern Oscillation (ENSO)
El Niño, in its original sense, is a warm water current that periodically flows along the coast of Ecuador and Peru, disrupting the local fishery. This oceanic event is associated with a fluctuation of the intertropical surface pressure pattern and circulation in the Indian and Pacific Oceans, called the Southern Oscillation.

Emissions
The release of a substance (usually a gas when referring to the subject of climate change) into the atmosphere.

Evapotranspiration
The combined process of evaporation from the Earth’s surface and transpiration from vegetation.

Forest biomass
Forest Biomass is the amount of living and/or dead biological material (such as wood and leaves) produced by trees and other plants in forest ecosystems. Biomass can be used for wood products, including timber, bioenergy and biofuels, or allowed to decompose and return its nutrients back to the ecosystem to be used by other plants and animals.

Glacier
A multi-year surplus accumulation of snowfall in excess of snowmelt on land and resulting in a mass of ice at least 0.1 km² in area that shows some evidence of movement in response to gravity. A glacier may terminate on land or in water. Glacier ice is the largest reservoir of fresh water on Earth, and second only to the oceans as the largest reservoir of total water. Glaciers are found on every continent except Australia.

Global Warming
Global warming is an average increase in the temperature of the atmosphere near the Earth’s surface and in the troposphere, which can contribute to changes in global climate patterns. Global warming can occur from a variety of causes, both natural and human induced. In common usage, “global warming” often refers to the warming that can occur as a result of increased emissions of greenhouse gases from human activities.
Greenhouse Effect
Trapping and build-up of heat in the atmosphere (troposphere) near the Earth’s surface. Some of the heat flowing back toward space from the Earth’s surface is absorbed by water vapor, carbon dioxide, ozone, and several other gases in the atmosphere and then reradiated back toward the Earth’s surface. If the atmospheric concentrations of these greenhouse gases rise, the average temperature of the lower atmosphere will gradually increase.

Greenhouse Gas (GHG)
Any gas that absorbs infrared radiation in the atmosphere. Greenhouse gases include, but are not limited to, water vapor, carbon dioxide (CO$_2$), methane (CH$_4$), nitrous oxide (N$_2$O), chlorofluorocarbons (CFCs), hydrochlorofluorocarbon (HCFC), and ozone (O$_3$).

Heterotrophic
An organism or entity that uses organic compounds to obtain carbon essential for its growth and development. In contrast, plants are autotrophic whereby it uses inorganic compounds such as sunlight to produce organic compounds.

Holocene
Is a geological epoch since 12,000 years ago of earth’s history (the time since the last ice age) to present day.

Infrared Radiation
Radiation emitted by the Earth’s surface, the atmosphere and the clouds. It is also known as terrestrial or long-wave radiation. Infrared radiation has a distinctive range of wavelengths (“spectrum”) longer than the wavelength of the red color in the visible part of the spectrum.

Intergovernmental Panel on Climate Change (IPCC)
The IPCC was established jointly by the United Nations Environment Programme and the World Meteorological Organization in 1988. The purpose of the IPCC is to assess information in the scientific and technical literature related to all significant components of the issue of climate change. The IPCC draws upon hundreds of the world’s expert scientists as authors and thousands as expert reviewers.

Micro-climate
A microclimate is created when and where the local climate differs from the larger surrounding area (macroclimate). Microclimates are usually associated with the interior of a forest, near large bodies of water, urban areas, and topographic variation. The temperature and humidity may be higher or lower than the surrounding area depending on the situation.

Mitigation
Actions to reduce greenhouse gas emissions and to enhance carbon sinks, to curb climate change. Examples include using fossil fuels more efficiently for industrial processes or electricity generation, switching to solar energy or wind power, improving the insulation of buildings, and expanding forests and other “sinks” to remove greater amounts of carbon dioxide from the atmosphere.

Neotropics
The biogeographic region of the New World southern from the Tropic of Cancer, which includes southern Mexico, Central and South America, and the West Indies.
**Nutrient cycle**  
Also referred to as ecological cycle, is the exchange of organic and inorganic matter back into the production of living matter. The process includes movement of energy through the food web and decomposition of matter into mineral nutrients.

**Photosynthesis**  
The process by which plants take CO₂ from the air (or bicarbonate in water) to build carbohydrates, releasing O₂ in the process. There are several pathways of photosynthesis with different responses to atmospheric CO₂ concentrations.

**Reducing Emissions from Deforestation and Forest Degradation (REDD)**  
A mechanism to reduce global greenhouse gas emissions by compensating countries for avoiding and/or reducing deforestation and forest degradation. It is currently being negotiated under the UNFCCC process.

**Reforestation**  
Planting of forests on lands that have previously contained forests but that have been converted to some other use.

**Respiration**  
The process whereby living organisms convert organic matter to CO₂, releasing energy and consuming O₂.

**Sink**  
Any process, activity or mechanism which removes a greenhouse gas, an aerosol or a precursor of a greenhouse gas or aerosol from the atmosphere.

**Soil Carbon**  
A major component of the terrestrial biosphere pool in the carbon cycle. The amount of carbon in the soil is a function of the historical vegetative cover and productivity, which in turn is dependent in part upon climatic variables.

**Solar Radiation**  
Radiation emitted by the Sun. It is also referred to as short-wave radiation. Solar radiation has a distinctive range of wavelengths (spectrum) determined by the temperature of the Sun.

**Water Vapour**  
The most abundant greenhouse gas, it is the water present in the atmosphere in gaseous form. Water vapor is an important part of the natural greenhouse effect. While humans are not significantly increasing its concentration, it contributes to the enhanced greenhouse effect because the warming influence of greenhouse gases leads to a positive water vapor feedback.

**Weather**  
Atmospheric condition at any given time or place. It is measured in terms of such things as wind, temperature, humidity, atmospheric pressure, cloudiness, and precipitation. In most places, weather can change from hour-to-hour, day-to-day, and season-to-season. Climate in a narrow sense is usually defined as the "average weather", or more rigorously, as the statistical description in terms of the mean and variability of relevant quantities over a period of time ranging from months to thousands or millions of years.