A special issue on Ecology and Biodiversity

FEATURES

Topics from the tropics
Why history matters
Greening Singapore’s seawalls
Singapore’s unfinished periodic table of biodiversity
How many species has Singapore lost?
The importance of tropical wild nature
## Table of Contents

### RESEARCH FEATURES

<table>
<thead>
<tr>
<th>Page</th>
<th>Title</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>Topics from the tropics</td>
</tr>
<tr>
<td>4</td>
<td>Why history matters</td>
</tr>
<tr>
<td>6</td>
<td>Greening Singapore’s seawalls</td>
</tr>
<tr>
<td>8</td>
<td>Singapore’s unfinished periodic table of biodiversity</td>
</tr>
<tr>
<td>10</td>
<td>How many species has Singapore lost?</td>
</tr>
<tr>
<td>12</td>
<td>The importance of tropical wild nature</td>
</tr>
</tbody>
</table>

### NEWS ROUNDPUP

<table>
<thead>
<tr>
<th>Page</th>
<th>Title</th>
</tr>
</thead>
<tbody>
<tr>
<td>14</td>
<td>Ecosystem functions in Singapore’s forest streams</td>
</tr>
<tr>
<td>14</td>
<td>Plant-based ingredients for supporting cell growth</td>
</tr>
</tbody>
</table>

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On the cover: Researchers measuring the light intensity as part of an ecological approach to enhance the water quality at Pandan Reservoir.
**Introduction**

Fresh waters in tropical Asia are poorly studied despite facing numerous challenges, including land use change, urbanisation, and exploitation. Singapore encapsulates these challenges, making it an ideal location for tropical freshwater research. Research in the Freshwater and Invasion Biology (FIB) laboratory focuses on three areas: (i) biodiversity and ecology, (ii) aquatic invasions and (iii) decapod crustaceans. The research incorporates both field and laboratory studies, including surveys and experimental work.

**Fundamental research**

*Freshwater biodiversity and ecology*

The biodiversity of Singapore’s freshwater habitats is relatively well-studied, but the ecology of these environments and their biota (e.g. species-species or species-environment interactions) are less well-known. An important part of the FIB laboratory’s research focuses on the ecology of both natural and artificial/urban fresh waters in Singapore and the surrounding regions. The studies in natural habitats (i.e. forest streams and freshwater swamps) include research on drivers of species interactions (biotic) that govern population dynamics (e.g. resource availability), characterisation of habitat parameters (abiotic) affecting key species, and determination of factors influencing species distributions and community structures.

Much of the ecological work is also conducted in urban habitats around Singapore (e.g. reservoirs, ponds and canals), which are dominated by introduced species. In one study, we characterise the biotic/trophic interactions in Singapore’s reservoirs using empirically-constructed food webs based on the gut content and stable isotope analyses, and decipher the mechanisms behind the assembly of these novel communities of non-native fish species [1].

Phytoplankton (algae) and aquatic plants in urban reservoirs are another major research topic. We investigated the potential environmental triggers for algal blooms. Populations of naturally occurring cyanobacteria were found to exhibit species-/strain-/habit-specific patterns of growth in response to changes in nutrient levels and temperature. Ongoing experiments are investigating the competitive effects of aquatic plants on phytoplankton communities at progressively larger scales, from small indoor tanks to large field mesocosms (Figure 1). These will identify optimal conditions for plants to effectively reduce algae growth and enhance reservoir water quality.

*Aquatic invasions*

International ornamental and live food trades in Singapore are pathways (sources) for the introduction of alien aquatic species. Together with an extensive network of urban water bodies already dominated by introduced species, this makes Singapore a good location to study aquatic invasions.

The FIB laboratory studies aquatic invasion topics along the lines of a well-defined invasion process comprising several stages (Pathway -> Translocation/Introduction -> Establishment -> Spread -> Impacts). At the “Pathway” stage, we recently completed a comprehensive study of freshwater molluscs in the ornamental pet industry, showing the trade origins of many mollusc species in Singapore waters. The outcome strengthens a long-held assumption that trade is a major source of alien aquatic species introduction in Singapore.

Research at the “Introduction” stage includes the investigation and discovery of freshwater alien species, with 27 new records reported from Singapore in the past seven years (Figure 2). In a recent study, we found that the damming of rivers to form reservoirs increases the proportion of alien species in the fish communities. This appears to be driven in part by local extinction of native riverine specialist species, and replacement of these by non-native generalist species [2]. This is a highly relevant finding for Southeast Asia, where numerous dams are built for water provisioning and/or hydroelectric power.

At the “Establishment” stage, the FIB laboratory endeavours to predict the risk of alien species establishment.
Darren C.J. YEO is an Assistant Professor at the Department of Biological Sciences where he leads the Freshwater and Invasion Biology Laboratory. He is also a research affiliate with the Lee Kong Chian Natural History Museum and the Tropical Marine Science Institute. He received his Ph.D. from NUS. His main research interests are in aquatic invasions, freshwater ecology and biodiversity, and freshwater decapod crustaceans.

Reference
[1] Liew JH; Jardine T; Lim RBH; Kwik JTB; Tan HH; Kho ZY; Yeo DCJ, “Bottom-up influences on freshwater food webs support the ‘environmental filtering’ hypothesis” LIMNOLOGY AND OCEANOGRAPHY (in review).


For full reference list, please refer to http://www.dbs.nus.edu.sg/lab/FW_lab/Main.htm

Translational freshwater research

Most of our fundamental research findings are extended towards benefiting society through translational freshwater research positioned downstream, and often combining aspects of the three basic research areas mentioned above. Examples include (i) restoration and management of forest streams, (ii) biomanipulation and biological control approaches in conservation and management of freshwater habitats based on the understanding of tropical food webs/ trophic cascades and alternate stable states, (iii) aquatic invasive species risk screening, and (iv) conservation strategy planning for species with national and natural heritage significance (e.g. the endemic Singapore freshwater crab, Johora singaporensis) (Figure 3).
Why history matters

Conserving marine biodiversity through the lens of evolutionary and ecological history

Introduction

Life is the consequence of historical contingencies. As mammals, we would never have made it had most of the dinosaurs—save the birds—not gone extinct some 65 million years ago. In fact, the vast majority of species are now extinct. That is why history matters in biology, and why past extinctions may provide lessons in our efforts to avoid the catastrophes projected in the current, sixth mass extinction event. But life is also about new opportunities as well as the origination of species and their traits. At the Reef Ecology Lab, we together with our collaborators are interested in understanding the origins, maintenance and loss of marine biodiversity.

Origins of biodiversity

Species move around. Many factors determine how widely a species can range, including intrinsic factors such as speed of movement and mode of reproduction, as well as extrinsic factors such as geographic barriers and climate. Humans originated in Africa, but we have since spread across the globe quickly, owing to our adaptability and intelligence. Marine species such as whales and dolphins are able to traverse vast seas, but many others live a more sedentary lifestyle, relying on specific stages of their lives to disperse.

Our research aims to reconstruct the origins of species living around coral reefs, which are some of the most diverse ecosystems on the planet. Coral reefs are most diverse in our part of the world, the Central Indo-Pacific region, with the number of species declining as we move away from this area (Figure 1). This diversity gradient has perplexed scientists since the time of Charles DARWIN, but it is only in recent years that researchers started to trace the origins of species based on their evolutionary history.

Different groups of coral reef species have generated this diversity gradient in different ways. Our research on corals, the foundational organisms of modern reefs, have shown that the high diversity of reef corals in the Central Indo-Pacific appears to be driven by range expansions into this region of species that evolved in less diverse regions [1]. On the contrary, most reef fishes originated and diversified primarily in the Central Indo-Pacific region. These differences can be attributed to the varied life histories of different organisms. For example, species that brood their young and those that broadcast their gametes for fertilisation are expected to have different abilities to disperse their offspring, affecting their range size and ultimately species diversity.

Supported by the National Research Foundation’s Marine Science Research and Development Programme, we are now testing these hypotheses within Singapore’s waters to reconstruct the historical movement of species with different life histories using high-throughput DNA sequencing techniques.

Evolution of species traits

Why do species have different investments and strategies in reproduction? Some species take very good care of a few offspring, while others produce plenty of offspring and only some survive. These parental investment strategies are fascinating because they are used by species in the present environmental context to survive and propagate, yet they have had to evolve in the past under vastly different conditions. What are the trade-offs in adopting one strategy over another? To address this question, we examined the relationship between corals and their mutualistic symbiotic relationship with microalgae symbionts, or zooxanthellae, which provide food for the corals in return for...
accommodation and nutrients offered by the coral host.

Theory suggests that it is better for parents to pass their symbionts directly to their offspring (vertical transmission) rather than have the offspring start with a clean slate and acquire symbionts from the environment (horizontal transmission). This is because symbionts present in the parents are likely to have adapted to the environment and therefore advantageous to their offspring. Paradoxically, many organisms, including most corals, do not pass symbionts directly to their offspring, which have to obtain the symbionts from the environment during development.

By tracking the changes in this life history strategy over hundreds of millions of years, we found that this trait is correlated to the reproductive mode of corals [2]. In other words, whether a species acquires their symbionts from their parents “vertically” or from the environment “horizontally” depends strongly on whether it broods larvae or broadcasts gametes. Offspring broadcast into the water column often disperse for large distances and are fertilised at the sea surface, where high temperature and light may hurt the symbiotic relationship. Therefore, by foregoing vertically transmitted zooxanthellae despite their necessity later in life, coral larvae may actually survive better and even acquire symbionts that are adapted to their new environment.

We are currently surveying reef communities in Singapore to better understand the spatial distribution of these life histories.

Predicting species loss

Finally, understanding the origins and evolution of species and traits is an important scientific task, but evolutionary history also provides valuable lessons in this age of heightened extinction rates. Life on Earth has experienced multiple extinction events in the past (Figure 2), including five major ones where a majority of species was lost. By analysing an extinction event that occurred during the boundary between the Pliocene and Pleistocene epochs about 2.5 million years ago, we found that half of all the scallop species in California went extinct. Yet the loss of evolutionary history was less than expected, suggesting the preferential extinction of younger species [3].

In recent years, there is increasing concern over threats against older lineages because they hold disproportionate amounts of evolutionary history. Our findings emphasise that younger species, which have important functional and ecological roles, could also be at risk. More broadly, the tools we have developed to compare loss of biodiversity during past and ongoing extinctions not only provide fundamental insights into the nature of the extinction process, but are also helping to improve evolutionarily-informed models of conservation prioritisation for maintaining marine biodiversity in the long run.

References


Greening Singapore’s seawalls

Enhancing native biodiversity on Singapore’s coastal defences through ecological engineering

Introduction

The Experimental Marine Ecology Laboratory (EMEL) focuses on increasing understanding of the ecology and functioning of Southeast Asian tropical marine organisms and communities, including the impact of urbanisation. It is predicted that by 2025, approximately three quarters of the world’s population, or over eight billion people, will reside in coastal zones. This has major implications for natural shoreline habitats, and EMEL is studying ways to reduce its impact.

Coastal development and land reclamation are occurring at huge scales. In addition, sea level rise and more intense storms have resulted in greater risk of flooding and coastal erosion. Globally, manmade coastal defences such as seawalls have become the primary means of protecting shorelines. These are generally designed based on civil engineering principles and do not function in the same way as the natural habitats they replace. Therefore, ecosystem services and resilience are lost. The main thrust of the research at EMEL is to find ways to enhance native biodiversity and ecosystem functioning on coastal defences in Singapore and beyond.

Seawalls differ from natural shores in various fundamental ways. They are usually very steep, increasing the effects of wave impact and compressing the intertidal zone such that species that are usually spaced far apart become superimposed. Seawalls have few microhabitats such as pits, rock-pools and overhangs, and little structural complexity. Furthermore, they are frequently made from materials that are not well-suited for colonisation by marine organisms, or exhibit thermal properties that result in unfavourably high temperatures during low tide (Figure 1).

Despite the growing prevalence of artificial coastal defences, researchers have only recently examined the ecological impacts of seawalls or thought of ways to mitigate their negative effects. As these structures are usually permanent, there is now a greater interest in maximising their ecological value. This can be done either by retrofitting solutions to existing seawalls or designing new ones from scratch. Designing urban infrastructure that includes ecological principles is known as ecological engineering.

To date, seawall ecology has mostly been studied in temperate regions. While we can learn from this research, studies in our tropical context are nevertheless urgently needed. In the last 200 years, 169 km$^2$ of land was reclaimed from the sea around Singapore [1]. Only 17.1% of its coastline is natural, while most (63.3%) is seawall (Figure 2). This makes Singapore an ideal location for the development of strategies and techniques to enhance native biodiversity on tropical coastal defences.

The “problem” of low biodiversity on seawalls cannot be fully resolved without understanding why they support so few species. A number of fundamental questions must first be addressed. We need to understand the environmental factors and biotic interactions that regulate seawall community composition and structure at local (centimetres) and landscape (metres) scales. Investigating the sources of diversity and processes underpinning ecological patterns can help link the evidence from local research and refine our understanding of the system and how to ecologically engineer seawalls in a way that helps conserve intertidal biodiversity and the ecosystem services that they provide.

Increasing habitat complexity

In most cases it is not feasible to replace coastal armour with “softer” alternatives. However, it is possible to manipulate seawalls to encourage colonisation by local species. Singapore is protected by more than 300 km of permanent seawalls. Hence, retrofitting them with blocks or tiles made of materials that encourage settlement of marine organisms is the most viable option for increasing biodiversity [1]. It has long been known that physically complex habitats support greater biodiversity. Recent experimental work has used microhabitat enhancements, such as pits and grooves, to increase species numbers. Integrating this knowledge, we at EMEL have focused on increasing the topographic complexity of Singapore’s seawalls [2].
Peter TODD is an Associate Professor with the Department of Biological Sciences, NUS. He has a B.Sc. (Hons) in Ecological Sciences and a Ph.D. in Tropical Marine Ecology. He is an experimental marine ecologist who focuses on organism-environment interactions in tropical seas. He specialises in designing, implementing, and analysing novel experiments to answer pressing environmental questions. His work falls into the following major research themes: “Tropical marine invertebrate ecology and behaviour” and “The effects of urbanisation on coastal ecosystems.”

There is a growing worldwide consensus that enhancing complexity in simplified habitats will be critical for future biodiversity restoration and ecological engineering efforts. Based on the results of our initial studies, we designed a new composite tile and tested the effects of varying deployment densities and spatial arrangements to answer the question “how much enhancement is enough?”. This is a first for seawall ecological engineering and a seminal experiment for translating ecological theory to practice.

Building on this work, we will test other regulatory influences of complexity, examining each component on ecosystem functioning and probing the mechanisms that affect species diversity, both at local (centimetres) and landscape (metres) scales. Clarifying the key processes that underlie community structure is not simply an academic pursuit—it is particularly crucial in light of increasing human impact on the environment. Issues with obvious negative implications for society (e.g. climate change, invasive species, habitat fragmentation and pollution-related effects) all relate back to these key processes. The more we know how communities respond to perturbations and understand the drivers of community assembly and persistence, the better we will be equipped to alleviate man-made impact, drive desired outcomes for the environment, and predict the results of change.

What next?

As natural coastlines are globally being replaced by man-made structures, a concerted and integrated effort is required if shoreline biodiversity is to be conserved and ecosystem services maintained. In our current project, funded by the National Research Foundation’s Marine Science Research and Development Programme, we aim to create nationally relevant and future-ready “green” seawalls that will host a diverse array of native species to increase overall ecosystem resilience. This project is a collaboration with the National Parks Board and the Housing Development Board, and makes use of the research facilities available at St John’s Island National Marine Laboratory. These sustainable infrastructure designs will improve aesthetics, provide more green space and ultimately lead to a more liveable city.

Peter TODD is an Associate Professor with the Department of Biological Sciences, NUS. He has a B.Sc. (Hons) in Ecological Sciences and a Ph.D. in Tropical Marine Ecology. He is an experimental marine ecologist who focuses on organism-environment interactions in tropical seas. He specialises in designing, implementing, and analysing novel experiments to answer pressing environmental questions. His work falls into two major research themes: “Tropical marine invertebrate ecology and behaviour” and “The effects of urbanisation on coastal ecosystems.”

Reference
RESEARCH FEATURES

Singapore’s unfinished periodic table of biodiversity

New genomic and imaging tools are showcasing the rich biodiversity of Singapore

The challenge

Approximately one third of Singapore’s land area is covered with greenery (e.g. parks, nature reserves, catchment areas, etc). These green areas provide essential ecosystem services which include the purification and provision of fresh water, lowering of outdoor temperature, improving of air quality and enhancing of mental and physical health of residents. These services are delivered by Singapore’s biodiversity, which we now estimate to comprise more than 50,000 species of plants, fungi and animals that interact in “trophic pyramids”. These pyramids consist of biomass producers (plants) that are consumed by, or interact with primary consumers (animals and fungi: plant eaters, pollinators, seed dispersers, etc.), secondary consumers (meat-eaters feeding on primary consumers) and tertiary consumers (feeding on secondary consumers). To maintain Singapore’s green ecosystem, it is important to understand and maintain the health of these trophic pyramids (i.e. one has to know the species involved and understand their interactions with each other). This requires the development of high-throughput identification tools for the plant and animal species, and efficient techniques for establishing species interactions based on DNA trace evidence.

Current status

We are addressing the species identification challenge by developing next-generation DNA “barcodes” which function like species-specific fingerprints. As current techniques are too expensive to be used on a large scale, we have developed a high-throughput and cost-effective DNA barcoding method that can generate sequences in large numbers at a low cost [1]. This technique has been used to barcode more than 100,000 specimens from Singapore, leading to the discovery of circa 10,000 species in Singapore alone. A large proportion of these species are new to science, with many still in the process of being formally described and named. In future, all of these species can be easily re-identified using their own unique barcodes. Apart from discovering and barcoding species, we also determine their evolutionary relationships. This contributes towards the international Tree-of-Life project for a better understanding and prediction of why certain species live together in specific habitats.

These DNA barcodes also have many other applications. For example, we generate species inventories for the National Parks Board which use this information for conservation planning (e.g. Bukit Timah Nature Reserve, Nee Soon Swamp Forest and mangrove remnants). We also use the DNA barcodes to identify the aquatic habitats of both the dragonfly and damselfly larvae. Unfortunately, the breeding sites for many dragonfly and damselfly species are still unknown and unless we can identify and protect these sites, the species may disappear.

DNA barcodes are also useful for evaluating environmental DNA (“eDNA”). In collaboration with the Public Utilities Board (PUB), Singapore’s national water agency, we determine the water quality in our reservoirs and waterways by sequencing eDNA that is extracted directly from the water. These DNA signals provide information on which species live in the reservoirs and allow for water quality assessment in an indirect way [2].

Barcodes are also essential tools for the high-throughput identification of species interactions. For example, DNA remnants in guts and faecal material can be used to quickly obtain information on the genetic health, diet, microbial fauna and intestinal parasites.
of Singapore’s endangered vertebrates [3]. Such studies have already yielded key insights into the biology of Singapore’s endangered Raffles banded langur (*Presbytis femoralis*; Figure 1), leopard cat (*Prionailurus bengalensis*) and Sunda pangolin (*Manis javanica*). Barcodes can also be used to identify pollinators and seed dispersers that are important for the regeneration of forests. Much of this research is conducted in collaboration with statutory boards and industry (e.g. Wildlife Reserves Singapore).

Many residents here are not aware that Singapore has a very rich biodiversity. We have therefore started a “Biodiversity of Singapore” website (Figure 2) that summarises and provides biodiversity information from many different sources online to create awareness. The website currently features more than 8,700 different species that are found in Singapore (https://singapore.biodiversity.online/). Each of these species is represented by an image. Pages for species with known interactions are interlinked. Species that were newly discovered with DNA barcodes are photographed with high-fidelity imaging to cater for future identification systems using artificial intelligence. Each of these images consists of many “slices” that can be used for creating simple three-dimensional models.

### Moving ahead

Global change makes it increasingly important to regularly monitor the health of Singapore’s green spaces. This will require the ability to identify all species, understand key species interactions, develop cost-effective techniques for regular sampling, and establish monitoring sites. We are currently developing the necessary tools so that Singapore can become the first nation that tackles its multicellular biodiversity by making it identifiable with methods that can be automated. This will allow for smart management of our green spaces.

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**Rudolf MEIER** is the Kwan Im Thong Hood Cho Temple Professor of Conservation in the Department of Biological Sciences and Lee Kong Chian Natural History Museum. He received his Ph.D. from Cornell University in 1995 and worked at the American Museum of Natural History for two years before joining the University of Copenhagen as an Associate Professor in 1997. He has been a faculty member at NUS since 2002.

**References**


[2] Lim NKM; Tay YC; Srivathsan A; Tan JWT; Kwik JTB; Baloglu B; Meier R; Yeo DCJ, “Next-generation freshwater bioassessment: eDNA metabarcoding with a conserved metazoan primer reveals species-rich and reservoir-specific communities” ROYAL SOCIETY OPEN SCIENCE Volume: 3 Issue: 1 Article Number: 160635 DOI: 10.1098/rsos.160635 Published: 2016.

RESEARCH FEATURES

How many species has Singapore lost?
Applying statistical models to historical data to understand extinctions

Introduction
Over the last two centuries, Singapore has transformed from a tropical rainforest to a glittering metropolis. This transformation has taken its toll on our island’s flora and fauna. How many species have gone extinct? How many might have gone extinct even before they could be detected? Our research laboratory specialises in theoretical ecology and modelling. A current project is to document the history of Singapore’s biodiversity over the past 200 years and apply statistical and mathematical models to estimate extinction rates. By understanding rates of extinction in Singapore, we can understand the legacy of humans’ effect on the environment here at home, and also get insights into future tropical extinction trends around the world as other tropical countries continue to develop.

Bird extinctions
Our research team has been collaborating with Frank RHEINDT to study bird extinctions locally. Singapore has a substantial number of bird species. Within the NUS campus alone, there are birds of all shapes, sizes and hues, including the Collared Kingfisher (Figure 1). Of the 195 native bird species that are known to have been resident in Singapore at some point over the last two centuries, 137 can still be seen here today. The downside of this is that 58 native bird species have gone extinct. For example, the Buff-necked Woodpecker (Figure 2), with its charming red cheek patches, was last seen in Singapore in 1949. Furthermore, these 58 extinctions do not account for “undetected extinctions”, i.e., species that went extinct without being detected in Singapore. This is where our statistical model comes in.

Statistical methods
The novel statistical methods we developed to estimate undetected extinctions can be understood via an analogy of water flowing between buckets, with the “water” representing species (Figure 3(A)). All the water initially starts off in one bucket, which is called the “undetected extant” bucket (labelled U). Over time, some water flows into the “detected extant” (S) bucket, as species are discovered, and some into the “undetected extinct” (X) bucket, as unknown species go extinct. Water also flows from the “detected extinct” (S) bucket to the “detected extinct” (E) bucket, as known species become extinct.

The catch is that we cannot directly observe the rate at which water flows from the U bucket to the X bucket, i.e., we do not know the rate at which undetected species are going extinct. To address this challenge, our statistical model assumes that this rate is equal, in percentage terms, to the rate at which water flows from the S bucket to the E bucket, i.e., that undetected and detected species become extinct at similar rates. Equations corresponding to this bucket model can be solved, yielding an estimate, in the case of Singapore’s bird species, of an overall extinction rate of 33%. That is to say, of the resident bird species present here in 1819, about two thirds are still here, but one third have vanished.

We are the first to estimate bird extinction rates in Singapore. Richard CORLETT, in 1992, estimated a rate of 28%, but did not have statistical methods that allowed him to account for undetected extinctions. A group of researchers in 2003 did account for undetected extinctions and estimated a rate of 59%, but we believe this to be far too high, because it assumes that Singapore once contained all the bird species of lowland Peninsular Malaysia—an area 200 times the size of Singapore. Our work on Singapore’s birds was published in 2016 in the journal Conservation Biology [1].

Extinctions in other taxonomic groups
We are now working on other major taxonomic groups in Singapore. For mammals, 14 of the originally known 40 species have gone extinct, including the tiger, the last individual of which was killed in the Choa Chu Kang area in
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Reference

Figure 3: (A) A conceptual model of species detection and discovery. All species start off in the upper-left box as undetected extant species. Over time, species are subject to detection and/or extinction. (B) Singapore’s bird diversity from 1819 to 2014, with detected extant species shown in green and detected extinct species shown in red. The black curve is the sum of the red and green curves. The blue dotted curve estimates undetected extinctions, inferred from a statistical model.

the 1930s. In addition to these known extinctions, our statistical model estimates about two undetected extinctions, and an overall mammal extinction rate of 38%.

For plants, we have completed compiling over 30,000 individual records representing over 2,000 plant species from herbaria in Singapore and around the world. This work has involved collaborations with staff in Hugh TAN’s research team and the Singapore Botanic Gardens. We are now using our plant database to estimate how many plant extinctions Singapore has suffered. Work is also underway on other taxa including butterflies and amphibians.

Implications

Pending the final results of our analyses, what should we make of an extinction rate in the range of 30 to 40%? Should we take a pessimistic or an optimistic perspective? On the pessimistic side, these extinctions represent an enormous loss of flora and fauna that could otherwise enrich our lives and enhance Singapore’s reputation as a “City in a Garden”. Moreover, the extinctions we have observed have been biased towards large charismatic species, such as tigers and hornbills (the latter were subsequently reintroduced to Singapore).

On the optimistic side, if Singapore, one of the most urbanised and developed areas in the tropics, can maintain the majority of its original species, this may bode well for future large-scale conservation efforts where deforestation and development are unlikely to be as drastic as they have been here. If Singapore is a window into the future of tropical biodiversity, then perhaps that future is one in which numerically the majority of species survive, in a patchwork landscape, but those extinctions that do occur are biased towards large and charismatic species.

In the end, it is up to society at large to decide how many extinctions are too many, and what kind of ecological future we want. For our part, we will continue to collate biodiversity data, and to develop and refine models for estimating extinction rates. Our findings have the potential to inform and influence conservation and development decisions in Singapore and throughout the tropics.
RESEARCH FEATURES

The importance of tropical wild nature
Reconciling biodiversity conservation and agricultural production

Introduction

The growing global population together with increasing consumption per capita means that more agricultural products need to be produced to satisfy demand. More forested land needs to be cleared for agricultural purposes, posing a threat to the sustainability of tropical ecosystems. This is especially acute in the tropics because the same piece of land which often sustains a high level of biodiversity also represents an economic opportunity when converted for agricultural purposes (Figure 1). This creates a developing trade-off between using the land for growing crops and preserving it for biodiversity conservation. Resolving this tension is a key sustainability challenge of the 21st century. It is important to find a balance between increasing agricultural production to meet global demand and minimising its potential impact on biodiversity. In Southeast Asia, this mounting pressure on the land is epitomised with the rapid expansion of forested areas for planting highly profitable crops such as oil palm and rubber (Figure 1).

At the Carrasco BioEcon Lab, our research focuses on this global sustainability issue: How can we reconcile agricultural production and biodiversity conservation in the tropics?

Trade-offs between agriculture and ecosystems services

One of the key arguments for tropical deforestation is that it generates economic benefits through agriculture and forestry products that would improve the living standards of the countries and communities involved. In reality, deforestation also has environmental costs, mainly through the loss of ecosystem services, or benefits that nature provides to people. When forested land is cleared, there will be, for instance, more carbon emissions and a loss of water and food provisioning services (material benefits people obtain from ecosystems). An important step for reconciling food production and biodiversity conservation is to recognise the fine balance between these two competing forces. When a patch of forested area is to be cleared, we need to understand in greater detail the impact on these different aspects. For some of these land areas, it may be a net loss while for others, there may be net economic gain.

To answer this question, we have developed detailed maps containing information on the benefits provided by tropical forests (ecosystem services, e.g. recreation, flood protection and water purification), agricultural rents and carbon emissions across the tropical forest biome. This is the first global study on the trade-offs between multiple ecosystem services and land conversion for agricultural use [2]. We found that, in most areas, there is a net loss when a tropical forest is converted for agricultural use, but there are some exceptions that point towards areas where agriculture could be intensified (Figure 2). This research finding helps in identifying the optimal areas which should be earmarked for conservation and those which are more suited for agriculture in the tropics. The maps identify forested land which presents the largest agricultural benefits with the lowest environmental costs when converted to agriculture. Policy makers can use the maps to make more informed decisions to balance...
L. Roman CARRASCO is an Assistant Professor in the Department of Biological Sciences, NUS. He obtained his Ph.D. from Imperial College London and joined NUS as a research fellow. He was appointed as Assistant Professor in 2012. He is a bioeconomic modeller focusing on tropical conservation science and sustainability. His main research focus is on the reconciliation between biodiversity conservation and agricultural production in the tropics.

References
[2] Carrasco LR; Webb EL; Symes WS; Koh LP; Sodhi NS, “Global economic trade-offs between wild nature and tropical agriculture” PLOS BIOLOGY Volume: 15 Issue: 7 Article Number: e2001657 DOI: 10.1371/journal.pbio.2001657 Published: 2017.

Health benefits from forests

Our lab also focuses on evaluating the benefits which nature provides (ecosystem services) to humans. It has been hypothesised that forests play a role in disease regulation but available evidence to support this claim is very limited. Using Cambodia as a case study [3], we analysed health survey data from 35,547 households in 1,766 communities between 2005 and 2014 (Demographic Health Survey). This dataset was combined with high resolution geographic information maps to establish the relationship between deforestation and health outcomes. We found strong evidence indicating that the loss of dense forested areas in Cambodia was associated with higher risk of diarrhoea, acute respiratory infection and fever in children. These health issues are major causes of global childhood mortality. The findings provide empirical evidence of the link between environmental degradation and childhood health conditions, suggesting that forest conservation efforts could help in mitigating the health burden in developing countries. This highlights the potential importance of forest conservation for health, especially in low-resourced settings, adding to a small but growing body of evidence for policy makers to assess trade-offs in land use planning.

Figure 2: Economic implications of deforestation in tropical forests from 2000 to 2012 in different parts of the world. The maps shows a comparison of ecosystem services which are lost from cleared forests minus agricultural rents. Positive values indicate areas where deforestation incurred net losses.
The forest streams in Singapore serve as a refuge for many rare and threatened native freshwater species, but the organisms in these stream habitats are under pressure from human activities such as land use change. There is a need to restore and rehabilitate degraded streams, and enhance their resilience to future threats. However, the scientific basis to enable such restoration efforts is currently lacking.

In collaboration with the National Parks Board, the Freshwater and Invasion Biology Laboratory, led by Prof Darren YEO from the Department of Biological Sciences, NUS, is studying ecosystem functions in forest streams. This builds upon their earlier work on the diversity and ecology of organisms in local forest streams.

“Ecosystem functions such as nutrient cycles and leaf litter breakdown represent basic processes that are crucial for sustaining Singapore’s forest streams,” said Prof YEO. He added that these processes are thought to be driven by the biological activities of the organisms living in these streams.

This study will investigate how organisms present in forest streams contribute to ecosystem functions and the response of these functions to human activity. It also seeks to understand how biodiversity could help buffer ecosystem functions from land use change and other anthropogenic challenges or stress factors. Besides addressing fundamental knowledge gaps in tropical stream ecology, the study will also support ecosystem management efforts by identifying key vulnerabilities and informing potential restoration strategies and targets for these streams.

**Plant-based ingredients for supporting cell growth**

Tissues in the human body are not made up entirely of cells. A substantial volume of space between cells is filled by an intricate network of large molecules, such as proteins and polysaccharides (or sugars), resulting in what is known as the extracellular matrix. The extracellular matrix not only stabilises the physical structure of tissues, but also entraps growth factors. These growth factors are important for regulating a variety of cell behaviour, thereby affecting their survival, growth and development. Emerging research has shown that plants may provide a huge reservoir of bio-compatible ingredients that fulfil these functions of the extracellular matrix.

Prof Rachel EE from the Department of Pharmacy, NUS is collaborating with Roquette, a French multinational company and global leader in plant-based ingredients, to curate their diverse library of plant-based materials for their potential in supporting cell growth for tissue engineering applications. Roquette recently established its Asia Pacific regional headquarters and innovation centre in Singapore. The research will involve students and scientists from NUS working closely with researchers from Roquette’s research and development (R&D) sites in Singapore and France.

Prof Ee commented, “Through close collaboration with the scientists at Roquette, we can synergise the complementary skills of academia and industry to develop new innovative products for real-world needs. This partnership is also a great opportunity to train our students in plant-based biomaterial research while exposing them to the dynamic research environment of the pharmaceutical industry.”