AECOM

Design Principles for High-performance Ecosystems

Delivering a better world

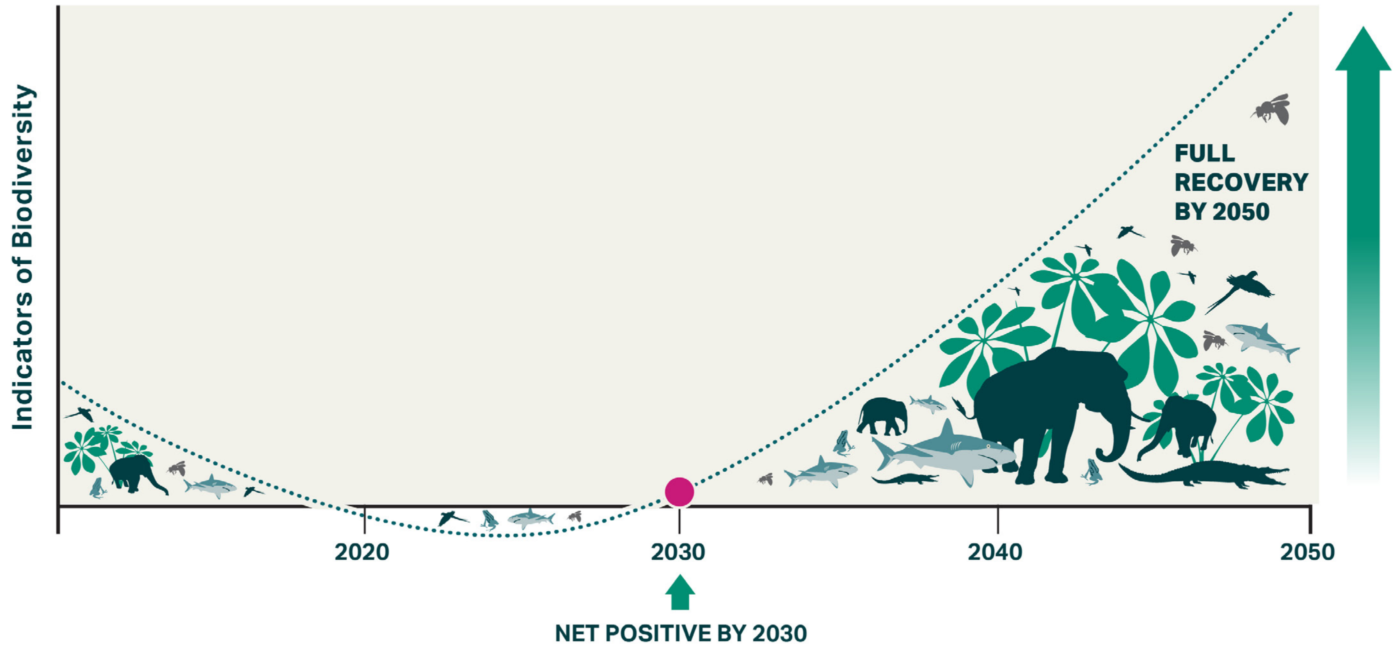
Introduction

The climate crisis and biodiversity loss are the two biggest global threats we are facing today. Moreover, these two issues are linked: rising global temperatures and the associated impacts of the climate crisis are degrading biodiversity resources and destabilizing ecosystems. As ecosystems are increasingly affected by the changing climate, their ability to sequester carbon and provide resilience is also diminished, further accelerating the climate crisis and hindering our planet's ability to regulate temperature.

The Kunming-Montreal Global Biodiversity Framework in 2022 (COP15) provided a watershed moment in addressing these issues, with 196 nations committing to an ambitious "30x30" target, pledging to conserve 30% of the Earth's oceans, lands, and freshwater ecosystems by 2030, helping to arrest declines in biodiversity. Additionally, nations agreed to use nature- and ecosystem-based solutions to help address the climate crisis through mitigation, adaptation, and disaster risk reduction actions; as well as contribute to other societal needs such as regulation of air, water and climate, soil health, pollination and reduction of disease risk (UNEP, 2022).

At COP15, it was estimated that funding nature conservation would require US$200 billion annually. Unfortunately, funding levels were significantly below this, with only an estimated US$15.4 billion made available in 2022 (OECD, 2024). During COP16 in 2024, there was a shortfall in pledges to the Global Biodiversity Framework (GBF) Fund, new financial mechanisms failed to gain traction, and there were challenges in establishing methods to monitor progress on the biodiversity targets. This reality check highlights the urgent need to intensify our actions to protect and restore our ecosystems.

Nature Positive by 2030



Graphic summary of Nature Positive, a global societal goal to 'halt and reverse nature loss by 2030 on a 2020 baseline, and achieve full recovery by 2050' (adapted from naturepositive.org)

In The Natural Capital Manifesto (AECOM, 2024), we outlined how investments in nature can be quantified and rewarded, fostering economies that benefit both people and the environment. This document outlines how to plan and design ***high-performance ecosystems*** that deliver these benefits, helping to address both the climate crisis and biodiversity loss.

A high-performance ecosystem refers to any nature-based solution or ecosystem-based approach that is planned, designed and managed to optimize ecosystem service delivery. By enabling high-performance, we can amplify the environmental benefits of all projects, whether they are infrastructure systems in urban centers or natural habitats in the hinterlands.

At AECOM, our close-knit, multi-disciplinary teams of landscape designers, engineers, and environmental specialists deliver enhanced performance across diverse projects, scales and geographic locations. Design goes hand in hand with science. Through this integrated approach, we have developed a set of core principles that underpin our design excellence. The principles capture critical best practices from our multi-disciplinary experts, conveyed in simple terms for clear communication.

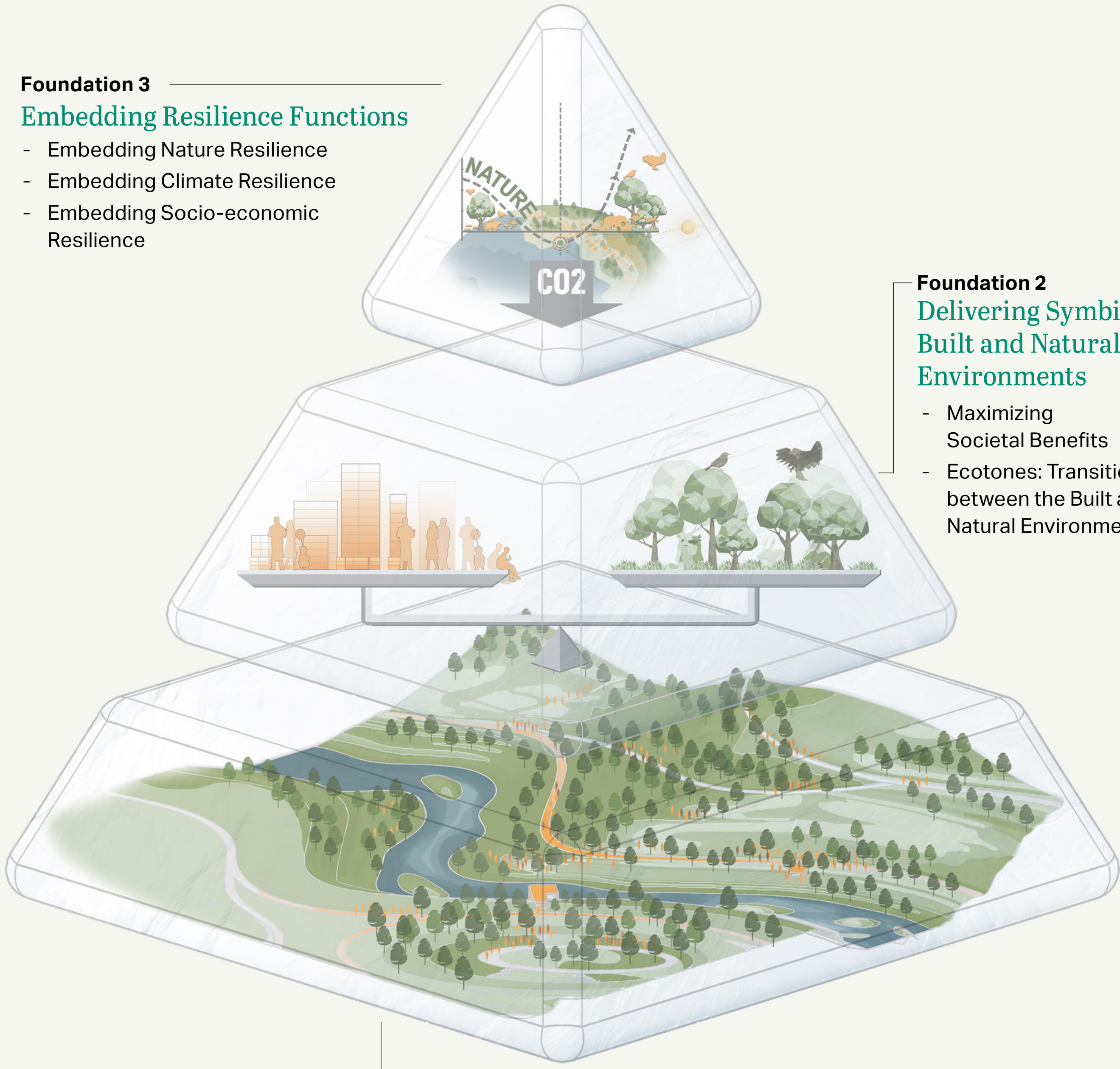
Three foundations for high-performance ecosystems

There are a total of eight principles anchored on three foundational points:

Foundation 3

Embedding Resilience Functions

- Embedding Nature Resilience
- Embedding Climate Resilience
- Embedding Socio-economic Resilience



Foundation 2

Delivering Symbiotic Built and Natural Environments

- Maximizing Societal Benefits
- Ecotones: Transitions between the Built and Natural Environments

Foundation 1

Maximizing Structural Diversity (Physical Complexity) of an Ecosystem

- Harnessing Spatial Diversity at Macro Scale
- Maximizing Composition Richness at Meso Scale
- Promoting Surface Complexity at Micro Scale

Foundation 1:

Maximizing Structural Diversity (Physical Complexity) of an Ecosystem

Natural variability found in intertidal habitats

Maximizing structural diversity (physical complexity) stands as a cornerstone principle for achieving high-performance ecosystems. This principle, rooted in a deep understanding of the organization and composition of ecosystems, serves as a guiding light for scientists, designers, and engineers.

Nature is a complex array of living and non-living elements, and design should strive to mimic this complexity. Structural diversity in the environment refers to the range of physical features within an ecosystem. More physically complex habitats, such as those with varied structures and layers, tend to support higher biodiversity as they offer a greater variety of niches and microhabitats that support different species (Kovalenko et al., 2011). Ecosystems that are structurally diverse (as well as rich in species and habitats) can also be more stable and resilient to disturbance than more simple ecosystems (Graham & Nash, 2012).

To truly harness the potential of ecosystems, we must first dissect our approach across various scales, ranging from the expansive macro to the intricate micro, which provide a framework for holistic ecosystem design.

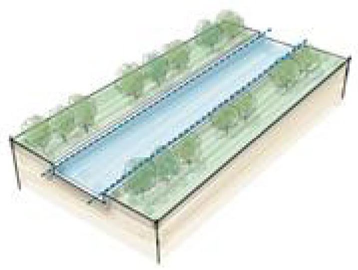
Macro Scale: At the macro scale, the physical environment drives the formation of different landscapes and habitats. This includes broad ecosystem typologies such as forests, rivers and various wetlands. Planning and designing at this scale require an appreciation of the overarching structural diversity of a particular location, and how the design should respond to these conditions to enhance ecosystem performance.

Meso Scale: Moving to the meso scale means delving into the components that constitute an ecosystem. Natural elements intertwine to form the fabric of ecological systems. It is important to note that natural media, such as diverse plant communities and rugged rock formations, can coexist with man-made interventions to enhance ecosystem functionality.

Micro Scale: Transitioning to the micro scale unveils the intricate textures and finishes that define individual elements within the ecosystem. Structural complexity at this scale provides a range of substrates offering different levels of exposure, water and nutrients, providing habitat and resources for a diverse array of smaller organisms. Textures and finishes of natural and man-made materials need careful consideration to drive biodiversity at the micro scale.

By navigating and integrating these scales of design, we may sculpt environments that not only thrive but also inspire appreciation for the complexities of the natural world. This multi-scale approach lays the foundation for creating resilient, biodiverse ecosystems that are as functional as they are captivating.

Marco example on Freshwater Watercourse



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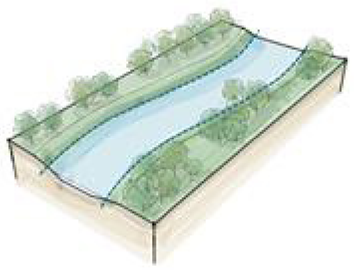

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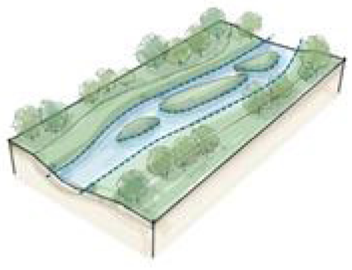

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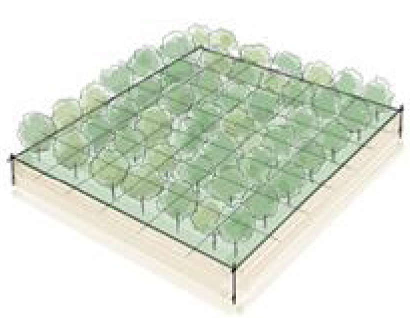
Marco example on Terrestrial



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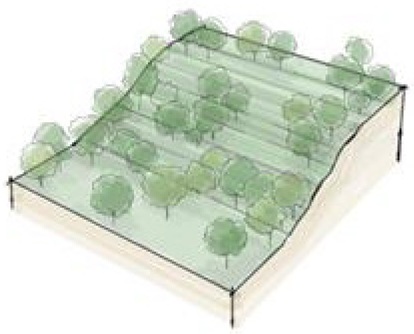

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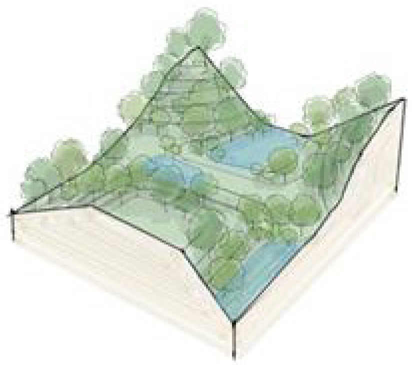

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Macro example of spatial variation in topographies

Harnessing Spatial Diversity at Macro Scale

At the macro scale, natural habitat diversity is driven by larger-scale variations in the surrounding environment. For example, intertidal shorelines are incredibly productive ecosystems that support biodiverse communities, while providing a first line of defence against climate risks, such as rising sea-levels and storm surges. They exhibit a high degree of spatial variation, and various habitats can be found along the shoreline such as rocky shores, sandy beaches, salt marshes, mudflats and mangroves. These different habitat types form in response to larger variations in the physical environment, particularly exposure to waves and currents, with hard shorelines (such as rocky shorelines) forming in exposed locations, and soft shoreline (such as mudflats and mangroves) developing in more sheltered environments (Morton & Morton, 1983).

This principle can be adopted in the planning and design of high-performance ecosystems. Incorporating various morphologies and topographies into project design supports the formation of different habitat types. As each habitat type is composed of a unique assemblage of species, designers can promote biodiversity and other ecosystem services through harnessing spatial diversity at this macro scale.

Design at this scale should also work with, rather than against, the prevailing environmental conditions. This approach creates more sustainable ecosystems that are matched with the natural environment, have a higher overall success rate and typically require less management and maintenance.

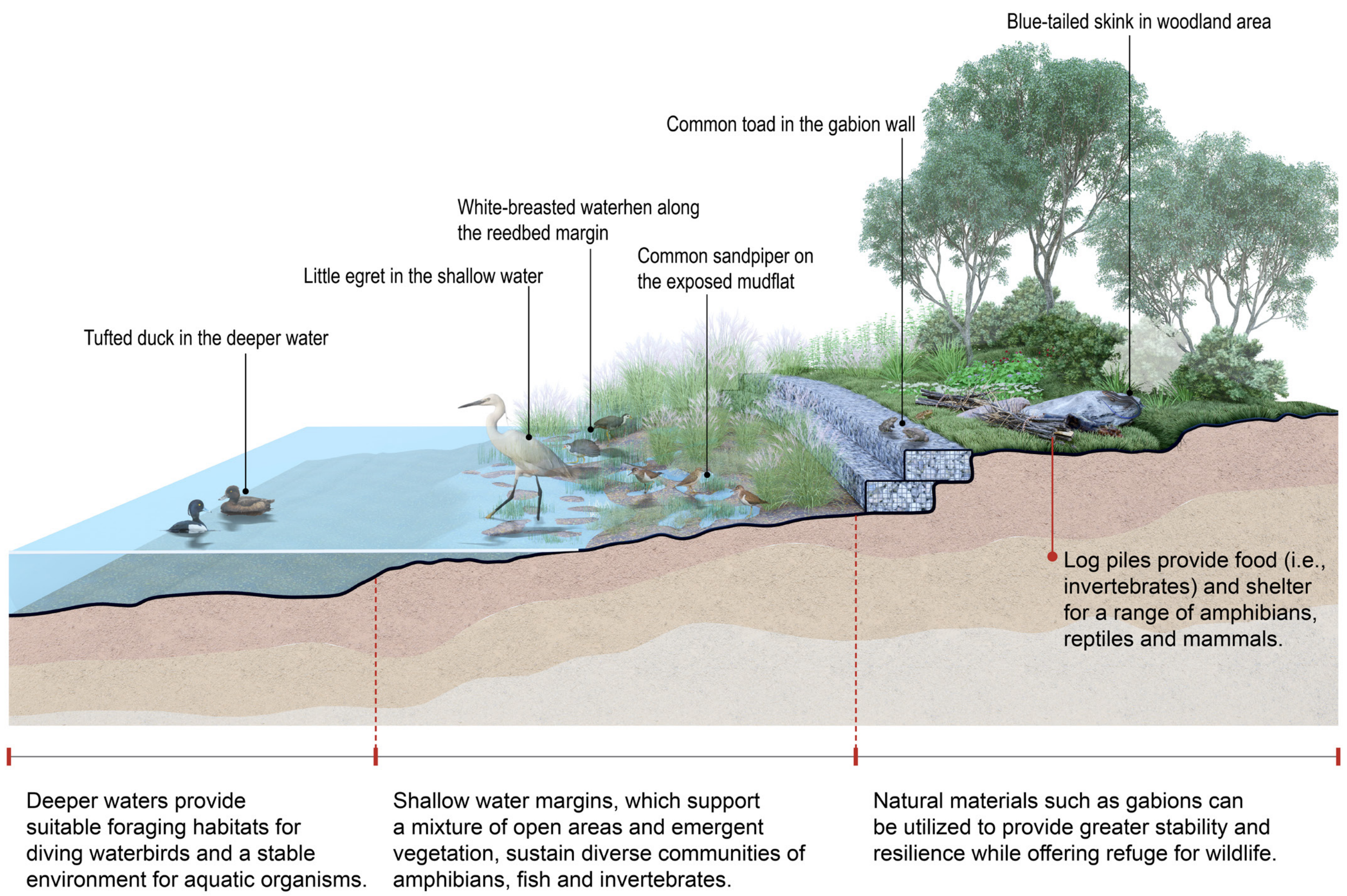
Maximizing Composition Richness at Meso Scale

Physical complexity at the meso scale refers to structural diversity within habitats and ecosystems. Besides increasing biodiversity, structural diversity at this scale is also linked with other important ecosystem services such as primary productivity and carbon sequestration (e.g., Hardman et al., 2011). Compositional richness in the fundamental building blocks of nature, whether natural or man-made, plays a crucial role in shaping diverse and functional ecosystems.

Within forest landscapes, structural diversity is largely provided by the trees and plants that characterize the overall community. By incorporating a diverse array of tree species, canopy structures, and understory vegetation, designers can create habitats that cater to a wide range of wildlife. Varying tree densities, age classes, and species compositions enhance the complexity of forest ecosystems, providing niches for different organisms to thrive. Features like clearings, deadwood habitats, and water bodies further contribute to the ecological richness of forests.

Within river and wetland ecosystems, meso-scale diversity is crucial for supporting a wide range of aquatic and terrestrial species. Water depth, for example, is a key consideration for wetland bird communities. Some birds such as rails prefer foraging for insects in very shallow waters along the water's edge. Other birds like herons and egrets hunt for fish and other prey in slightly deeper waters, whereas diving birds such as tufted ducks prefer waters several metres in depth to feed in. Designing wetlands with varying water depths, as well as diverse plant communities, and additional structural elements such as log-piles creates habitats for amphibians, birds, fish, and invertebrates. Maximizing composition richness in ecosystems also enhances other functions such as nutrient cycling (e.g., Oelmann et al, 2011) contributing to the overall resilience and adaptability of ecosystems.

Nature is a complex array of living and non-living elements, and design should strive to mimic this complexity.



Landscape elements contribute to composition richness along a waterway, making it a more conducive habitat for various species.

The same approaches used in natural habitats can also be applied in urban settings: maximizing compositional diversity by integrating various habitat elements and native planting. Species selection is crucial for maximizing biodiversity. In urban parks for example, diversity can be promoted by utilizing plant species that flower and fruit throughout the year, supporting local wildlife. Incorporating pollinator-friendly plant species enhances biodiversity, supports essential ecosystem services, and helps maintain healthy urban ecosystems (e.g., Poole et al, 2024).

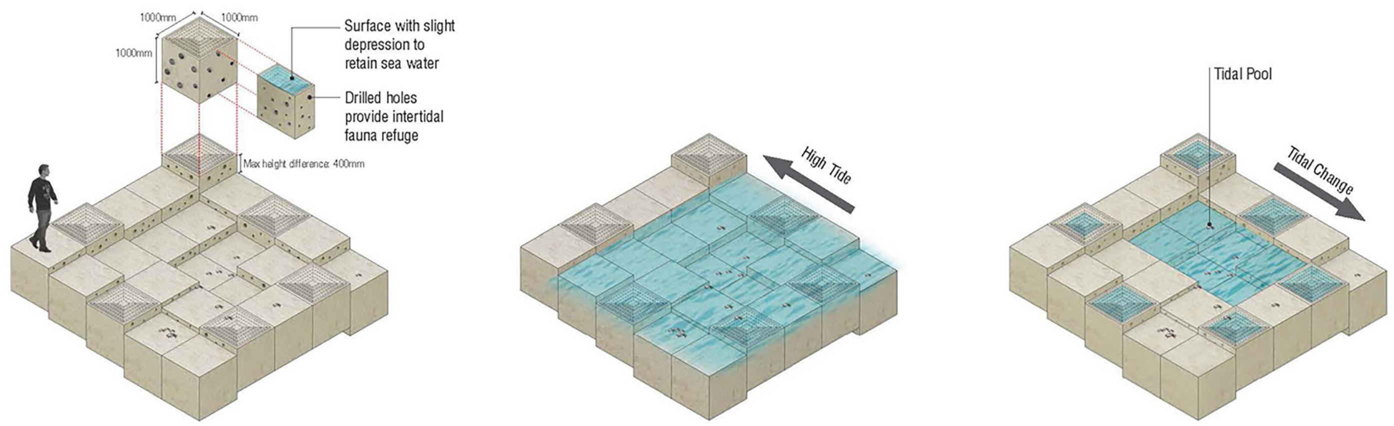
Promoting Micro Scale Complexity

At the micro scale, complexity plays a pivotal role in sustaining habitats for a wider range of life forms. Intricate textures and finishes are essential in providing shelter, food, and breeding grounds for smaller organisms, contributing to the overall biodiversity of ecosystems.

Natural materials such as tree bark, soils, and fallen leaves and branches form remarkably complex and diverse micro-habitats. They are host to a richness of organisms in forest ecosystems including lichens, mosses, fungi and invertebrates, many of which play critical roles in ecosystem functions including nutrient cycling and ecosystem dynamics. In contrast, within urban areas, there is a tendency to "over-manage" landscaped areas by removing all fallen leaves and branches. Adopting a lighter touch can help urban greenery better replicate the ecosystem services provided by natural habitats.

Deadwood and leaf debris ecologies

AECOM's award-winning Eco-shoreline design at Tung Chung East in Hong Kong

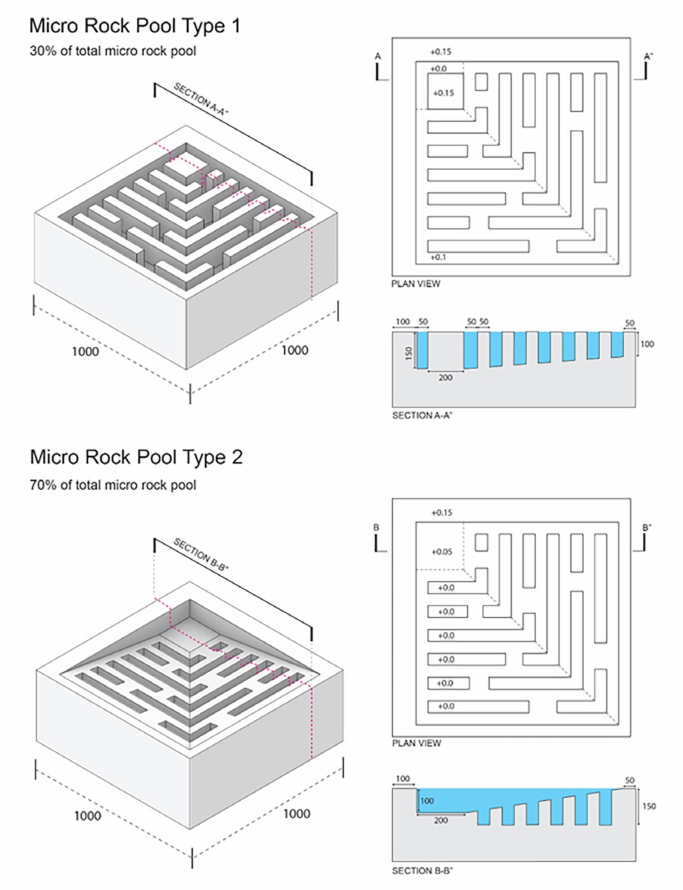


Tung Chung East Eco-shoreline: Typical rocky shoreline module (5x5m created from twenty-five 1m³ bio-block unit)

Nature-inspired hard landscape features can also enhance urban biodiversity. Gabion walls, made from wire cages filled with rocks, provide structural support and create habitats for insects, amphibians, reptiles, and plants. Eco-shorelines can be created in intertidal zones, where enhanced surface complexity creates and maintains rich marine ecosystems. Different niches responding to physical stress (e.g. heat and desiccation) and biological stress (e.g. competition and predation) drive higher biodiversity: from algae to invertebrates to fish. Similarly, concrete printing can be used to mimic the micro scale complexity of sub-tidal reefs. Key factors to be considered in creating complex artificial structures include number of components, variability and range of their dimensions, density, relative abundance, and spatial arrangement (Loke et al., 2015).

Finally, specific artificial enhancement features that replicate natural structures can be used in both natural and urban settings to enhance the value for wildlife. These most commonly include nest boxes and bat boxes that mimic holes and cavities found in natural structures (such as trees and sandbanks).

In ecosystem design, considering diversity at different scales is essential for creating thriving, resilient and productive habitats. At the macro level, spatial formations and habitat richness lay the foundation for diverse natural conditions. Maximizing compositional diversity at the meso scale and carefully selecting "nature's building blocks" allows designers to create landscapes that support biodiversity, ecosystem services, and human well-being. The micro level, focusing on intricate textures and niches, provides shelter and sustenance for smaller organisms, enhancing ecosystem complexity. By synergizing these levels, designers can establish high performance ecosystems that promote biodiversity and other ecosystem services.



Tung Chung East Eco-shoreline: Micro Rock Pool design at selected 1m³ bio-block unit

Foundation 2:

Delivering Symbiotic Built and Natural Environments

For too long, human behavior towards nature has been extractive and destructive. With the effects of the climate crisis and biodiversity collapse now pummelling even urban enclaves and capital cities, more people are realizing that our behavior must change. Nature-based solutions and ecosystem-based approaches not only deliver biodiversity gains, but also provide ecosystem services that address societal needs such as clean water, flood management, and food production, to name a few. By taking a high-performance ecosystem approach, we can maximise the benefits that natural systems provide to people.

We also recognise that high-performance ecosystems are not limited to wilderness areas of forests and oceans, but are also integral components of human landscape: shaping our rural and built environments and providing multiple benefits to the people who work and live in them.

The term symbiotic describes a relationship where two different entities live closely together and derive mutual benefits from their association. By emphasizing the interdependence between the built and natural realms, a philosophy of symbiosis emerges — one that envisions built spaces not as isolated entities but as parts of dynamic ecosystems. This principle underscores the critical importance of a holistic design approach, recognizing the profound impact humans have on the natural world and vice versa. Understanding our role in the delicate balance of ecosystems underscores our responsibility to protect and sustain other species.

Maximizing Societal Benefits

The well-being of human societies is intricately tied to the health of the natural world, especially those ecosystems closest to them. The Millennium Ecosystem Assessment by the United Nations, which took place from 2000 to 2005, was an early attempt by the scientific community to fully describe and evaluate on a global scale the range of services people derive from nature. Ecosystem services were identified, evaluated, and categorized into four groups (MA, 2003).

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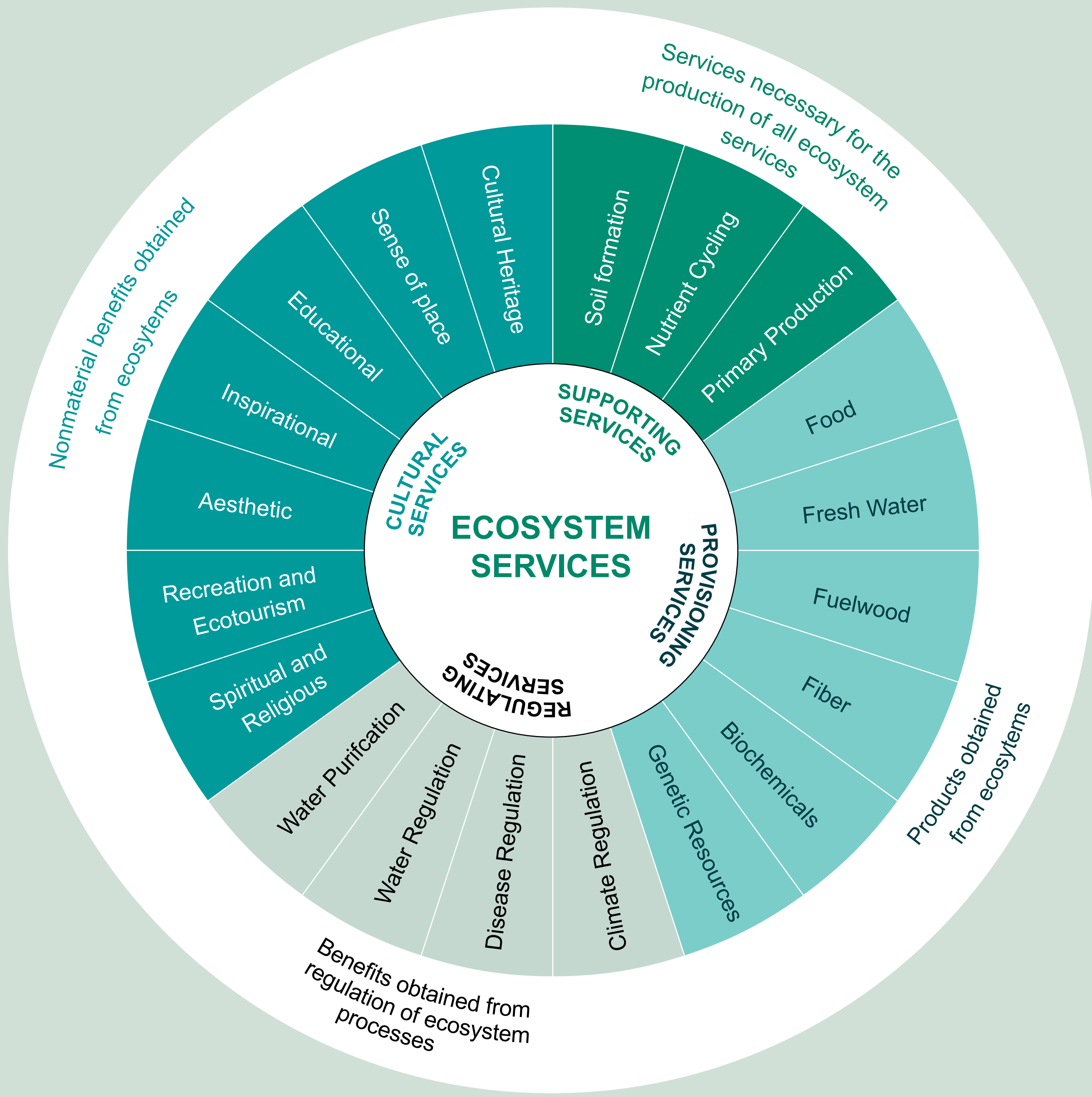
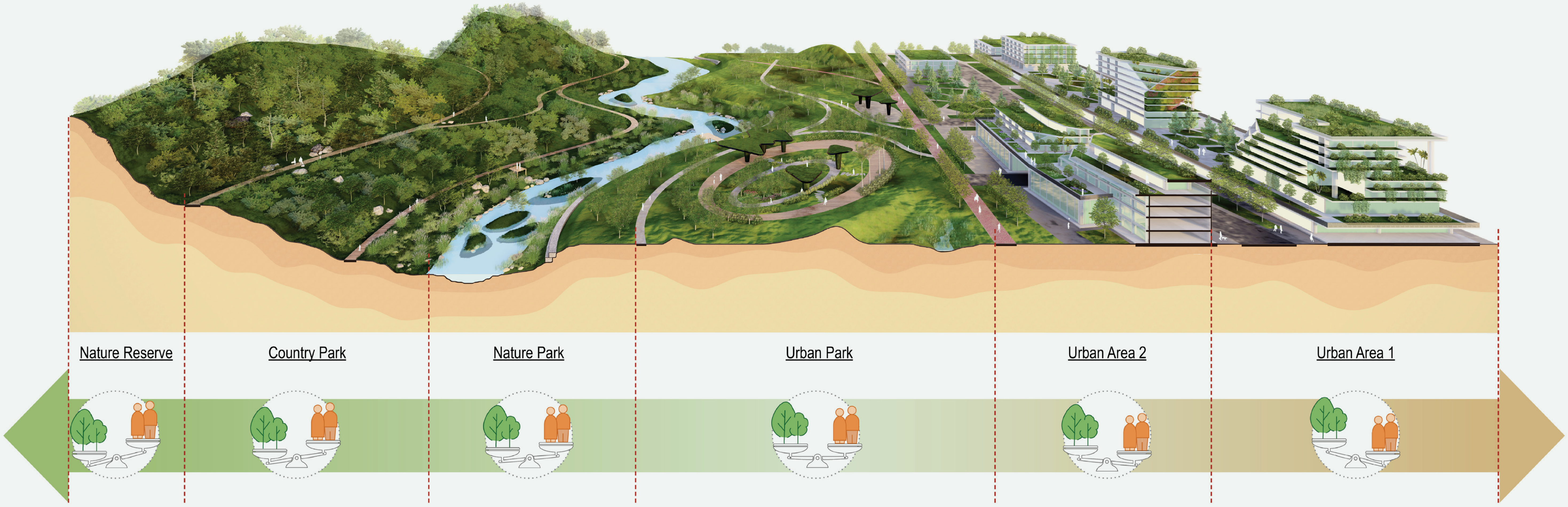


Ecosystem services (adapted from MA, 2003)



Example of gradation of potential ecosystem interventions from intense urban developments to wilderness areas

Even in a densely populated city such as Hong Kong, we can find various examples of such ecosystem services provide by natural environments:

- **Supporting** – Despite comprising less than 0.1% of China's land area, Hong Kong supports over 500 bird species, more than a third of that found across all of China (HKH, n.d. & BIOFIN, n.d.)
- **Provisioning** – In 2023, Hong Kong's capture fisheries industry produced an estimated $2.4 billion worth of fisheries products, ensuring a steady supply of marine fish for local consumers. (AFCD, 2023)
- **Regulating** – A 2010 study estimated that Hong Kong Country Parks sequestered a total of 3,214,404 tonnes of CO2 in 2004. (Delang & Huang, 2010)
- **Cultural** – Approximately 13 million visitors were recorded in Hong Kong Country Parks in 2023, engaging in activities such as hiking, leisure walking, fitness exercise, barbecuing, camping, and family outings (AFCD, 2024).

For designers, it is important to understand the range of potential ecosystem services that can be provided by any given landscape, and which of these services would be of most value to local populations as well as society more generally. High-performance ecosystems aim to deliver multiple services with the maximum benefits given the location, scale and type of project. For example, restoration of large areas of degraded forest would focus on carbon sequestration and biodiversity provision, whereas creation of an urban pocket park might focus more on water regulation, recreation and education.

Stakeholder engagement is an important aspect in the design of sustainable environments, particularly when ecosystem services are being considered. Local communities, government agencies, businesses, and non-governmental organizations will each have their own ideas and priorities for the targeted benefits. A collaborative approach ensures that ecosystem services are maximized and equitably distributed. Recognizing and integrating local knowledge into the planning process also helps create more effective solutions.

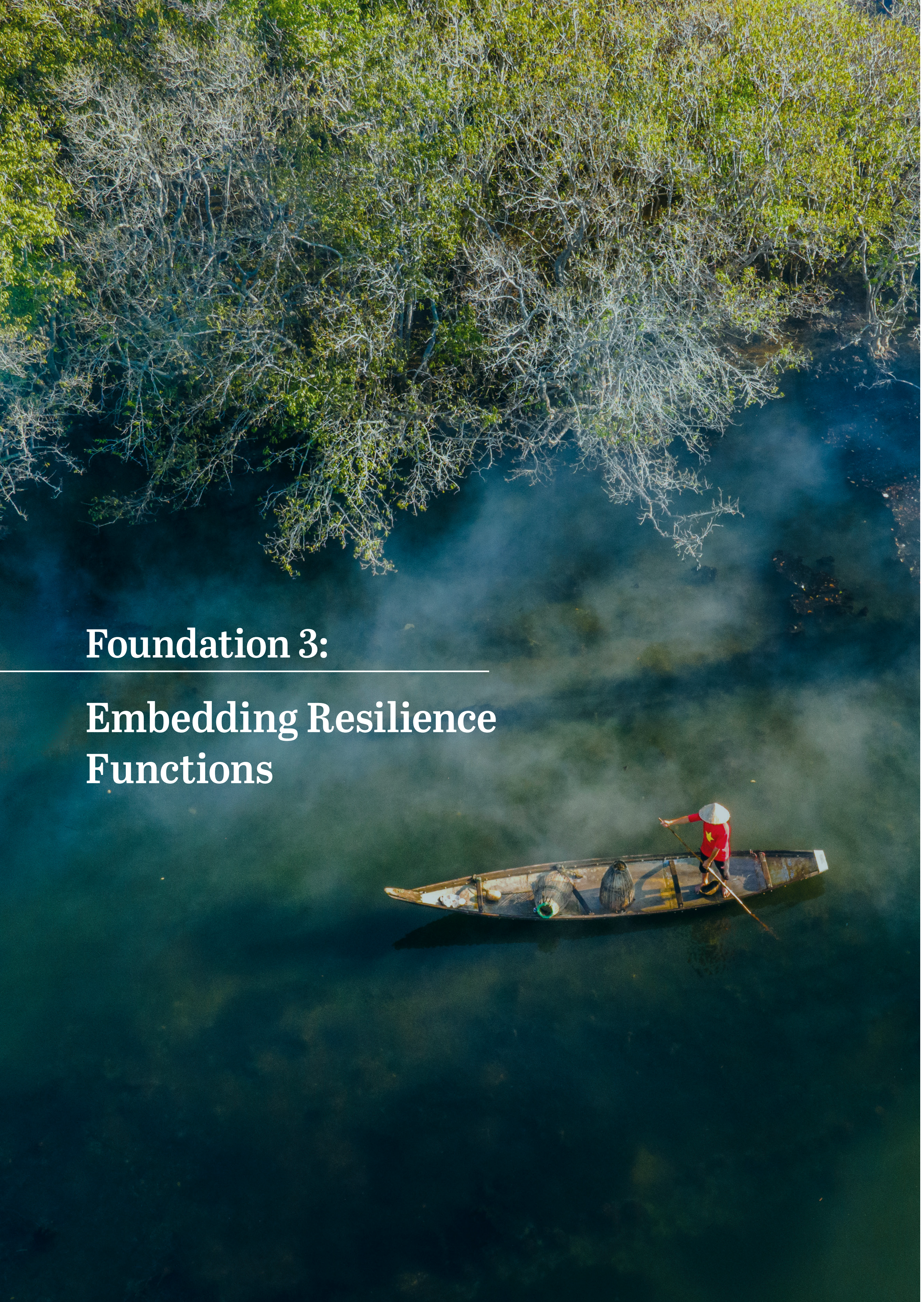
Ecotones: Transitions between the Built and Natural Environments

Ecotones are dynamic interfaces where the characteristics of adjacent ecosystems intermingle, creating a unique blend of flora, fauna, and environmental conditions. Functioning as transition zones, ecotones play a vital role in supporting diverse species, facilitating nutrient cycling, and serving as buffers that enhance ecosystem resilience (e.g., Dai et al, 2023).

The concept of ecotone transitions can be adopted when considering the relationships between high-performance ecosystems and the surrounding environments, particularly in urban settings. There is a gradation of potential ecosystem interventions, from intense urban developments through to wilderness areas, along which the relative influence of human and natural environments changes. At each step along this gradient, we should carefully calibrate the interface between human activities and nature, creating vibrant and sustainable environments that deliver both ecological health and human well-being.

At the outset of planning, it is crucial to identify and value ecologically sensitive areas so that human activities are carefully situated around them, ensuring a harmonious coexistence. Zoning within conservation parks exemplifies this, where designated areas cater to both human recreation and wildlife habitat, fostering a shared landscape where the needs of nature and humanity intersect and flourish in tandem. Even in more urban landscapes, quiet spaces can be created with less human access that provide a refuge for wildlife.

A seamless transition design approach serves as the foundation for harmonizing urban and natural environments, integrating visual aesthetics, landscape programs, and ecological functionality to create a unified landscape. Integrating ecosystems into urban planning is not just a design choice but a necessity for sustainable urban environments.



Foundation 3:

Embedding Resilience Functions

Resilience refers to several different functions of ecosystems. Firstly, it is the capacity of an ecosystem to endure through adversity or significant stress. Design choices can enhance the ability of ecosystems — whether deep in nature or integrated within urban environments—to adapt to climate challenges and recover from disturbances. Secondly, it characterizes the regulating services provided by ecosystems that can help societies adapt to and mitigate the impacts of the climate crisis. Finally, it also pertains to socio-economics: designing, building and managing high-performance ecosystems can be considered an additional 'cost' by governments and other stakeholders. Providing ecosystems that minimize capital investment and management financing, as well as simplifying the way in which ecosystem services can be measured and valued, offers resilience to changing socio-economic contexts. By embedding resilience at multiple levels, we can create ecosystems that not only withstand adversity but also self-regulate and thrive, ensuring vitality in an ever-changing world.

Embedding Nature Resilience

The changing climate is having significant impacts on the natural world: the distribution, seasonality and behavior of plants and animals are shifting in response to changing climatic conditions and associated phenomena such as sea-level rise (Zeng, 2023). The design of high-performance ecosystems needs to respond to these changes to create nature resilience and ensure the continued delivery of ecosystem services.

At a global scale, creating landscapes that promote biodiversity moves us closer to nature positivity. Larger areas of high-quality habitats will increase the resilience of nature to climate related changes and other types of human disturbance, helping to secure the viability of threatened species and habitats.

At a project level, measures that need to be considered in designing resilient ecosystems include using species tolerant of future temperatures and those capable of withstanding flooding and drought conditions. Additionally, it is crucial to provide sufficient space for ecosystems to respond to changing environmental conditions. Particularly, maintaining eco-corridors will enable species to migrate in response to shifting climates.

Furthermore, it is important to avoid the use of exotic species that could potentially become invasive. Studies have shown that the disruption to natural systems caused by climate change can facilitate the spread of invasive species (Cho, 2024). By considering these measures, we can design ecosystems that are better equipped to adapt to future environmental challenges.

By embedding resilience at multiple levels, we can create ecosystems that not only withstand adversity but also self-regulate and thrive, ensuring vitality in an ever-changing world.

Embedding Climate Resilience

Embedding climate resilience considerations is paramount for creating ecosystems that can effectively combat climate impacts. Natural and semi-natural systems serve as powerful mechanisms for enhancing resilience, leveraging their inherent functions to mitigate environmental stressors and extreme weather. One key area where this is evident is in flood resilience, where innovative approaches to river and coastal design can significantly improve flood storage capacity.

For instance, natural river design focuses on restoring rivers to their original, meandering state, which enhances their capacity to absorb and manage excess water during heavy rainfall events. By reintroducing features such as wetlands and floodplains, these systems can act as natural sponges, reducing the speed and volume of floodwaters that reach urban areas. Similarly, upgrading forest areas can enhance their ability to retain water and manage floods. Implementing practices such as selective logging and the creation of buffer zones can increase soil permeability and vegetation density, allowing forests to store more water during storms.

Another compelling example of embedding climate resilience through natural systems is their use for coastal defense. Constructing living shorelines — integrating natural elements like wetlands and mangroves — provides a buffer against storm surges and rising sea levels. These can be combined with engineered structures to reduce erosion while working in harmony with natural ecosystems.

Embedding Socio-economic Resilience

Creating self-sustaining ecosystems is essential for fostering resilience while ensuring cost-effectiveness in environmental design. As we confront increasing ecological challenges and resource constraints, developing systems that can thrive independently reduces the need for continuous maintenance and intervention.

The first crucial aspect of creating self-sustaining ecosystems is utilizing existing assets through a thorough baseline understanding. Conducting a comprehensive assessment of the current ecological conditions — including soil health, water availability, and native biodiversity — allows designers to leverage these existing resources. For example, preserving native plant communities provides a resilient foundation for restoration efforts, ensuring the ecosystem is built on a strong ecological framework.

Another important strategy is to apply natural and native materials. Utilizing local resources minimizes transportation costs and environmental impact while ensuring compatibility with the local ecosystem. Native plants, adapted to regional climates and soil conditions, require less water and maintenance over time, creating landscapes that thrive naturally and support local wildlife.

Natural capital may also provide additional resources for the management of an ecosystem. Data monitoring and the quantification of benefits can create synergy with the commercial world by demonstrating the returns of conservation or enhancement efforts. By providing clear metrics and measurements, natural capital presents a compelling opportunity to invest in nature. This approach not only highlights the ecological and economic value of enhancing ecosystems but also enables businesses to evaluate the impact of their investments in natural resources.

High-performance Ecosystems:

A First Step in Balancing Development and Conservation

The world continues to urbanize, necessitating the provision of shelter, employment, education, and healthcare to an ever-growing influx of people in our cities. However, our planet remains in a fragile state. Development and conservation are often seen as opposing forces, but this need not be the case.

Those leading development projects must recognize that they not only shape human life but also leave a lasting impact on our planet. We are stewards of the land and not masters of it. To help the planet recover, we must tap the natural rhythms that allow biodiversity to prosper through high-performance ecosystems.

Meanwhile, those working in conservation could become more innovative in terms of project execution and unlocking capital. For example, governments are beginning to mandate biodiversity net gain for new developments. Many independent organizations are racing to standardize metrics for biodiversity credits while avoiding the pitfalls associated with carbon credits.

Embracing complexity and working across all scales, regardless of professional turf or specialty, can deliver inspiring and sustainable solutions that enhance the quality of life for both people and our planet.

Despite international efforts, progress on financing nature-positive initiatives remains uncertain. Discussions around financing climate and nature initiatives were contentious at both the recent COP16 and COP29. This uncertainty presents an opportunity for the private sector, governments, and organizations to step in and develop ambitious funding solutions. Creating high-performance ecosystems is a first step in building common ground between conservation action and the commercial world.

Embracing complexity and working across all scales, regardless of professional turf or specialty, can deliver inspiring and sustainable solutions that enhance the quality of life for both people and our planet.

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David is an Ecological Specialist with over twenty years professional and academic experience in Asia. His expertise spans environmental (planning, conservation, impact assessment, audit and monitoring), ecological (design, surveys and research), transplantation and faunal re-location projects, nature-based solutions (NbS) and natural capital assessment. Key high-profile projects include developing a biodiversity masterplan for Yunnan Province, designing the world's first large-scale eco-shoreline at Tung Chung East in Hong Kong, and developing Hong Kong's first Agricultural Nature Park at Long Valley. David is the Executive Committee Secretary of the Hong Kong Institute of Environmental Impact Assessment and serves on the Ecology & Biodiversity Group Qualification Panel for the Hong Kong Institute of Qualified Environmental Professionals.

Stephen Suen

Director, Landscape Architecture,
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Stephen is a UK-chartered landscape architect and urban designer with twenty years of professional experience, ranging from master planning to detailed landscape/architectural design on international projects. He received his master's degree in urban design from the Bartlett School of Architecture (UCL) in 2004 and has a degree in engineering with business finance (UCL).

As Project Director for the Hong Kong Design Studio, Stephen's diverse background in engineering and urban design has enabled him to lead multi-disciplinary teams on large scale development and regeneration projects. Stephen's work has included projects in Europe, the Middle East and Asia. Notable projects include London 2012 Olympic and Legacy Masterplan and Parkland Design; Education City, Doha; West Kowloon Cultural District; Tung Chung East Landscape Masterplan and the award-winning Eco-shoreline.

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