Strategic Paper on

Precision Biodiversity

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CONTENT

EXECUTIVE **SUMMARY**

Two decades into the twenty-first century and planet earth's citizens have been impacted by a global pandemic due to a zoonotic disease – Covid-19! How is it that despite all the amazing and spectacular advancements in Science, Technology and Innovation (STI), this catastrophic disaster could not be averted?

Emerging out of this disaster is the stark reality that the underlying cause of the problem is wanton destruction of biodiversity by anthropogenic activities. Humankind, without sufficient regard for sustainable development, has displaced and destroyed habitats of other living organisms. Thus, wild animals have entered environments where humans live, bringing along with them millions of microbes that otherwise coexist naturally in them. But once these microbes cross species boundaries and enter humans, disaster strikes as has happened with increasing frequency over the last forty years.

How can we turn this around so that we have a healthy planet and healthy societies?

The key lies in judicious management of Earth's biodiversity. The Academy of Sciences Special Interest Group in Biodiversity has formulated this Strategic Paper on Precision Biodiversity (PBD), to chart the way forward by leveraging emerging technologies of the Fourth Industrial Revolution (4IR) and advanced technologies to repurpose and redesign strategies that have not been effective so far, i.e. to do things differently for biodiversity.

Being the 12th mega-biodiverse country on earth, Malaysia has a global responsibility to conserve its biodiversity. By adopting PBD, the country will show the world how this first-time-ever approach, can more effectively protect the planet AND simultaneously deliver socio-economic returns. The vision is for Malaysia to be a nation that is informed and inspired to value and conserve bioresources while recognising the importance of investment in frontier technologies for the protection of biodiversity. Responsible and ethical stewardship of our ecosystem and establishment of a biodiversity-linked economy supported by sustainably managed biological resources will be driven by precision technologies alongside conventional approaches. Establishment of a national genome database to generate economic growth and promote human wellbeing is set to open up opportunities for translational research. Efforts powered by 4IR will also attract young tech-savvy talent and proficient human resource.

Since the last decade, high-end and advanced technologies of artificial intelligence (AI), machine learning (ML), robots, drones as well as genomic information have begun to be utilized in a few key fields like precision agriculture, precision medicine

and precision conservation. Biodiversity issues, however, are also wrapped around considerations such as climate change, population growth, environmental health and the need to be a source of food, pharmaceuticals, nutraceuticals and countless other spin-offs for the well-being of humankind. Hence a more robust approach is required for managing biodiversity.

Microsoft and other technology companies are deploying resources to ensure participation in what promises to be a greatly rewarding engagement with biodiversity that will help to protect the planet, while also generating economic benefits. Such an agenda jives well with what Malaysia's PBD expects to achieve. This is particularly relevant given the country's vast biological resources and the extensive repository of traditional knowledge available that can now be judiciously utilized, researched and managed. However, several challenges are threatening this agenda. Among the major road-blocks are a short-fall in staff trained in biodiversity issues, lack of harmonization between Federal and State biodiversity laws and programmes, insufficient funding, unregulated deforestation as well as encroachment on marine and coastal resources and the pressure on threatened, endangered and rare species. PBD is set to address these biodiversity-associated issues and challenges.

How can this be done?

PBD will utilize the country's 10-10 MySTIE Framework introduced in early 2020 to help Malaysia move up the global innovation value chain (Academy of Sciences Malaysia (ASM) and Monash University, 2019). There are 10 advanced Science & Technology Drivers mapped against 10 Socioeconomic Drivers, of which one is Biodiversity (and Environment). With the application of next-generation technologies, trade-offs from the challenges (e.g. deforestation) will be transformed to trade benefits (e.g. sustainable reforestation), with high Return on Value (ROV) that factors as both tangible (e.g. financial returns) and intangible (e.g. improvement in the environment and conservation) value-based outcomes derived from investing in PBD.

However, while it is important to leverage the transformational potential of these powerful technologies, it is also pertinent to acknowledge their destructive potential if left unguided. The risks must be assessed. The application of technologies will be ethics- and value-driven to ensure the safety of people and the planet remains a top consideration.

In streamlining the use of innovations for biodiversity, three general models are being advocated. The first is Climate Engineering, which entails large-scale interventions in natural landscapes to mitigate climate change. The second is Nature-Based Solutions that involve monitoring, managing and restoring natural and modified ecosystems. The final model is Green Disruptive Innovations to develop new strategies to provide specific approaches with time-based patterns to optimize conservation.

Precision technologies leveraging AI will be used to manage biodiversity (see page 66). The impact is expected to be even more powerful as it will be coupled to high-end precision biotechnology platforms tagged to the genome revolution. Conventional and disruptive biotechnology procedures such as next-generation genome sequencing will come together to deliver value-added products and services (see page 72). Whole-genome sequencing of entire forest reserves or selected organisms invaluable for conservation purposes, and enhancing crop and livestock yields (without encroaching on more forested land) are just a few examples.

A Malaysian success story that has gained global recognition is that of the oil palm (*Elaeis guineensis*) genome. The release of the oil palm reference genome sequence by the Malaysian Palm Oil Board was a key step in establishing Malaysia's prowess in harnessing genome technology for valuable outputs, including increasing productivity and sustainability. The immediate impact of the genome sequence was the identification of the *SHELL* gene (Singh et al., 2013a, b), the most important determinant of oil yield. Such efforts can now be replicated for other nationally useful PBD priorities (see Appendix 3).

Once PBD is implemented nationwide, Malaysia can beneficially contribute to global biodiversity projects such as the Consortium for the Barcode of Life (CBOL) and the Genome 10K (G10K) Project. Access to benefit-sharing will then be mutually rewarding provided safeguards are built-in via suitable intellectual property instruments. Creating a national genome database for Malaysia's flora and fauna, similar to the China National GeneBank will serve as a valuable infrastructure for agriculture, biology, conservation, medicine, and the growing global bio-economy. It is timely also to establish a natural history museum (physical or digital) to showcase our unique biodiversity for posterity.

The full implementation of PBD will generate copious amounts of information which will be captured, digitized and stored in user-friendly databases. These will be made freely accessible through various collaborative platforms, including the ASEAN Open Science Platform. This valuable resource should give the country an additional global profile as it becomes accessible also to international users. Our efforts to responsibly conserve, manage and utilize tropical biodiversity for environmental, socio-economic and health benefits will thus be disseminated to the global community. The catalyst will be scientific discovery and translational research powered by the 10-10 *My*STIE Framework. Details of the application of the Framework to PBD is mapped out in this Strategic Paper (see page 83). Six supportive strategic programmes and interventions are planned alongside action plans, timelines, and the key partners responsible for their execution (see page 95). The latter include Federal and State entities along with other stakeholders in the Quadruple Helix.

PBD has recently been earmarked as one of thirty National Niche Areas to be prioritised under 10 socio-economic drivers (Academy of Sciences Malaysia, 2020) of the 10-10 *My*STIE Framework. Accordingly, it is envisaged that PBDs narrative, goals, recommendations and strategic plans detailed in this Strategic Paper will be mainstreamed in all future five-year Malaysia Plans, including the 12th Malaysia Plan (MP12), and relevant national policies and initiatives. The establishment of a National Committee to coordinate all PBD and conservation activities will ensure proper management of PBD roll-out plans in line with the Shared Prosperity Vision and the United Nations Sustainable Development Goals.

The overarching requirement for success, as always, will hinge on strong political will and commitment. Given the impact of the global crisis of the Covid-19 pandemic, it is clear that business as usual is no longer an option. PBD, if successfully implemented, will go a long way towards ensuring a healthy planet and societies, powered by the transformation of trade-offs into trade-benefits between biodiversity and economic development.

INTRODUCTION
PURPOSE OF STRATEGIC PAPER

The Covid-19 pandemic has once again brought into sharp focus how vulnerable humankind is to the impact of changes to ecosystems, the natural environment and biodiversity. This virus is just the latest zoonotic disease i.e. infectious agent to cross from animals to people. In the past 40 years, we have experienced alarming proportions of zoonotic diseases (Wood et al., 2012), including HIV (1980s), Nipah (1998), SARS (2003), bird flu (2009), MERS (2012) and Ebola (2014). Humans come in contact with these alarmingly dangerous pathogens primarily due to their own activities by habitat destruction through deforestation, wildlife exploitation, industrial agriculture, population growth and urbanization.

It is estimated that 1.6 million unknown viruses reside in the bodies of various non-human organisms without causing much damage to their hosts while they reside in their own niche natural habitats.

However, once humans disrupt ecosystems and cause wanton damage to natural habitats, as is happening across the globe in modern times, the hosts are offered connectivity to other environments and often migrate (with their resident microbes) to new and varied ecosystems, now that their natural food-chain is disrupted. In time, their migration patterns bring them closer and closer to human habitats and increase the likelihood of human and non-human encounters. These encounters provide an opening to the numerous exotic and often lethal zoonotic diseases as the microbes may even cross species barriers.

The Covid-19 pandemic has been widely accepted as a failure to control zoonosis: a failure in responsible biodiversity efforts. The methods to reverse this self-destructive trend can be very simple and straightforward. Firstly, ensure that the microbes do not come in contact with humans by keeping their hosts' habitat undisturbed and at the same time ensure that the hosts themselves are not trapped and removed from their natural habitats. Secondly, humankind must strategise how best to judiciously conserve, preserve and manage biodiversity for economic well-being, using not only currently available methods but augmented by powerful modern technologies, to ensure the health of the planet.

The aim is to utilize next-generation precision technologies for research, data collation, retrieval and management as well as to deploy modern genetic tools to add value to economical and socially beneficial biodiversity. This approach is the first of its kind to ever be deployed to address issues of biodiversity in the country. A successful outcome will ensure that our precious biodiversity is carefully managed for posterity, using sophisticated modern tools of computer and communications technology as well as biotechnology, alongside other relevant methods currently in use. The strategies are set to ensure that the attendant socio-economic benefits will not destroy natural ecosystems or harm the environment, and above all to guard against a recurrence of any other dangerous pandemics from zoonotic diseases.

It is anticipated that such a novel approach will also align well with the UN Convention on Biological Diversity (CBD, 2020) and the Sustainable Development Goals (UNDP, 2016). But best of all, it could help to excite and draw the younger generation and society as a whole into wanting to contribute towards protecting and managing our unique and precious biological diversity, responsibly and sustainably.

Continuing with the same practices alone is no longer an option, more so in biodiversity-rich regions of the world. Malaysia as a mega-biodiverse country abounding in wild plants and animals in pristine tropical forests, and a variety of coastal and marine habitats, has the potential to utilise these resources for the well-being and socio-economic benefit of the nation. However, it is imperative to find a balance between utilizing and preserving these invaluable natural resources. The time is ripe now for next-generation biodiversity platforms, techniques, and guidelines to improve global solidarity to tackle biodiversity efforts and also ensure that such devastating diseases never plague humans again in line with the One Health Initiative (https://www.onehealthcommission.org/). To achieve these goals the Academy of Sciences Special Interest Group in Biodiversity has formulated this Strategic Paper entitled "Precision Biodiversity" to chart the way forward.

Precision Biodiversity: A Working Definition

Precision Biodiversity (PBD) is a complementary next-generation technological approach to conserve, monitor and manage biological resources by the use of advanced technology platforms for protection of the planet as well as for socio-economic returns.

The major technology drivers are advances in computer and communications technology (e.g. AI, ML, robotics, drones, Internet of Things (IoT)) as well as biotechnology (e.g. cloning, Omics, gene editing, synthetic biology).

When applied correctly, PBD reduces uncertainties related to managing natural resources, while also helping to ensure optimum deployment for profitability, sustainability and protection of the environment.

Precision Biodiversity Across Various Ecosystems

Ecosystems cover all living organisms as well as non-living elements in a particular area with which they interact such as air, soil, water, and sunlight. When in cyclical equilibrium, the relationship ensures that ecosystems such as pristine tropical forests, marine and other aqua habitats, coral reefs, wetlands, mangroves as well as other land- and seascapes, will provide a rich array of benefits that people depend on including fisheries, fresh drinking water, fertile soils for growing crops, climate regulation, as well as cultural and aesthetic responses. These benefits are called "ecosystem services" as summarised in Figure 1. These four types of ecosystem services separately and collectively contribute to a healthy and sustainable environment for beneficial utilization of biodiversity.

Figure 1 Ecosystem services in biodiversity (publicwiki)

However, human intervention has dangerously upset this equilibrium, to such an extent that it has been predicted that the planet is headed for its Sixth Mass Extinction (Ceballos et al., 2015).

Such destruction is primarily triggered by wanton loss of biodiversity and habitat degradation often carried out to meet the increasing influence of humans and the need for resources to satisfy modern lifestyles. Concomitantly, the energy budgets are expanding thus driving climate change that has also triggered catastrophic natural disasters (e.g. 2019-2020 'Black Summer' bushfires in Australia). In addition, continued habitat destruction and disregard for animal welfare could once again escalate the possibility of more global pandemics from zoonosis, maybe even worse than Covid-19.
Another crisis building up is insufficient food to feed a rapidly growing global population, expected to reach 9.7 billion by 2050 and to peak at 10.9 billion by 2100 (UNDESA, 2019). Further encroachment into natural landscapes for expansion of agriculture should not be an option, as it will dangerously threaten the survival of countless species and their ecosystem services in the Asia-Pacific region.

These unique ecosystems anchor food supply chains and once disrupted endanger the livelihood and health of communities as well as the environment (FAO, 2019). Current and future food production, as well as food security, relies heavily on judicious conservation of agro-biodiversity to ensure that the basic needs of communities can be assured for present and future generations. What needs to be done is to harness new technology-driven and innovative approaches to boost productivity and yield without further encroachment into biodiversity-rich ecosystems (see page 66).

The damage to biological diversity includes a declined population of rare and endangered plants, large wild mammals and birds, and as much as 37% of aquatic and semiaquatic species. Biodiversity losses have escalated over the last century probably at a rate of about 22 times the base extinction rate for a total of 2 million species described so far. These figures represent only about 1% of the number of species projected to be on Earth (Mora et al., 2011) which proves that a minuscule change in nature brings heavy consequences. Insects, so vital to ecosystem services which include pollination activities were reported to be down by 25% in numbers since 1990 (van Klink et al., 2020). All of these are the result of anthropogenic activities, including overfishing, poaching, illegal logging activities, pollution, farming, infrastructure development, urbanisation and the presence of invasive alien species. Taken together, all this damage has correctly raised red flags about future catastrophes.

It is generally acknowledged the current Covid-19 pandemic is largely an expression of our failure to address the adverse effects of Man's footprint on biodiversity. Ecosystem disruption poorly monitored and managed by the use of traditional approaches as in the Brazilian Amazon (Palmer, 2019) is affecting all fronts of human endeavour to offset environmental and habitat destruction. Even our knowledge of the global record of the Earth's population of the total number of species discovered and described so far (about 2 million), has a shortfall of about 8 million. This conclusion was deduced from a recent study using innovative tools. Time and the lack of funds have been the primary hurdles that have stymied progress in closing the gap. Invaluable genomes useful to humankind may be hidden or even lost forever without some realistic strategies in hand to unearth and document them. These challenges (see page 49) need to be acknowledged so that the proper strategies can be implemented.

It is therefore timely to repurpose the on-going efforts by engaging new tools immediately to help ensure ecosystem services are sustainably managed and conserved. Precision technologies such as AI, ML and associated technologies can now be utilized to address the problems. These technologies, which first gained traction in 2016, have become increasingly cost-effective and power-efficient. If judiciously applied, they can revolutionize current approaches to discovery, conservation, protection, monitoring and utilization of biodiversity and ecosystems.

Communications technology and computer companies are already committing resources in this direction. Microsoft has provided the required leadership and after launching in 2018 its "AI for Earth" programme to help deserving ecologists and conservationists in their biodiversity research efforts, the computer giant opened an even more ambitious programme, "Planetary Computer" (Smith, 2020). This programme will fully utilize the latest in AI technology, ML and

Lucas Joppa,
Microsoft's first chief environmental officer, boiled down the concept of Planetary Computer succinctly in an interview for the Engadget Podcast.

metadata computing facilities via a platform that will provide access to trillions of data points collected by people and various AI fitted machines. These will be deployed to monitor activities of humans, animals, fishes, birds and plants, on the ground, in the sky or at sea. Even mosquitoes are being considered as small, self-powered data collection devices. These technologies can provide vital information to ensure an increase in the productivity of scarce resources while maintaining a balance between human development and environmental protection.

Early results from the Planetary Computer programme indicate that the algorithms created can, at phenomenal speed, sift through massive amounts of data from monitoring systems like tracking cameras, microphones, electronic sensors, robots or others.

By mining the metadata generated, humans and machines working together can more effectively and efficiently address the challenges confronting biodiversity issues today. The ultimate goal is to establish healthy societies, inclusive of indigenous societies, supported by a healthy planet.

Malaysia has already rolled out plans for Industry 4.0 and is moving fast to promote AI and ML technologies across industries and society at large. The time is right therefore to also employ these high-end technologies in biodiversity-related activities. Engaging these new-age tools will allow for accurate, rapid and safe systematic collection and collation of data from widely diverse ecosystems while machine-managed monitoring will facilitate more effective administration to ensure biodiversity is being catalogued, preserved, redistributed, protected and yet deployed judiciously for the common good. AI equipment will be able to provide real-time information on the status quo of natural resources, especially those in less accessible/visible areas where poaching, illegal logging, and environment-damaging poisons are often destroying and polluting land and waterways.

Additionally, if AI and associated technologies merge with modern genetic tools and platform technologies to address biodiversity issues, the benefits would be unparalleled. For example, genetic tools in combination with AI will allow for genomes from whole botanical gardens to be catalogued, dissected, characterized and mined to derive value-added benefits, be they for knowledge on gene function, evolutionary history, preservation or to repurpose for man's benefit. Germplasm of endangered species can be appropriately stored and monitored electronically while extinct and endangered species may be revived and reestablished for posterity in designated environments after genome recovery using appropriate biotechnology protocols (see page 72).

Today's cutting-edge technologies may also be deployed to produce better food crops, especially when coupled with bioinformatics to mine for relevant information generated from complex Omics data. Other technologies such as new generation sequencing, CRISPR-Cas9 gene-editing, cloning and synthetic biology can also be constructively applied to ensure that biodiversity products are processed into value-added products without compromising the status of natural resources.

To successfully roll out such a revolutionary new platform where ecosystems are carefully preserved and managed by new generation technologies, there must be collaborations between all components of the Quadruple Helix i.e. Government, Academia, Civil Society and Industry. Furthermore, appropriate governance with good policies and regulatory frameworks must be in place. Implementation and rigorous monitoring which are of paramount importance can generate successful outcomes only if Federal and State legislations are harmonized in an atmosphere of close collaboration and sharing of resources. For such beneficial buy-ins to materialize, the social and economic benefits must be evident to all stakeholders. They need to realize that apathy or rejection is not an option if the nation wants to play its part in working towards saving the planet and protecting humans from another global pandemic. The overarching driver of these new-age phenomena will be a strong political will.

There is a common belief that the arrival of humans spelt the beginning of the destruction of the world. This theory can be effectively debunked once PBD is judiciously applied to all ecosystems, alongside the repertoire of traditional tools which on their own somehow do not seem to be enough to protect planet Earth.

NATIONAL STRATEGIC **POSITIONING**

VISION STATEMENT

A Nation that is informed and inspired to value and conserve bioresources, and recognises the importance of investment in frontier technologies for the protection of biodiversity

MISSION STATEMENT

To ensure responsible and ethical stewardship of our ecosystem and establish a biodiversity-linked economy supported by sustainably managed biological resources and application of precision technologies, in harmony with other relevant technologies.

GOALS

1. Leverage on frontier technology to conserve, restore, document and research university.
2. Generate a national genome database targeted towards economic growth and human well-being.
3. Increase socio-economic benefits from biodiversity-linked engagement.
4. Increase capacity building for precision biodiversity.

CURRENT **DEVELOPMENT-DRIVERS OF CHANGE**

> “Must save lives, protect livelihoods and safeguard Nature to reduce the risk of future pandemics”

There is much discussion on a "New Normal" now that the global pandemic has paralysed Human's regular activities. This scourge has infected 30.5 million people and killed more than 900,000 (as at 19 September 2020; Figure 2), caused economic losses predicted to exceed trillions of US dollars, to say nothing of soaring unemployment numbers. A zoonotic disease which began in Wuhan, China in December 2019 has rapidly spread globally to 212 countries and territories (www.worldometers.info/coronavirus). As the world recovers and reopens "for business" it will be into a changed world. Most significantly is the universal acknowledgement that Humans themselves are responsible for the catastrophe.

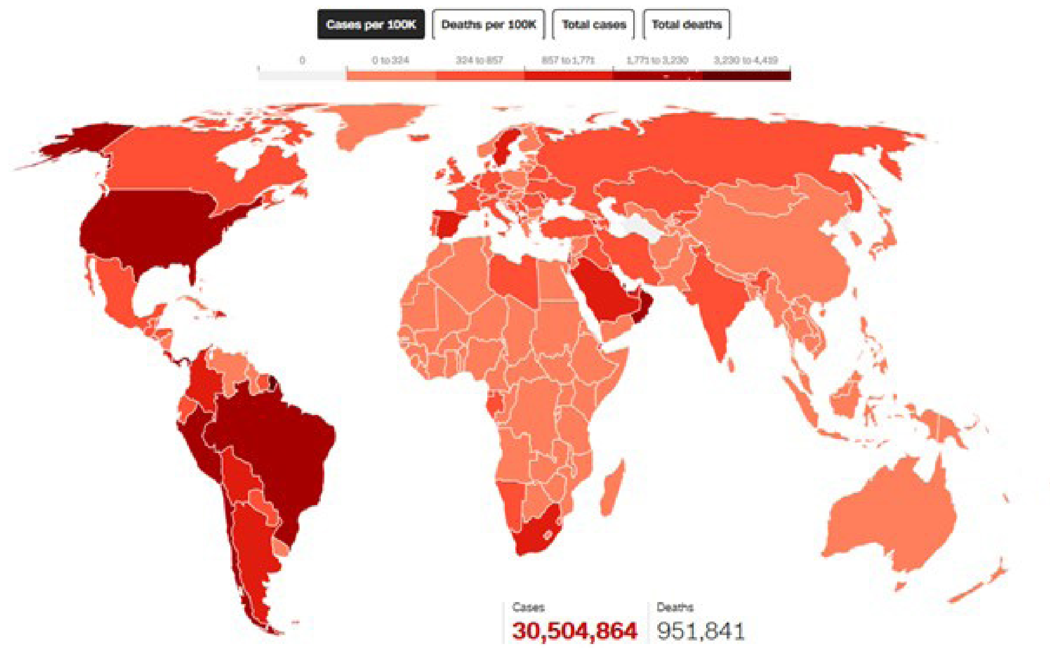


Figure 2 Covid-19 cases and deaths globally as at 19 September 2020 (CNN)

Unregulated and blatant destruction of natural resources, wildlife habitats and ecosystems often for monetary benefits, has brought drastic land-use changes and thrown humans within close proximity to lethal microorganisms that the human immune system cannot handle. Eminent experts affiliated to the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) have eloquently articulated that post Covid-19 stimulus measures "must save lives, protect livelihoods and safeguard Nature to reduce the risk of future pandemics". The drivers of change need to include sustainable and nature-positive initiatives. What better way then than to responsibly manage biodiversity both globally and in the country?

The National Policy on Biological Diversity 2016-2025, a comprehensive roadmap to show the way forward for Malaysia, has had little traction in preventing ruthless damage to natural resources, endangered species and the environment. In the current climate of a new norm, it is timely to revisit the traditional methodologies for conserving, protecting, monitoring and deploying biodiversity for socio-economic benefits and merge them with fast-developing new and emerging technologies – a suite of high-end tools driving Industry 4.0. With this approach, biodiversity too would gainfully benefit from harnessing exciting new tools to time-tested older methods to address its numerous challenges.

Such efforts are already in place for agriculture and medicine as well as for conservation. A closer look at these engagements should provide a valuable template for PBD.

PRECISION AGRICULTURE

Precision Agriculture (PA) refers to **a concept of agricultural management that uses digital technology to enable optimum production processes** (Rouse, 2016). Precision technology, in particular, targets resources, identifies contexts and enables optimization. The use of such technologies in agriculture has been seen as a timely entry to overcome the numerous environmental and economic challenges faced by growers. Using sensors, the precise measuring and managing of variabilities involving land, energy, water, fertilizers, pesticides etc. are carried out. The data collected are then processed using predictive analytics software and subsequently managed with targeted interventions. The targeted interventions are basically crop management strategies meant to guide farmers which include input on the best practices of crop rotation, soil management, optimal planting and harvesting schedule etc.

One example of how precision agriculture intervenes with crop management can be seen in the way the natural soil variability in a field is evaluated (Pepitone, 2016). Identifying the precise area which has better water-holding capacity enables sound decision-making where planting of crops or choice of grazing area is concerned. The identified area can then be planted more densely with crops or used as grazing area for cattle as compared to areas with poorer soil quality. In the same manner, precision approaches can also be used to identify the chemical properties, toxicity, temperature and nutrient status of soil. Water availability, irrigation schemes, labour costs, and accessibility of equipment are some aspects of agriculture that can greatly benefit from the regular adoption of PA. In the long run, precision strategies as such ensure a sustainable supply of food, which contributes to the overall economic wellbeing of the community.

Through the optimized management of crop science, environmental sustenance and economic growth, PA is in fact, creating an avenue for farmers to revolutionize farming practices by creating a new farming culture with greater access to traceability, enhanced decision making, strategic marketing and quality improvement insights, real-time agricultural solutions etc. It is through such systematic and customized approaches to agriculture that PA succeeds in driving the industry forward with enhanced agricultural practices that boost productivity, economic outcomes, and agricultural outputs, and minimize waste of resources; which result in improved crop yields, increased cost-effectiveness and reduced environmental impact. PA plays a fundamental role in minimizing uncertainties that farmers are traditionally faced with, and by addressing them using emerging tools in communications and computer technologies (Figure 3), PA can play a key role in creating a culture of economic profitability and environmental sustenance.

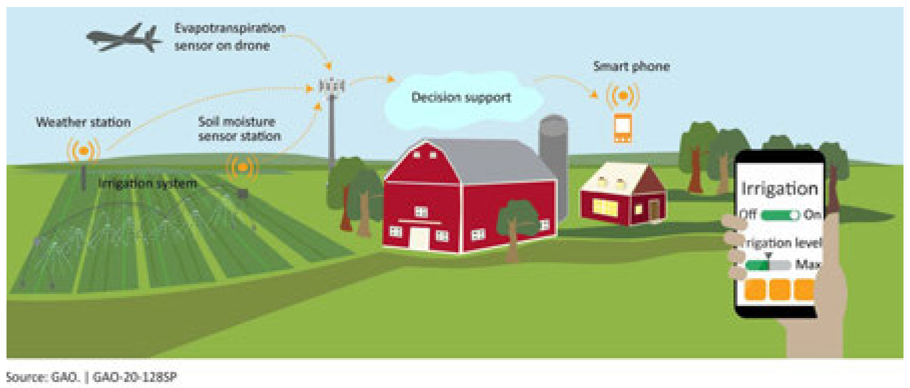


Figure 3 A possible configuration of a smartphone-integrated precision agriculture system (GAO)

PRECISION MEDICINE

Moving away from the traditional one-drug-fits-all approach, precision medicine has brought to the forefront **a patient-specific healthcare system, which customizes medical decisions and treatments of patients based on their genetic make-up** as reviewed recently by Ho et al (2019). Specifically, precision medicine's perspective of diagnosis begins with a person's genomic data, which are essentially individualized information about his/her physiological composition. Precision medicine, through rigorous computation of the genomic data of a patient, analyses and interprets the genetic origin of the patient's disease to facilitate customized diagnosis and treatments. The fundamental characteristic of precision medicine is its preparedness to provide a patient just the right treatment he/she needs at the right time. The effective functionality of precision medicine requires a cohesive network of an organized management system

of relevant data such as genetic databases, medical records, advanced computing technologies, and analytical expertise and aptitude of medical professionals.

One of the key contributory factors to precision medicine's greater success has to be the complementary role played by bioengineering technology. Precision in medical care can be actualized only with the right engineering tools and approaches and related enabling technologies, which possess the capability to transform traditional biomedical knowledge into precise clinical solutions and medical procedures as illustrated in Figure 4.

In precision medicine, it has been proven that the differences in genetic composition have varied impacts on patients' responses to diseases, thus necessitating the coalescing of various medical interventions to arrive at feasible treatment options. In deciding on the treatment options, everything from the patient's genetic history right up to the physical location and its environmental components, and the patient's lifestyle and inclinations, must be taken into account.

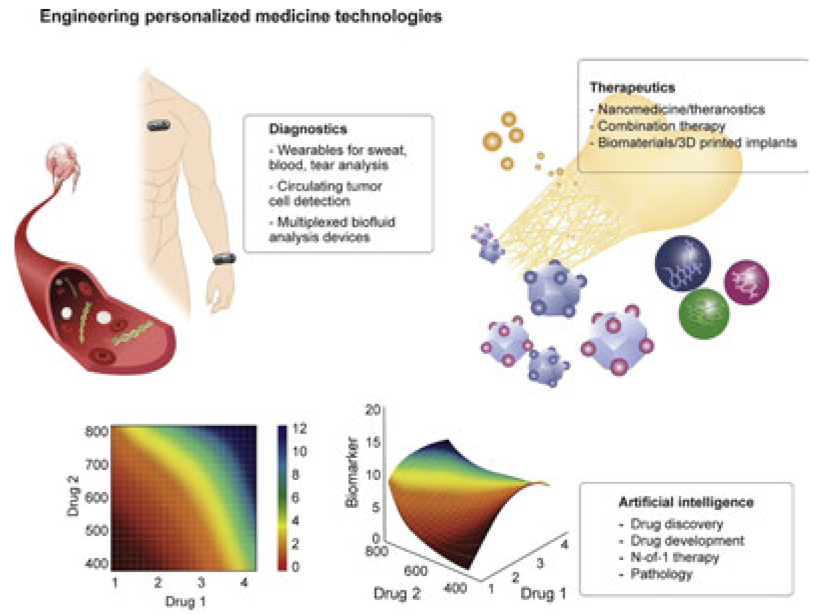


Figure 4 Engineering Personalized Medicine Technology Platforms (Trends in Biotechnology)

Precision medicine's conceivable potential in providing insights into diseases and their progressive capacities has been long recognized and the relevant biological targets and biomarkers duly identified. Collectively, these interventions can improve a patient's medical condition. Being positioned as a point of convergence between biological, engineering, computer, physical, and health sciences, precision medicine is essentially a healthcare approach that is data-driven and mechanism-based.

However, precision medicine is believed to be a practically feasible option only if it employs machine-learning algorithms in its practice, i.e. AI. AI's ability to examine big data, its deep learning technology, fast data processing, and high level of accuracy, are requisites for the effective practice of precision medicine. AI also projects outcomes of potential patients' chances of contracting a disease and this particular feature is especially crucial in pandemic situations. AI's ability to project such outcomes makes it an indispensable tool in the training of medical personnel because it allows them to know what symptoms to look out for thus enabling effective risk mitigation of diseases.

PRECISION CONSERVATION

The conservation of biological diversity is, in essence, protecting the continuity of its food chains, preserving in the process, the genetic diversity of organisms on land, in the sea and in the sky alongside sustainability of its natural systems. When carefully managed, it can lead to the wellbeing of a nation and provides socio-economic benefits. Unfortunately, Human activities have challenged such beneficial outcomes. Current methods of biodiversity conservation are often tedious, time-consuming, labour intensive and expensive, not to mention being fraught with danger from covert activities that are designed to render maximum monetary benefits to the perpetrators at any cost, regardless of environmental damage. This uphill challenge to conserving the world's biodiversity took a welcome turn for the better in the last decade once Precision Conservation came into the picture. Precision Conservation **engages with emerging technologies like AI, robotics, drones etc**.

Drones as a relatively risk-free, low-cost, low-energy but high technology application have begun to be deployed to monitor the destruction of natural environments and habitats as well as to map biologically diverse populations (Lopez and Mulero-Pazmany, 2018). One success story in precision conservation was recently reported in the Peruvian Amazon where high-end technology was engaged in helping to rescue the area from unchecked environmental destruction due to illegal and irresponsible gold mining activities (Palmer, 2019). Expectations are high that the precision conservation approach will go a long way towards ensuring that one of the most biologically diverse regions in the world will be protected. However, to be fully effective a multidisciplinary

approach to precision conservation is necessary, as opined also by Lopez and Mulero-Pazmany (2018).

Besides conservation, biodiversity issues are wrapped around considerations such as research, climate change, environmental health and also as a source of food, pharmaceuticals, nutraceuticals and countless other spin-offs for humankind. Hence a more robust approach is required. PBD offers such an approach. The project will involve full engagement with emerging communications and computer technologies as well as with platform technologies in genetics and biotechnology (see page 72) while also being aligned with traditional methods currently in use.

Unfortunately, on their own, present-day methods have failed to ensure a healthy planet. PBD offers a novel and doable pathway to research, conservation, monitoring and management of biodiversity by full application of next-generation technologies to strengthen current methodologies.

With full buy-in by all relevant stakeholders, such an approach should go a long way towards ensuring not only a healthy planet but more importantly a healthy society where human wellbeing including socio-economic benefits co-exist with conservation of biological diversity.

One of the ways to make biodiversity interesting for industries besides managing it, is to introduce "biodiversity banking". This would make it possible to create tradeable permits designed for market exchange and devised from the assessment of an industry's impact on biodiversity.

BIODIVERSITY BANKING

Biodiversity Banking (BB) refers to conservation activities that compensate for the loss of biodiversity, with the goal of biodiversity maintenance through a framework which allows it to be reliably measured, and with market-based solutions applied to improve biodiversity. BB provides a means to place a monetary value on ecosystem services. Typically, this involves land protection, restoration, and/or enhancement. According to IUCN, since 2004, interest in voluntary biodiversity offsets has been growing in the United States, Brazil, Australia, Canada and the EU (Ten Kate et al., 2004). The experience gathered suggests that industry, governments, local communities and conservation groups all benefit from biodiversity offsets or BB.

The Biodiversity Offsets Scheme (BOS) is now in place to create biodiversity credits and biodiversity offset obligations generated from development and clearing of natural spaces (NSW Department of Planning, Industry and Environment, 2020). Biodiversity credits are generated from management actions that improve biodiversity value and are used to offset the loss of biodiversity value on development sites. These credits may also be obtained through judicious conservation of biodiversity through good management and environmental conservation that conserves, protects or enhances biodiversity of ecosystems. Similar to the concept of "carbon credits", biodiversity credits would be tradable permits designed for the market exchange and devised from the impact assessment on biodiversity by industries.

Trading of credits

Today, there are many companies that sell carbon credits to commercial and individual customers who are interested in lowering their carbon footprint voluntarily. These carbon offsetters purchase the credits from an investment fund or a carbon development company that has aggregated the credits from individual projects. Buyers and sellers use an exchange platform to trade, which would then act like a stock exchange for carbon credits. The quality and price of the credits depend, in part, on the validation process and sophistication of the fund or development company that acts as the sponsor to the carbon project. Voluntary units typically have less value than the units sold through the rigorously validated Clean Development Mechanism. In 2018, The European Union's carbon credits traded from $7.78 to $25.19 averaging $16.21 per tonne (Ember, 2020).

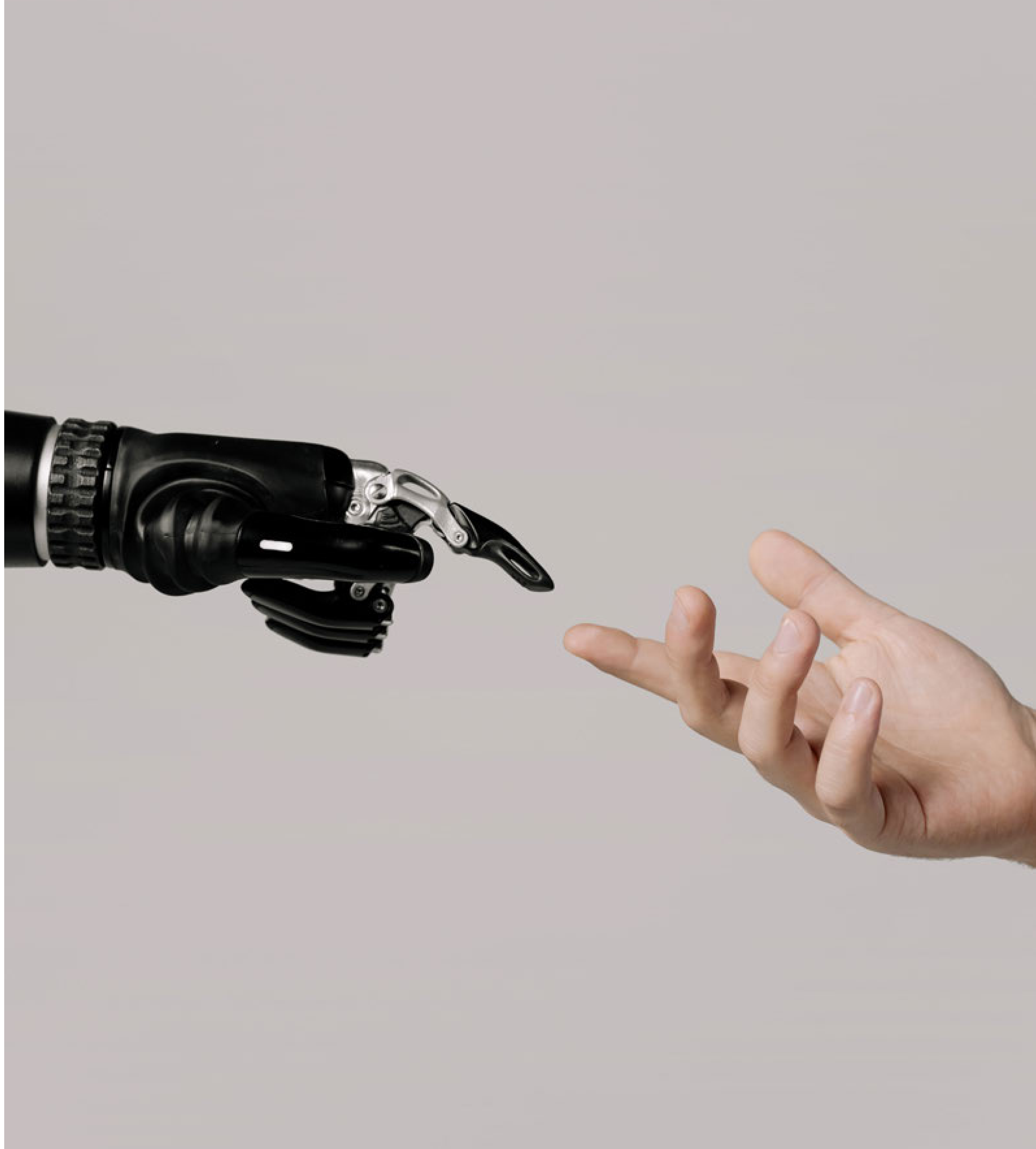
Similarly, in BB anyone may buy biodiversity credits subject to the regulations. A typical purchaser of biodiversity credits could be a developer seeking to offset his/her project's impact on biodiversity. Other buyers could be government bodies using the market to achieve conservation outcomes or philanthropic organizations using the scheme's robust structure to ensure the benefits of their endowments are maintained in perpetuity.

Ultimately, the market will determine the overall price paid for each credit. The landowner and credit purchaser will be free to negotiate any price as long as the Total Fund Deposit is secured in a BioBanking Trust Fund.

How can Malaysia benefit

Malaysia is recognized as a "mega-biodiversity" country and therefore could potentially gain from the trading of biodiversity credits. The operational mechanisms have not yet been formalised but if approved in principle it can readily be put in place, coupled with the services of bankers or accountants competent and familiar with such schemes.

By its current trading of carbon credits, the stage has been set for Malaysia to now embark and gain benefits from not only carbon credits but also biodiversity credits as a mega biodiverse country. The actual mechanism of harnessing this potential benefit remains to be carefully structured and formalised. As far as is known, this scheme of Biodiversity Credits or Biodiversity Banking has not been used in any country as yet. Malaysia could lead the way and be the pioneer country to develop and promote this scheme globally once government approval both at the Federal and state levels has been obtained.



CRITICAL CHANGES IN **GLOBAL ENVIRONMENT**

We examine the critical changes within the current global environment that have heavily impacted on biodiversity.

It was the Rio Summit in 1992 (UNCED) that first drew global attention to the dangers confronting the planet due to rapidly disappearing biodiversity around the world. The plea for sustainability to better manage biological diversity touted in the same summit was further consolidated ten years later during the Rio Earth Summit. At this summit in 2012, alarm bells were also raised to warn delegates and the world of the damage to biodiversity and the environment arising from the toxic effects of released petroleum-based chemicals, industrial wastes, environmental pollutants, radioactive chemicals and the likes, due to a relentless continuum of unregulated economic activities (Tollefson and Gilbert, 2012).

It was also recognized for the first time that alternative energy sources to fossil fuels needed to be developed and utilised to reduce the damage wreaked on nature and thereby on the health of the planet and society. The Kyoto Protocol (UNFCC, 2012) and the Paris Agreement (UN, 2015) sought to consolidate efforts to check environmental degradation and climate change, besides increasing sensitivity to the alarming extinction of species and even loss of indigenous knowledge especially in the mega-biodiverse parts of the world. But the rape of the forests and environmental destruction continued. And now in 2020, this laissez-faire attitude has been a major contributing factor for the current Covid-19 pandemic.

In this section, we examine the critical changes within the current global environment that have heavily impacted on biodiversity.

Population Growth

The world population currently stands at 7.8 billion (World Population Clock, 2020; retrieved 3 June 2020) of which more than half is found in urban environments. This number is expected to increase even further (Ritchie and Roser, 2018) and will present much more severe and critical challenges to current resources during the next three decades when the global population is expected to reach 9.7 billion (UNDESA, 2019). The UN World Urbanization Prospects estimates that 68% of the world's population will live in urban areas by 2050 (Figure 5).

Do more people live in urban or rural areas?, 2050

Share of the population which live in urban versus rural areas. Here, 'majority urban' indicates more than 50 percent of the population live in urban centres; 'majority rural' indicates less than 50 percent. Urban populations are defined basd on the deginition of urban areas by national statistical offices.This is basd on estimates to 2016, combined with UN projections to 2050.

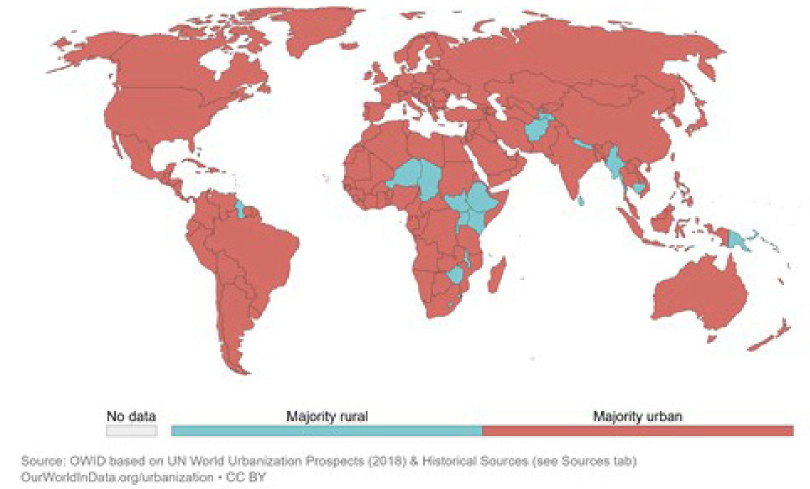


Figure 5 Urban population projection by 2050 (Ritchie and Roser, 2018)

The growth of urbanization is closely linked to economic growth. Over the last fifty years, while population growth has doubled, the global domestic product has increased four times. As populations get richer, they strive for improved living conditions such as better access to electricity, sanitation, drinking water, nutrition and healthcare, all of which are much more readily accessible in urban rather than rural settings (Ritchie and Roser, 2018). These developments generate increased demands for more land clearance, especially for economic development, housing, agriculture, farming and food production, pressures which then deplete biodiversity.

The greatest rate of change is taking place in developing countries. By 2050 more than 70% of the world's population will be centred in Asia, Africa and South America, parts of the most mega-biodiverse areas in the world (UN, 2018). Sustainability of natural resources will therefore be of paramount importance in these highly populated regions. And yet according to the Global Resource Outlook 2019 (Nijman, 2019), the planet's finite natural resources so very important for a sustainable world population are being depleted at an alarming rate. Data puts it as having tripled since 1970 and has been the single most important factor contributing to climate change and biodiversity loss.

Depleting Natural Resources

The depleting of the earth's natural resources both renewable and non-renewable is primarily due to human activities that lead to the rate of resource renewal being slower than the rate of consumption. The resources concerned fall under the category of forests, minerals and energy and include agricultural land and protected areas too. The Global Resources Outlook 2019 reveals that over the last five decades, the annual global extraction of materials grew 3.4 times by 2017 from an initial 27 billion tonnes. It is projected that based on current trends, the value will keep increasing to further double by 2060. It has also been found that the extraction and processing of materials, fuels and food contribute to about half of the total global greenhouse gas emissions and more than 90% of biodiversity loss and water stress. By 2010, land-use changes had even caused an 11% loss among recorded global species, including those classified as rare, threatened and endangered. The IUCN Red List reported there are more than 31,000 species threatened with extinction from the current 116,000 species on the list, including 41% of amphibians, 34% of conifers, 33% of reef-building corals, 25% of mammals and 14% of birds (IUCN, 2020a).

Continuous development that involves land clearing, natural habitat loss and industrial activities can have a direct or indirect impact on natural ecosystems and other resources besides affecting the economy. For example, activities upstream of a river often affect the downstream river mouth and coastal ecosystems, causing floods, and affecting riverine activities. And when mangrove forests are logged, the buffer they offer to ravages from storms and tsunamis are compromised alongside an effect on the coastal and marine biodiversity. The livelihood of fishermen is particularly sensitive to such activities as breeding grounds for fish are affected.

Other sources of concern around riverbeds are land erosion, siltation and chemical pollution, which can poison aquifers as well as disturb intertidal mudflats. Mudflats, besides being home to much marine life are also important feeding grounds for migratory shorebirds. Malaysia is committed to conserving these ecosystems as a member of the East Asian Australian Flyway Partnership (EAAFP, 2013).

The encroachment on natural resources and loss of ecosystems and habitats that are characteristically home to a multitude of living organisms not only cause severe loss of precious biodiversity, and climate change but can also lead to human-wildlife conflicts. Such scenarios are already being played out globally and could well have been a primary catalyst for the rise of zoonosis over the last fifty years as wildlife venture beyond their traditional comfort zone to survive the rampage on their homes. But what is becoming increasingly clear is that Human intervention and irresponsible depletion of biodiversity and natural resources is causing alarming climate change due to global warming. If left unmitigated, the catastrophe that is predicted could be even more devastating than a pandemic caused by microorganisms.

Endangered Mangrove Forest

In 2018, The New Straits Times reported the indiscriminate clearing of the last remaining mangrove forest in Juru, believed to be for the development of aquaculture ponds, was being carried out illegally without the approval from Seberang Prai Tengah Land and Mineral office. Based on information and previous studies, Sahabat Alam Malaysia (SAM) found that more than half of the mangrove forests in the state were converted before 1990.

According to one study, in the 1950s, Penang was covered with about 3,500ha of mangrove forests. Currently, the remaining area of mangrove forests in Penang island and Seberang Prai is not more than 400ha. (Shamsul, 2018)

Climate Change

Healthy ecosystems and rich biodiversity are fundamental to living organisms on planet earth. Human activities including agriculture, mining and exploration, urbanization, manufacturing, construction, transport and warfare, modify the environment in many ways. These actions have systematically led to an alarming global threat: climate change. Climate change immensely affects biodiversity and natural ecosystem. Since the start of the 20th century, the global average surface temperature has increased by more than 0.9°C (see Figure 6 on the next page). The Intergovernmental Panel on Climate Change (IPCC) also predicts a continuous rising of temperature between 1.1°C to 6.4°C by the end of the 21st century relative to the 1980-1999 baseline (IPCC, 2013).

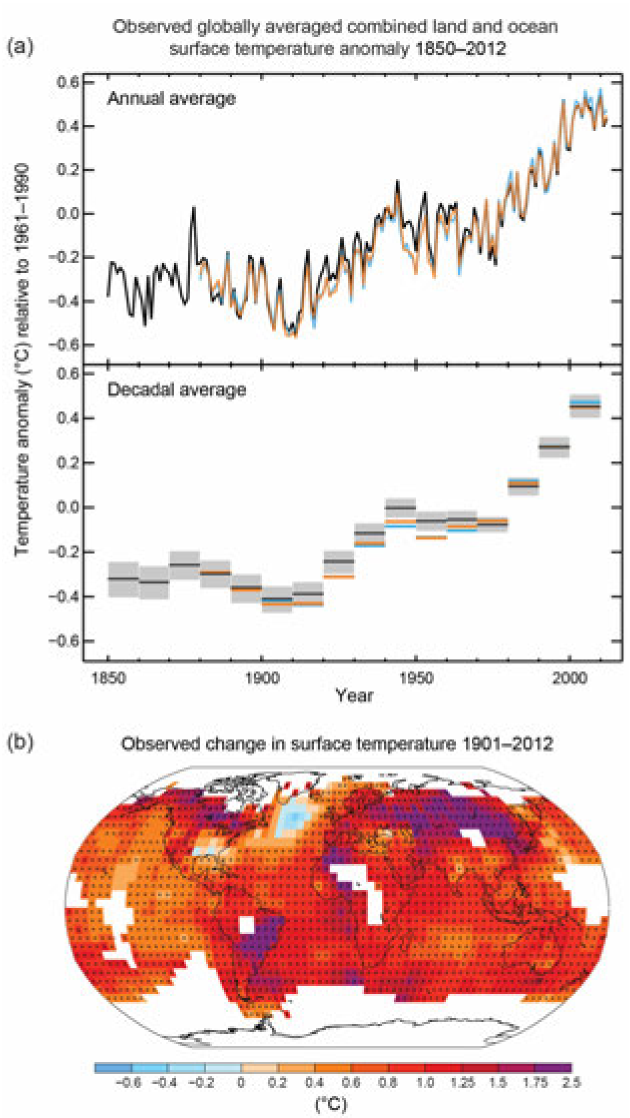


Figure 6 Observed global temperature change. (a) Observed global mean combined land and ocean surface temperature anomalies, from 1850 to 2012 from three data sets. Top panel: annual mean values. Bottom panel: decadal mean values including the estimate of uncertainty for one dataset (black). Anomalies are relative to the mean of 1961–1990. (b) Map of the observed surface temperature change from 1901 to 2012 derived from temperature trends determined by linear regression from one dataset (orange line in panel a). Trends have been calculated where data availability permits a robust estimate (i.e., only for grid boxes with greater than 70% complete records and more than 20% data availability in the first and last 10% of the time period). Other areas are white. Grid boxes where the trend is significant at the 10% level are indicated by a + sign (IPCC,2013)Ritchie and Roser, 2018)

Climate change has happened before throughout earth's history (e.g. The Great Ice Age); however rapid climate change affects ecosystems and species ability to adapt thus increasing the loss of biodiversity (or complete annihilation) which for Humans, translates into a risk to human security (Shah, 2014). While some species may benefit from climate changes occurring over the last fifty years, the rapid rate at which temperatures are shifting from previous norms suggests that most species will not find it beneficial and therefore will not be able to adapt (Shah, 2014).

In general, animals and plants may be able to adapt to small changes in temperature and humidity, or in the case of animals, they may even migrate to survive. But the loss of plants or animals from their normal ecosystem breaks the food chain they support and thus upsets food-web systems and the original ecological equilibrium. Some organisms will increase in numbers while others may decrease, until a new normal is established, maybe even with some species disappearing altogether. Such is the case with the fast depleting numbers of large mammals (e.g. elephants and rhinos) in deforested tropical ecosystems.

Without doubt, depletion of natural biodiversity and natural resources is the major driver of the extraordinary global warming and climate changes that have been taking place over the last five decades (Nijman, 2019). The major contributor to this phenomenon comes via rapid industrial and Human engagement in urbanization activities, and the attending conduit through greenhouse gas emissions. The impact is felt by all ecosystems even in the oceans. Besides damage to marine life in ocean waters, coral reefs too have lost their biodiversity mainly from the bleaching effects of raised temperatures.

An increase in ocean temperatures has also dramatically impacted the environment around the polar regions of the Arctic and Antarctic Oceans. Huge slabs of glacial ice breaking away and drifting out into open waters are signals of the impending catastrophes Humans are headed for.

As the polar caps melt, coastal shorelines are raised. Based on sea-level projections for 2050, land, currently home to 300 million people will fall below the elevation of an average annual coastal flood. By 2100, land now home to 200 million people could sit permanently below the high tide line (Climate Central, 2019). Islands and countries will lose precious landmass so vital for the livelihood of rapidly growing populations.

Melted polar ice
Image Source: Shutterstock

The endangered Sceloporus gadsdeni Species (EL Universal)

Losing Lizards to Climate Change

Climate change has been identified as one of the causes of species extinction and diversity shifts. A study by Sinervo et al. (2010) reported that extinctions by climate change are reducing lizard diversity globally. The study compared detailed surveys of 48 Mexican lizard species at 200 sites over 30 years and extended the model to all families of lizards at more than 1000 sites worldwide. The global projection model predicted that climate change threatens to wipe out 20% of the world's lizard population by 2080 suggesting that lizard populations have crossed a threshold for climate change tolerance and induced extinction.

Global Benchmarking

How well is the world addressing the challenges and threats to biodiversity as posed above? The Global Biodiversity Outlook (GBO), a flagship periodic publication of the UN Convention on Biological Diversity (CBD), provides the status of biological diversity and an analysis of the steps being taken by the global community to ensure that biodiversity is conserved and used sustainably, and that benefits arising from the use of genetic resources are shared equitably.

On 15th September 2020, the Secretariat of the CBD released Global Biodiversity Outlook 5 (GBO-5). It is the final report card on progress towards the implementation of the Strategic Plan for Biodiversity 2011-2020 (see Figure 7) and the Aichi Biodiversity Targets as summarised in Appendix 1, on agreements made in 2010 (GBO-5, 2020). The report records the alarming failures and limited successes achieved over the 10-year period. It summarises lessons learnt and best practices for getting back on track after having missed the 2020 deadline but resolutely determined to meet the 2050 Vision for Biodiversity.

GBO-5 reported that none of the 20 Targets have been fully achieved although six targets namely Targets 9, 11, 16, 17, 19 and 20 were partially achieved. The national reports submitted by 163 countries to CBD provided an overall picture of evident progress, even though at unsatisfactory levels to achieve completely the set Aichi Targets.

The bleak GBO-5 report did however put on record some significantly successful outcomes, such as for Goals A and B. Thus for Goal A, relating to the underlying causes of biodiversity loss, it was reported that almost 100 countries have incorporated biodiversity values into national accounting systems (Target 2) and for Goal B, relating to the direct pressures on biodiversity, the rate of deforestation was reported to have fallen globally by about a third compared to that in the previous decade (Target 5). These encouraging outcomes offer hope that more can be done, although not much progress has been made to address climate change or the fact that a total of about 1 million species are currently endangered.

Moving forward with the global biodiversity framework post-2020, GBO-5 advocates for urgent action that will bend the curve of biodiversity decline so as to attain the 2050 Vision for Biodiversity, "Living in harmony with nature". Paraphrasing the vision, this translates to having a world in which "by 2050, biodiversity is valued, conserved, restored and wisely used, maintaining ecosystem services, sustaining a healthy planet and delivering benefits essential for all people". Although there was limited progress in attaining the goals and targets set for biodiversity over the last decade, the 2050 Vision for Biodiversity will remain as the benchmark to guide global action on biodiversity in the years leading up to the half-century mark.

Lest we forget... even with all our technological advances, humans are still completely dependent on healthy ecosystems for food, shelter, medicine, energy and water to survive and sustain life. Small wonder then that on this year's Day for Biological Diversity, celebrated annually on 22 May, there was a clarion call for the global community to re-examine our relationship to the natural world with the spotlight set on hope, solidarity and the importance of working together at all levels to build a future where life and nature are in balanced harmony.

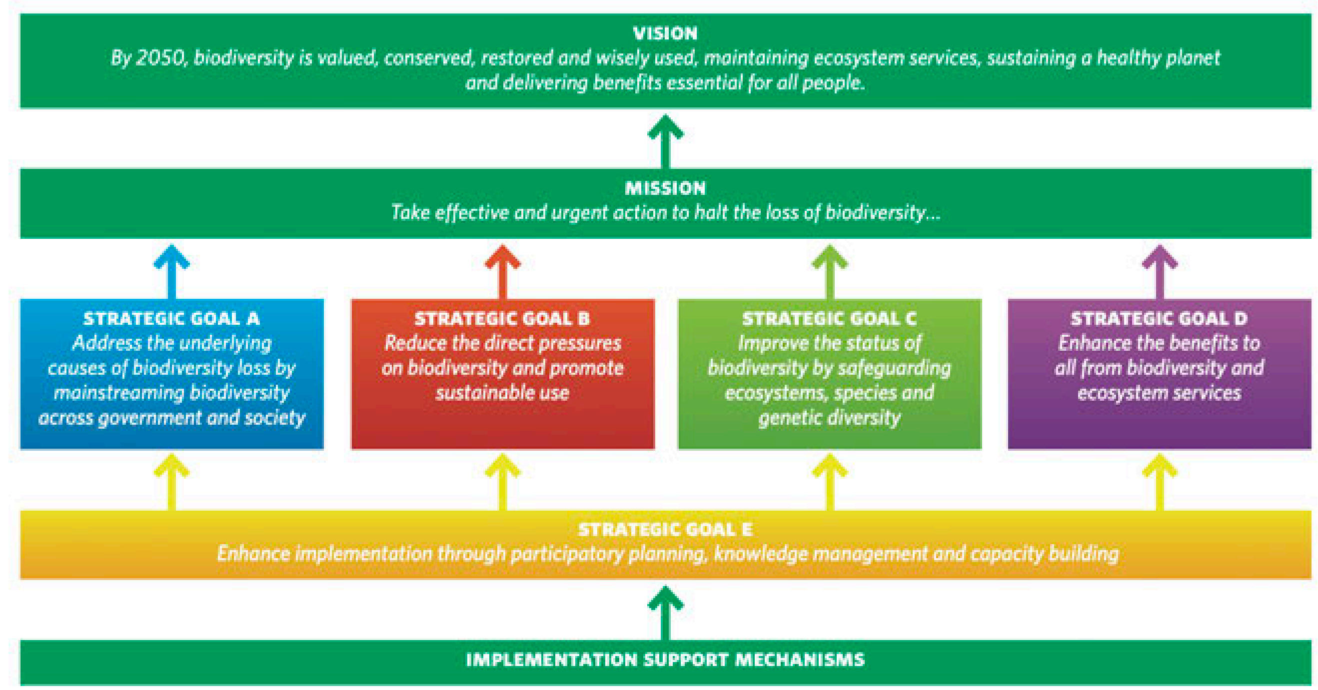


Figure 7 Structure of the Strategic Plan for Biodiversity 2011–2020 (CBD)

BIODIVERSITY LANDSCAPE **IN MALAYSIA**

The Malayan tiger, Malayan tapir, Sunda pangolin, Sunda clouded leopard, Asian elephant and Orangutan represent iconic Malaysian species.

Malaysia is ranked as the 12th most biodiverse country in the world and encompasses about 15,000 vascular plant, 449 freshwater and 1,619 marine fish, 742 bird, 567 reptile, 306 mammal, 242 amphibian and over 150,000 invertebrate species (Sixth National Report of Malaysia to the Convention on Biological Diversity, 2019). The Malayan tiger, Malayan tapir, Sunda pangolin, Sunda clouded leopard Asian elephant and Orangutan represent iconic Malaysian species. Sabah and Sarawak together are home to the richest rainforests in the world with a large diversity of Dipterocarps, comprising 291 species or 75% of the family. Malaysian waters host more than 77% of the world's known coral species. Seagrass and mangrove ecosystems in Malaysia are some of the most diverse in the world and provide important feeding grounds for juvenile fish, marine mammals and migratory sea birds.

Malaysia is also home to more than 1,100 threatened flora and fauna species according to 2008 IUCN Red List (CBD, 2020) and more species are yet to be discovered. Malaysia is also a vast repository of traditional knowledge associated with biological resources. The country ratified the Convention on Biological Diversity in 1994 as well as the Cartagena Protocol in 2003, thus continually supporting conservation efforts to preserve local biodiversity. A commitment to the 2020 Aichi Biodiversity Targets has been made recently, which outlines 17 clear actions towards preventing biodiversity loss by 2025 (Sixth National Report for the Convention on Biological Diversity, 2019) by employing national policies and programmes to empower children and to build indigenous awareness, as well as to develop dedicated databases to store information. However, there are several challenges (see Figure 8) threatening Malaysia's biodiversity agenda as listed and described in the following pages.

NATIONAL **CHALLENGES**

Figure 8 National Challenges in Biodiversity Landscape

1. Lack of sufficient trained staff in high-end technology to support PBD

The lack of basic scientists such as geneticists, plant breeders, tissue-culturists, taxonomists, pathologists, agronomists and biochemists is critical even in well-established research institutes in Malaysia. There should be an effort to make these fields more attractive in combination with high-end technologies such as AI, ML, IoT, robotics as well as modern science fields like biotechnology. Competencies in technology-driven sciences should be given importance. This would make the listed career opportunities more attractive.

It is envisaged that the solution lies in educational institutes exploring interdisciplinary approaches to curricula development in order to design holistic and exciting educational options that amalgamate traditional and emerging technologies in the sciences. This would be particularly attractive to the technology-savvy younger generation.

Future manpower training efforts must ensure that graduating biologists are also able to be part of the national pool of data collectors, analysts and computer specialists. This would ensure that they would be able to successfully contribute towards the management and interpretation of big data gathered from various ecosystems and biodiversity-related activities, so vital for accurate interpretation of the biodiversity story in the country. Biological resources responsibly managed will certainly lead to the well-being of Man, The Planet and the economy.

2. Lack of harmonization between Federal and State authorities regarding biodiversity management and enforcement

Forests, water and land come under the jurisdiction of the state governments. States have to balance their budgets, and income from natural resources frequently plays an important role, especially when states do not have sufficient other resources within their jurisdictions.

Sustainable consumption and production which seeks to decouple economic growth and environmental degradation by increasing the efficiency of resource use in the production, distribution and use of products should be promoted for biodiversity conservation.

3. Paucity of immediate economic benefits derived from biodiversity

Value is an intrinsic part of biodiversity but unfortunately, it is not always obvious or appreciated. There are practical problems with assigning value to biological diversity because it is highly complex (Editorial Nature, 2019). From an economic perspective, it is not possible to determine the true (economic) value of any individual component of biological diversity, let alone the value of diversity in the aggregate.

However, it has to be emphasized that biodiversity is priceless. Species play major roles in capturing and storing energy, providing food, minimising erosion, controlling pests and regulating climate. The myriad plants and animals in Malaysia's rainforest may contain a great many chemical compounds of potential benefit to human health. Ecotourism is a multi-billion-dollar industry that is dependent on biodiversity. Appreciation of the value of biodiversity requires long term vision instead of focus on short term economic benefits.

Although biodiversity is a complex aggregate which makes it impossible to put an exact value, the concept of Biodiversity Banking described earlier (page 30) is an innovative mechanism to monetise ecological value. It can contribute to Malaysia's green economy through sustainability-related global business opportunities. Biodiversity Credit is an economic incentive for biodiversity conservation, and Malaysia's mega biodiversity can be leveraged as a new capital-bearing asset that can be traded.

Genetic Conservation for Economic Sustainability

45 years ago, the Malaysian Palm Oil Board (MPOB) recognized the importance of genetic diversity of the oil palm, and over the years diligently assembled the largest oil palm genetic resources in the world. Almost half a decade later, MPOB molecular scientists leveraged the oil palm germplasm collection to identify genes of economic importance. Similar germplasm collection efforts were carried out for rubber. In 1981, a joint expedition of the International Rubber Research and Development Board (IRRDB) and the Brazilian Government was organized to collect fresh wild germplasm from the center of diversity in Brazil. The Rubber Research Institute of Malaysia led an expedition to the Amazonas and Para states in 1995 and successfully collected more than 50,000 genotypes to broaden the existing gene pool.

4. Absence of digitalized national repository to house information on expertise and data on biodiversity (e.g. genome database, ecosystems, management practices)

While there are several databases related to biodiversity in Malaysia, the majority of them are not accessible to the public. Examples of repositories which are not accessible to the public include the Agrobiodiversity Information System (AgrobIS) developed by MARDI, the Malaysia Traditional Knowledge Digital Library (MyTKDL) developed by the Intellectual Property Corporation of Malaysia (MyIPO) the Systematic Marine Biodiversity Information System (SyMBiosIS), and Marine Park Management Information System (MPMIS).

An exception is the Malaysia Biodiversity Information System (MyBIS) developed by the Ministry of Energy and Natural Resources (KeTSA) to gather resources from various experts, publications and other specimen databases on biodiversity in Malaysia and is arguably the best repository for Malaysian biodiversity. However, this database must be curated and compared with all other available databases. Nearly 48,000 species information has been deposited in this repository to date (MyBIS, 2016). Sabah established the Sabah Biodiversity Integrated Information System (SaBIIS) while Sarawak continues using the Botanical Research Herbarium Management System (BRAHMS) for their record-keeping (Sixth National Report for the Convention on Biological Diversity, 2019).

Elements lacking from the databases above are genetic and molecular information. High throughput molecular research has been conducted recently for native species including Rafflesia flowers (Safoora et al., 2019), mangosteen (Syuhaidah et al., 2017) and pitcher plants (Muhammad Mu'izzuddin et al., 2017). However, they are yet to be consolidated in a proper database. Hence, a future digitalized national repository should house such molecular data, together with information on ecosystems as well as management practices to better preserve biodiversity and increase awareness among the general public.

5. Over-reliance on fossil fuels

Fossil fuels (coal, oil and natural gas) play a pivotal role in powering much of human activity today. The extraction of fossil fuels directly impacts biodiversity through conversion, degradation, pollution, and disturbance of habitats at extraction sites, and indirectly through climate change. The combustion of fossil fuels results in increased emission of carbon dioxide and other greenhouse gases. It is imperative to introduce sustainable strategies to advocate the generation of power through renewable sources. Of great importance too, are energy storage solutions such as carbon capture, utilisation and storage (CCUS). Natural gas which is much cleaner than oil in terms of emissions has gained importance as a potential alternative to oil.

Malaysia is heavily dependent on fossil fuels for its energy requirements, with natural gas and coal accounting for about 43.5% and 42.5% respectively of its fuel generation (Wan Syakirah et al., 2019). To sustainably meet the rapidly growing energy demand in end-use sectors, Malaysia must focus its efforts on the development of renewable energy (RE) like solar energy, as well as green technology and energy conservation. The fact that Malaysia is contemplating mining of coal to meet domestic power demand especially when it has natural gas reserves is worrying. Coal extraction and coal-fired power plants are among the biggest contributors to greenhouse gas emissions. The coal-rich Maliau Basin, a pristine and protected rainforest also known as the Lost World was targeted for this mining activity and fortunately has drawn a lot of public outcry. Malaysia has substantial gas reserves but prefers coal, most of which is imported because it is cheaper. Coal is approximately half the cost of natural gas, but doubly polluting. Natural gas can help countries including Malaysia reduce greenhouse gas emissions while transitioning to renewable carbon-neutral energy forms.

Coal plant in Manjung, Perak (Image Source: Asian Power)

The National Biofuel Policy was launched in 2006 to encourage the use of environmentally friendly, sustainable and viable sources of biomass energy. Biodiesel was identified as one of the potential renewable energy sources for vehicle fuel. The mandatory use of palm oil biodiesel was initiated in 2011 with the B5 Programme (blending of 5% palm oil biodiesel with 95% fossil diesel) for the transportation sector. The palm biodiesel content was increased in stages and the mandatory use of B10 for the transportation sector commenced in February 2019. The B20 programme was launched in February 2020 and targeted for full nationwide implementation in the transportation sector by June 2021. Worldwide, about a quarter of the palm oil produced goes to industrial uses, largely biodiesel. It is thus essential that sustainable practices are adhered to in order not to threaten biodiversity with large scale expansion of oil palm to cater for demand.

Although much has been achieved in the implementation of the biodiesel programmes in Malaysia, progress in the development and utilization of other renewables has been slow, and a well-defined roadmap is essential to outline an agenda that will strengthen and spur the growth of clean energy. The Renewable Energy Transition Roadmap (RETR) 2035, being developed by the Sustainable Energy Development Authority (SEDA) of Malaysia in collaboration with industry stakeholders, defines strategies, action plans and resources necessary to transit to a future electricity system that can achieve a target of 20% RE in the national installed capacity mix (excluding large hydro of more than 100MW) by 2025 and to determine the future landscape for electricity by 2035. The outcome of the roadmap will be incorporated into MP12 (2021-2025). Although Malaysia has a wealth of resources with potential to generate RE such as solar and biomass, currently, RE only accounts for about 2% of its energy mix. It is imperative that we educate citizens on the effect of carbon footprint on the environment, and strengthen collaboration between academia, research institutes and industry, to inspire and innovate technologies and services that will reduce the country's carbon footprint. Intensified action to make gas and renewables the fuels of choice will advance Malaysia's journey towards carbon neutrality by 2050. The direct and indirect value of this would be a reduction in expenditure from importing coal, besides also conserving biodiversity through protection of the rainforests, seas (coal-powered plants are located along the coast) and the atmosphere.

6. Insufficient funding for biodiversity issues

Funding in Malaysia for biodiversity is often not prioritized, due to the lack of immediate commercialization potential. With funders insisting on seeing returns of investment monetarily, issues in biodiversity and conservation are often neglected. There are only four main national funding bodies that support biodiversity research: National Conservation Trust Fund for Natural Resources (NCTF) and Man and Biosphere (MAB) programme under the purview of the Ministry of Energy and Natural Resources, as well as Fundamental Research Grant Scheme (FRGS) and Transdisciplinary Research Grant Scheme (TRGS) managed by Ministry of Higher Education. Other private funders and trusts who are contributing to conservation efforts include The Habitat Foundation (https://habitatfoundation.org.my/), Yayasan Petronas (https://www.yayasanpetronas.com.my/) and the Rufford Foundation (https://www.rufford.org/projects/byCountry/my). However, as reported in the Sixth National Report for the Convention on Biological Diversity, financing towards conservation and natural resource management is still insufficient.

7. Deforestation and degradation of tropical rainforests impacting climate change, habitat destruction, pollution and the loss of invaluable natural resources including indigenous species

Although Malaysia has taken steps to protect forests, rivers, seas and species using various legal instruments, the pressures on our biodiversity are increasing and the loss of forest cover continues. Poaching and illegal wildlife trade threaten to inflict more damage and some species have been poached to the point of extinction. Forty-eight of the known 292 mammal species are threatened. The leatherback turtle and the Sumatran rhinoceros are functionally extinct in this country while several large mammals, including the Malayan tiger, banteng and the orangutan, face serious threats. Many species of plants are also threatened (Saw et al., 2010).

Although there is still a significant amount of forest cover, much of the forest is fragmented. This results in a loss of ecological connectivity, and movement of animals, particularly large mammals, is reduced, thus limiting the resources available to them and causing their genetic isolation. This also forests through the establishment of ecological corridors between forest complexes and forest islands brings numerous benefits to the country. Although ambitious programmes such as the Central Forest Spine, Heart of Borneo and the Kinabalu Ecolinc have been initiated to combat the problem of fragmentation, there remains lots of work to be done.

There is strong scientific evidence for a link between reduced biodiversity and the outbreak of zoonotic diseases (Keesing et al., 2010). Deforestation changes the dynamics of the ecosystem and results in new breeding terrain for diseases by reshaping existing ecosystem boundaries. Human encroachment into wildlife habitat creates the potential for zoonotic infections to move from animal to human populations. The majority have spilled from wildlife reservoirs, either directly to humans or via domestic animals. The Covid-19 pandemic, sparked by the transmission of the coronavirus from animals to humans, has put a spotlight on zoonotic diseases that are spread by animals forced out of their natural habitats. There is compelling evidence that these shifts in animal-human interactions also played a key role in initial outbreaks of HIV and Ebola virus. The Nipah Virus outbreak in Malaysia in 1999 was associated with rampant deforestation that resulted in fruit bats which are a reservoir for the virus, losing their forest habitat, and moving into pig farms where they spread the virus to pigs, which subsequently jumped species to humans (Pulliam et al., 2012). This is a wake-up call for us to appreciate the importance of preserving intact ecosystems and their endemic biodiversity.

Clockwise from top-right: Deforested hillsides in the Cameron Highlands (Image source: Kelantan) and some of the endangered species in Malaysia (Malayan tiger, tapir, sea turtle, pitcher plant (Image source: Pixabay) and rafflesia (Image source: Shutterstock))

Fisheries are showing signs of collapse in coastal areas due to pollution and the prevalence of bad fishing practices. Some of our coral reefs, seagrass beds and mangrove forests have been lost or degraded. Physical impacts from tourism, including divers, snorkelers and boats also create problems. Mass coral reef bleaching has emerged over recent years as a major threat with potentially devastating effects. Although Malaysia has introduced a zoning system in coastal waters which prohibits fishing vessels from encroaching on nursery and

breeding grounds as well as expanded marine protected areas and banned the sale of turtle eggs and catching of sharks, the problems persist.

The threat of climate change is well-established although its actual impact is not easily predictable. Temperature changes may cause shifts in current ecosystems both latitudinal and altitudinal, meaning that species have to migrate to keep up with their optimal habitats. In one well-documented example, various species of moths native to Mount Kinabalu are moving their ranges uphill, exactly as would be expected if they are following temperature zones that are also moving uphill due to climate change (Chen et al., 2009).

8. Lack of food security and an ever-increasing food import bill

Malaysia's food import bill escalated from RM43 billion in 2013 to RM54 billion in 2018 (Mohamad Ikmal et al., 2019) and underscores the importance of achieving self-sufficiency in food production. Biodiversity is an important component of food security because species diversity provides genetic material for future food and crops. Breed conservation programmes of indigenous farm animal genetic resources, such as Kedah-Kelantan cattle, are very important in providing broad gene pools and genetic improvement for future food security through quality meat production. Plant genetic resources are the raw material for plant breeding for increased productivity as well as for disease resistance and other characteristics. In the light of climate change, plants with the ability to withstand drought and flood conditions have important potentials for future food security.

Rice is an important staple food for Malaysians, and many wild varieties and landraces of rice are found in the country including those uniquely cultivated by indigenous people. At the moment, 12,700 accessions of rice from indigenous, wild and cultivated sources are conserved in gene banks as genetic materials for further improvement. Two new high yielding rice varieties, UKMRC-2 and UKMRC-8, developed via advanced backcrossing of a cultivated rice, Oryza sativa subsp. indica and a wild rice, *Oryza rufipogon* (Wickneswari and Bhuiyan, 2014), were released to farmers in 2019.

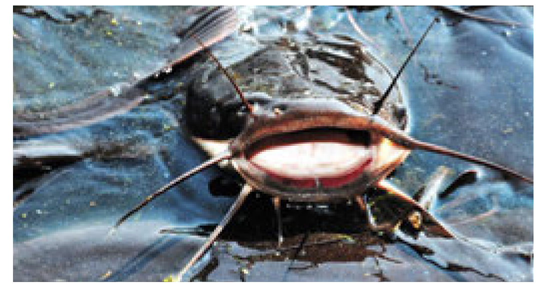
Protection of such biological diversity is critical for the breeding of improved varieties with higher yields and/or resistance to pests and diseases.

Agroforestry or agroecology is a sustainable land-use system that incorporates planting, cultivation, and conservation of trees alongside crops or livestock farming. It integrates the unique relationships within a given ecosystem, and offers environmental, economic, and social benefits and is thus an important strategy for maintenance of biodiversity. Because of its attractive benefits, it was incorporated as one of the strategic action plans of the Third National Agricultural Policy, NAP3 (1998-2010). The objectives included the integration of forest trees, rattan, bamboo, and medicinal plants with cultivation of food crops, rubber and oil palm, rearing of livestock and aquaculture on a large scale to maximize utilization and returns on the same piece of land. Herbal and medicinal materials with potential for commercial production including *Eurycoma longifolia* (Tongkat Ali) *Labicia pumila* (Kacip Fatimah), *Andrographis paniculata* (Hempedul Bumi), *Cucurma xanthorriza* (Temulawak), *Casia alata* (Gelenggang), and *Morinda cirtrifolia* (Mengkudu) were identified. Efforts by Crops For the Future (CFF), an international independent organisation have been directed at promoting the greater use of underutilised crops for diversification of agriculture and human diet to achieve food security in a sustainable manner using local agricultural biodiversity (Gregory et al., 2019).

9. Invasion by destructive alien species (e.g.Golden Apple Snail, Tilapia, Acacia mangium)

Invasive species prey upon, or out-compete native species, or modify natural ecosystems, causing the extinction of native populations. For example, the water hyacinth, a fast-growing aquatic plant from South America, is now found in many of our waterways. The weed blocks waterways and prevents sunlight and oxygen from reaching the water column and submerged plants. Many of the oxbow lakes along Kinabatangan River in Sabah are infested with these weeds and have to be cleared regularly. The lotus plants in Tasik Chini are now being replaced by the South American cat's tail weed. This weed blocks waterways and reduces the species diversity in the lake. A survey of the lake in 2009 recorded only 24 fish species compared to 84 species recorded earlier (Mushrifah et al., 2009). Although efforts to identify invasive species have been undertaken (e.g. the Department of Fisheries has the Action Plan for Aquatic

Invasive Species), much remains to be done. An example of an alien fish that can cause havoc to our aquatic ecosystem is the African catfish (*Clarias gariepinus*). The numerous challenges described above glaringly point to the fact that monitoring, conservation and sustainable management of biodiversity for economic benefit, is being dangerously compromised. High-end precision technology presents a unique and doable driver as PBD mitigates the daunting challenges. This is an area of research and implementation that needs to be intensified.



The African catfish
(Image source: Deccan Chronicle)

Negative Impact of an Alien Species

The African catfish was first introduced in Malaysia from Thailand between 1986-1989 for aquaculture. It is popular among fish-breeders as it grows fast and can be raised in large numbers because of its high fecundity and survival rate. C. gariepinus culture in Malaysia grew tremendously to become the highest cultured finfish, overtaking the red tilapia(in 2008), as the most cultured fish (Dauda et al. 2018). However, the large-scale introduction of this alien fish to fish farms and hatcheries for commercial purposes, import for the aquarium fish trade and release into water systems by the public pose major dangers to our aquatic ecosystem. The general public and key sector groups do not fully appreciate the magnitude of the problem. Being a large top predator, it can wipe out native fish fauna. This species tolerates adverse water quality conditions, is air-breathing and can crawl on dry ground and survive in mud and hide in vegetation. These features make it difficult to control. It is a serious menace, disturbing the natural trophic status of the aquatic ecosystem and depriving other native species of their food and breeding space. A 2kg African catfish can produce about 45 000 eggs. This species also has negative ecological effects on aquatic invertebrate, amphibian and insect populations. It also carries parasites which could lead to reduction in numbers of indigenous fish populations owing to susceptibility to these parasites. It is important to prevent further spread of this alien species and mitigate its negative impact.

10. Lack of attention to urban biodiversity

While there has been much focus on Malaysia as a mega biodiverse country and conservation of the natural environment, much less attention has been given to biodiversity in urban areas i.e. the built environment. According to a 2016 World Bank Report, 75% of Malaysians now live in urban areas. There is thus a need to preserve flora and fauna in urban green spaces to conserve the human experience of appreciating nature and wildlife. Urban green spaces confer important ecosystem services and play a key role in improving health and well-being by improving air quality through absorbing and shielding from particulates, buffering noise pollution, and reducing heat stress by providing shade. Biodiverse urban green spaces also help to improve humans' psychological well-being (Sandifer et al., 2015). These restorative ecosystem services emphasise the importance of biodiversity conservation in an urban setting.

However, urban green space planning has largely been implemented to fulfil the immediate social needs of people with little emphasis on environmental aspects such as wildlife and biodiversity, wetlands and woodlands. Intensive land-use change and standard landscaping practices that aim to neaten landscapes, often make them inhospitable to native biodiversity. These practices are contributing to the global loss of flora and fauna from ecological urban communities. The result is fragmented and isolated patches of green space.

In order to implement better planning, it is important to understand the human ecosystem with respect to urban vegetation and urban wildlife. Urban wildlife has adapted to new urbanized environments. Species richness and density are an indication of the quality of urban environment. Birds are often used as a biological indicator for other wildlife types. Since they sing, are generally colourful and active during the day, they are broadly more familiar to the public, and therefore easier to count than nocturnal animals that are generally shy. Several studies have shown that urban centres record lower species richness. A study by Karuppanan et al. (2014) concluded that urban wildlife in Kuala Lumpur is rapidly declining and that there is a greater need for the development of comprehensive acts, policies and guidelines to protect urban wildlife. It is a stark reminder that just planting trees, building green roofs and smart streets is not enough. The green spaces should provide habitats for breeding, shelter, and food for wildlife too. Where possible, the habitats need to incorporate corridors where wildlife can safely travel. The community and stakeholders should also play a role in promoting programmes and activities to preserve and enhance urban wildlife.

It is heartening that initiatives focused on urban biodiversity are catching on especially in university campuses. **The Rimba Ilmu Botanical Garden**, modelled after a rainforest, was developed by the Universiti Malaya (UM) in 1974 to conserve the abundant plant life indigenous to the tropical rainforest of Malaysia. It is an important repository for various plants, including rare and endangered plant conservation collections, and special collections of economically useful plants and their wild relatives. Occupying an area of 60 hectares, it is located at the main campus of the university and reputed to be the only scientifically organized botanic garden in Kuala Lumpur that is accessible to the public. Urban Biodiversity Initiative (UBI) based at the Rimba Ilmu Botanical Garden at UM is an independent cooperative enterprise for urban ecology research, conservation and environmental education. UBI promotes the re-wilding of urban landscapes through education and community engagement. The Rimba Project, a campus sustainability and urban conservation Living Lab with a mission to protect, document and promote biodiversity on campus and beyond, was founded in 2014 and operates within the Garden. It is essentially an education and outreach programme in urban ecology and conservation and strives to help urban communities reconnect with nature. It is now collaborating with the United Nations University Institute of Global Health which has an interest in urban health and well-being.

The Case for Urban Biodiversity

Trachypithecus obscurus, distributed from Southern Myanmar to Peninsular Malaysia, including the island of Penang goes by many names including dusky leaf monkey, spectacled langur and lotong or lutong in Malay. The langur plays a critical role in forest regeneration as an important seed disperser. It is considered part of the natural heritage of many countries and is also valued for its immense ecological importance and biological interest. Penang's rapid urban development has resulted in deforestation and loss of natural habitats which has driven the langur into urban areas. They often have to ply between fragmented forests in search of food and expose themselves to road accidents and confrontation with other animals.

The Role of Citizen Science in Addressing Challenges in The National Biodiversity Landscape

Citizen Science, also known as crowd-sourced science or community science, refers to scientific research and environmental monitoring carried out wholly or partly by non-professionals on a voluntary capacity. Citizen Science is increasingly becoming a common approach for gathering data on ecosystems and biodiversity. Citizen scientists can help to map, record and preserve biodiversity. Citizen Science has great potential to support global needs for biodiversity monitoring and allows for massive amounts of data to be collected over large spatial and temporal scales at minimal cost and time. Such economies of scale free up funds. It was reported that 2.3 million volunteer citizen scientists who contribute to biodiversity research have an economic value of up to $2.5 billion per year (Korte, 2016). Citizen Science also resulted in the discovery of six new species of beetles in the Maliau Basin of Malaysian Borneo (Scientific Malayan, 2017).

The Global Biodiversity Information Facility (GBIF), an international network and research infrastructure aimed at providing open access to data on all types of life on Earth, currently comprises almost 500 million records from Citizen Science projects. Besides the invaluable role of Citizen Science in collecting data on a global scale, it catalyses public engagement with the environment, raises awareness and scientific literacy, potentially leading to positive behavioural change.

Technology is one of the main drivers of the recent explosion of Citizen Science activities. The advent of the internet and social media has greatly boosted public participation in scientific endeavours. Smartphone technologies and mobile phone apps such as eBird and iNaturalist facilitate capturing photographs and biological information. They enable the reporting of sightings of species which are then uploaded to large databases like the National Biodiversity Network in the UK, Artsobservasjoner in Norway or GBIF (see above), an open-source database used by scientists and policymakers around the world. Citizen Science thus allows people across the world to connect with a common purpose.

To tap on the traditional knowledge of villagers, Universiti Malaysia Terengganu (UMT) and the World Wide Fund for Nature-Malaysia (WWF-Malaysia) in collaboration with the state government engaged with villagers within the Setiu Wetlands and appointed them as citizen scientists to provide information that could vastly improve data collection. The villagers engage with visitors, including research students and scientists from all over the world. This has provided a great opportunity to add value to existing outreach, awareness and education programmes involving local communities

(Rosli Zakaria, 2018).

Citizen Science is especially powerful in urban landscapes as a large pool of potential volunteers may be leveraged. A Citizen Science project on combined effects of landscape factors on the bird assemblages in Kuala Lumpur and its conurbation, showed that the area of green cover had the most important influence on the abundance of individuals and the number was increased by the presence of river corridors and roadside reserves. The study highlighted the importance of incorporating varied landscape into urban planning to preserve urban bird diversity and showed the utility of citizen science in biodiversity monitoring (Puan et al., 2019).

The Role of Advanced Innovations in Addressing Challenges in The National Biodiversity Landscape

Innovation will be the vital solution to navigate the challenges in the national landscape. Fortunately, these challenges coincide with a period of unparalleled innovation and technological revolution - the Fourth Industrial Revolution. The digital transformation encompassing artificial AI, ML and IoT among others, in combination with biotechnology and other advanced technologies such as quantum computing, offers unprecedented opportunities to address these challenges. However, while it is important to leverage the transformative potential of these powerful technologies, it is also pertinent to acknowledge the destructive potential of such potent technologies if unguided, and the risks should always be assessed and factored in our efforts in moving forward.

Application of technologies should be ethics- and value-driven and the safety of the people and the planet should be an integral dimension. High-end precision technologies will play an increasingly key role in managing and adding value to our rich biodiversity.

Types of **Intervention**

Currently, three models are being advocated to ensure biodiversity makes use of a suite of technologies that could be beneficially engaged to address long-standing biodiversity issues and challenges that also impact on climate change. These are Climate Engineering, Nature-based Solutions and Green Disruptive Innovations.

1. Climate Engineering

The technology entails large-scale interventions in natural landscapes like oceans, soil and atmosphere to help mitigate climate change. Useful parameters that may be investigated include the measurement of carbon dioxide removal and how to limit the amount of solar radiation. Various techniques have been used to reduce carbon-based pollution and direct solar radiation as summarised in Figure 9.

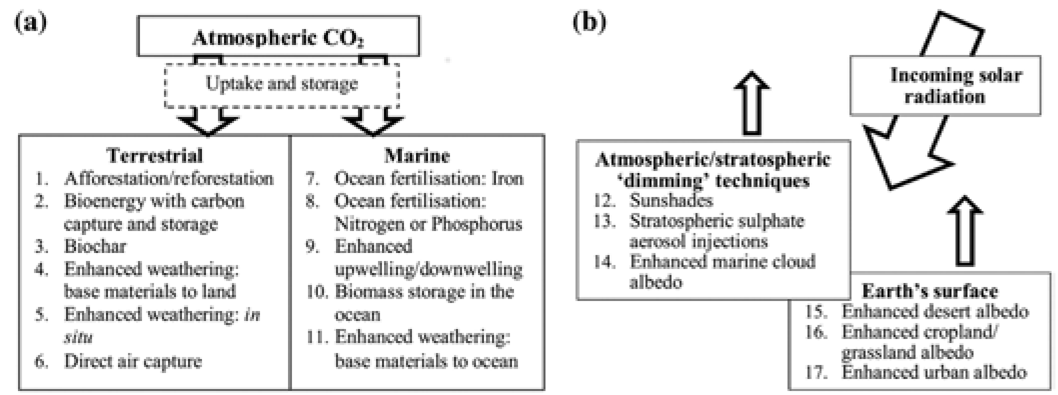


Figure 9 Techniques of climate engineering (for details refer to Appendix 2) (McCormack et al., 2016)

2. Nature-based Solutions

In this model, monitoring, managing and restoring both natural and modified ecosystems are effected to provide humans with well-being advantages. The IUCN applicWation of this model is targeted to support the achievement of society's development goals and safeguard human well-being in ways that reflect cultural and societal values, enhance the resilience of ecosystems, their capacity for renewal and the provision of services. These include ecological restoration, ecosystem-based

disaster risk reduction, integrated coastal zone management, area-based conservation approaches, as well as protected area management as represented in Figure 10.

Figure 10 IUCN's Nature-based Solution model (IUCN, 2020b)

3. Green Disruptive Innovations

In this model, disruptive innovations are leveraged so that new strategies may be developed to provide specific approaches with time-based patterns to optimize natural conservation. For example, a crowd-sourcing venture capital model called Mosaic (Kelly-Detwiler, 2013) has been working on how to generate people-powered, decentralized low-carbon energy creations using solar energy-based technologies. Such a model will apply recent technologies like AI, cloud computing, and robotics as enablers to conserve natural resources.

Application of High-End Technologies

The application of next-generation biodiversity platform technologies is needed to ensure the successful roll out of the models mentioned in the previous section to address the current challenges faced in conserving, monitoring, and protecting biodiversity and responsible deployment for economic benefits. They fall into two main categories, namely, emerging technologies (such as Robotics, AI, Drones and IoT)) and biotechnology.

1. EMERGING TECHNOLOGIES

Documented below are some instances of how conventional methods paired with emerging technologies help overcome biodiversity issues. To implement PBD, some of these can be adapted/adopted for application to similar issues in Malaysia.

Precision Data Capture

Several innovations have been introduced to help capture biodiversity-linked data to better understand, manage and conserve natural resources. These can be adapted also for application in Malaysia. Products such as a 3D-printed robotic fish equipped with AI systems are being deployed to mimic real-life movements of fish. This AI-driven device can provide useful information about fish biology including responses to environmental factors (Føre et al., 2018). **Underwater robots** such as remotely operated vehicles may be used to monitor underwater life and to collect habitat data using sensors to record and relay information through wireless communication technology. **IoT technologies** can also be used to collect forestry data such as plant growth, temperature, soil, salinity and other valuable research data. Information garnered should provide better in situ analyses of biodiversity for more effective real-time monitoring, planning and management of natural resources.

The most rapid advance in collecting location data comes from smartphone-wielding citizen scientists. For example, eBird (www.ebird.org) became an international depository in 2010 and already has more than 100,000 observers and over 100 million observations. It permits fine-scale mapping and month-by-month changes in the distribution of some species. Data collected can now be digitalized, catalogued and managed to enable effective monitoring, fast communication and networking as well as for global dissemination. The Smithsonian LeafSnap iPhone application (http://leafsnap.com) uses image recognition to identify Eastern North American tree leaves. Automated identification of bird or bat calls has been an active area of research for over a decade. Such an approach would be useful in Malaysia too as bats, besides being very useful pollinators of the durian, are also among the small animals that are known to be a host to numerous viruses responsible for zoonosis.

Examples of apps used by Citizen Scientists

Databases on species occurrence have also expanded rapidly. For example, GBIF (www.gbif.org) has 420 million records and 1.45 million species names, while Tropicos (www.tropicos.org) has 4.4 million plant records. Records enter these databases via four main routes: museum and herbarium specimen collection, DNA sampling, crowdsourced observations, and remotely sensed images or sounds. Natural history collections detect species at a specific location, including the identification details of these detections. These are archived in museums before being digitized and incorporated into GBIF. Museum specimens require considerable expertise and expensive curation but offer the best evidence for the presence of a species and subsequent morphological, genetic, or isotopic research. Through the use of AI-driven tools in PBD, much more effective data sourcing on species, populations, habitats etc. can be mined to usefully populate the GBIF's databases.

Similarly, genomic databases can also be built up especially for endangered and threatened species. Globally, DNA libraries have already been built for 2,000 endangered species and an additional 2,891,971 specimens, making up 192,480 species (The Barcode Library, Barcode of Life Data Systems; http://ibol.org/resources/barcode-library/). However, both these sources limit the pace and scale of what can be collected. To complement these expert-driven efforts, new tools are being utilized that also engage with the community i.e. citizen scientists. Such efforts can also be deployed in Malaysia.

Monitoring Endangered Species

Various 4IR technologies offer real-time information about the location of endangered species and facilitate monitoring and surveillance for enforcement purposes. For instance, satellite tracking of such species provides insights into their ecology and facilitates the formulation of plans for their conservation.

Another technology is the **Footprint Identification Technique**, developed by the non-profit organisation, WildTrack4 to assist in identifying endangered species using digital images of their footprints without the need to fit tracking devices to the animal or interfere in the animal's life in any way. For underwater monitoring, World Wide Fund for Nature (WWF) staff have used, for example, camera tags to study the challenges being faced by marine turtles and the habitats they frequent. The information gathered will help the non-governmental organization (NGO) make strategic conservation decisions (Turtle Camera Tagging, 2019).

Drones and AI, through deep learning analysis (density-based spatial clustering), as used to detect livestock (Zool Hilmi et al., 2019) can also be harnessed to track endangered species. Drone technology offers several advantages. It is a low-cost technology (compared to aeroplanes and satellite imagery), and can be used for example, to efficiently monitor poachers preying on wildlife in protected territories, or even to function as relays for communication in remote areas less traversed by humans.

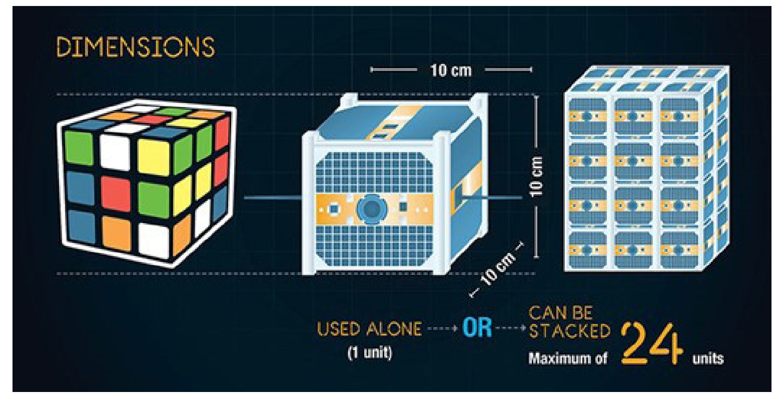
Methods for obtaining locations of species have also shown impressive improvements. Digital camera traps have replaced film-loaded ones, greatly expanded the ability to detect rare or hidden species. Satellite-borne cameras can detect and monitor some animals in open habitats. Examples include using Landsat 30m resolution satellite data to detect the presence and size of emperor penguin colonies in Antarctica (Schwaller et al., 2013), and Geo-Eye 1.65m resolution satellite data to estimate population sizes of elephants, wildebeest, and zebra (Yang et al., 2014; Kuenzer et al., 2014). Aeroplane surveillance has been utilized to monitor wildlife for decades, but unmanned aerial vehicles or unmanned automated vehicles (UAVs) capable of taking photos and videos could provide better, cheaper, and more timely information compared to manned aircraft surveillance or satellite images.

Monitoring the Depletion of Marine Biodiversity

Overharvesting by industrial fishing is regrettably what contributes to two-thirds of world fish production (Rowland, 2017). It is estimated that getting rid of unsustainable practices can improve fish catch by 16 million tons, and boost profits by US$53 billion, besides improving ocean health. Currently, in Malaysia, new and innovative technologies such as unmanned water drones, AI, and Big Data analytics are being used to monitor fish stocks and catch, as well as to police individual fishing boats, spot illegal fishing and enforce regulations (e.g. by UMT). With better and more sophisticated technology, such efforts could help ensure a healthy and more sustainable industry.

Monitoring Environmental Disruptions

Emerging technologies are increasingly contributing towards efforts to monitor and regulate disruptions to the natural environment. Environmental changes can cause species to decline or, in the case of invasive or introduced species, their expansion. Responding to a request from the conservation community, NASA provided free Landsat imagery for 1990 and 2001. Now, much higher resolution imagery first developed for consumer markets is becoming freely and widely available. Unprecedented amounts of data can be sourced by the use of constellations of CubeSats. CubeSats are low-cost, small satellites that harness consumer technology rather than bespoke technologies and that have exceptional power in constellations. They are an alternative to the single and powerful satellite which may be outdated once it reaches space. CubeSats look to revolutionize medium resolution imaging through global, daily coverage (e.g., Skybox/ Google, Planet Labs) and are being launched by an increasing number of countries and private companies (Boshuizen et al., 2014; Kumagai, 2014; Pettorelli et al., 2014).



CubeSats can be used alone or stacked to suit the needs of a specific mission (Image source: Canadian Space Agency)

Between 2012 and 2027, member agencies of the Committee on Earth Observation Satellites (CEOS) plan to operate 268 individual satellite missions (Selva and Krejci, 2012). Recently, the European Commission agreed to make the new Sentinel satellite data freely available. These new instruments in combination with drone technology are set to provide increasingly sophisticated and affordable methods for unprecedented coverage of environmental disruptions that can harm biodiversity and health of the planet.

Reducing Pollution from Plastic Waste

Disruptive technologies are also being engaged to address the problem of plastic wastes. The distribution of plastic debris is highly variable as a result of certain factors such as wind and ocean currents, coastline geography, urban areas, and trade routes. Humans too play a large role in this. Plastics are more likely to be found in enclosed regions such as the Caribbean. Plastic debris can move organisms to remote coasts that are not in their native environments. It serves as a means for distribution of organisms to remote coasts that are not their native environments. This could potentially increase the variability and dispersal of organisms in specific areas that are less biologically diverse. Plastics may also act as "vehicles" for the transport of chemical contaminants such as persistent organic pollutants and heavy metals.

As of 2016, it was estimated that approximately 150 million tonnes of plastics polluted the world's oceans, and this amount is estimated to grow to 250 million tonnes by 2025 (Ellen MacArthur Foundation, 2016), whereas an earlier study in 2012 estimated it was approximately 165 million tonnes (Knight, 2008). The Ocean Conservancy reported that China, Indonesia, Philippines, Thailand, and Vietnam dump more plastic in the sea than all other countries combined. A recent study estimated that there are more than 5 trillion plastic pieces (defined into the four classes of small microplastics, large microplastics, meso- and macroplastics) afloat at sea (Eriksen, 2014).

Besides developing appropriate substitutes for plastics to reduce plastic wastes, scientists are working on developing robots that can operate using solar energy to pick up large amounts of plastic waste littering both land and sea. In Malaysia, the government has initiated a roadmap towards zero single-use plastics, which is targeted to be fully implemented by 2030 (Ministry of Energy, Science, Technology, Environment & Climate Change, 2018). One of the key actions planned is for SIRIM Berhad to revise the ECO001:20186 (SIRIM QAS International, 2018) criteria document to include only biodegradable and compostable products and exclude photo- and oxo-degradable products in the national policy.

According to a recent report from the World Economic Forum, "Harnessing Artificial Intelligence for the Earth" (2018), the maturation of key technologies including big data and ML is opening up new possibilities for Earth conservation. For example, with increased computing power and AI algorithms, climate scientists can better understand natural systems and optimize interventions by modelling and predicting climate patterns in the new field of "climate informatics." It also allows for better coordination between researchers to share and analyse key data on pollution. In addition, a grassroots organization, The Plastic Bank, offers Blockchain secured digital tokens for the exchange of recycled plastics. The aim is to stop the flow of plastics into oceans by rewarding those who recycle, thereby reducing trash and helping fight poverty. It is working with partners at Cognition Foundry and IBM to implement the scheme, The Plastic Bank aims to scale its blockchain solutions to meet growing demand and secure the transactions that run on it. These efforts could also be linked to BB (see page 30).

Plastic-eating Robot

A marine drone called the WasteShark is an electric vehicle that traverses waterways and autonomously gather up to 132 pounds of plastic waste at a time. If it is deployed five days a week, it can remove 15.6 tons of plastic waste from a body of water per year, according to the machine's creator, the Dutch technology company RanMarine. (Global Citizen)

Preserving and monitoring plants

Image-recognition algorithms can be applied to pictures of species to automate identification such as the LeafSnap Application (Leafsnap, 2011), created by the Smithsonian Institution together with Columbia University and University of Maryland, which uses digital processing to identify Eastern North American tree leaves. The application uses visual recognition software to help identify tree species from photographs of their leaves. It enlists people of all ages to use photography to document leaves, flowers or buds from plants of interest, in order to assist in identification.

Yet another strategy was initiated by Ericsson, namely the Connected Mangroves Program (Alarilla, 2019). This is a reforestation project which leverages connected technologies such as solar-powered sensors and real-time camera footage to collect critical data and present it to local communities on a digital dashboard. Initiated in 2017, the project offers the local community a platform to check on water, soil and humidity conditions, and remotely monitor any intrusions on a mangrove site. Mangroves are a priced natural resource. Not only are they effective in trapping carbon which can help to mitigate climate change, but they also protect villages near coastlines and riverbanks from environmental disasters such as tsunamis, thus contributing greatly to the health of the ecosystem.

Processing the millions of photographs typical of large-scale camera trap monitoring is one of many examples of challenges that require sophisticated data-management tools (Kays et al., 2015). The challenge is particularly acute for conservation where the species of interest are rare and observations are few amid a flood of other information. Most image processing is still carried out manually, for example, using citizen scientists to classify 1.2 million camera trap images from the Serengeti National Park (Swanson et al., 2015). Computer vision tools and crowdsourcing are starting to be integrated into the data workflow to add efficiency (Erb et al., 2015). Several new efforts are testing completely automated paths by relying on remote sensing to detect species and image analysis to identify species. PBD will adopt and adapt appropriate technologies to facilitate the acquisition of accurate and comprehensive information to conserve, monitor and manage the nation's biodiversity.

2. BIOTECHNOLOGY

Among the most crucial scientific and social challenges of the 21st century is to increase our understanding of Earth's biodiversity, and responsibly stewarding its resources. These challenges require basic knowledge of the evolution, organization, functions, and interactions among millions of organisms. Biotechnology is a powerful modern tool that has recently been increasingly utilised to acquire this knowledge for the conservation, evaluation, and application of biodiversity. This is made possible by the use of technology in the areas of genomics, proteomics and metabolomics that now offer unparalleled opportunities for the exploration, identification, and commercial utilization of bio-resources in the agricultural, environmental, nutraceutical, and pharmaceutical sectors.

Oil Palm Phenolics (OPP)

World's First Palm Phenolic Commercial Production Facility in Mexico (Image source: Sambanthamurthi)

Palm oil milling produces an aqueous stream that is discharged as palm oil mill effluent (POME). Globally, more than 85 million tonnes of POME are produced annually which can be an environmental burden. MPOB scientists discovered that the aqueous stream is a valuable source of phenolic bioactives, and developed a process for extracting OPP (Sambanthamurthi et al., 2011 a,b).

Gene expression, animal, and clinical studies confirmed that OPP has antioxidant and anti-inflammatory properties that confer multiple health benefits. This technology has attracted the interest of global entrepreneurs as it has tremendous economic, environmental and health impacts. The innovation provides an opportunity to reduce pollution and increase the productivity and sustainability of the oil palm industry. The project was identified as one of the ventures benefiting mankind under the United Nations Millennium project. The project has been successfully commercialised and the world's first OPP production plant started operation in 2019 in Chiapas Mexico. The commercial bioactive product emerged as one of the top 3 new ingredients in the NutraIngredients USA 2019 Awards.

Biotechnology can also indirectly protect and conserve biodiversity by increasing productivity of crops, thus reducing the acreage of land cleared for agriculture, increasing resistance to biotic and abiotic stresses and reducing pesticide use. The recognition of the potential positive impact of biotechnology in the conservation of biodiversity led to the Cartagena Protocol on Biosafety.

Conventional biotechnology techniques like tissue culture, cryopreservation and molecular markers play important roles in conserving biodiversity. Pairing those with advanced technologies will certainly bring about quicker and more effective results.

Tissue culture can be used in germplasm conservation of economically important plants species. It also has tremendous importance in crop improvement programmes in the face of increasing depletion of natural resources. Plant and animal cell and tissue culture can rescue endangered species. In vitro fertilization (IVF) has been suggested to be the single most important step in the conservation of endangered species. Pertinent examples are the Sumatran and Northern White Rhinos, both of which are on the verge of extinction. In May and November 2019 respectively, the last male and female Sumatran Rhinos in Malaysia died. Although an attempt at IVF using cryopreserved sperm and a single egg respectively from these two last Sumatran Rhinos in Malaysia was unsuccessful (Gokkon, 2019), it is imperative to persevere and optimise this valuable technique with the remaining precious few rhinos in Borneo.

Cryopreservation is the storage of biological tissue at ultra-low temperatures. This technology can be used to store germplasm indefinitely. For example, cryopreservation of sperm is invaluable for the preservation of genetic diversity of fish species especially those with rare, vulnerable, threatened or endangered status. Fish sperm cryopreservation has been used in Malaysia to save endangered indigenous species such as *Probarbus jullieni* and *Tor spp*. (Chew and Rashid, 2014). Cryopreservation has also been successfully applied in the conservation of plants using seeds/embryonic axes/shoot tips. For example, *Citrus halimii* B.C. Stone, a species endemic to Malaysia and noted to be at the edge of extinction, was successfully cryopreserved using embryonic axes (Normah and Siti Dewi Serimala, 1997) while for *Fortunella polyandra*, a native of the Malay Peninsula, shoot tips were used (Chandrabalan et al., 2011). Cryopreservation of zygotic embryos of oil palm offers a cost-effective method for long-term conservation of oil palm genetic resources. So far, 68,850 accessions from the MPOB African germplasm collection have been cryopreserved (Rajanaidu et al., 2017).

Fortunella polyandra or Malayan kumquat (Image source: Oscar Tintori)

Molecular markers can be used as a taxonomic tool to study individual organisms or to identify species. This is similar to DNA fingerprinting in forensic molecular biology. Molecular markers are useful for the conservation of plants and microorganisms such as culture collections and gene banks. They allow for the estimation of biodiversity at all levels e.g., kingdom/class/family/species level, in a comparatively small environmental sample.

Molecular cataloguing can help safeguard against biopiracy, the act of stealing knowledge or genetic resources from traditional and indigenous communities or individuals. Biopiracy has negative effects on biodiversity such as extinction of endemic living organisms, and privatization of bio treasures of a country. Examples of biopiracy include the patenting of basmati rice, neem and turmeric by the US which fortunately was revoked following protests by India. A Malaysian example is latex from the Bintangor tree (*Calophyllum lanigerum*) in Sarawak which has been traditionally used by the Dayaks as a poultice for headaches, skin rashes and other ailments. US scientists discovered it contains Calanolide A which has potential application for anti-HIV therapy. Although the pharmaceutical company that subsequently synthesised the drug entered into a joint venture with the Sarawak government, where 50% of profits return to Sarawak, the indigenous people are unlikely to reap the benefit. There is currently no international protection for traditional knowledge. Intellectual property only recognises individual rights and not communal rights. A committee of 193 countries has been discussing international guidelines on the protection of genetic resources, traditional knowledge and folklore without significant headway.

Current approaches to the study of biodiversity are seriously hampered by the limited ability of humans to recognise and recall morphological variation. Few taxonomists can reliably diagnose even 1,000 species and that means that we will need up to 100,000 taxonomists simply to sustain the ability to recognise Earth's 10 to 100 million species, once they have all been described. It is this stark reality that is driving a new approach to species recognition called **DNA barcoding**. DNA barcoding is a method of identifying species using a short section of DNA from a specific gene or genes. Metabarcoding is the identification of organisms from a sample containing DNA from more than one organism. It allows for cheaper, quicker, and more accurate assessment of biodiversity in groups that are difficult to determine by traditional methods.

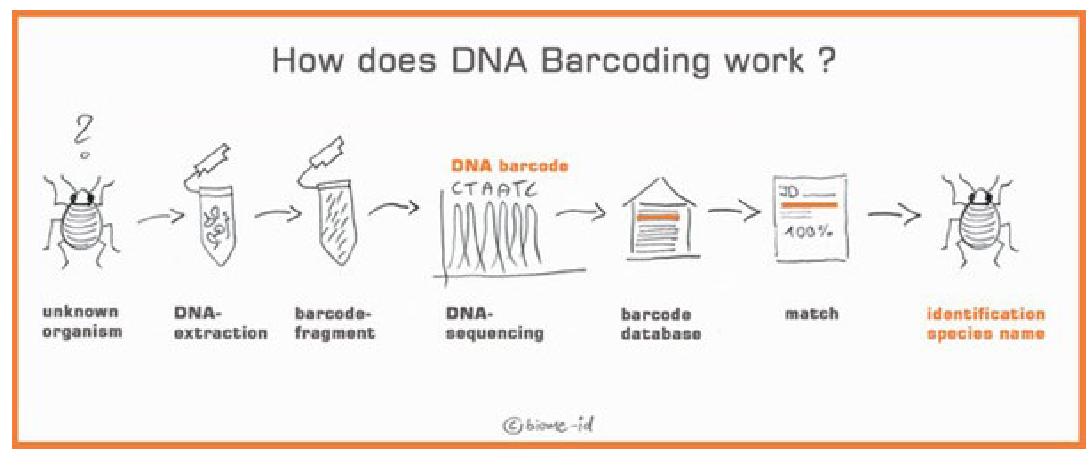


Image Source: biome-id

Conservation genomics currently focuses on monitoring and managing existing genomes of species. However **advanced genomic technologies** can allow for the manipulation of genomes to help achieve conservation goals. Genome-editing technologies such as CRISPR–Cas9 enable precise genome editing at relatively low cost. Gene functions can either be knocked out or specific sequences with desired genome edits can be inserted. In the near future, gene-editing tools may help endangered species adapt to change. De-extinction has thus become a real prospect. The ability to use genome editing to replace alleles might facilitate the evolution of species by enhancing adaptation to climate change or improving disease resistance (Supple and Shapiro, 2018). Developments in synthetic biology, an intersection of biotechnology, engineering and computing have facilitated the design and synthesis of new DNA sequences which can support the design of cells and organisms with novel functions. Synthetic biology may have important implications for biodiversity. Potential benefits include protecting threatened species, restoring degraded ecosystems and making synthetic alternatives to wildlife products. However, the negative impact of novel organisms and associated new economic arrangements on ecosystems and rural societies which largely depend on biodiversity has to be carefully considered.

While conventional biotechnology can play a pivotal role in biodiversity, impressive advances in genome sequencing technology, bioinformatics, automation, and AI have opened up new vistas for understanding, utilizing, and conserving biodiversity. The declining cost of genome sequencing has allowed for the sequencing of thousands of organisms. Sequencing the genomes of all known species and using genomics for the discovery of unknown species is now a real possibility. The segments of genome responsible for adaptation to various biotic and abiotic stresses like climate change, pest and disease can be identified using genomic tools. Genome sequences may be able to point to species that may be endangered. For example, advanced genomic approaches can detect any deleterious mutations in the genes for important functions such as metabolism and immunity. Conversely, these can also detect any genomic changes which may improve survival traits, such as those related to enhanced brain function and metabolism. Such information is very useful for making conservation recommendations for threatened biota. Genomic data can also provide information essential to allow us to exploit the economic potential of living organisms. Leveraging genetic and genome data allows for improved productivity and sustainability and thus reduction of the environmental footprint.

International Efforts

An open digital repository of genomic information on global biodiversity would have far-reaching potential benefits. However, it can only be realized by a coordinated international effort.

Consortium for the Barcode of Life (CBOL) is an international initiative created in 2004 and devoted to developing DNA barcoding as a global standard for the identification of biological species. CBOL has more than 130 Member Organizations from more than 40 countries. International Barcode of Life (iBOL) was launched in 2010 to extend the geographic and taxonomic coverage of the barcode reference library, Barcode of Life Data Systems (BOLD) to store the resulting barcode records, provide community access to the knowledge they represent and create new devices to ensure global access to this information. iBOL completed phase 1, BARCODE 500K – a USD125 million project that generated DNA barcodes for 500,000 species in 5 years. Malaysia should join iBOL and derive the many benefits of capacity building and priority setting of national DNA barcoding.

In 2009, the **Genome 10K (G10K) Project** was established by a consortium of worldwide genome scientists with the objective of sequencing and analysing the complete genomes of 10,000 vertebrate species. Building on the G10K Project, the Earth BioGenome Project (EBP), the world's largest sequencing programme, was launched in 2018 with the aim of sequencing, cataloguing, and characterizing the genomes of all 1.5 million known species of eukaryotes on Earth over a period of 10 years (Lewin et al., 2018) Important issues and challenges of the project discussed included data-sharing policies to ensure a permanent, freely available resource for future scientific discovery while acknowledging and committing to the access and benefit-sharing guidelines of the Nagoya Protocol.

The **10,000 Plants (10KP) Genome Project** was announced in Science in 2017 (Cheng et al, 2018). It aims to sequence over 10,000 genomes representing every major clade of plants and eukaryotic microbes. Data generated is to be freely available, as a foundation for future scientific discoveries and applications. Malaysia should consider sequencing its many natural products and traditional medicinal plants mentioned earlier as part of this endeavour.

The **China National GeneBank (CNGB), Beijing Genomics Institute (BGI), and the Forestry Bureau of Ruili, China** reported on the molecular digitization of a botanical garden. 761 samples, representing 689 vascular plant species from 137 families growing in the Ruili Botanical Garden in China were sequenced (Liu et al., 2019). This project is the world's first scientific and systematic attempt to digitize a whole botanical garden based on genomic as well as voucher specimen information.

It is important for Malaysia to be part of the international effort to access the benefits of the initiatives while protecting its intellectual property. As an example, the Malayan tapir (*Tapiris indicus*) is one of the most iconic animals in Malaysia and is the only surviving member of its species in Asia. It was first listed as endangered in 1986 and its numbers continue to decline. The G10K Project mentioned above targets to especially sequence endangered species including the Malayan tapir. It would be advantageous for Malaysia to be part of this initiative.

Biotechnology Landscape in Malaysia

It is important for Malaysia to leverage the powerful tools of biotechnology to protect and capture value from its rich biodiversity. Although there have been substantial reductions in the cost of genome sequencing, budget constraint is still a major issue and it is not feasible to carry out whole genome sequencing of Malaysia's entire biodiversity. Malaysia's strategy should be to carry out whole genome sequencing of organisms that are unique to Malaysia or where there is a competitive edge (see Appendix 3). Cheaper yet powerful alternatives like metabarcoding which allow for the sequencing of hundreds or thousands of samples simultaneously should also be leveraged. For example, the benthic (living in the seafloor) macro-invertebrate community is a good indicator of ecosystem health for environmental bio-monitoring in coastal and marine ecosystems. They have been shown to rapidly respond to a range of natural and anthropogenic pressures (Johnston and Roberts, 2009). Previously, species identification required extensive taxonomic expertise and was expensive, time-consuming, and laborious and thus a limitation of bio-monitoring based upon benthic organisms. However, DNA metabarcoding (Taberlet et al., 2012) coupled with high-throughput sequencing enables more comprehensive community analysis as it facilitates the rapid and cost-effective identification of the entire taxonomic composition of thousands of samples simultaneously (Zepeda Mendoza et al., 2015). Malaysia could leverage metabarcoding to study its marine and coastal biodiversity as well as other water bodies.

The overall objective of the biotechnology endeavour should be to create a digital backbone of sequences of Malaysia's flora and fauna using genomics that will serve as a valuable infrastructure for agriculture, biology, conservation, medicine, and the growing global bio-economy. Specifically, the objective should be to generate a national genome database targeted towards economic growth and human well-being.

Creating a national gene bank similar to the China National GeneBank will serve as an effort in protecting endangered and endemic plants, including the preservation and archiving of Malaysian germplasm resources to assist with their long-term conservation. A genome database of flora and fauna in the forests of Sabah and Sarawak would be a good starting point. Efforts should include microbes and fungi. Plants such as the Rafflesia plant and several species of rare and endangered orchids, as well as animals such as the Sabah grey langur and Malay partridge are some examples of unique Malaysian organisms. Crops of economic importance whose genomes should be included are plantation crops like oil palm, rubber and cocoa and agricultural crops like banana, durian and rice, the genomes of which could furnish data towards further economically useful crop improvement (see Appendix 3).

It is disappointing that Malaysia played no leading role in the whole genome sequencing of the durian, the king of fruits which is native to Borneo and Sumatra and banana *Musa acuminata* which is native to tropical Indomalaya. The durian (*Durio zibethinus*) genome was sequenced by Singapore scientists (Teh et al., 2017) and the banana (*Musa acuminata*) genome by French scientists (D'Hont et al., 2017).

Malaysia successfully sequenced the oil palm (*Elaeis guineensis*) genome. The release of the oil palm reference genome sequence (Singh et al., 2013b) by the Malaysian Palm Oil Board (MPOB) was a key step toward increasing productivity and sustainability by understanding the molecular basis of agronomically important traits. The genome sequence was made freely available to the global scientific community for further improvement of the oil palm.

The immediate impact of unravelling the genome sequence of the oil palm was the identification of the *SHELL* gene (Singh et al., 2013a), the most important determinant of oil yield. The decoding of the oil palm genome also led to the landmark discovery of the epigenetic basis of clonal abnormality in oil palm (Ong-Abdullah et al., 2015). These discoveries were featured in three issues of Nature (Singh et al., 2013a, b; Ong-Abdullah et al., 2015).

The oil palm genome discoveries also underscored the importance of germplasm collections. MPOB has the world's largest oil palm germplasm collection and this was leveraged in the genome sequencing programme for gene discovery. The first draft genome sequence of the rubber tree (*Hevea brasiliensis*) was published by USM (Ahmad Yamin et al., 2013). Key genes associated with rubber biosynthesis, rubberwood formation, disease resistance, and allergenicity were identified. This effort will augment recent interest in reviving the rubber industry.

Unlocking the Potential of Oil Palm Genome for Sustainability

News of the successful sequencing of the oil palm genome was carried in major newspapers of the world including The New York Times. The unlocking of the oil palm genome provides an opportunity to boost yield and improve sustainability. Palm oil production can be increased without increasing the number of fields to plant them in. This is a huge advantage to an industry which has been heavily criticised for the deforestation it has caused, and which is under pressure to curb its environmental impact. David Edwards, a conservation biologist at James Cook University in Australia was quoted in The New York Times as saying, "The new study is a major breakthrough…The only way that we will be able to feed the projected human population of 9 to 10 billion without huge waves of deforestation is through increases in crop yield." The breakthrough also spawned a new biotech industry in Malaysia providing high throughput genomic services for the oil palm industry.

Oil Palm Tissue Culture for High-yielding Palms

The development of oil palm tissue culture in the 70s heralded a new opportunity for sustainable intensification of oil palm cultivation through the mass propagation of superior high-yielding palms. Yield increases of over 30% were anticipated. However, a tissue culture abnormality known as MANTLED emerged in the 80s and halted large-scale exploitation of this valuable technology. Although mantled palms are genetic carbon copies of their high performing parents, their fruits are often abnormal and result in bunch failure and oil loss. For 30 years scientists across the globe looked for clues for the cause of the abnormality. Malaysia scored a major scientific breakthrough when MPOB and its collaborators unravelled the underlying mechanism for MANTLED by leveraging the oil palm genome sequence. An epigenetic factor known as KARMA is responsible for the abnormality. A diagnostic assay that predicts clonal fidelity with almost 100% accuracy is now finally available.

Big Data and Access to Information

Biotechnology has resulted in an explosion of information. It is imperative that this information is captured and stored in user-friendly databases and made available. These huge data collections are likely to identify significant opportunities in scientific discovery and translational research. Free access to information is fundamental to the rapid improvement of crops, livestock, forestry, and fish species. ML and data mining techniques are expected to be instrumental in managing biodiversity, by taking advantage of big data. Databases on risks and potential negative effects of biotechnology should also be available to allow people to make informed choices and for consensus-building. The current Covid-19 pandemic highlights the considerable risk of zoonoses to human health, and emphasises the importance of understanding the dynamics, distribution and infection of zoonotic agents, especially viruses. Zoonoses constitute 61% of all known infectious diseases (Taylor et al., 2001). Next-generation sequencing (NGS) is enabling high-throughput prospections to identify pathogens including viruses in animals (Barzon et al., 2011). Global sequencing efforts to prospect the viral/microbial composition of any organism are necessary to improve our understanding of zoonoses. Intelligent handling of the big data can help detect disease trends, outbreaks, pathogens and causes of emergence in humans and animals. Consequently, the collected data would be useful in translational research that may help to prevent future biological disasters.

PBD MOVES FORWARD WITHIN A 10-10 MySTIE FRAMEWORK & ECOSYSTEM[1]

[1]For this section, the SIG Team would like to gratefully acknowledge the advice and help rendered to it by ASM Fellow Professor Mahendhiran Nair from Monash University Malaysia. The information and figures were sourced/adapted from his presentation to the SIG team on 1 September 2020 at ASM

As Malaysia embraces Industry 4.0 and the talent pool is equipped to engage with next-generation technologies for PBD, there must also be in place a more effective ecosystem for conserving, monitoring and managing the country's biological resources, while also delivering socio-economic benefits. It is timely that Biodiversity (alongside Environment) has been included within a recently introduced Science, Technology, Innovation and Economic (STIE) development plan, known as the 10-10 *My*STIE Framework, designed to help Malaysia move up the global innovation value chain once it is powered by a strong supportive ecosystem (Academy of Sciences Malaysia and Monash University Malaysia, 2019; see Figure 11).

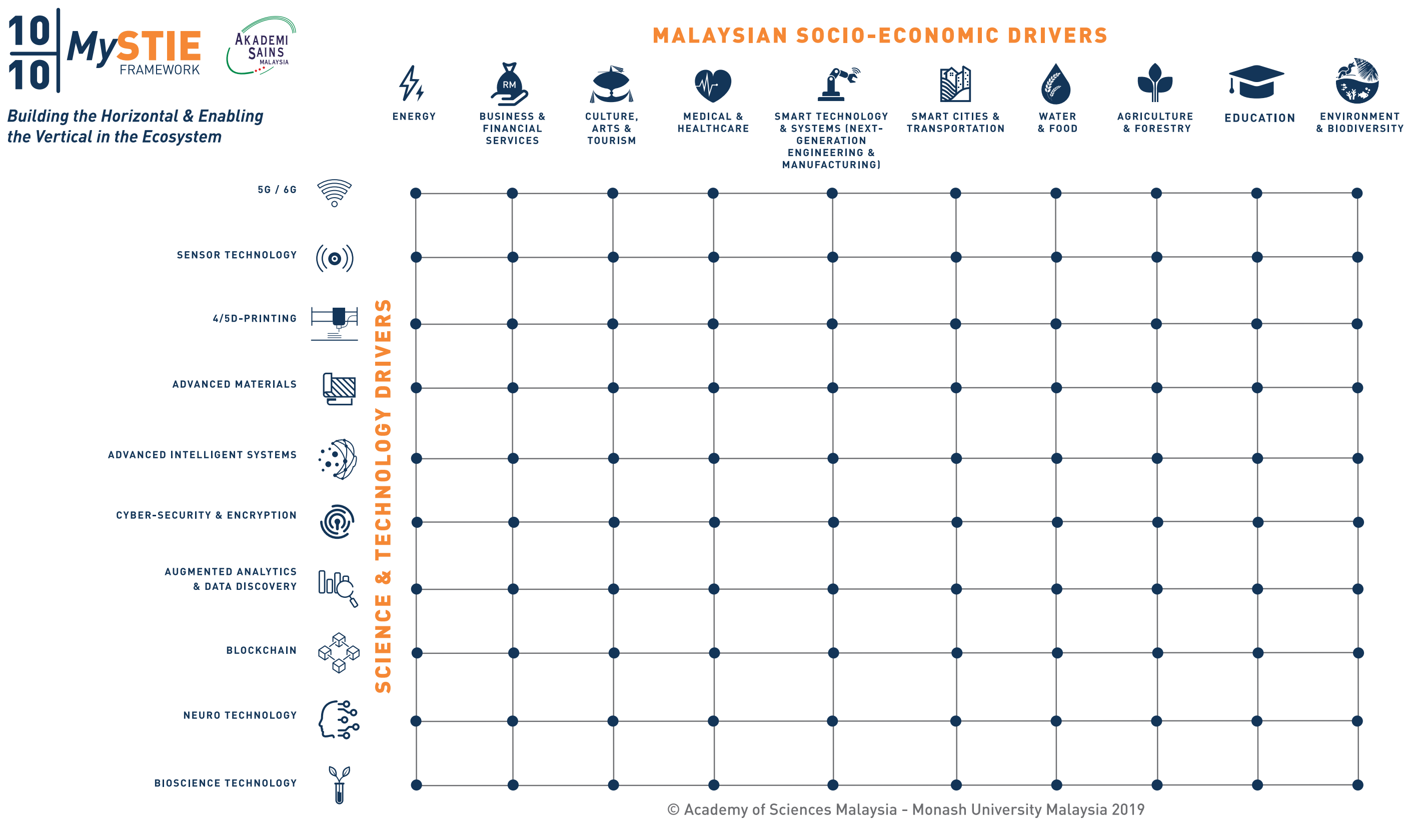


Figure 11 The 10-10 MySTIE Framework

The framework was accepted by the National Science Council (chaired by the Prime Minister) on 14 July 2020. It formulates how 10 socioeconomic drivers identified for Malaysia, (including Environment

The framework was accepted by the National Science Council (chaired by the Prime Minister) on 14 July 2020. It formulates how 10 socioeconomic drivers identified for Malaysia, (including Environment and Biodiversity) when harnessed to the power of 10 globally recognised technology drivers can deliver catalytic and spill-over effects on countless industries (see Figure 16 for how this happens with PBD).

To deliver on expectations, the 10 technology drivers as next-generation platforms for PBD must operate under the framework of an STI ecosystem that can function as its DNA. Such a model for innovation is characterised in Figure 12 and covers the eight described elements of infrastructure, infostructure, intellectual capital, integrity systems, incentives, institutions, interaction and internationalisation.

Unfortunately, such an innovative ecosystem does not exist at present. Instead and for a long time, there have been numerous gaps and challenges (see page 49) which could explain why biodiversity policies and plans have not progressed far and still have a lot of room for improvement. The issues include depletion of natural habitats, low internet connectivity, talent deficits, weak governance, insufficient fiscal support, superficial institutional support, a *silo* mentality among stakeholders and insufficient commitment to being a global player, as detailed in Figure 13, all of which in toto contribute to a weak ecosystem for PBD.

Clearly, the way forward for PBD is to remedy the shortcomings within the PBD ecosystem and also to adopt a next-generation approach to STIE with disruptive technologies for research, data collection, retrieval and management and also to add socio-economic value to biodiversity. Such innovative strategies are summarised in Figure 14.

Infrastructure
Quality and sophistication of the physical and natural infrastructure that support growth and development of the PBD ecosystem

Internationalisation
Proactive engagement with global knowledge and innovation networks, institutions of governance and standards boards and global value chains – expansion of global innovation footprint and market reach

Interaction
Level and quality of cooperation, collaboration and knowledge sharing among all stakeholders in the PBD ecosystem

Infostructure
Digital infostructure that provides seamless integration of multiple value chains within and across the ecosystem - these systems provide seamless flow of information for strategic decision-making and market intelligence

Institutions
Quality of the institutions of governance (government agencies, Regulatory bodies, standard bodies, industry associations, community organisation, institutions of learning/ research institutes) that supportthe systematic development of the PBD ecosystem

Intellectual Capital
Talent stock in the field and related industries - this covers general, specialised, technical, entrepreneurial and leadership skills

Incentives
Fiscal and non-fiscal incentives to encourage R&D, the adoption of innovations, commercialisation of local technologies, and market expansion strategies, including globalisation of local technologies and knowledge

Integrity Systems
Governance systems to manage the ecosystem efficiently - continuous improvement system to raise the Return on Value (ROV) for all stakeholders

Figure 12 Characterising the STIE Ecosystem for PBD

Infrastructure
Natural habitats are not well-maintained, and inventories not regularly updated despite the availability of sophisticated new technologies

Internationalisation
Engagement with global institutions is patchy and limited. Knowledge spillover is low

Interaction
Partnerships among key stakeholders are weak or at best patchy.

Infostructure
Internet connectivity issues and low-level usage of ICT in managing the ecosystem. Lack of active media response to biased reporting

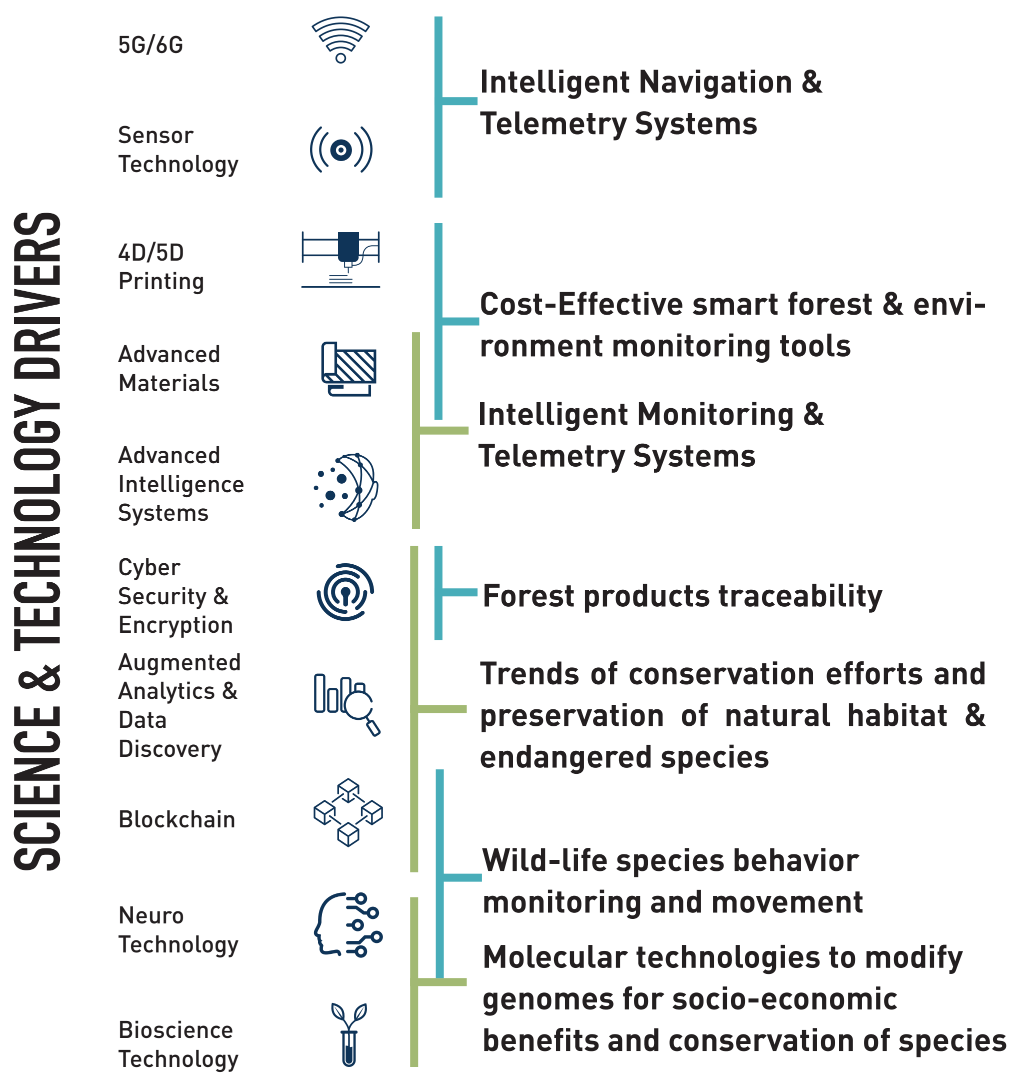
Institutions
Supporting institutions at the federal and state levels are not effective in managing biodiversity

Intellectual Capital
Lack of talent with specialized skills in the field. Labour intensive - low levels of skills & ICT literacy

Incentives
Fiscal and non-fiscal incentives are low for innovations and adoption of technology

Integrity Systems
Governance systems are weak – lack of tracking, traceability. High moral hazard and rent-seeking behaviour

Figure 13 Gaps in the PBD STIE Ecosystem

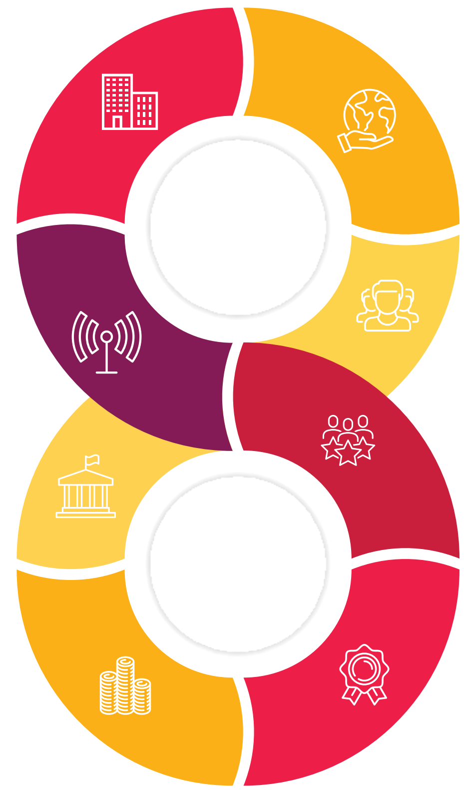


Infrastructure
Use the best STIE (10x10) to conserve, monitor, research and manage the physical and natural infrastructure.

Interaction
Framework for building strong partnership among all stakeholders is in place to raise Return on Value for The Rakyat.

Institutions
Key institutions (government, industry, educational institutes/training and community organizations) are in place to support the precision biodiversity ecosystems.

Incentives
Fiscal & non-fiscal incentives for development and adoption of innovations.



Internationalisation
Strong international partnerships and linkages that foster knowledge technology-transfer and adherence to global best practices.

Infostructure
Nationwide access to high-speed, affordable digital infrastructure. Surveillance and response to biased media.

Intellectual Capital
Next-generation talent and technopreneurs / innopreneurs, with greater affinity to biodiversity development initiatives. Educational and R&D Institutions become the source for multi disciplinary knowledge and skills development in biodiversity.

Integrity Systems
Adherence to good governance and global best practices and standards – e.g. environmental management practices.

Figure 14 Addressing STIE ecosystem Gaps to move PBD forward with S&T Drivers

With a conducive ecosystem in place, it is possible to show how application of the 10-10 *My*STIE Framework, will enable Malaysia to incorporate leap-frogging STIEs to enhance the development of PBD for the benefit of the Rakyat and the global community. Figure 15 shows how a combination with all 10 STIE drivers will spawn new technologies that contribute to the development of PBD in Malaysia, e.g. automated wildlife species monitoring and digitization of flora and fauna. Such a framework also encompasses next-generation research and applications that will show cross-linkages with other sectors within the Shared Prosperity Model, such as Water and Food Security.

Best of all, PBD as one of the socio-economic drivers that is set to harness the 10 technology drivers shown in Figure 15, will additionally have a strong catalytic and spill-over effect on countless industries and other socio-economic drivers, once a robust biodiversity culture and ecosystem is in place. Examples of the new sectors that could spawn and increase revenue streams delivering beneficial ROV to the people, are as indicated at the foot of each vertical axis below the respective socio-economic drivers mapped in Figure 16 on the next page.

A win-win scenario will eventually evolve as the *My*STIE framework is set to bridge STI and economic development (measured as gross domestic product or GDP per capita) juxtaposed on the country's rich biodiversity and linked to a vibrant and agile PBD ecosystem. Such an innovative PBD ecosystem will safeguard against wanton trade-offs from the depletion of natural resources and environmental damage and instead provide trade-benefits from the expected boost to the economy by judicious engagement with all three. As indicated earlier (Figure 16), it will spawn new sectors, increase revenue streams and enhance ROV to the people.

With higher biodiversity/conservation engagements using 10-10 *My*STIE, there will be enhanced business activities promoted by a green biorevolution. PBD can then take its rightful place as a major contributor not only to the health of the planet and its peoples, but also to the socio-economic well-being of global citizens for...... **GREEN is the new GOLD**!

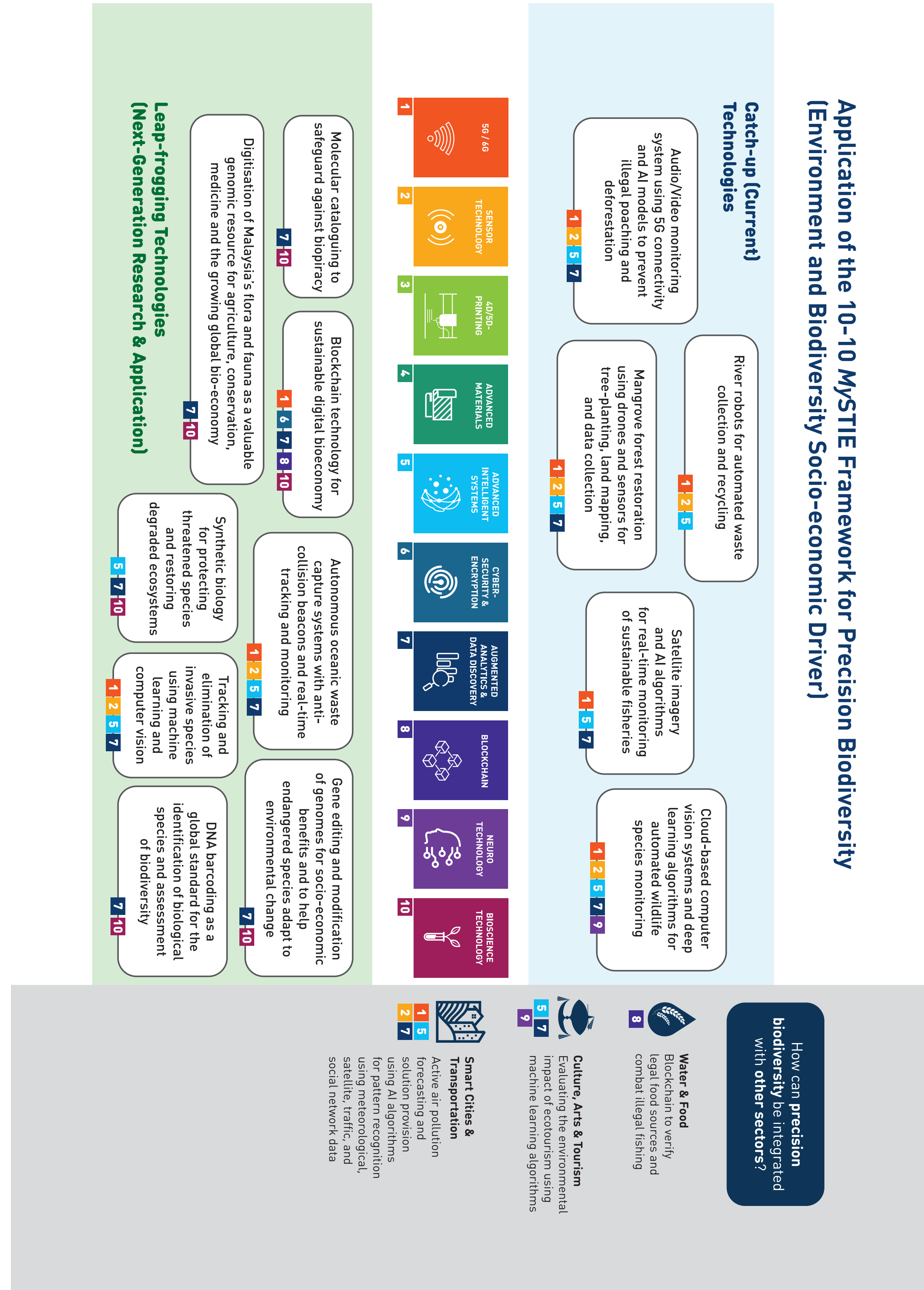


Figure 15 Applications of the 10-10 MySTIE Matrix to PBD with Spillover Benefits to Other Sectors (Shared Prosperity Model)

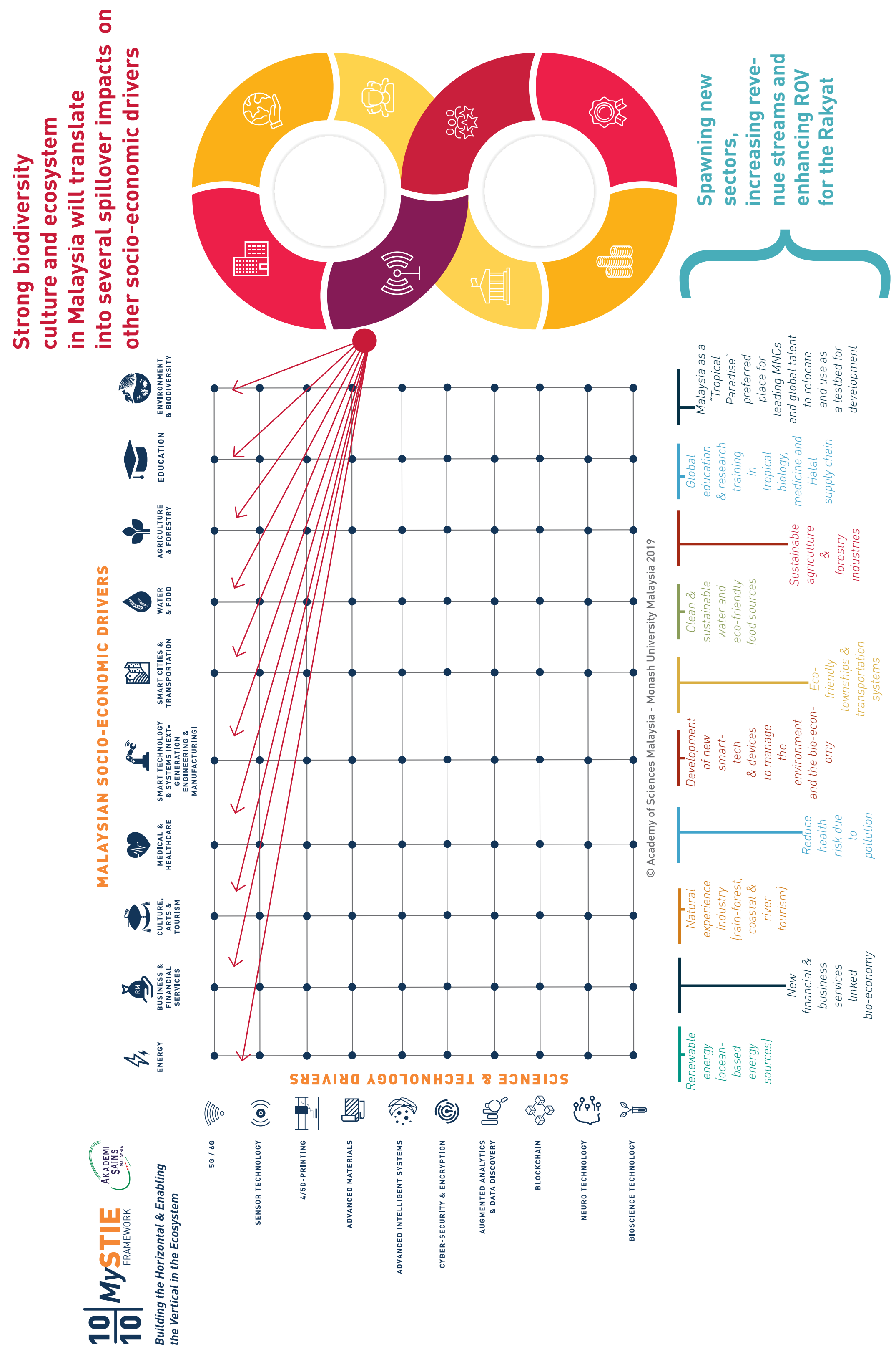


Figure 16 Socioeconomic Impact of a Sound Biodiversity Ecosystem to Other Socio-economic Drivers

SWOT ANALYSIS ON **MALAYSIA'S BIODIVERSITY LANDSCAPE**

STRENGTHS

- Malaysia has one of the world's richest biodiversity that can be digitised and codified for precision conservation and management.
- Malaysia houses the world's largest field gene bank of plantation crops (e.g. oil palm, rubber, cocoa, pepper, etc.) contributing to the national economy.
- Numerous institutional centres with expertise and knowledge on biodiversity and molecular biology that can be shared digitally for economic benefit.
- Precision technologies (e.g. AI, Big Data, IoT, Robotics, Drones, CRISPR-CAS, cloning, etc.) are available and can be deployed to monitor, manage and harness biodiversity.
- NGO participation in biodiversity has been substantial and needs to be leveraged for community engagement through digitalisation platforms.

WEAKNESSES

- Lack of sufficient trained staff in high-end technology to support PBD.
- Lack of harmonization between Federal and State authorities regarding biodiversity management and enforcement.
- Paucity of economic benefits derived from biodiversity.
- Absence of digitalized national repository to house information on expertise and data on biodiversity (e.g. genome database, ecosystems, management practices).
- Insufficient funding for biodiversity issues.

OPPORTUNITIES

- Application of precision technology for better monitoring, sustainable management and to generate economic benefits from biological diversity.
  - i. Prevention of illegal logging and poaching.
  - ii. Conservation of endangered species.
  - iii. Food security and wellness.
  - iv. Sustainable management of natural resources, including indigenous knowledge.
  - v. Metabarcoding for reliable, verifiable and efficient monitoring of biodiversity.
  - vi. Ecotourism with community engagement.
- PBD would help enhance appreciation for biodiversity and create more career opportunities that are attractive for the younger generation.

THREATS

- Without precision technology, monitoring and sustainable management of biodiversity for economic benefit is compromised.
- Deforestation and degradation of tropical rainforests impacting climate change, habitat destruction and pollution.
- Lack of food security and an ever- increasing food import bill.
- Loss of invaluable natural resources including indigenous species.
- Invasion by destructive alien species (e.g. Golden Apple Snail, Tilapia, *Acacia mangium*).

Way Forward

Overarching Recommendations

1. Mainstream precision biodiversity conservation and restoration through a total government approach that is cohesive and integrative so that all policies and blueprints converge and align with it e.g. The Economic Plan, STI Masterplan, Industry Master Plan, Education and Higher Education Blueprint, 4IR and RMK-12. Leverage PBD through the existing conservation channels including state governments

2. Leverage precision biodiversity through the existing conservation channels of the Quadruple Helix, inclusive of state governments

3. Implement open data sharing and transparency on biodiversity issues inclusive of all digitalised information via platforms such as the Open Science Malaysia Platform and i-Connect

4. Establish genome database of organisms of strategic importance for socio-economic benefits by drawing on government-academia-industry partnerships

5. Strengthen educational and awareness programmes to incorporate knowledge and wisdom for application of precision biodiversity nationwide

6. Establish collaborative platforms for conservation and precision biodiversity at national and international level towards achieving the United Nations Sustainable Development Goals and the Shared Prosperity Vision

7. Establish a National Natural History Museum (digital/physical) within a Biodiversity Act

8. Establish National Committee to coordinate all precision biodiversity activities including roll-out of PBD *My*STIE Framework

Strategic Programmes and Interventions

Strategic Programmes/Interventions	Actions	Timeline	Key Partners
Development and documentation of multidisciplinary conservation, restoration and research strategies for precision biodiversity-linked in-situ and ex-situ efforts	• Establish/maintain in-situ and ex-situ genetic resources in key biodiversity areas and national biological resource centres* • Develop digitised data management systems for in-situ and ex-situ collections • Develop a module for integrating data management processes for in-situ and ex-situ collections *Some relevant databases: MyGenebank, Malaysia Biodiversity Information System (MyBIS), Agrobiodiversity Information System (AgrobIS), Marine Park Data Centre (MPDC), Systematic Marine Biodiversity Information System (SyMBiosIS), Marine Park Management Information System (MPMIS), Sabah Biodiversity Integrated Information System (SaBIIS) and Botanical Research Herbarium Management System (BRAHMS)	Medium to long term (~3 years)	KASA KeTSA MOSTI MOHE MOE MEA MPIC IHLs RIs

Strategic Programmes/Interventions	Actions	Timeline	Key Partners
Digitisation & IoT Programme for biodiversity	• Apply AI technologies to generate digitised data inclusive of growth characteristics, behavior and distribution • Provide incentives to ground operators	Medium term (~1-2 years)	KASA KeTSA MEA MOSTI MPIC MIMOS NGOSs Citizen Scientists Civil Society
Genome data bank of economically valuable biodiversity	• Establish gene bank for priority organisms** • Sequence genomes of priority organisms** **(see Appendix 3)	Medium term (~1-2 years)	MOSTI KeTSA MOHE MOE MEA MPIC
Platform for data mining collation and translation into economic benefits, including Biodiversity Credits	• Create and analyse big data for strategies/protocols to translate gene bank data into economic products** **(see Appendix 3)	Medium term (~1-2 years)	MOSTI MOHE MOE MEA MPIC Chambers of Commerce

Strategic Programmes/Interventions	Actions	Timeline	Key Partners
AI and ML training for various layers of operators	• Upskill selected biodiversity field officers, scientists and practitioners with AI application and concepts including benefits of digitalisation • Provide relevant career opportunities	Medium term (~1 year)	MOHR HRDF MOHE MOE IHLs RIs
National Precision Biodiversity Agenda	• Formulate Precision Biodiversity agenda within a Biodiversity Act • Establish a Natural History Museum • Harmonisation at Federal and State levels • Provide technology roadmap that manages biodiversity for posterity and prosperity	Long term (~3 years)	KASA KeTSA MOSTI MEA MOHE AGC Chambers of Commerce Civil Society

Conclusion

The global Covid-19 pandemic has sounded a clarion wake-up call to warn the world to stop the wanton destruction of natural resources and ecosystems, that can open the door to human-wildlife interactions and zoonosis. Malaysia as the 12th most mega-biodiverse country on earth has a global responsibility for conservation and biodiversity management.

By adopting Precision Biodiversity, the country will show the world how next-generation technologies can more effectively help to conserve, monitor and manage our valuable biological resources alongside a biorevolution, to protect the planet as well as for socio-economic returns to The Rakyat through ROV via collaboration with the Quadruple Helix. Only a collaborative approach both at the national and international level can ensure success.

The four goals together with the overarching recommendations, encapsulated within the strategic programmes and powered by the MySTIE Framework cascading to the localities, set the stage for Malaysia to be a global leader in the application of Precision Biodiversity to support both the UN Convention on Biodiversity and the Sustainable Development Goals.

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COMMITTEE MEMBERS OF SIG ON PRECISION BIODIVERSITY

Dr. Helen Nair FASc, FMSA, DF-MABIC Chairperson

Helen Nair has had an illustrious career in academia, having served at University of Malaya (UM) for more than 30 years, including as holder of the Professorial Chair in Plant Physiology, before resigning and helping to establish two private universities. She served as the inaugural Senior Professor and Dean of the Science faculties prior to retiring. A pioneering interest in postharvest physiology continues through an advisory role in her former Postharvest Biotechnology laboratory at UM. Currently, a council member of Academy of Sciences Malaysia, she also holds Emeritus Membership in the American Society of Plant Biologists.

Academician Tan Sri Dr Salleh Mohd Nor FASc

A forester by profession, Senior Fellow of the Academy of Sciences Malaysia, author of 13 books and winner of the prestigious Merdeka Award, Salleh was founder Director General of the Forest Research Institute Malaysia, President of the Malaysian Nature Society for 30 years and President of the International Union of Forestry Research Institutions. He led FRIM to be a global leader in tropical forestry research and was instrumental in creating Endau Rompin and Belum as national parks.

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Ahmad Ismail is a Professor of wildlife ecology and ecotoxicology at Department of Biology, Faculty of Science, Universiti Putra Malaysia (UPM). Currently he is the President of the Malaysian Nature Society (MNS), Council Member of Academy Sciences Malaysia (ASM) and is involved in biodiversity and environmental issues with many agencies. In community services, he is committed to various science education activities and with CEPA (communication, Education and Public Awareness) on issues relevant to environment and nature.

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Ravigadevi Sambanthamurthi is a scientific consultant to the Malaysian Palm Oil Board (MPOB). She was the former Director of the Advanced Biotechnology and Breeding Centre of MPOB and Honorary Professor of Biosciences, University of Nottingham Malaysia Campus. She was one of the pioneers in research on oil palm biotechnology, and led the MPOB Oil Palm Genome Project. She has numerous publications, including three in Nature as corresponding author, and holds more than 40 patents/patent applications. She is a Fellow of the Academy of Sciences Malaysia and member of Malaysian Mensa.

Emeritus Professor Dr Normah Mohd Noor FASc

Emeritus Professor Dr Normah Mohd Noor is a pioneer of research on plant cryopreservation in the country. Her research at Universiti Kebangsaan Malaysia on cryoreservation and conservation of tropical recalcitrant fruit species of Garcinia, Citrus and Nephelium, has led to the development of techniques for long term conservation and micropropagation of these important species. Her research on understanding recalcitrant seed behaviour continues with the application of a systems biology approach. She is a Fellow of the Academy of Sciences.

Professor Dato' Dr Mohamed Shariff Mohamed Din FASc

Prof Dato Mohamed Shariff Mohamed Din has 42 years of teaching and research experience in fish health management at Universiti Putra Malaysia. He was the founding director of Innovation and Commercialisation Centre (now Putra Science Park) and works for the World Intellectual Property Organization (WIPO) in more than 20 countries promoting innovation and the use of appropriate technology. Currently, he is the editor-in-chief of the Asian Fisheries Science, a Scopus indexed journal.

Dr Rajanaidu Nookiah FASc, KMN

Rajanaidu Nookiah worked for nearly 50 years as an oil palm breeder and was also a former Head of the Biotechnology and Plant Science Unit, at Malaysian Palm Oil Board. He was responsible for the collection of the largest Elaeis guineensis, oil palm germplasm collection in the world from 11 African countries and Elaeis oleifera from 8 Central/ South American countries. Dr Rajanaidu co-authored "Oil Palm Genetic Resources", which documents extensive information on the collection expedition. Besides being a Fellow of the Academy Sciences Malaysia, he is also the Honorary Secretary/Vice President to International Society of Oil Palm Breeders (since 1983) and recipient of Life Time Excellence Award Palm Oil Industry (LEAP).

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List of Abbreviations

4IR	Fourth Industrial Revolution
10KP	10,000 Plants Genome Project
AgrobIS	Agrobiodiversity Information System
AI	Artificial intelligence
ASEAN	Association of Southeast Asian Nations
ASM	Academy of Sciences Malaysia
BB	Biodiversity Banking
BGI	Beijing Genomics Institute
BOLD	Barcode of Life Data Systems
BOS	Biodiversity Offsets Scheme
BRAHMS	Botanical Research Herbarium Management System
CBD	United Nations Convention on Biological Diversity
CBOL	Consortium for the Barcode of Life
CCUS	Carbon capture, utilisation and storage
CEOS	Committee on Earth Observation Satellites
CFF	Crops For the Future
CNGB	China National GeneBank
Covid-19	Coronavirus disease 2019
CRISPR	Clustered Regularly Interspaced Short Palindromic Repeats
DNA	Deoxyribonucleic acid
EAAFP	East Asian Australian Flyway Partnership
EBP	Earth BioGenome Project
FAO	Food and Agriculture Organization of the United Nations
FaSC	Fellow of the Academy of Sciences Malaysia
FRGS	Fundamental Research Grant Scheme
G10K	Genome 10K Project
GBIF	Global Biodiversity Information Facility
GBO	Global Biodiversity Outlook
GDP	Gross Domestic Product
HERG	Henipavirus Ecology Research Group
HIV	Human immunodeficiency virus
HRDF	Human Resources Development Fund
iBOL	International Barcode of Life
IHL	Institute of Higher Learning
IoT	Internet of Things
IPBES	Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services
IPCC	Intergovernmental Panel on Climate Change
IRRDB	International Rubber Research and Development Board
IUCN	International Union for Conservation of Nature
IVF	In-vitro fertilization
KASA	Ministry of Environment and Water
KeTSA	Ministry of Energy and Natural Resources
LPP	Langur Penang Project
MAB	Man and Biosphere
MARDI	Malaysian Agricultural Research and Development Institute
MEA	Malaysian Economic Association
MERS	Middle East Respiratory Syndrome
ML	Machine learning
MOE	Ministry of Education
MOHE	Ministry of Higher Education
MOHR	Ministry of Human Resources
MOSTI	Ministry of Science, Technology and Innovation
MP12	12th Malaysia Plan
MPDC	Marine Park Data Centre
MPIC	Ministry of Plantation Industries and Commodities
MPMIS	Marine Park Management Information System
MPOB	Malaysian Palm Oil Board
MPS	Malaysian Primatological Society
MyBIS	Malaysia Biodiversity Information System
MyIPO	Intellectual Property Corporation of Malaysia
MySTIE	Malaysia Science, Technology, Innovation and Economy
MYT	Malaysia Time
MyTKDL	Malaysia Traditional Knowledge Digital Library
NAP3	Third National Agricultural Policy
NASA	National Space Agency
NCTF	National Conservation Trust Fund for Natural Resources
NGO	Non-governmental organization
NGS	Next-generation sequencing
OPP	Oil Palm Phenolics
PA	Precision agriculture
PBD	Precision biodiversity
POME	Palm oil mill effluent
RE	Renewable energy
RI	Research Institute
RETR	Renewable Energy Transition Roadmap
ROV	Return on Value
SaBIIS	Sabah Biodiversity Integrated Information System
SARS	Severe acute respiratory syndrome
SEDA	Sustainable Energy Development Authority
SIG	Special Interest Group
SIRIM	Standard and Industrial Research Institute of Malaysia
STI	Science, Technology, and Innovation
STIE	Science, Technology, Innovation and Economy
SyMBiosIS	Systematic Marine Biodiversity Information System
TRGS	Transdisciplinary Research Grant Scheme
UAV	Unmanned automated vehicles
UBI	Urban Biodiversity Initiative
UM	Universiti Malaya
UMT	Universiti Malaysia Terengganu
UN	United Nations
UNDP	United Nations Development Programme
UNCED	United Nations Conference on Environment and Development
UNDESA	United Nations Department of Economic and Social Affairs
UNFCC	United Nations Framework Convention on Climate Change
USM	Universiti Sains Malaysia
WWF	World Wide Fund for Nature
WWF-Malaysia	World Wide Fund for Nature-Malaysia

APPENDIX 1:
Assessment of Progress for Strategic Plan for Biodiversity 2011–2020 (GBO-5, 2020)

Strategic Goal A: Address the underlying causes of biodiversity loss by mainstreaming bivodiversity across government and society	
Aichi Biodiversity Target	Summary of Progress
Target 1 By 2020, at the latest, people are aware of the values of biodiversity and the steps they can take to conserve and use it sustainably	There has been an apparent increase in the past decade in the proportion of people who have heard of biodiversity and who understand the concept. Understanding of biodiversity appears to be increasing more rapidly among younger people. A recent survey suggested that more than one third of people in the most biodiverse countries have high awareness both of the values of biodiversity and the steps required for its conservation and sustainable use. The target has not been achieved (low confidence).
Target 2 By 2020, at the latest, biodiversity values have been integrated into national and local development and poverty reduction strategies and planning processes and are being incorporated into national accounting, as appropriate, and reporting systems.	Many countries report examples of incorporating biodiversity into various planning and development processes. There has been a steady upward trend of countries incorporating biodiversity values into national accounting and reporting systems. At the same time, there is less evidence that biodiversity has been truly integrated into development and poverty reduction planning as required by the target. The target has not been achieved (medium confidence).
Target 3 By 2020, at the latest, incentives, including subsidies, harmful to biodiversity are eliminated, phased out or reformed in order to minimize or avoid negative impacts, and positive incentives for the conservation and sustainable use of biodiversity are developed and applied, consistent and in harmony with the Convention and other relevant international obligations, taking into account national socio economic conditions.	Overall, little progress has been made over the past decade in eliminating, phasing out or reforming subsidies and other incentives potentially harmful to biodiversity, and in developing positive incentives for biodiversity conservation and sustainable use. Relatively few countries have taken steps even to identify incentives that harm biodiversity, and harmful subsidies far outweigh positive incentives in areas such as fisheries and the control of deforestation. The target has not been achieved (medium confidence).

Target 4 By 2020, at the latest, Governments, business and stakeholders at all levels have taken steps to achieve or have implemented plans for sustainable production and consumption and have kept the impacts of use of natural resources well within safe ecological limits	While an increasing number of governments and businesses are developing plans for more sustainable production and consumption, these are not being implemented on a scale that eliminates the negative impact of unsustainable human activities on biodiversity. While natural resources are being used more efficiently, the aggregated demand for resources continues to increase, and therefore the impacts of their use remain well above safe ecological limits. The target has not been achieved (high confidence).
Strategic Goal B: Reduce the direct pressures on biodiversity and promote sustainable use	
Aichi Biodiversity Target	Summary of Progress
Target 5 By 2020, the rate of loss of all natural habitats, including forests, is at least halved and where feasible brought close to zero, and degradation and fragmentation is significantly reduced	The recent rate of deforestation is lower than that of the previous decade, but only by about one third, and deforestation may be accelerating again in some areas. Loss, degradation and fragmentation of habitats remain high in forest and other biomes, especially in the most biodiversity-rich ecosystems in tropical regions. Wilderness areas and global wetlands continue to decline. Fragmentation of rivers remains a critical threat to freshwater biodiversity. The target has not been achieved (high confidence).
Target 6 By 2020 all fish and invertebrate stocks and aquatic plants are managed and harvested sustainably, legally and applying ecosystem-based approaches, so that overfishing is avoided, recovery plans and measures are in place for all depleted species, fisheries have no significant adverse impacts on threatened species and vulnerable ecosystems and the impacts of fisheries on stocks, species and ecosystems are within safe ecological limits.	While there has been substantial progress towards this target in some countries and regions, a third of marine fish stocks are overfished, a higher proportion than ten years ago. Many fisheries are still causing unsustainable levels of bycatch of non-target species and are damaging marine habitats. The target has not been achieved (high confidence).
Target 7 By 2020 areas under agriculture, aquaculture and forestry are managed sustainably, ensuring conservation of biodiversity.	There has been a substantial expansion of efforts to promote sustainable agriculture, forestry and aquaculture over recent years, including through farmer-led agroecological approaches. The use of fertilizers and pesticides has stabilized globally. Despite such progress, biodiversity continues to decline in landscapes used to produce food and timber; food and agricultural production remains among the main drivers of global biodiversity loss. The target has not been achieved (high confidence).
Target 8 By 2020, pollution, including from excess nutrients, has been brought to levels that are not detrimental to ecosystem function and biodiversity.	Pollution, including from excess nutrients, pesticides, plastics and other waste, continues to be a major driver of biodiversity loss. Despite increasing efforts to improve the use of fertilizers, nutrient levels continue to be detrimental to ecosystem function and biodiversity. Plastic pollution is accumulating in the oceans, causing severe impacts on marine and other ecosystems but with still largely unknown implications. Actions taken in many countries to minimize plastic waste have not been sufficient to reduce this source of pollution. The target has not been achieved (medium confidence).
Target 9 By 2020, invasive alien species and pathways are identified and prioritized, priority species are controlled or eradicated, and measures are in place to manage pathways to prevent their introduction and establishment.	Good progress has been made during the past decade on identifying and prioritizing invasive alien species in terms of the risk they present, as well as in the feasibility of managing them. Successful programmes to eradicate invasive alien species, especially invasive mammals on islands, have benefited native species. However, these successes represent only a small proportion of all occurrences of invasive species. There is no evidence of a slowing down in the number of new introductions of alien species. The target has been partially achieved (medium confidence).
Target 10 By 2015, the multiple anthropogenic pressures on coral reefs, and other vulnerable ecosystems impacted by climate change or ocean acidification are minimized, so as to maintain their integrity and functioning.	Multiple threats continue to affect coral reefs and other vulnerable ecosystems impacted by climate change and ocean acidification. Overfishing, nutrient pollution and coastal development compound the effects of coral bleaching. Corals have shown the most rapid increase in extinction risk of all assessed groups. Hard coral cover has declined significantly in some regions, and there has been a shift towards coral species less able to support diverse reef habitats. Other ecosystems especially in mountains and polar regions have experienced significant impacts from climate change, compounded by other pressures. The target was missed by the stated date of 2015, and was not achieved even by 2020 (high confidence).

Strategic Goal C To improve the status of biodiversity by safeguarding ecosystems, species and genetic diversity	
Aichi Biodiversity Target	Summary of Progress
Target 11 By 2020, at least 17 per cent of terrestrial and inland water, and 10 per cent of coastal and marine areas, especially areas of particular importance for biodiversity and ecosystem services, are conserved through effectively and equitably managed, ecologically representative and well-connected systems of protected areas and other effective area-based conservation measures, and integrated into the wider landscapes and seascapes.	The proportion of the planet's land and oceans designated as protected areas is likely to reach the targets for 2020 and may be exceeded when other effective area-based conservation measures and future national commitments are taken into account. However, progress has been more modest in ensuring that protected areas safeguard the most important areas for biodiversity, are ecologically representative, and connected to one another as well as to the wider landscape and seascape and are equitably and effectively managed as well. The target has been partially achieved (high confidence).
Target 12 By 2020 the extinction of known threatened species has been prevented and their conservation status, particularly of those most in decline, has been improved and sustained.	Species continue to move, on average, closer to extinction. However, the number of extinctions of birds and mammals would likely have been at least two to four times higher without conservation actions over the past decade. Among well-assessed taxonomic groups, nearly one quarter (23.7%) of species are threatened with extinction unless the drivers of biodiversity loss are drastically reduced. There is an estimated total of one million threatened species across all groups. Wild animal populations have fallen by more than two-thirds since 1970, and have continued to decline since 2010. The target has not been achieved (high confidence).

Target 13 By 2020, the genetic diversity of cultivated plants and farmed and domesticated animals and of wild relatives, including other socio-economically as well as culturally valuable species, is maintained, and strategies have been developed and implemented for minimizing genetic erosion and safeguarding their genetic diversity.	Genetic diversity of cultivated plants, farmed and domesticated animals, and wild relatives, continues to be eroded. The wild relatives of important food crops are poorly represented in ex situ seed banks that help guarantee their conservation and are important for future food security. The proportion of livestock breeds that are at risk or extinct is increasing, although at a slower rate than in earlier years, suggesting some progress in preventing the decline of traditional breeds. Wild relatives of farmed birds and mammals are moving closer to extinction. The target has not been achieved (medium confidence).

Strategic Goal D: Enhance the benefits to all from biodiversity and ecosystem services	
Aichi Biodiversity Target	Summary of Progress
Target 14 By 2020, ecosystems that provide essential services, including services related to water, and contribute to health, livelihoods and well-being, are restored and safeguarded, taking into account the needs of women, indigenous and local communities, and the poor and vulnerable	The capacity of ecosystems to provide the essential services on which societies depend continues to decline, and consequently, most ecosystem services (nature's contributions to people) are in decline. In general, poor and vulnerable communities, as well as women, are disproportionately affected by this decline. Mammal and bird species responsible for pollination are on average moving closer to extinction, as are species used for food and medicine. The target has not been achieved (medium confidence).
Target 15 By 2020, ecosystem resilience and the contribution of biodiversity to carbon stocks has been enhanced, through conservation and restoration, including restoration of at least 15 per cent of degraded ecosystems, thereby contributing to climate change mitigation and adaptation and to combating desertification.	Progress towards the target of restoring 15 per cent of degraded ecosystems by 2020 is limited. Nevertheless, ambitious restoration programmes are under way or proposed in many regions, with the potential to deliver significant gains in ecosystem resilience and preservation of carbon stocks. The target has not been achieved (medium confidence)

Target 16 By 2015, the Nagoya Protocol on Access to Genetic Resources and the Fair and Equitable Sharing of Benefits Arising from their Utilization is in force and operational, consistent with national legislation.	The Nagoya Protocol on Access to Genetic Resources and the Fair and Equitable Sharing of Benefits Arising from their Utilization entered into force on 12 October 2014. As of July 2020, 126 Parties to the CBD have ratified the Protocol and 87 of them have put in place national access and benefit sharing measures, as well as establishing competent national authorities. The Protocol can be considered operational. The target has been partially achieved (high confidence)
Strategic Goal E: Enhance implementation through participatory planning, knowledge management and capacity building	
Aichi Biodiversity Target	Summary of Progress
Target 17 By 2015 each Party has developed, adopted as a policy instrument, and has commenced implementing an effective, participatory and updated national biodiversity strategy and action plan.	By the December 2015 deadline established in this target, 69 Parties had submitted an NBSAP prepared, revised or updated after the adoption of the Strategic Plan. An additional 101 Parties have since submitted their NBSAP, so that by July 2020, 170 Parties had developed NBSAPs in line with the Strategic Plan. This represents 85% of the Parties to the Convention. However, the extent to which these NBSAPs have been adopted as policy instruments and are being implemented in an effective and participatory manner, is variable. The target has been partially achieved (high confidence).
Target 18 By 2020, the traditional knowledge, innovations and practices of indigenous and local communities relevant for the conservation and sustainable use of biodiversity, and their customary use of biological resources, are respected, subject to national legislation and relevant international obligations, and fully integrated and reflected in the implementation of the Convention with the full and effective participation of indigenous and local communities, at all relevant levels.	There has been an increase in the recognition of the value of traditional knowledge and customary sustainable use, both in global policy fora and in the scientific community. However, despite progress in some countries, there is limited information indicating that traditional knowledge and customary sustainable use have been widely respected and/ or reflected in national legislation related to the implementation of the Convention, or on the extent to which indigenous peoples and local communities are effectively participating in associated processes. The target has not been achieved (low confidence).

Target 19 By 2020, knowledge, the science base and technologies relating to biodiversity, its values, functioning, status and trends, and the consequences of its loss, are improved, widely shared and transferred, and applied.	Significant progress has been made since 2010 in the generation, sharing and assessment of knowledge and data on biodiversity, with big-data aggregation, advances in modelling and artificial intelligence opening up new opportunities for improved understanding of the biosphere. However, major imbalances remain in the location and taxonomic focus of studies and monitoring. Information gaps remain in the consequences of biodiversity loss for people, and the application of biodiversity knowledge in decision making is limited. The target has been partially achieved (medium confidence).
Target 20 By 2020, at the latest, the mobilization of financial resources for effectively implementing the Strategic Plan for Biodiversity 2011-2020 from all sources, and in accordance with the consolidated and agreed process in the Strategy for Resource Mobilization, should increase substantially from the current levels. This target will be subject to changes contingent to resource needs assessments to be developed and reported by Parties.	There have been increases in domestic resources for biodiversity in some countries, with resources remaining broadly constant for others over the past decade. Financial resources available for biodiversity through international flows and official development assistance have roughly doubled. However, when all sources of biodiversity finance are taken into account, the increase in biodiversity financing would not appear to be sufficient in relation to needs. Moreover, these resources are swamped by support for activities harmful to biodiversity (see Aichi Target 3). Progress on identifying funding needs, gaps and priorities and the development of national financial plans and assessments of biodiversity values has been limited to relatively few countries (see Aichi Target 2). The target has been partially achieved (high confidence).

APPENDIX 2:
Techniques of Climate Engineering

Terrestrial

1. Afforestation/reforestation
Afforestation and reforestation involve the establishment of forest on land that is not currently forested. It is intended that the established trees will absorb and store a greater amount of CO_2 than the existing land cover.

2. Bioenergy with carbon capture and storage
Biomass can be burned as biofuel to provide energy. There are a wide range of feedstocks that could be used for the three main types of biofuel:
- Lignocelluloses fuel: forestry residues, wood, straw, coppice pellets/chips, Miscanthus
- Biodiesel: oilseed rape, canola, sunflower, palm oil, soy oil, algae
- Bioethanol: wheat grain, barley, sugar beet, sugar cane, sweet sorghum, fruits.

3. Biochar
Biochar is a charcoal-like product produced by the decomposition of biomass in low or zero-oxygen conditions using pyrolysis or gasification (Secretariat of the Convention on Biological Diversity, 2012). The flammable gases driven off in the process are available as an energy source. Potential sources of biochar include dedicated biomass feedstocks, as well as agricultural, forestry and food wastes, other organic wastes including manure and sewage, or 'slash and char' shifting agriculture

4. Enhanced weathering: based materials to land
One suggested method of enhanced weathering would involve quarrying of basic or alkaline materials such as olivine (magnesium iron silicate) or serpentine (magnesium iron phyllosilicate), grinding them to form fine particles, and spreading the materials on agricultural and forest soils and river catchments to increase the surface area exposed to weathering (Secretariat of the Convention on Biological Diversity, 2012).

5. Enhanced weathering: in situ
Proposals for enhanced weathering in situ aim to enhance carbonation of peridotite rock formations (formations containing a high proportion of the mineral olivine) in the Earth's upper mantle, by injecting CO_2-rich fluids into the geology (Kelemen & Matter, 2008; Kelemen et al., 2011). The olivine reacts with CO_2 to form solid carbonate minerals.

6. Direct air capture
Direct Air Capture involves the capture and isolation of CO_2 from ambient air. Large, free-standing structures would be constructed with surfaces covered in CO_2-sorbing materials, such as solid ion-exchange resins, amines on silica, or strongly alkaline solutions such as sodium hydroxide (The Royal Society, 2009). These 'artificial trees' would be constructed on open areas of land with good air flow (Socolow et al., 2011). The isolated stream of pure CO_2 would then be transferred to long-term stores in geological formations

Marine

7. Ocean fertilisation: Iron
Iron fertilization has received the most attention as it is anticipated to be the most effective in many (but not all) ocean regions (Williamson et al., 2012). Iron (in a soluble form such as ferrous sulfate) would be added to High Nutrient Low Chlorophyll regions of the ocean which cover approximately 20% of the ocean surface (Edwards et al., 2004). In these regions, although other macronutrients are available, low iron concentrations limit productivity. This technique would be primarily focused on the Southern Ocean, where it is anticipated to be most effective (Williamson et al., 2012), although the equatorial Pacific and northern Pacific would also be suitable (The Royal Society, 2009). Continual injections of iron would be required. However, the quantities of iron required would be several orders of magnitude smaller than the quantities of the (macro)nutrients phosphorus and nitrogen required for ocean fertilization (Lampitt et al., 2008). The maximum conceivable fertilization - to sequester ~1.5Gt C/yr - would require around 2% of annual iron production. For more realistic fertilization scales, at most ~0.2% of annual iron production would be required

8. Ocean fertilisation: Nitrogen or Phosphorus
Phosphorus and nitrogen are also suggested for direct ocean fertilization as they are limiting across a significant proportion of the ocean. They would be added in soluble or finely powdered forms (such as anhydrous monosodium phosphate or phosphoric acid for phosphorus, and urea, ammonia or nitrates for nitrogen; Williamson et al., 2012) to Low Nutrient Low Chlorophyll regions of the ocean, which cover approximately 40% of the ocean surface, including tropical and sub-tropical gyres (The Royal Society, 2009; Secretariat of the Convention on Biological Diversity, 2009; Vaughan & Lenton, 2011). It has been suggested that macronutrients should only be applied to surface waters over the deep ocean, not shallow bays or coastal waters where they would lead to significant eutrophication.

9. Enhanced upwelling/downwelling
Enhanced upwelling methods would bring nutrient-rich waters from the deep ocean to the surface. The abundance and growth of phytoplankton, which absorb CO_2 during photosynthesis, would be enhanced resulting in an increased 'drawdown' of CO_2 from the atmosphere. Carbon is stored within the phytoplankton, and, after they die or are eaten, a small proportion sinks into the deep sea in fecal matter and other detritus where it is removed from the atmosphere for decades to centuries. Downwelling methods aim to increase the rate at which CO_2-rich surface waters sink to the deep ocean where the CO_2 is retained over long timescales (Secretariat of the Convention on Biological Diversity, 2012).

10. Biomass storage in the ocean
Proposals include 'Crop Residue Oceanic Permanent Sequestration' (Metzger & G., 2001; Strand & Benford, 2009). This would involve baling crop residues and placing them on ocean sediments at depths over 1000-1500 m (Strand & Benford, 2009). At such depths there is limited mixing between the deep and upper oceanic layers and terrestrially derived organic matter is relatively stable due to the cold, limited oxygen availability and the apparent lack of a marine mechanism for the breakdown of lignocellulose (Strand & Benford, 2009). Effects could also be minimized by placing bales in areas of high sedimentation (Strand & Benford, 2009). The type of packaging would be a significant factor when assessing potential impacts as its permeability to water and gases would influence the flux of substances into near-seabed water. Additionally, if the bales were buried within the sediment, such impacts are likely to be significantly reduced (Secretariat of the Convention on Biological Diversity, 2012).

11. Enhanced weathering: base materials to ocean
Ocean alkalinity methods involve spreading basic or alkaline materials – such as powdered rocks containing olivine minerals, powdered limestone or liquid calcium hydroxide – across the surface ocean (Lenton & Vaughan, 2009; Secretariat of the Convention on Biological Diversity, 2012). The minerals would react with dissolved CO_2 to form carbonates and silicates (Kohler et al., 2013). The concentration of CO_2 in the ocean would be reduced, leading to increased uptake of atmospheric CO_2. Some dissolution products (e.g. silicic acid) would also fertilize phytoplankton, increasing the biological pump
Atmospheric/Stratospheric 'dimming' technique

12. Sunshade
Sunshields or deflectors would be placed between the sun and the Earth to reflect a proportion of incoming solar radiation back into space, offsetting warming caused by anthropogenic greenhouse gas emissions. Suggestions include placing millions of mirrors in a near-Earth orbit, or establishing a ring of dust particles or lightweight satellites above the equatorial region (The Royal Society,

2009). Other proposals consider placing reflectors at a point 1.5 million km from Earth towards the Sun (referred to as the Lagrange L1 point), where the surface area of shades needed would be considerably smaller (The Royal Society, 2009). Options include a superfine aluminum mesh, large reflective shield or trillions of reflective metallic discs or lenses (~50cm diameter). Shades could be launched into orbit using high-powered electromagnetic cannons (Angel, 2006), or put in place by dedicated space craft.

13. Stratospheric sulphate aerosol injection

Sulfur dioxide or hydrogen sulfide would be injected into the lower stratosphere, where they would form reflective sulfate aerosol particles. These particles scatter incoming solar radiation back into space. This method was suggested as a means to replicate the effects of large-scale volcanic eruptions during which the release of sulfate aerosols led to global cooling (Kirchner et al., 1999; Keith, 2000). Studies using climate modelling suggest that artificial enhancement of stratospheric sulfate aerosols could be effective in counteracting the effects of anthropogenic climate change (e.g. Caldeira & Wood, 2008; Rasch et al., 2008; Robock, 2008).

14. Enhanced marine cloud albedo

The albedo of clouds in the troposphere (lower atmosphere) can be enhanced by increasing the availability of cloud condensation nuclei and therefore the concentration of water droplets within clouds (Twomey, 1977; Albrecht, 1989). Stratocumulus clouds cover approximately 25% of the oceanic surface and currently reflect between 30-70% of the sunlight that reaches them (Latham et al., 2008). It has been suggested that increasing the reflectivity of all stratocumulus clouds by 10% could offset the warming caused by a doubling of atmospheric CO2 (Latham et al., 2008). Proposed methods include spraying seawater particles from large (300 ton) wind-powered satellite-guided ships or from conventional vessels or aircraft (Salter et al., 2008). It is estimated that approximately 1500 vessels would be required to offset the warming from a doubling of CO2 levels (Latham et al., 2008).

Earth Surface

15. Enhanced desert albedo

The albedo of desert regions, which cover 2% of Earth's total surface area (The Royal Society, 2009), would be increased by covering large areas with reflective polyethylene-aluminum materials (Gaskill, 2012). It has been estimated that an area of 4 million square miles (approximately 43 times the land area of the UK) – across the Saharan, Arabian and Gobi deserts – would be required. The areas deemed suitable are stable, largely uninhabited, sparsely vegetated and flat (Vaughan & Lenton, 2011). It is suggested that covering this entire area in a material that increases albedo from 0.4 to 0.8 (albedo is measured on a scale of 0 to 1, where 0 is 100% absorption of all incoming radiation and 1 is 100% reflection) could offset about three quarters of the radiative forcing caused by a doubling of CO2 (Gaskill, 2012), although, other estimates find a much weaker effect (Vaughan & Lenton, 2011).

16. Enhanced cropland/grassland albedo

Under this proposal, plant varieties with variegated or light-colored leaves, high leaf glossiness or a greater amount of leaf hair would be established on croplands and perhaps more broadly on grassland, shrubland and savanna habitats (Hamwey, 2007; Ridgwell et al., 2009) to increase vegetation albedo.

17. Enhanced urban albedo

Roofs, roads and other urban surfaces – constituting 0.05-1% of global land surface (Akbari et al., 2009; Lenton & Vaughan, 2009) - would be made bright, reflective white (e.g. by painting). This measure could potentially be extended to all areas of human settlement (Hamwey, 2007), and would be most effective in regions receiving high rates of solar radiation (i.e. lower latitudes).

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APPENDIX 3:
List of Suggested Organisms for Genome Sequencing and Inclusion in the Proposed National Gene Bank

Animals

Banded Peacock Butterfly, *Papilio crino* (endemic to Langkawi)

Bornean orang-utan, *Pongo pygmaeus* (already sequenced)*

Brown-winged Kingfisher, *Halcyon amauroptera* (endemic in Langkawi)****

Bumhead wrasse, *Cheilinus undulatus* (ecologically important to keep the health of coral reefs)**

Dusky langur, *Trachypithecus obscurus***

Geckos Mahsuri's Rock Gecko, *Cnemaspis mahsuriae* (endemic Langkawi)*****

Gunung Raya Green-crested Lizard, *Bronchocela rayaensis* (endemic Langkawi)*****

Langkawi Island bent-toed gecko, *Cyrtodactylus langkawiensis* (endemic to Langkawi)*****

Langkawi Skinks, *Sphenomorphus langkawiensis* (new species), *Eutropis novemcarinata* (new species)

Leatherback turtle or Penyu Belimbing, *Dermochelys coriacea**

Lesser mousedeer (Sang Kancil), *Tragulus kanchil******

Malayan pangolin, *Manis javanica**

Malayan tapir, *Tapirus indicus* (already being sequenced)**

Malayan tiger, *Panthera tigris jacksoni* (already sequenced)**

Dugong or Sea Cow, *Dugon dugong* (rarest and most endangered marine mammal in Malaysia)***

Molluscs, *Tridacna gigas* (largest shellfish in the world)***

Proboscis monkey, *Nasalis larvatus***

Ray fish, *Urogymnus lobistoma* (found only in brackish to marine waters of Sabah)

Rhinoceros hornbill, *Buceros rhinoceros****

Sabah grey langur, *Presbytis hosei****

Sea Cucumbers, *Stichopus horrens* (partial genome sequenced), Stichopus fusiformiossa (endemic species found in Pulau Songsong Kedah)*****

Siamang, *Symphalangus syndactylus***

Snake eel, *Ophichthnus grandoculis* (endemic to Malaysia)

Soft Coral, *Corallium borneense* (endemic to Malaysia)

Plants

Banana, *Musa acuminata* (already sequenced) (economic importance; food security)*****

Benuang, *Octomeles sumatrana******

Bogak/Paku Aji, *Cycas clivivola* (endangered under Malaysia Plant Red List)*****

Borneo Camphorwood, *Dryobalanops aromatic****

Bungor Langkawi or Rose of India, *Lagerstroemia langkawiensis* (endemic to Langkawi)**

Chengal, *Neobalanocarpus hemii***

Cocoa, *Theobroma cacao* (already sequenced) (significant contributor to Malaysia's economy)

Dark red meranti, *Shorea curtisii* *****

Durian, *Durio zibethinus* (already sequenced) (economic importance)

Gelenggang, *Casia alata* (medicinal value)

Gouty balsam, *Impatiens mirabilis*****
Hempedu bumi, *Andrographis paniculata* (medicinal value)
Jelutong, *Dyera costulata******
Kacip Fatimah, *Labicia pumila* (medicinal value)
Kadam, *Neolamarkia cadamba*
Kempas, *Koompassia malaccensis*
Light Red Meranti or Engkabang, *Shorea macrophylla****
Mangosteen, *Garcinia mangostana* (economic importance)
Mengkudu, *Morinda cirtrifolia* (medicinal value)
Merbau, *Instia palembanica*
Nepenthes species, e.g. *N. ampullaria, N. gracilis and N. macfarlanei* (endemic, economic potentials)
Rafflesia cantleyi (native and unique) *****
Oil palm, *Elaeis guineensis* (already sequenced) (significant contributor to Malaysia's economy)*****
Oil palm, *Elaeis oleifera* (already sequenced) (economic importance)
Red meranti, *Shorea leprosula***
Red Striped Begonia, *Begonia phoeniogramma*****
Rice, *Oryza sativa* (already sequenced) (socio-economic importance, food security)
Rubber, *Hevea brasiliensis* (already sequenced) (significant contributor to Malaysia's economy)*****
Sambung nyawa, *Gynura procumbens* (medicinal value)
Kesum, *Polygonum minus* (medicinal value)
Serdang batu, *Maxburretia gracilis* (endemic to Langkawi)
Temulawak, *Cucurma xanthorriza* (medicinal value)
Tongkat Ali, *Eurycoma longifolia* (medicinal value)
Tualang, *Koompassia excelsa* (tallest tree in Malaysia)*****

Fungi

Cendawan budak sawan, *Amauroderma rugosum* (medicinal value)
Cendawan senduk, *Ganoderma neojaponicum* (medicinal value)
Pleurotus giganteus (culinary purpose)
Pleurotus tuberregium (culinary purpose)
Tiger milk mushroom, *Lignosus rhinocerus* (already sequenced) (medicinal value)
Termite mushroom, *Termitomyces heimii* (culinary purpose)

* categorised as Critically Endangered under the IUCN Red List of Threatened Species
** categorised as Endangered under the IUCN Red List of Threatened Species
***categorised as Vulnerable under the IUCN Red List of Threatened Species
**** categorised as Near Threatened under the IUCN Red List of Threatened Species
*****categorised as Least Concern under the IUCN Red List of Threatened Species

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