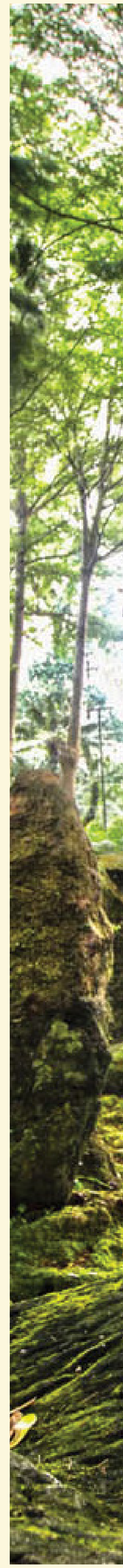
ESSAY

Urban Systems

Learning from Rainforests

Tropical rainforests are ecosystems that have evolved over millions of years. **Prof. Peter Edwards** outlines the lessons that rainforests hold for cities that are aiming to grow sustainably.



On an ecological timescale, cities are a new invention. Singapore, for example, was founded less than 200 years ago in an area that had previously been tropical rainforest. Indeed, there still remain a few fragments of that original forest, such as in the Singapore Botanic Gardens and in the Bukit Timah Nature Reserve. Each time I visit the fragment in the botanic gardens, I am caught by the thought that those magnificent trees, now in the centre of a bustling, modern city, started their lives in a pristine forest, with tigers and other wildlife roaming in the undergrowth.

What can we learn from tropical rainforests about making cities sustainable? For me, the most important lesson is that rainforests have developed gradually to their present form over many millions of years. By definition, the ecosystems that exist today are those that proved most stable, since those that were unstable have now disappeared. For this reason, it is interesting to ask: what are the features of a stable rainforest ecosystem, and how do urban ecosystems compare in this respect?

Regulating the Environment

One feature of rainforests is that they regulate environmental conditions. For example, trees cool the air by evaporating water through minute pores in the leaves, in a process known as evapotranspiration. From the studies of rainforests that used to cover Singapore, we know that the amount of water lost in this way was equivalent to around 1,300 millimetres of rainfall per year.

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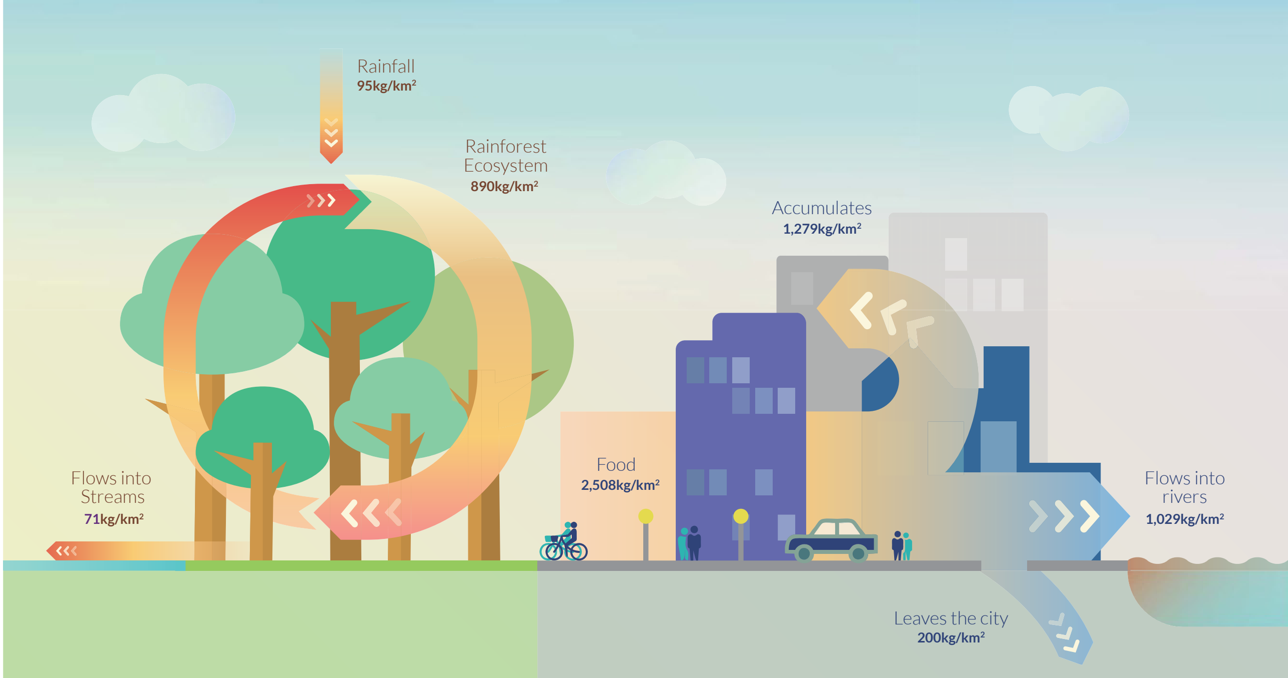
Patches of primary rainforest, at the Singapore Botanic Gardens.

Cities are more vulnerable to floods

Compared to a rainforest (left), the city experiences much more surface runoff due to the lack of permeable surfaces and greenery, which may lead to floods.

Rainforests have better ecological balance than cities



The fluxes of phosphorus (in kilograms per square kilometre) in a tropical rainforest, and associated with food consumed in Bangkok.

In a rainforest, large amounts of phosphorus are recycled within the ecosystem, with a very small amount entering or leaving it. In contrast, very little phosphorus is recycled in a city, with large amounts being consumed in the form of food or discharged through sewage. The loss of phosphorus means a greater need for fertilisers for farming needs.

And from this we can calculate that the average rate of cooling due to evapotranspiration was about 100 watts per square metre. For comparison, the total electricity demand of Singapore averaged over the entire island is only one fifth of this amount.

A rainforest also reduces the risk of flooding after heavy rain by absorbing and storing water like a huge sponge. This is because each of the millions of leaves in a hectare of forest holds a few drops of water, which, long after the rain has stopped, either evaporate or drip to the ground. And even water reaching the ground is absorbed in the leaf litter and soil, or taken up by the roots, so that only a small fraction of the rain ever reaches the streams and rivers.

These important functions of evaporation and storage, however, are severely disrupted in urban areas. With fewer trees, the air can be several degrees warmer than in a rainforest. Indeed, it is no coincidence that the urban heat island effect in many cities is similar in magnitude, though opposite in direction, to the cooling effect of evapotranspiration in a tropical rainforest. The absence of trees also increases the risk of flooding in urban areas, since impermeable surfaces do not retain rainwater, which flows rapidly to low-lying areas.

Striking a Balance

A second feature of stable ecosystems is that they are in balance with their surroundings. Many ecological studies have shown that the quantities of raw materials—carbon dioxide, water and nutrients—entering a pristine forest ecosystem in rain and dust almost exactly balance those that are lost through leaching and erosion. Nutrients that are in short supply are mainly recycled within the ecosystem, so that growth does not depend upon inputs from the outside. For example, the fluxes of phosphorus and potassium within a tropical rainforest can be very large, yet the

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quantities of these nutrients entering and leaving the ecosystem are extremely small.

So how do cities perform according to this criterion? Not well! When it comes to material flows, most cities are severely out of balance with their environment, being net importers of huge amounts of sand, concrete, metals, plastics, fossil fuels and a vast array of other chemical compounds. As an example, consider the nutrients contained in food, most of which is imported, often over large distances. It has been calculated that 60% of all nitrogen and phosphorus entering Hong Kong, and over half of the phosphorus entering Bangkok do not leave the system. Of greater concern, though, is the fact that because almost none of these nutrients are ever returned to the land where the food was produced, the use of fertiliser becomes necessary. Meanwhile, a large proportion of the nutrients discharged in sewage end up in the sea, where they can cause problems of pollution.

Redundancy Aids Resilience

A third characteristic of stable ecosystems is resilience, which means the capacity to recover from disturbances and shocks. Resilience is harder to measure than homeostasis or material flows, but is an essential property that enables a system to persist and keep functioning despite severe disturbance. In natural ecosystems, resilience has been linked to the presence of more species than are needed to fulfil essential ecological functions.

Mimicking the Ecosystem

A typical urban system (left) where essential services are provided by large, highly centralised facilities has little or no built-in redundancy as compared to an urban system that mimics the ecosystem (right) by decentralising essential services and including alternative sources. These include tapping solar power to generate electricity for individual buildings, reducing reliance on the central power supply; composting to reduce the amount of waste going to landfills; and collecting stormwater for industrial use, reducing demand for clean water.

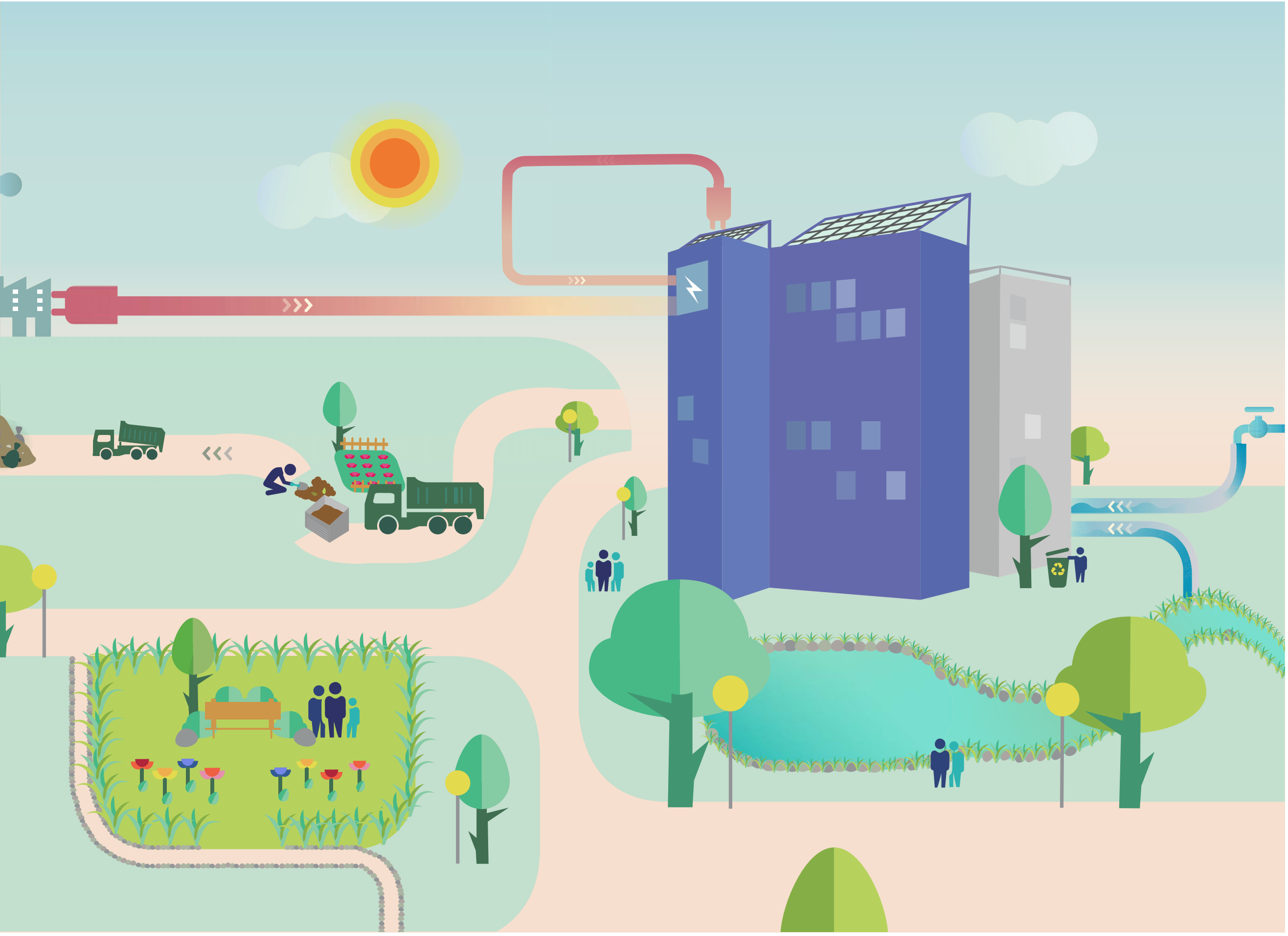
For example, a rainforest ecosystem might support many different species of earthworms in the soil, or several different kinds of nitrogen-fixing trees, or many different birds that feed on insect herbivores. This species "redundancy", as it is sometimes called, helps to make natural systems resilient, because one species can replace another without affecting the functioning of the ecosystem.

The essential services in modern cities include the provision of electricity and clean water, and the processing of waste. In sharp contrast to natural ecosystems, these services are mainly provided by large, highly centralised facilities with little or no built-in redundancy. When one of them fails for some reason, it can cause great disruption in the lives of many people.

Yet major breakdowns in electricity and water supplies and in waste disposal are frequent occurrences in cities throughout the world, with consequences that become increasingly severe as the systems grow larger and more complex.

Learning from Nature

Much can be learned from the study of ecological systems and incorporated into the urban ecosystem. For example, an obvious solution to the twin problems of urban warming and flooding is to plant more trees. Recent studies have shown that a patch of woodland in a built-up area can reduce the average air temperature by as much as 2.5°C, with this benefit extending well beyond the woodland itself. And trees can reduce



surface runoff—by as much as 60% compared with asphalted surfaces. These are big effects and just two examples of how ecosystem services make the urban environment not only more attractive and liveable, but also more sustainable. As for enhancing the resilience of municipal services, this can be achieved by decentralising these services and including alternative sources of supply. Indeed, we are already seeing a significant step in this direction in the case of power generation. With photovoltaic panels becoming cheaper and more efficient, the production of electricity by individual households is becoming a realistic option, while the development of smart grids means that surplus production can be fed into the urban grid.

However, much more can be done. There is growing interest in buildings that can be operated independently of centralised services, including not only the electric power grid but also municipal gas and water systems, sewage treatment systems and storm drains. Such autonomous buildings meet an obvious need in rapidly urbanising areas where infrastructure is poor or non-existent. But there are also benefits for modern cities, where autonomy can reduce dependence on centralised infrastructure while dramatically reducing the costs associated with transporting resources and waste. Perhaps the greatest gain in resilience would be achieved by having buildings that can operate autonomously, yet connected through urban networks, thereby evening out variations in demand and ensuring continued supply despite local failures.

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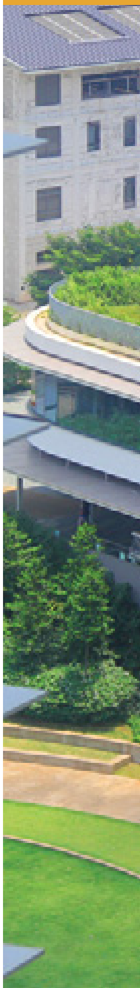
> ...retrofitting 80% of all air-conditioned buildings in the United States with 'white roofs' would reduce annual energy costs for cooling by US$735 million.

Ecology teaches us that ecosystems only persist if they are in balance with their environment. Yet cities, as presently conceived, are severely out of balance, and this must change. From being systems that appropriate large volumes of water from lakes and rivers across the region, cities must become systems that recycle their water and even serve as their own catchments. From being systems that import large amounts of chemicals and then dispose of them—whether in the sea, or through incineration, or in landfill sites—they must become systems that recycle materials internally or, in the case of plant nutrients, return them to where they are needed to grow crops. And from being systems that generate heat, and so increase the need for air conditioning, cities must find ways of moderating the urban climate by using new materials, by managing air flow, and by cooling through evaporation.

To some extent, these goals can be achieved by strengthening ecosystem services, for example by planting trees to cool the city and clean the air, or by using wetlands to reduce floods and purify water. However, this will never be enough. We also need to change the urban fabric. The good news is that many types of green infrastructure already exist, which would greatly improve urban sustainability if applied at a suitable scale. For example, "cool pavements" that use reflective materials to reduce the absorption of solar radiation and porous materials to enable evaporative cooling can greatly reduce the urban heat island effect, especially when constructed with a sub-layer that provides a reservoir for water. And the same approach can be used to construct "cool roofs", with considerable benefits for the environment and the economy. In fact, one study estimated that retrofitting 80% of all air-conditioned buildings in the United States with "white roofs" would reduce annual energy costs for cooling by US$735 million.



01 Cool pavements drain water quickly as they are made with permeable tiles that allow water to seep through. The remaining water on the tiles cools the pavements.

02 The green roof at the Education Resource Centre at University Town, National University of Singapore uses native plants to reduce the heat absorbed into the building, reducing the amount of energy needed to cool the building. The plants also serve as filters for rainwater collection. The ERC won the Skyrise Greenery Awards in 2013.

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For many cities, green infrastructure offers the only hope for ensuring a sustainable water supply and preventing floods. Currently, "green roofs" planted with vegetation are widely used to reduce storm-water runoff, and "blue roofs" achieve the same effect using various kinds of flow controls to regulate and retain water. The water that is retained by these structures can be used directly for purposes such as garden irrigation, flushing toilets and recharging aquifers. Indeed, using "greywater" in this way not only reduces the demand for clean water—by as much as half for residential buildings —but also by reducing the amount of wastewater that must be conveyed and treated. As these technologies develop, we will see many more buildings equipped with their own treatment plants for recycling both water and nutrients, and therefore able to operate more or less independently of centralised water services.

In conclusion, the goal of urban sustainability can be achieved, but doing so will require radical changes in how we design, build and manage our cities. And I am convinced that once we have reached this goal, we will have created a system that closely resembles a tropical rainforest ecosystem. Like the rainforest, it will moderate its local climate, recycle limited materials with almost no wastage, and be resilient even to extreme disturbances.

So, as we strive towards this ambitious goal, let us be inspired by the small patch of rainforest in the Singapore Botanic Gardens, as a model of a truly sustainable ecosystem!

01 A Strangling Fig *Ficus kerkhovenii*, in the rainforest at the Singapore Botanic Gardens.

02 At the Osborne Association in New York, the green and blue roof not only aids in stormwater management, but are also a habitat for honey bees that are kept on site.