Figure 1. The entrance to Kings Park in Perth, Australia. Photograph courtesy of Graeme Churchard. https://www.flickr.com/photos/graeme

The Surprising Benefits of Biodiversity

By Geoffrey H. Donovan

One of my most vivid urban-tree memories is walking into Kings Park in Perth, Australia. The street entering the park is lined on both sides with huge eucalyptus trees with polished silver trunks (Figure 1). The effect is breathtaking. There is something majestic about the symmetry and uniformity of an avenue of mature trees of the same species. Unfortunately, as the number of invasive tree pests exponentially increases (Boyd et al. 2013), planting and maintaining these sort of urban-tree monocultures is becoming untenable. In fact, urban foresters now recognize that species diversification is essential to safeguarding the urban forest and the benefits it provides (Raupp et al. 2006).

However, increasing the diversity of the urban forest does more than just improve resilience to pests. More diverse trees and plants also provide habitat for more diverse bacteria and fungi (Kowalchuk et al. 2002). This is important, because exposure to these microbes can stimulate the human immune system, which helps protect against not only common immune diseases such as asthma and hay fever (Douwes et al. 2007), but also rarer and more serious diseases with an immune component like childhood leukemia (Greaves 2018).

But how can exposure to bacteria and other microbes improve our health? Don't these microbes cause disease? Certainly, exposure to some bacteria can cause disease. However, over the last 30 years we have improved our understanding of the human immune system and we now know that for our immune system to develop properly, we need to be exposed to certain types of bacteria. These bacteria tend not to cause diseases; rather, they are the ones humans have evolved with for millennia. In consequence, these bacteria are often referred to as "old friends" (Rook et al. 2003), because without exposure to them our immune system doesn't work properly, and we become more susceptible to allergies and other immune diseases. Simply put, our immune systems need training in much the same way as the rest of our body. If you want to run a marathon, it might be wise to go running a few times before race day, otherwise things might not go well.

One scientist who has fundamentally changed our understanding of how the immune system develops is David Strachan. In 1989, he found that children who had more older siblings were less likely to get hay fever (Strachan 1989). He suggested that the reason for this was that having older siblings exposes children to more microbes, so that their immune systems function better. He coined the term "hygiene hypothesis" to explain this link between increased microbial exposure and a lower risk of immune diseases. Since his pioneering work, scientists have shown that a wide range of microbial exposures can protect against immune diseases, including attending daycare, growing up on a farm, and breastfeeding (Greaves 2018).

But what does all this have to do with urban trees? The world's trees and plants are an important habitat for microbes. They have a collective area of 1,017,260,200 km^2, which is twice the world's land area, and they support approximately 10^{26} bacterial cells (Vorholt 2012). Interestingly, as global plant diversity has declined, rates of immune diseases have risen, especially in high-income countries. These two trends are causally linked by the biodiversity hypothesis, which suggests that reduced exposure to biodiversity has negatively affected human immune development, leading to an increase in immune diseases (Haahtela et al. 2013). This effect is likely brought about by changes in the human microbiota—the microbes that live in and on our bodies. In particular, the diversity of microbes in our guts have been linked to a rapidly expanding list of diseases, from the intuitive—stomach cancer, for example—to the less obvious, such as depression (Cho and Blaser 2012).

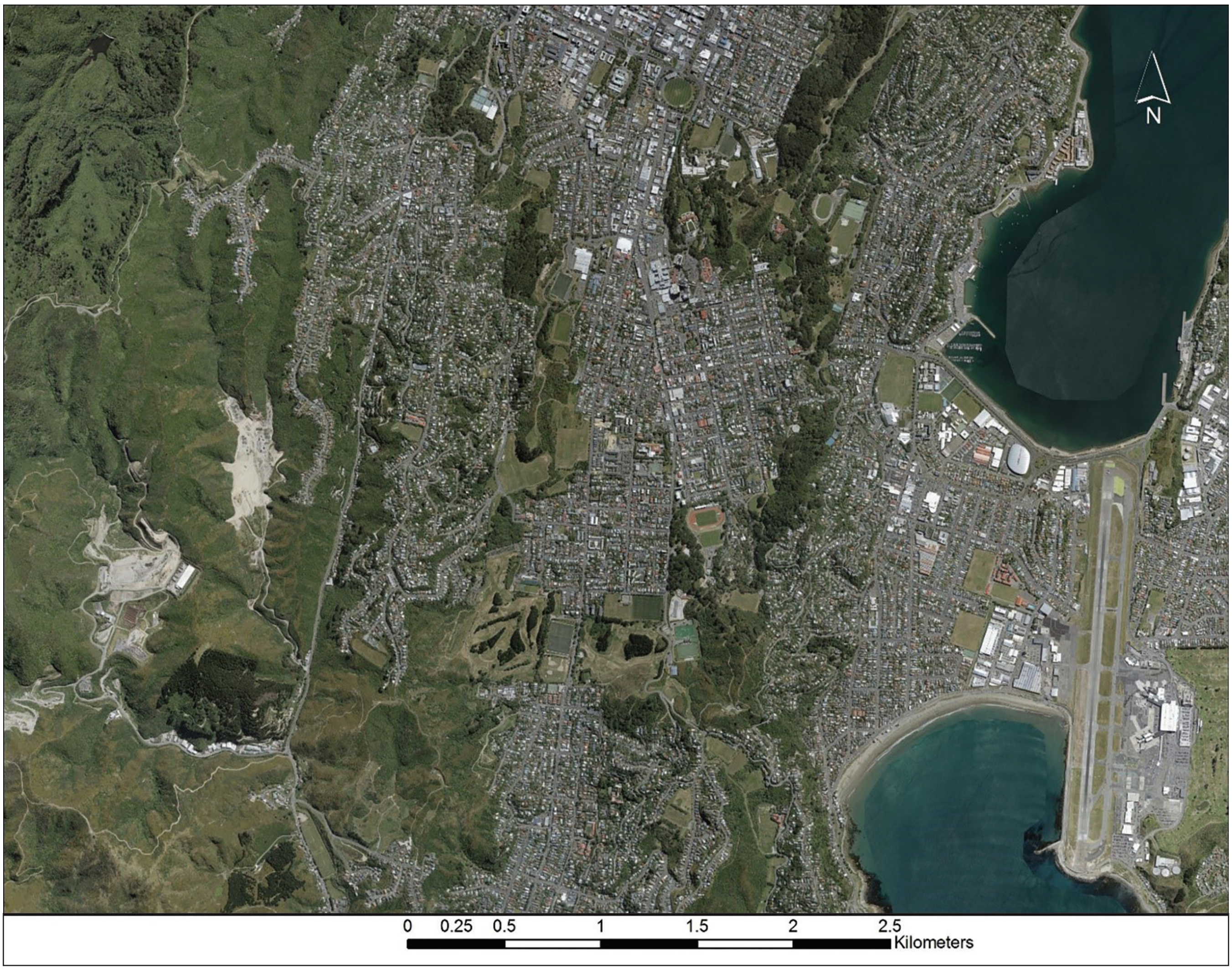

Figure 2. Aerial photograph of the area around Wellington airport in New Zealand. Photograph courtesy of the author.

The general concept underlying the biodiversity hypothesis—that the planet's ecological health and human health are inextricably linked—is intuitively appealing. However, scientists have not been able to show that exposure to plant diversity protects against many specific diseases. I saw this as a major gap in our knowledge. In particular, if I was able to show that plant diversity improves our health, then this would provide important new evidence for the benefits of urban forestry, as trees are a major component of urban biodiversity. Therefore, I teamed up with a group of US and New Zealand scientists to study the relationship between exposure to plants and human immune diseases.

I chose to do this research in New Zealand, because, over 20 years ago, Statistics New Zealand established the Integrated Data Infrastructure, which is a system of linked individual-level databases covering the entire New Zealand population. This allowed me to comb through health records for the entire country from a secure data lab, looking for patterns. Specifically, I wanted to know whether people who lived in areas with higher plant diversity had lower rates of immune diseases. In the first part of my study I focused on asthma, which is one of the most common immune diseases in the world. For example, about 1 in 12 people in the US have asthma (Moorman et al. 2011). In the second part of the study, I looked at childhood acute lymphoblastic leukemia, which is the world's most common pediatric cancer affecting approximately 1 in 2,000 children in the US (Linabery and Ross 2008). Unfortunately, both diseases are on the rise in many high-income countries.

Asthma

We tracked approximately 50,000 children who were born in New Zealand in 1998 from birth until age 18. To determine which children had asthma, we looked at prescription records for asthma drugs. Calculating a child's exposure to plant diversity was a challenge, as New Zealand (and other countries) doesn't have comprehensive

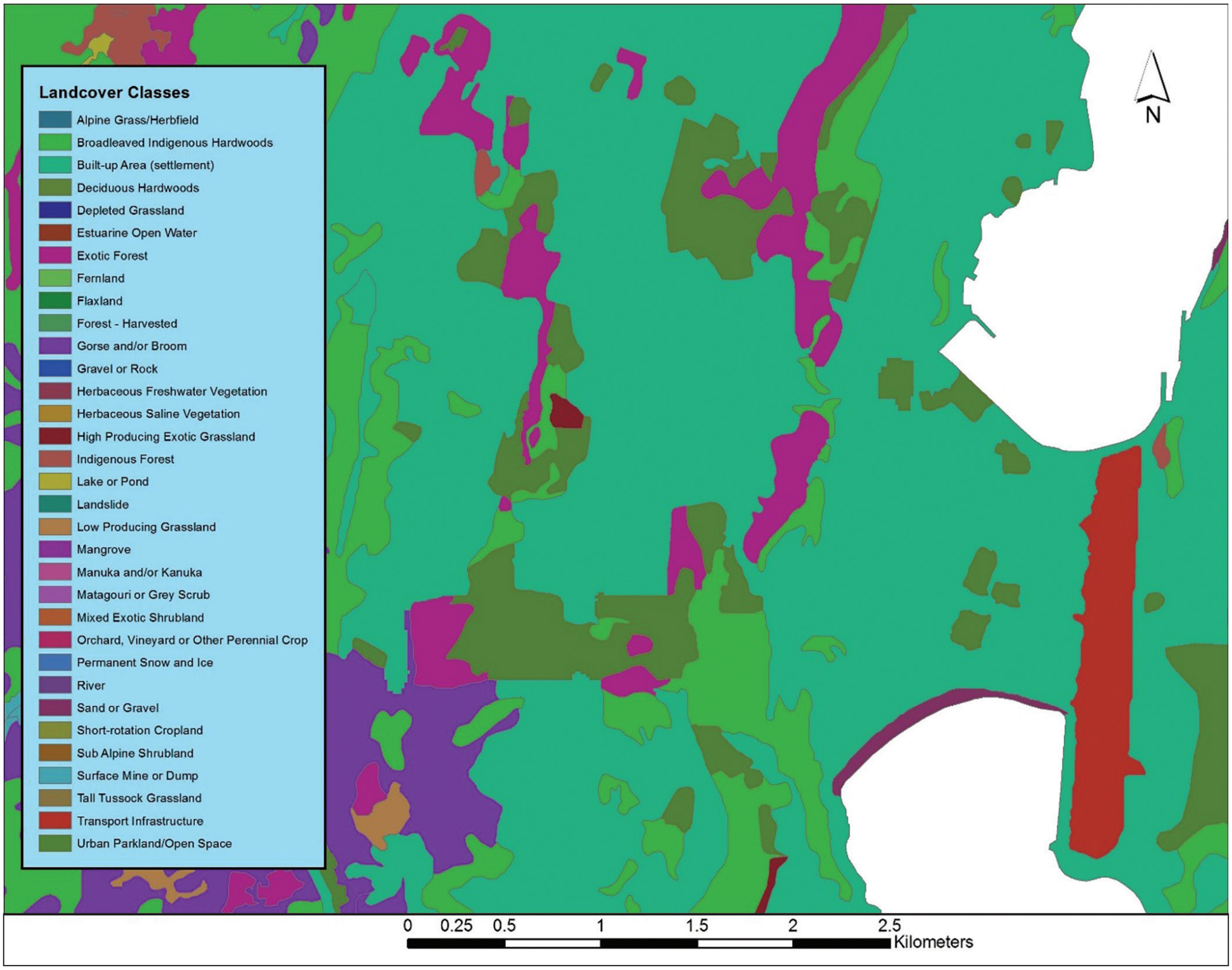

Figure 3. New Zealand Land Cover Database (LCDB) v4.1 for the area around Wellington airport. Image courtesy of the author.

plant-diversity maps. New Zealand does, however, have land-cover maps in which all land cover is split into 1 of 33 categories. Figure 2 shows an aerial photograph of the area around Wellington airport in New Zealand, and Figure 3 shows land-cover types for the same area. Although land-cover diversity isn't a perfect proxy for plant-diversity, we reasoned that more diverse land cover could support more diverse plants. We also accounted for the overall greenness of a child's neighborhood using the normalized difference vegetation index (NDVI), which we derived from satellite imagery (Figure 4).

We found that children who lived in greener neighborhoods, as well as children who were living in neighborhoods that featured more plant biodiversity, were less likely to get asthma. Specifically, a 1 standard-deviation increase in neighborhood greenness was associated with a 6% decrease in the risk of getting asthma, and a 1 standard-deviation increase in biodiversity was associated with a 7% decrease in asthma risk (Donovan et al. 2018). If you lived in a neighborhood with an average amount of greenness (50% of neighborhoods were greener than your neighborhood and 50% were less green), then a 1 standard-deviation increase in greenness would mean that your neighborhood would now be greener than 84% of neighborhoods and less green than 16% of neighborhoods.

Our results are consistent with the biodiversity hypothesis: exposure to biodiversity was associated with a lower risk of developing an immune disease.

Childhood Leukemia

Childhood leukemia is less common than asthma, so we needed to use a larger sample to detect the possible impact of plant diversity on disease risk. Specifically, our sample was all children born in New Zealand from 1998 to 2011 (approximately 900,000 children). During this time, 264 children developed acute lymphoblastic leukemia before their 5th birthday. We took a different approach to measuring plant diversity than in our asthma study. We used the Global Biodiversity Information Facility (GBIF), which contains over 2 billion geocoded plant records globally (over 2 million in New Zealand). This approach was an advance on how we measured biodiversity in the asthma study. Specifically, we linked childhood leukemia directly to plant diversity rather than to land-cover diversity.

We found that children who lived in neighborhoods with more diverse plants before their 2nd birthday (the first 2 years of life are especially important for immune development) were less likely to develop acute lymphoblastic leukemia in the next 3 years. Specifically, children whose exposure to plant diversity was in the top 3rd of the sample were 35% less likely to get acute lymphoblastic leukemia compared to children whose exposure to plant diversity was in the bottom 3rd of the sample.

Implications for Urban Forestry

Our findings have important scientific and practical implications. In common with other microbial exposures, such as daycare attendance and having an older sibling, plants are associated with a reduced risk of two major immune diseases. However, in contrast to other sources of microbial exposure, trees and plants are a modifiable component of the environment. You can't issue a child an older sibling or send them to daycare just to reduce the risk of developing an immune disease. It's just not practical. You can, however, change a child's exposure to trees and plants relatively easily, cheaply, and at little risk.

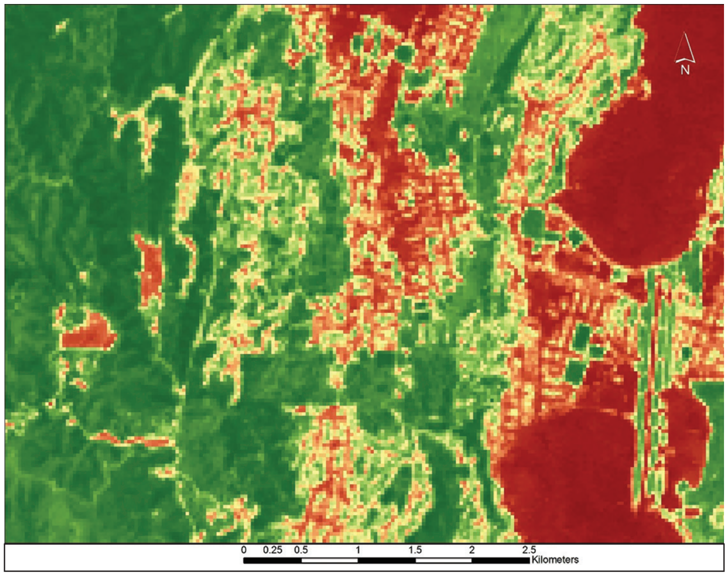

Figure 4. 2017 LandSat 8-derived Normalized Difference Vegetation Index (NDVI) for the area around Wellington airport. Photograph courtesy of the author.

As we better understand which microbes provide the greatest immune benefit at the lowest risk, we can investigate what species of trees and plants best support these microbes. With this knowledge in hand, plantings in places young children spend a lot of time—playgrounds and daycares, for example—could be designed to promote immune development. Healing gardens are now accepted as an evidence-based component of many health-care facilities. Perhaps in the future, immune gardens will also be a normal part of a city's infrastructure?

As with many urban-tree benefits, the positive impact of trees and plants on immune development is not a typical market good like bananas or laundry detergent. It doesn't have an established price that can be efficiently bought and sold in the marketplace. Therefore, it's important that research identifies and values these benefits so that urban trees get the credit they deserve, and urban forestry receives the appropriate level of support.

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BUREAU OF LAND MANAGEMENT CALIFORNIA

Plant I.D.

Did you correctly identify this tree from page 20?

Sequoiadendron giganteum

The famous giant sequoia is renowned for being the most massive tree in the world. It primarily thrives in the Sierra Nevada Mountains in central California, where groves of the trees have been sought out by visitors for decades. Because of its narrow range, it is not especially adaptable, being both intolerant of dry soils, temperature extremes, and anything more than light shade. The best conditions for the giant sequoia include moist, loose, well-drained loams with full sun and a cool, moist climate. These trees can be planted in the eastern United States, but will not grow to their full potential and will typically only reach 40 to 60 feet (12 to 18 m) in height.

Botanical name:	*Sequoiadendron giganteum*
Common names:	Giant sequoia, Big tree.
Mature size:	60 to 275 feet (18 to 83.5 m) height and 25 to 60 feet (7.5 to 18 m) width.
Foliage:	Short, bluish-green needles approximately 0.125 to 0.5 inches (0.3 to 1 cm) in length, with broad bases and tapered points.
Fruit:	Reddish brown cones 1.5 to 3 inches (3.5 to 7.5 cm) long, 1 to 2 inches (2.5 to 5 cm) wide.
Growth rate:	Fast
Autumn color:	Evergreen
Geographic range:	Native to the Sierra Nevada Mountains in California, United States.
USDA Hardiness Zone:	6–8
Pests and diseases:	No serious pests or diseases. May experience dieback, blight, and butt rot.

Content sources: *Dirr's Encyclopedia of Trees & Shrubs,* the Urban Forest Ecosystems Institute, and the Missouri Botanical Garden