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Akademi Ilmu Pengetahuan Indonesia

SCIENCE for Indonesia's Biodiversity

In celebration of 150 years of publication
of *The Malay Archipelago* by Alfred Russel Wallace.

Science for Indonesia's Biodiversity

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Introduction

The writing of *Science for Indonesia's Biodiversity* grew out of the excitement surrounding the success of the previous book published by AIPI, called *SAINS45: Indonesian Science Agenda Towards a Century of Independence*. The preparation of *SAINS45* had involved many alumni of the Frontiers of Sciences activities facilitated by AIPI in the 2014-2016 period, and it had been a milestone in the birth of ALMI, the Indonesian Young Academy of Sciences in 2016. The young scientists belonging to ALMI are working hard in this very young organization, trying to contribute to a country whose natural wealth is a world laboratory that never ceases to inspire.

When *SAINS45* was adopted by the Indonesian Science Fund (DIPI) to produce the focus areas of research for its first research funding, the authors realized that *SAINS45* really had become the living document that they had hoped for. *SAINS45* was introduced to schools through ALMI members, when these prominent young scientists at the peak of their careers returned to their schools through an ALMI initiative called Scientist Goes to School. They introduced science and the importance of science, while carrying the *SAINS45* book and inviting Indonesian young people to dream for Indonesia. These young scientists are like preachers who call on the young generation to always base their thinking on scientific knowledge, and to view the land of Indonesia as a field of work that must be cared for and guarded for the benefit of the world. *SAINS45* keeps rolling and does not end as a dead document.

To keep *SAINS45* alive and inspiring, not only for the general public, but also for policy makers, it needs to be extended through other documents. The preparation of *Science for Indonesia's Biodiversity* is an effort to build on the impact of *SAINS45* while strengthening ALMI itself, through its members' involvement in the Study Committee for the formulation of *Science for Indonesia's Biodiversity*.

Science for Indonesia's Biodiversity is a document that seeks to translate some of the inspirations in *SAINS45* into recommendations that are ready to be developed as policies. This document starts from the questions raised in *SAINS45*, and focuses on the importance of basic research for sustainable development in an effort to strengthen the economy. *Science for Indonesia's Biodiversity* invites the government to transition from economic development based on natural resources to a science-based economy—which will lead to the transformation of Indonesia as a developed country in 2045. To aid the transition and transformation, this document focuses on the richness of Indonesia's biodiversity, as a comparative advantage that has not yet been much explored, emphasizing strengthening the contribution of science and technology to maximize its benefits. As a policy recommendation document, this book can be the basis for developing a national research agenda.

Science for Indonesia's Biodiversity consists of three main sections. These were specified in the mandate of the Study Committee set out in the Statement of Tasks, as a reference for the preparation of documents which must be absolutely complied with. The three sections are, first, to identify Indonesia's biodiversity richness, as well as to identify its great challenges so that science can contribute to solutions. Second, to formulate a science-based policy strategy to achieve Sustainable Development Goals (SDGs) for life under water and on land, as well as for life between them. And thirdly, to identify priority interventions and proposals for development steps and implementation plans. This document also provides a scale of priorities and ambitions, as well as the economic and scientific impacts arising from each priority.

The three sections that are also part of the Study Committee's Statement of Tasks served as a reference for the quality assurance process for this *Science for Indonesia's Biodiversity* document. The draft edition of this document was sent to 265 members of the Indonesian young scientists' network who were invited to provide input, comments and criticism for the document's compliance with the Statement of Tasks. Fortyone reviewers sent very valuable criticisms and suggestions for this document, and we are very grateful to these peer reviewers. The Study Committee's response to the input and criticism from peer reviewers was finally judged and considered adequate by an AIPI monitoring team. This process is the final round of efforts to ensure the quality of AIPI documents, as well as to ensure that this document complies with the mandate of the Statement of Tasks.

AIPI is fortunate to have the support of various parties which together are trying to realize this document. ALMI is the main driver of the preparation of *Science for Indonesia's Biodiversity*, represented by its 12 of its members in the Study Committee. Through the US National Academy of Sciences (NAS), USAID Indonesia continues its support because it believes that *Science for Indonesia's Biodiversity* is an important document for those policy makers seeking to develop a science-based national policy agenda for sustainable economic development, which is also in line with the world agenda. AIPI is very grateful for this trust, especially to Dr. Clara Davis.

A grant from The Scientific Programme Indonesia-the Netherlands of the Royal Netherlands Academy of Arts and Sciences (KNAW) enabled us to conduct science enrichment for this report in The Netherlands in September 2018. We are grateful for the support received from NIOO-KNAW (The Netherlands Institute of Technology), Wageningen University, and De Jonge Akademie (DJA), as well as The Royal Netherlands Institute of Southeast Asian and Caribbean Studies (KITLV) throughout this program. We also extend our gratitude for the assistance given by the State Secretariat that has enabled us to conduct important meetings in the process of preparation of this document. We also thank Biology Research Center of the Indonesian Institute of Sciences (LIPI) for their valuable input to this document.

The presence of the Tempo Institute gives a different color to this document. Just as *SAINS45* had a touch of *Tempo*, so does the preparation for *Science for Indonesia's Biodiversity*. Without repeated meetings with *Tempo*, this book could have become a dry, boring document. We are thankful for the help of our good friends in *Tempo*, who always inspire us to speak and tell stories.

This document would never have been published without the determination and strong commitment of the Study Committee and its supporting secretariat: the study director, editor, writer and media relations, and other staff.

We are indebted to Dr. Bruce Alberts for spending so many hours amid his extremely busy schedules in making sure the sound quality of this English Edition. We are also grateful to receive the support of Dr. Clara Davis in proofreading the English Edition of this book, just like during the preparation of *SAINS45*. We would like to thank Ibu Tuti Gunawan for translating the Bahasa Indonesia version of the book into English. Her knowledge and experience on Indonesia is reflected the quality of translation of this document.

Above all, we are grateful to receive support and cooperation from many parties that's has enabled the English edition of *Science for Indonesia's Biodiversity* to be published on time. For this, AIPI expresses its immense gratitude. We hope you enjoy reading it.

I

WHAT AND WHY BIODIVERSITY

What is Indonesia like in 2045, one century after independence? Would Indonesia be successful in transforming itself into a developed country? Doesn't Indonesia possess a vastly superior biodiversity as the capital to achieve it?

Promoting general welfare and enriching intellectual life of the nation are two lofty ideals declared by the founders of our nation as the basis of statehood. After more than 70 years of independence, Indonesia has succeeded in increasing the welfare of the people so that it has become a middle-income country. Now Indonesia has arrived at a crossroad: to stay and be trapped as a middle-income country, or to go forward to become a developed nation.

We have huge capital in the form of richness in natural and human resources which potentially can make this nation a developed country, respected the world over. If we already have strong faith and basic capital, the question is, what strategy will lead us towards an advanced Indonesia?

The natural environment and the people of Indonesia are the main capital for development. However, its management in the 21st century requires a new paradigm. Indonesia's biodiversity is indeed abundant and is our significant advantage, but if it is not managed intelligently and sustainably and utilized optimally, then this natural biodiversity richness can be eroded over time, such as the case with mineral, petroleum and gas resources.

We also have to look at this natural wealth from its diversity, namely the diversity of flora, fauna, and microbes, both on land and at sea, which is called biodiversity, as one of the keys to improving the welfare of its people. Indonesia can take inspiration from nature in making technological innovations in the future.

Indonesia's biological wealth can indeed be the main capital for transformation from a country that relies on resources (a resource-based society) to a country that relies on knowledge, science and technology (a knowledge-based society). Along with that, high quality human resources can be built.

When Georg Eberhard Rumphius documented flora and fauna of the Moluccas in the mid-17th century, the term 'biodiversity' was not yet known. It was three centuries later in 1968, when a conservationist, Raymond F. Dasmann, introduced the term biodiversity in his book titled *A Different Kind of Country*.

Biodiversity or the varieties of biological life is often understood in different ways. Biodiversity for farmers may mean a variety of seeds that they plant in their farms. For children, biodiversity may mean cute animals in wild forests that they see on their gadgets. It is a different case for sellers of wild animals: biodiversity is a highly priced commodity.

To understand the concept of biodiversity as a whole, we need to understand it at various levels, from the level of genes, species, communities, ecosystems, and even planets. Therefore, the Convention of Biological Diversity defines it as "the variability among living organisms from all sources including terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are part; this includes diversity within species, between species and of ecosystems". *Kamus Besar Bahasa Indonesia* (Great Dictionary of the Indonesian Language) gives a definition which is not very different, that is "*keseluruhan keanekaragaman makhluk yang diperlihatkan suatu daerah mulai dari keanekaragaman genetik, jenis, dan ekosistemnya*" (the overall diversity of living beings found in an area, from diversity of genes, species, and ecosystems).

Climate, geology, hydrology, ecology, and the processes of evolution are factors that produce biodiversity and make it constantly changing. Some changes occur naturally and slowly, but changes can occur more quickly and widely due to human activities. For example, climate change, natural disasters, environmental pollution, introduction of new species, deforestation, over-exploitation, and loss of certain species.

Furthermore, biodiversity can be understood through its hierarchical components—genes, species and ecosystems. At the smallest level, genetic diversity is the main source of biodiversity at all levels. The more diverse the genetic variations of a species, the more it will be able to withstand threats and changes.

Each species will develop and collect genetic differences that will benefit its survival. The magnitude of genetic differences within and between species can indicate the rate of evolution and map phylogenetic relationships between living things.

The number of unique genes and the morphological and physiological characteristics they encode over time will increase in size within lineage. This is the mover of evolution.

The variation between populations is a result of local ecological conditions. A population can have great conservation value because of its ability to adapt to certain environments, including the ability to adapt at the genetic level to a variety of habitat characteristics. In an ecosystem, there exist interdependent relationships among various populations and species. The loss of population or extinction of a species reduces the carrying capacity of ecosystems for other species that live there. This is why diversity—at various levels—must always be maintained.

Biodiversity in the Indonesian Context

As the largest archipelagic country in the world, Indonesia has many unique and exceptional features compared to other biodiversity centers. The combination of its land and marine biodiversity, including its microorganisms, makes Indonesia the richest biodiversity country on planet Earth. In the sea, Indonesia is at the heart of the coral triangle which has the largest number of hard coral species in the world. Fifteen percent of the world's coral reefs are found in Indonesia, complete with thousands of species of reef fish, far exceeding the rich marine resources of Australia, Hawai'i and the Caribbeans. Even in the waters of the southern part of the Maluku Islands, the number of coral fish reaches 28% of global reef fish (Limmon *et al*. 2018).

Various studies in genetics and archeology show the importance of Indonesia's land forms in the complex process of human migration and evolution. Indonesia's high and unique biodiversity is a result of the contribution of many factors. Its geographical position, tropical climate, the complexity of the landscape, the isolation of the region over a long period of time, the movement of tectonic plates, the vastness of the area have all affected evolutionary processes. Millions of years of evolution in certain habitats, both on land and in the water, have produced ecosystems that support natural balance, including human life. The evolution of human creativity that produced key civilizations such as the technology of crossing seas is seen in ancient paintings in various places in the Indonesian archipelago.

Indonesia's biodiversity has also inspired major global scientific discoveries. In the 19th century, Alfred Russel Wallace documented biodiversity from various parts of the country. Wallace wrote about the butterflies of Bantimurung, South Sulawesi, and on to *The Ternate Paper* which tells the story of the survival of the fittest as the basis of natural selection, which made him with Charles Darwin the co-discoverers of the theory of evolution. Rumphius's documentation two centuries earlier opened up the horizons of the science of tropical botany and contributed greatly to the development of the scientific naming system in the 18th century by Carolus Linnaeus, known as Linnaean taxonomy.

The Rumphius manuscript was pored over by researchers at the Mayo Clinic in the United States for drug discovery (Buenz *et al*. 2006). Rumphius noted the efficacy of green beans as an anti-beriberi medicine, although this plant was not yet cultivated in the Moluccas at that time. Two hundred years later in Jakarta, at that time was still called Batavia, a laboratory led by Christiaan Eijkman discovered vitamin B1 as an anti-beriberi drug made from the bran of rice, which marked a new era of vitamins in medicine. For this breakthrough, Eijkman was awarded the Nobel Prize in Medicine in 1929.

Now vitamins and vitamin supplements are becoming billion-dollar businesses. In the United States, sales reach USD 37 billion a year (National Institute of Health 2016).

In Indonesia, the market research institute Euromonitor International estimates that sales of vitamins and dietary supplements in 2018 will reach IDR 20.74 trillion, up from the previous year, around IDR 20.11 trillion.

The above example shows how science and technology add value far greater than the original value of biodiversity. That's just one example from land. The Indonesian sea is also a paradise for a diverse marine biota that has not yet been identified fully, nor its benefits known. Furthermore, Indonesia with its human genetic diversity and local wisdom regarding natural resources is an ideal natural laboratory for the research on drug, food, cosmetics and other inventions.

Strategic Issues

Indonesia's wealth in biodiversity is a very important asset for economic progress, food security, and national competitiveness. The following strategic issues should receive more serious attention and therefore become the main theme of this book:

1. **Adequate knowledge of Indonesia's rich biodiversity.** To benefit from our rich biodiversity, we fundamentally need to have complete data on biodiversity on land and at sea, including data on microbes. Biodiversity data, both historically and biogeographically, are far from adequate. The data currently available is still limited, scattered, not standardized, and not yet open. Indonesian biodiversity data in public institutions is still largely produced and managed using project approaches with relatively low sustainability. The availability of data related to biodiversity is a fundamental prerequisite in the development of knowledge and utilization of Indonesia's biodiversity.

2. **Realization of the potential benefits of Indonesia's biodiversity in an optimal way.** The wealth and uniqueness of Indonesia's biodiversity can be Indonesia's main capital in its transformation to become a developed country. Knowledge about its potential utilization and economic value, as well as its strategic and sustainable management, will boost the potential of biodiversity, for example in drug discovery, ecotourism, and renewable energy.

3. **Mitigation of damage to various important ecosystems and the threat of extinction of various species.** Habitat destruction and extinction of various types of biota continue to occur due to human behavior. Government policies and their implementation both at the national and regional levels have not been able to protect Indonesia's biodiversity from damage and extinction. Although the government has established protected areas or conservation areas both on land and at sea, there are still very many community and industrial activities that cause habitat degradation and threaten the extinction of various species. The extinction of a species will have an impact on decreasing the resilience of other species which then has a negative impact on overall biodiversity. Therefore, public knowledge, awareness, and participation in the importance of protecting and sustainably using the wealth of biodiversity must be improved.

4. **Strengthening science and technology in relation to conservation and utilization of biodiversity for the nation's competitiveness.** Strong science and technology are an absolute necessity as an innovation lever which would place Indonesia on the map of the world advancing science. Indonesian biodiversity is able to sustain progress in various fields, such as in the discovery of new species, genetic diversity, biomimicry technology, bioprospecting for new drugs and biomaterials, exploration of the potential of the deep sea, climate change, and the environment. Competence and infrastructure that includes basic and applied sciences including big data management needs to be strengthened.

5. **Mainstreaming science for biodiversity in the formulation of various related policies.**

Biodiversity and the environment must become the part of the mainstream of development policy. Nature and its ecosystem are the foundation that supports the sustainability of life on Earth, so socio-economic growth must heed the preservation of nature. Thus, all policies on development must place them as the primary consideration, with a knowledge -based or science-based approach.

The government has tried to compile various documents to support the conservation of Indonesia's biodiversity, such as through the Indonesian Biodiversity Strategic Action Plan (IBSAP 2015-2020) which focuses on environmental conservation efforts. Local wisdom in maintaining biodiversity has actually also been reflected in the lives of various indigenous peoples in the Indonesian archipelago who, for centuries, have lived in harmony with nature. More than 700 ethnic groups in Indonesia depend on the natural resources around them to meet their food, water, clothing and medical needs. They have customary behavior, habits, culture and rules relating to the appreciation and management of nature and their various aspects, both on land and at sea. This is a good example of what the ecological, economic and community interests can grow in accord with the carrying capacity of the biosphere. The challenge is how we can utilize this local wisdom for the development of Indonesia in facing rapid social change and how to maintain continuity?

Science for Indonesia's Biodiversity

The book *Science for Indonesia's Biodiversity* is one of the efforts to better understand biodiversity as a significant advantage that Indonesia has. This book discusses the importance of science and what kind of science is needed to manage our biodiversity more productively and sustainably.

The seven chapters in this book describe what biodiversity is, what biodiversity we have and how biodiversity is formed; the potential benefits of our biodiversity; threats, challenges and biodiversity conservation efforts; science as a vanguard needed to optimize the benefits of biodiversity; and how to mainstream science in policies related to biodiversity.

The book concludes with a number of important recommendations in the management of Indonesia's biodiversity, for example, the development of ecotourism, strengthening bioprospection for drug and energy discovery, deep sea exploration, and promoting public awareness about the importance of biodiversity.

This book is a sequel to the *SAINS45—Agenda Ilmu Pengetahuan Indonesia: Menyongsong Satu Abad Kemerdekaan/SAINS45—the Indonesian Science Agenda towards a Century of Independence* (AIPI 2016). In *SAINS45* that encased 45 fundamental scientific questions on how science can contribute to the efforts in advancing the Indonesian state and nation, the theme of biodiversity on land and in the ocean is quite prominent. The book *Science for Indonesia's Biodiversity* is intended, among other things, to answer the government's question about in what field should the state allocate strategic investment for the progress of the nation.

We hope this book will be a trigger and guide for the country to carry out strategic investment programs in key areas that will transform our comparative (biodiversity) advantage into a competitive advantage for the nation.

The Blind Seer from Amboina

Georg Eberhard Rumphius
(Hanau, Germany, 1 November 1627-
Ambon, Dutch East Indies, 15 June 1702)

Georg Eberhard Rumphius, a German-born botanist, arrived in Ambon in 1653 and spent his life there until he died in 1702. Rumphius spent nearly half a century to document Maluku's biodiversity. In his magnum opus, *Herbarium Amboinense*, which consists of 12 volumes, Rumphius recorded 1,200 species, 140 of which were identified to genus level. In his other major works he recorded a variety of marine animals, including shellfish, shrimp, crabs, even sea urchins, in the book titled *D'Amboinsche Rariteitkamer*.

Rumphius was Beethoven in a different world: science. He was blinded by glaucoma when he wrote *Herbarium Amboinense*, just as Beethoven was deaf when he composed some of his compositions that have lasted until now.

How did the deaf Beethoven find notes he did not hear, then wove them into a melody? How did Rumphius identify various plants when he was blind? He must have used all of his five senses besides the eyes: biting, smelling, touching, and listening to the stories by those around him. His wife and sonfaithfully helped Rumphius record his findings.

Rumphius recorded the names of all plants in Ambon in the local language and in Latin, along with their characteristics and medicinal properties. He described the characteristics of the plants like moving pixel by pixel images taken by the camera in HDR format. Really highly detailed. Based on these characteristics, he then gave them Latin names and grouped them.

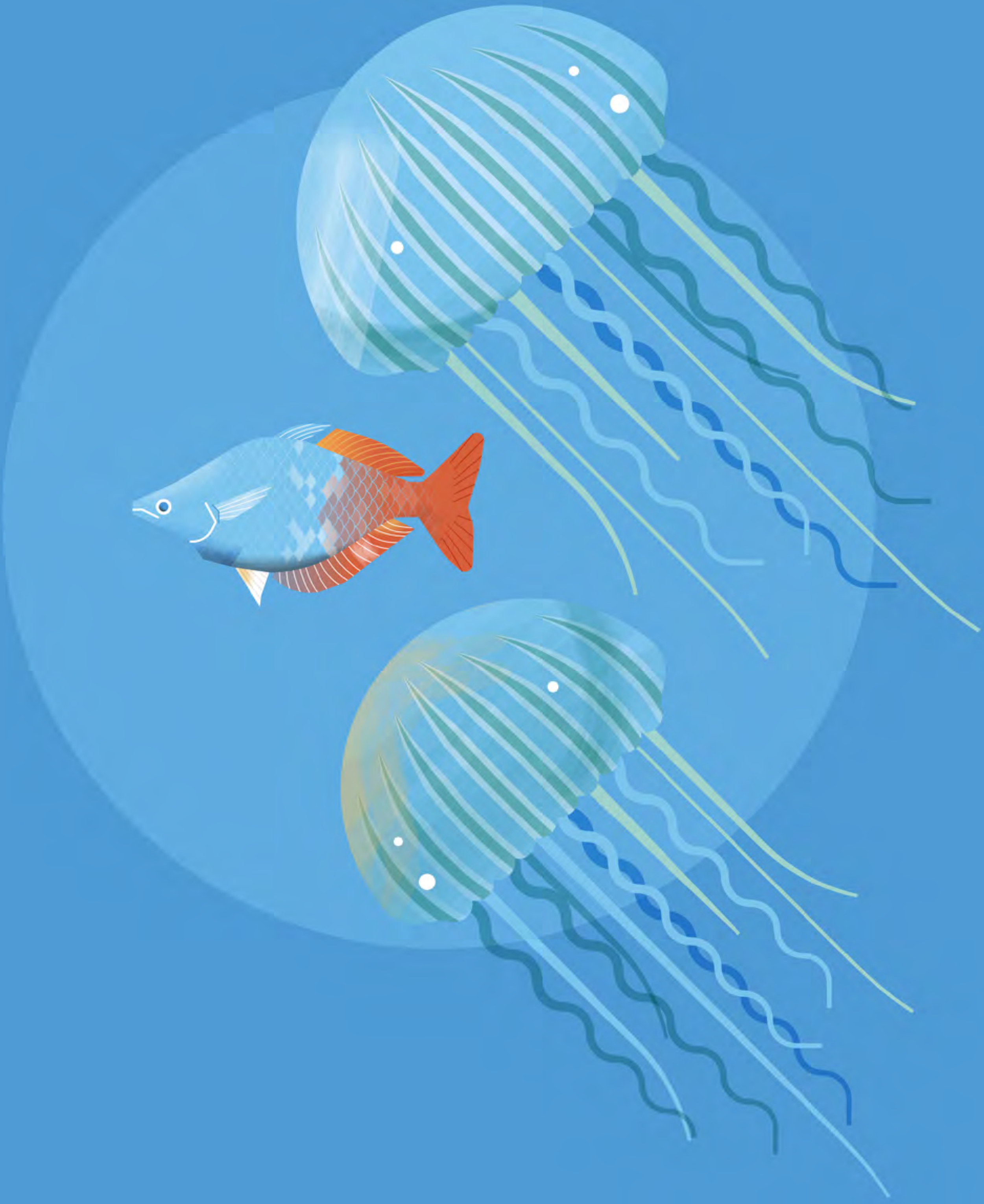
Not only that, Rumphius also sought out the medicinal properties of these plants. For Europeans at the time, this information was very valuable. Europeans in The Renaissance already knew a lot about symptoms of diseases, but did not have enough knowledge about medicine. The time of Rumphius was when Europeans sought these drugs in the East. Rumphius wrote, for example, on the efficacy of green beans or *katjang idjo* as a cure for beriberi, two centuries before Christiaan Eijkman and Gerrit Grijns identified deficiencies of these as a cause of disease and found the same properties in rice bran and then isolated the active substance, which was later named vitamin B1. The laboratory where they worked is now named the Eijkman Institute for Molecular Biology, in Jakarta.

It's no exaggeration if *Herbarium Amboinense* is seen to be as important as *Systema Naturae*, the masterpiece of Carolus Linnaeus, or possibly even more impressive. Both proposing procedures for binomials naming of plants, but Rumphius' book was actually completed 50 years earlier. If Linnaeus is known as the Father of Taxonomy, then it is similar to the case of Alfred Russel Wallace who carried outstudies on the distribution of animals and evolution in the Nusantara or Indo-Malayan archipelago, but Charles Darwin is better known as the Father of Evolution. In the case of Rumphius, the Dutch East-Indian Company only allowed the publication of the 12 volumes of his work 40 years after Rumphius died. The reason was simply the fear of the Company that Rumphius' work might contained information that could endanger Dutch interests. That's the way it was.

Perhaps that is also another similarity between Rumphius and Beethoven. Beethoven could never hear his work being played, Rumphius never saw his work published. And the works of these two great men are still important today. *Für Elise* and other Beethoven works are still being played today, Rumphius's book is also still being studied. The Mayo Clinic, the world's top medical research institution headquartered in the United States, is poring over Rumphius' notes for medicinal plants. This masterpiece, written in Indonesia nearly three centuries ago, invites Indonesian youth to read it.

II

MEGABIODIVERSITY: GIFT FROM NATURE FOR INDONESIA



Stretched across the equator, Indonesia has a very rich biodiversity. The history of its unique formation has endowed this country of seventeen thousand islands with this abundance. This natural capital needs to be understood so that it can be managed sustainably.

Physical Drivers for Indonesia's Biodiversity

Paleontology and Evolutionary Perspectives

"We now come to the Island of Celebes, in many respects the most remarkable and interesting in the whole region, or perhaps on the globe, since no other island seems to present so many curious problems for solution."—AR Wallace, 1876.

In his adventures in our archipelago in the 19th century, Alfred Russel Wallace, the founder of the theory of the evolution of living things by natural selection with Charles Darwin was astonished at the striking differences, especially in the distribution of animals. In this archipelago one not only found animals typical of Asia and Australia, but also animals that are not Asian or Australian. This was especially true in Sulawesi, where the origins of the endemic species are still sparking a debate that began 150 years ago.

The distribution of animals in the archipelago made Wallace raise questions such as: why are cuscus not found in Sumatra? Why aren't the kakaktua (cockatoos) which were common in Lombok not seen in Bali, which is only separated by a narrow strait from Lombok. As Wallace mused, "The strait is here fifteen miles wide, so that we may pass in two hours from one great division of the Earth to another, differing as essentially in their animal life as Europe does from America".

Wallace was the first to realize the striking differences between the fauna of western and eastern Indonesia, between Kalimantan and Sulawesi, and between Bali and Lombok. To mark this difference, in 1859 Wallace drew an imaginary line between Bali and Lombok, as well as between Kalimantan and Sulawesi. Then in 1896, Richard Lydekker identified fauna differences between Papua and the Maluku Islands to the west. Like Wallace, Lydekker drew an imaginary line to mark it. The area between the line created by Wallace and the Lydekker line further east is now called the Wallacea Region (Figure 2.1).

Figure 2.1 *The Wallacea Region, spread between the Wallace Line and the Lydekker Line*

As Wallace suspected, the striking difference in fauna was apparently caused by a distribution and position of the land and oceans that are constantly moving—which we now know to be due to a shifting of continental plates that has occurred since the beginning of Earth's formation. The richness of biodiversity in Indonesia is a manifestation of the pattern of movement of the continental plates. Geographically, the Indonesian archipelago is the most dynamic region affected by plate shifts, climate, and patterns of sea currents. All three contribute to the richness of biodiversity and its complexity.

This complex and intertwined natural history is strikingly reflected in Sulawesi, whose process of formation had gone through various collisions, subductions, and obductions. Sulawesi represents the results from meetings between volcanic margins and various micro plates that have appeared and joined in different periods.

Sulawesi's three micro plates illustrate how the island is such a hodgepodge so that it was dubbed an "anomaly" by Wallace. These three pieces are the West Sulawesi Plutono-volcanic Arc, the East Sulawesi Ophiolite Belt, and the Central Sulawesi Metamorphic Belt, with two smaller plates, the Banggai-Sula in the northeast and the Tukang Besi Block or the Wakatobi Islands in the southeast.

The geology of the Indonesian archipelago and the Philippines in general, and the Wallacea region in particular, is the most complicated on Earth. A series of abiotic events due to tectonic plate movements actually formed a biotic natural environment, which then drove the emergence of the biodiversity centers in this country.

The history of the formation of Wallacea dates back 200 million years when there were only two giant continents on this planet: Laurasia and Gondwana. Laurasia was located in the northern hemisphere, consisting of North America, Europe and most of the Asian continent. Gondwana was in the southern hemisphere and includes Antarctica, Australia, Africa, India, South America, New Zealand, New Caledonia, as well as parts of eastern and southeastern Asia.

The Ancient Lake of Wallace's Dreams

The Bugis classic epic *I La Galigo* also noted the peculiarities of Sulawesi. At the southern end of Soroako, a mining town in South Sulawesi, lies Lake Matano, in the Malili chain of ancient lakes. The Malili Lake System consists of five lakes, namely Matano, Mahalona, Towuti, Masapi, and Lontoa, all of which are interconnected by rivers. This is the only series of ancient lakes in the world that are connected to one another by the flow of water. Between 1-4 million years in age, the Malili Lake System has an unusually unique biota that provides an ideal natural laboratory for studying evolution and speciation. A strange biogeochemistry makes the Malili Lake chain isolated from other aquatic ecosystems not only geographically, but also ecologically.

Of the five lakes in the Malili Lake System, Matano is the oldest, and deepest (reaching 590 m), with the highest iron concentration of any freshwater lake on Earth (Vaillant *et al.*

2011). Lake Towuti is the largest in area (560 km^2, compared to Matano which is only 164 km^2), and it is the richest in species, 39 of which are endemic to Lake Towuti. Each lake in the Malili Lake System has its own endemicity. Being interconnected but having their own endemicity is an oddity that makes the Malili chain of lakes a dream laboratory.

Given the long isolation in the history of these ancient lakes, the endemic species in this ecosystem have different characters. A number of species in the Malili Lake chain exhibit morphologically new characteristics and behavior that are characteristic in their taxonomic groups—which again, differ for each lake. Lake Mahalona and Towuti, for example, have Calanoida with large genetic differences. This is strange, considering that plankton species usually spread easily in interconnected ecosystems. Another example of the endemicity of each lake is a genus of rainbow fish, *Telmatherina*. Lake Matano has 10 species of *Telmatherina*, while Mahalona and Towuti each have five species of *Telmatherina*, while Lake Masapi is not inhabited by *Telmatherina*. Strangely, *Telmatherina* are also not found in the Petea River, which connects Matano and Mahalona. This river also marks a boundary for freshwater crabs between the two lakes. The same pattern applies to shrimp.

The limited existence of a species in interconnected lakes shows the existence of ecological barriers to the distribution and colonization of species, which continue to this day. Physical, chemical, biological, and geographical conditions are aspects that contribute to the grouping of Malili endemic species. Each lake in Malili was formed in different ages, and was subjected to different "experiences". Matano and Towuti, for example, experienced water level fluctuations, which might have caused changes in habitat as well as in isolation periods.

The Malili Lake System, which has different endemicity for each lake including its connecting rivers, is an extraordinary system for the study of evolution. Physical conditions with different levels of isolation at different periods offer ideal natural models for speciation research, which can be approached through various fields, namely geology, limnology, ecology, genomics, and anthropogenics.

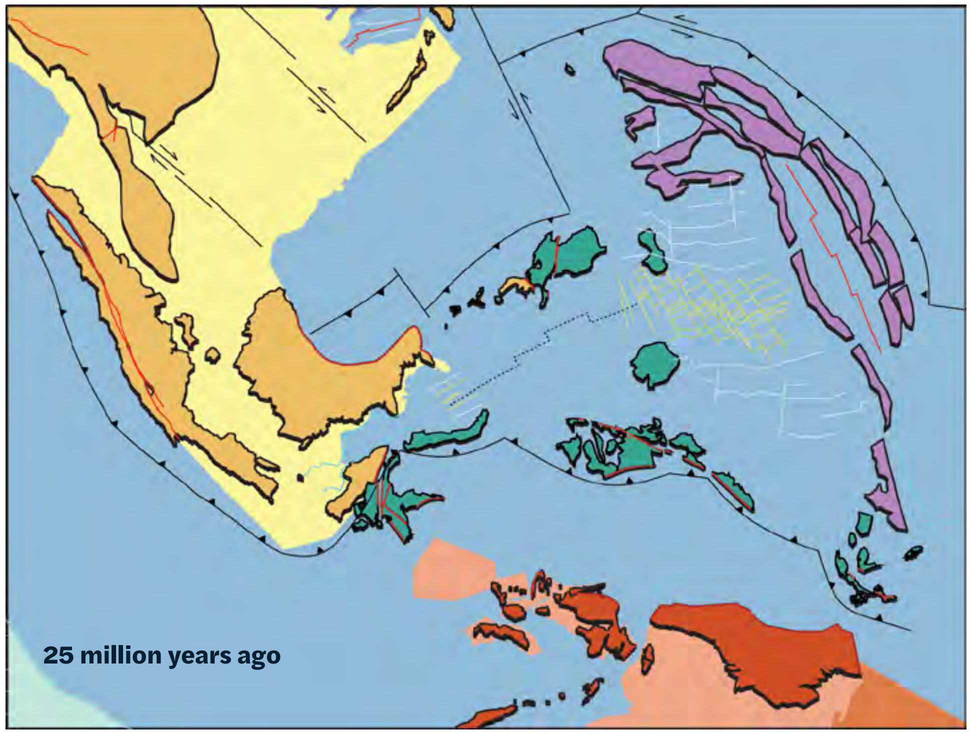
If only Wallace hadn't missed Lake Malili!

The southeast Asian fragments floated between 160 million and 100 million years ago, and were isolated in the Tethys Ocean, an ancient vast ocean between Laurasia and Gondwana. Then, about 70 million years ago, a plate carrying Australia, Papua, East Sulawesi, Seram, Timor, and Tanimbar split from the Antarctic plate—the remaining part of Gondwana—and sailed north. This brought to Indonesia primitive forms of mammals and birds and flowering plants that has originated in Gondwana.

Around 40 million years ago, fragments of southeastern Asia reached the equator. At that time, the western part of the archipelago was in a position more or less the same as today, and the Malay Peninsula became one with Laurasia (Figure 2.2). This juxtaposition is thought to have functioned as a great stepping stone, allowing two-way movement between biota of the continents of Asia and Australia, especially for those organisms capable of crossing the ocean. On the island of Sulawesi, for example, there was a meeting between cuscus that were typical of Gondwana and between babirusa that were typical of Asia.

During the last glacial maximum (LGM) period, 21,000 years ago, the waters of the Sunda and Sahul Shelves had not yet been formed. The islands of Sumatra, Java and Kalimantan were still integrated with Asia, and parts of the Natuna Sea to the Java Sea were still land. Likewise, Papua was still one with Australia, the Arafura Sea was still land, and the Gulf of Carpentaria was still a large lake. Post-LGM, the sea level increased by 125 meters, forming the islands as they are today.

The formation of the islands in the Sunda Shelf in the west and the Sahul Shelf in the east had a very complex impact on Indonesia's biodiversity. In the middle, there are several islands known as the Lesser Sunda Islands, Sulawesi, Halmahera, Maluku, and many small islands surrounded by deep waters. The Banda Sea, for example, has a depth of approximately 7 km. There was no land that connected the deep sea between the Sahul and Sunda Shelves. This isolation was the most powerful factor in determining endemicity and species richness, giving rise to a "Noah Ark" of flora and fauna.



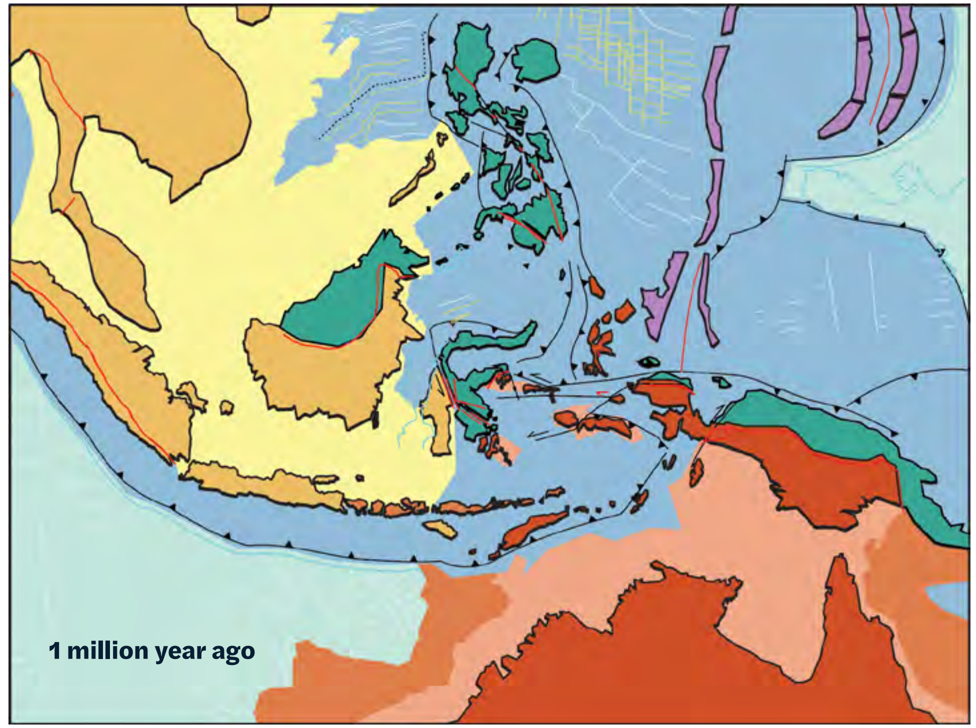


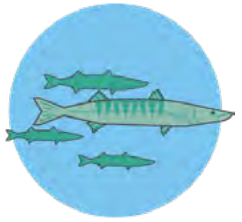
Figure 2.2 *The movement of Southeast Asian tectonic plates starting 50 million years ago, which formed the Island of Sulawesi (Hall et al. 2002)*

Climate Variability and Sea Current Patterns

The diversity of marine biogeography that contributes to the rich biodiversity of Indonesia is determined by, among others, Indonesia's unique geographical position, the presence of large and small islands, bathymetry, patterns of currents, and climate variability.

The maritime climate of the Indonesian archipelago is influenced by climatic patterns that beat on various time scales. Being in the tropics, the seasonal climate variability in Indonesia is influenced by changes in the direction of monsoons that carry water vapor from mainland Asia through the South China Sea at the height of the rainy season (January-February). The opposite happens in the dry season, which peaks in June-August. This climate variability has shaped the life patterns of Indonesian people, such as determining the time to do farming and the time to do fishing. But every 2-7 years, this climate pattern is disrupted by the climate phenomena El Niño Southern Oscillation (ENSO) in the Pacific Ocean and the Indian Ocean Dipole (IOD) in the Indian Ocean. In the positive phase of ENSO or El Niño, most parts of Indonesia experience drought in the peak of the rainy season, even though it remains the rainy season (due to monsoon winds). And during the negative phase of ENSO or La Niña, an increase in rainfall occurs. Although there are similarities between IOD and ENSO in as much as the positive phase of IOD carries drought and vice versa, the two phenomena involving the interaction of the ocean and the atmosphere have their own characteristics and can occur at different times.

On a regional scale, surface sea currents carry biota, both from the waters of the West Pacific and East Indies, as well as the Sunda and Sahul Shelves. This pattern of ocean currents ultimately shapes the broader patterns of diversity and distribution of marine biogeography.

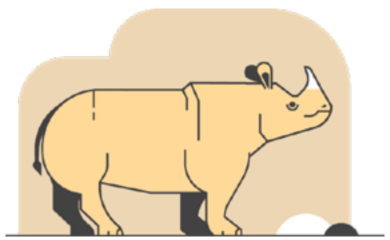


Terrestrial Biodiversity

Like Pandora's box, Indonesia's nature stores a wealth of biodiversity that is often unpredictable. In the 12th century, the Venetian traveler, Marco Polo, was stunned by the strange animals he saw in Sumatra. It was reported that he saw a unicorn. "There are wild elephants in the country, and numerous unicorns, which are very nearly as big. They have hair like that of a buffalo, feet like those of an elephant, and a horn in the middle of the forehead, which is black and very thick... There are also monkeys here in great numbers and of sundry kinds; and goshawks as black as crows." (Marco Polo and E. Latham 1958)

The fantastic creature that Marco Polo saw could have been a one-horned rhino. Eight centuries later in the 21st century, scientists are still discovering new species, such as the Tapanuli orangutan (*Pongo tapanuliensis*) and the Jatna tarsier (*Tarsius supriatnai*). The lands of Indonesia never stop giving surprises to science. The discovery of the Tapanuli orangutan, for example, expands the evolutionary path of the genus *Pongo*. This third species of the genus *Pongo* reveals the distribution and mating of *Pongo* after the eruption of Mount Toba 75,000-100,000 years ago. Not only endemic in the Tapanuli region (south, central, and north), the evolutionary history of *Pongo tapanuliensis* can be traced to 3.38 million years ago, continuing to expand our understanding of the history of the Great Apes group consisting of chimpanzees, gorillas, orangutans, and bonobos.

Although Indonesia's land area is only 1.28% of the world's land area (1.9 million km^2/148.9 million km^2), the richness of biodiversity on the islands of Indonesia is one of the highest in the world. Our very unique geographical position is the key to that abundant wealth. Indonesia is home to 720 species of mammals, 36% of which are mammals endemic to Indonesia. At least 781 reptile species and 61 primate species live in this country. Our number of bird species exceeds 1,800, making Indonesia ranked fifth in the world of birdlife.



As a tropical country, the lands of Indonesia are a paradise of biodiversity of flora, third after Brazil and Colombia with high species diversity. Most of this high species diversity is contributed by the biodiversity found in forest ecosystems which include mangrove forests, swamp forests, peat forests, coastal forests, rain forests, and tropical rain forests. Indonesia and Brazil share the title of champion for the number of endemic plant species. For the flowering plants (Spermatophyte), Indonesia has 19 thousand species, which account for 8% of the total flowering plant species in the world. With respect to plants having spores, Indonesia accounts for 9% of the total species of ferns (Pteridophytes) in the world. Indonesia is also blessed with hundreds of species of mosses (Bryophyte) from the Hepaticae class and 21 species from the Musci class, which account for 40% of the global species (Figure 2.3-2.6).

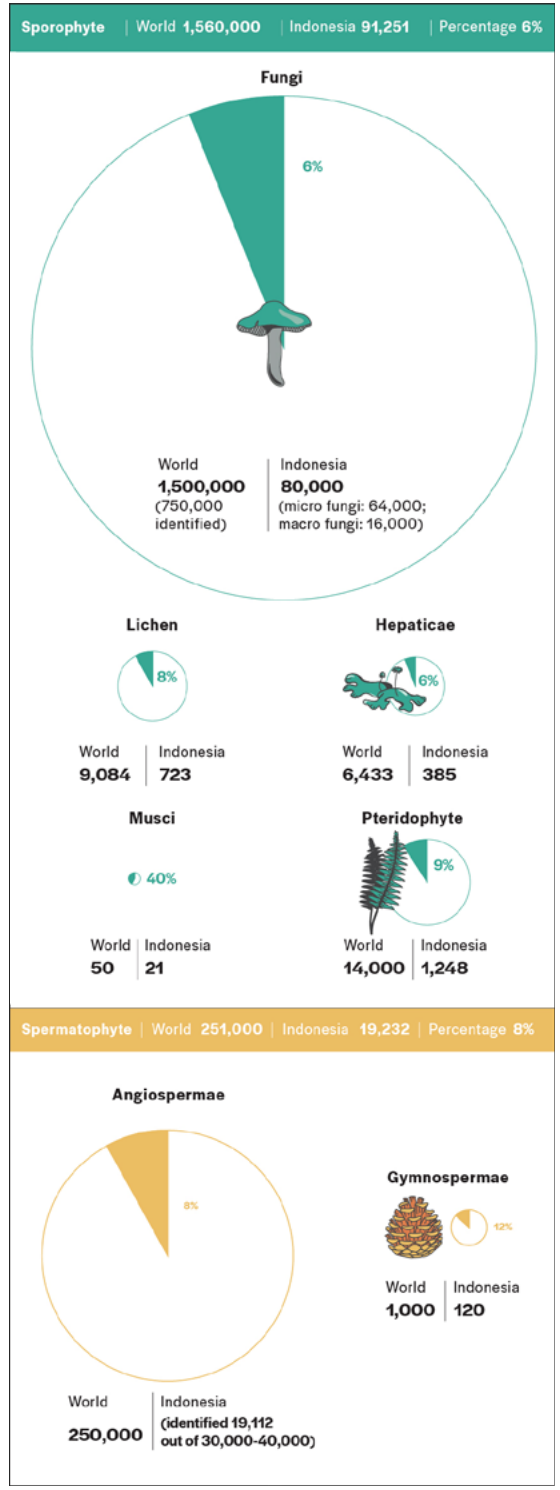


Figure 2.3 *Comparison of the numbers and types of Indonesian flora to the world (data taken from Widjaja et al. 2014).*

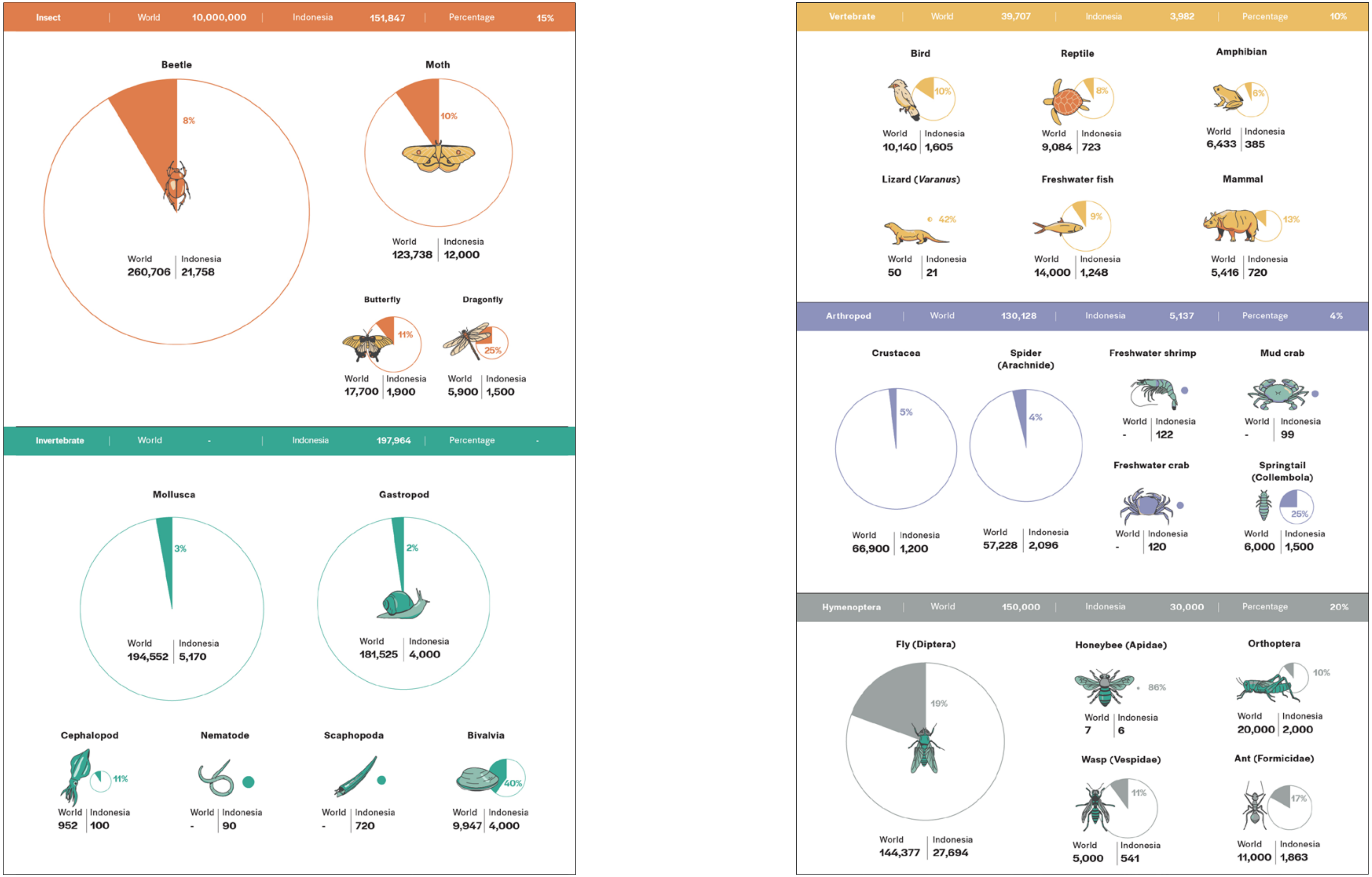


Figure 2.4 *Comparison of the numbers and types of Indonesian fauna to the world (data taken from Widjaja et al. 2014).*

In an area stretching from Sabang to Merauke, and from Miangas to Rote Island, the various flora groups are spread across many islands. Ferns, for example, are most often found in Sumatra, followed by Kalimantan, Papua, Sulawesi, Java, Maluku, and the Lesser Sunda Islands. The largest distribution of open seed plants is in Sulawesi, Sumatra, and Papua. Meanwhile, many closed seed plants are found in Kalimantan, followed by Papua and Maluku, Sumatra, and Java combined.

The Diversity in High Plants among Megabiodiversity Countries

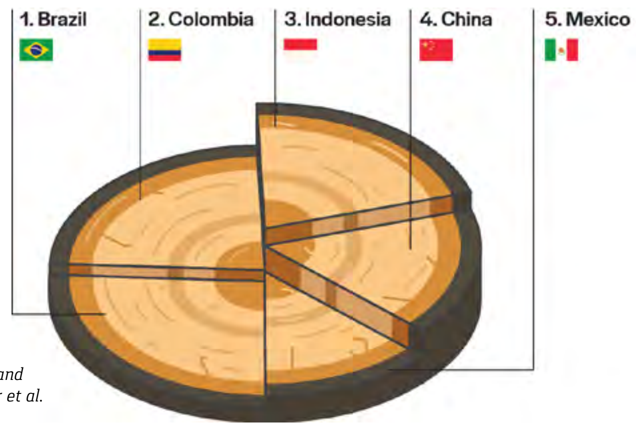


Figure 2.5 *Indonesia ranks third after Brazil and Colombia in high plant diversity (Mittermeier et al. 1998).*

The Endemicity of Plants at the Global Level

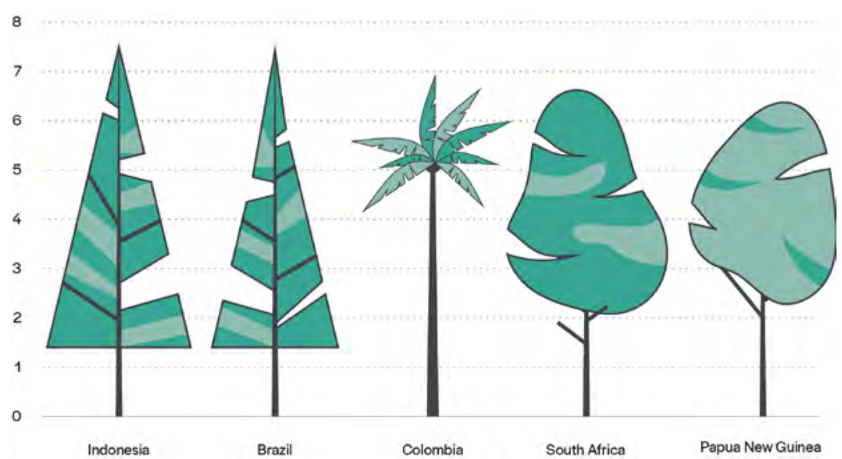


Figure 2.6 *Indonesia and Brazil share the title of champion in endemicity of high plants. (Mittermeier et al. 1998).*

Endemicity of Terrestrial Fauna

Compared to other places, Indonesia's terrestrial biodiversity is quite unique with respect to endemic terrestrial fauna. This country has around three thousand vertebrate species, representing 10% of the total vertebrate species in the world. Of that number, half are endemic species. For bird species with a limited flight range (less than 50 thousand km^2, for example), Indonesia has the largest number of endemic species. The number is even more than double that of any country in the world (Figure 2.7).

Some examples of fauna endemic to Indonesia include Komodo dragons, orangutans, Javan gibbons, Sulawesi monkeys, rainbow fish from the family Telmatherinidae, and five species of honey bees from the genus *Apis*. Unfortunately, most of the terrestrial fauna is threatened with extinction. And of the 117 bird species that are going extinct, 66 species of them are restricted-range terrestrial birds.

Countries with the Highest Number of Restricted-Range Terrestrial Birds

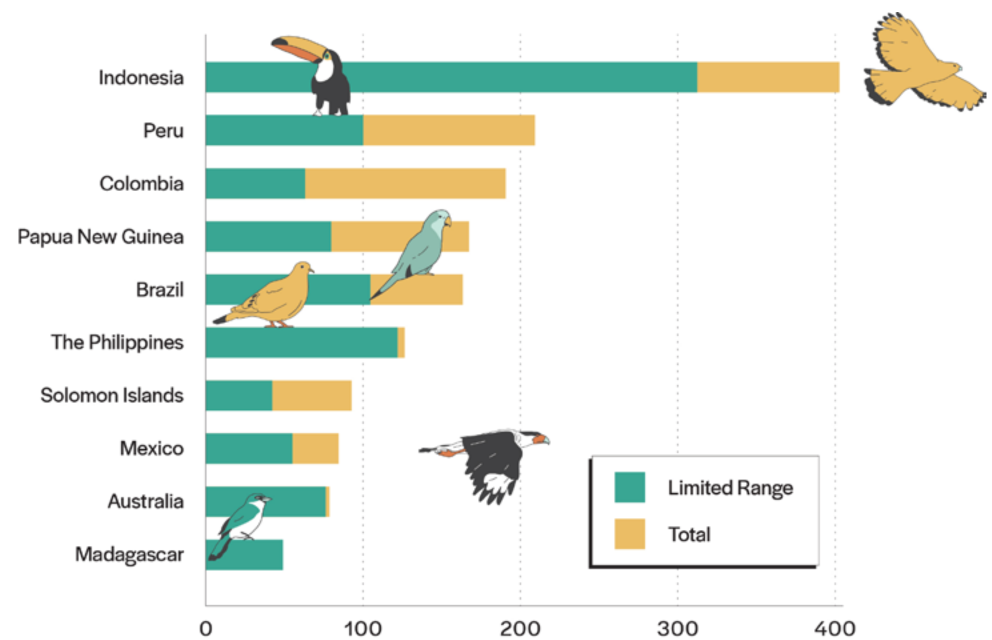


Figure 2.7 *Indonesia is unmatched as the home for restricted-range terrestrial birds, marking its endemicity (Stattersfield et al. 1998).*

The patterns of distribution of species richness and endemicity in Indonesian biogeographic regions are very different (Figure 2.8). For birds, for example, the Sunda Shelf has high biodiversity but low endemicity.

In the Wallacea Region, the number of bird species is low but the level of endemicity is high. The Sahul Shelf has very diverse birds with moderate endemicity.

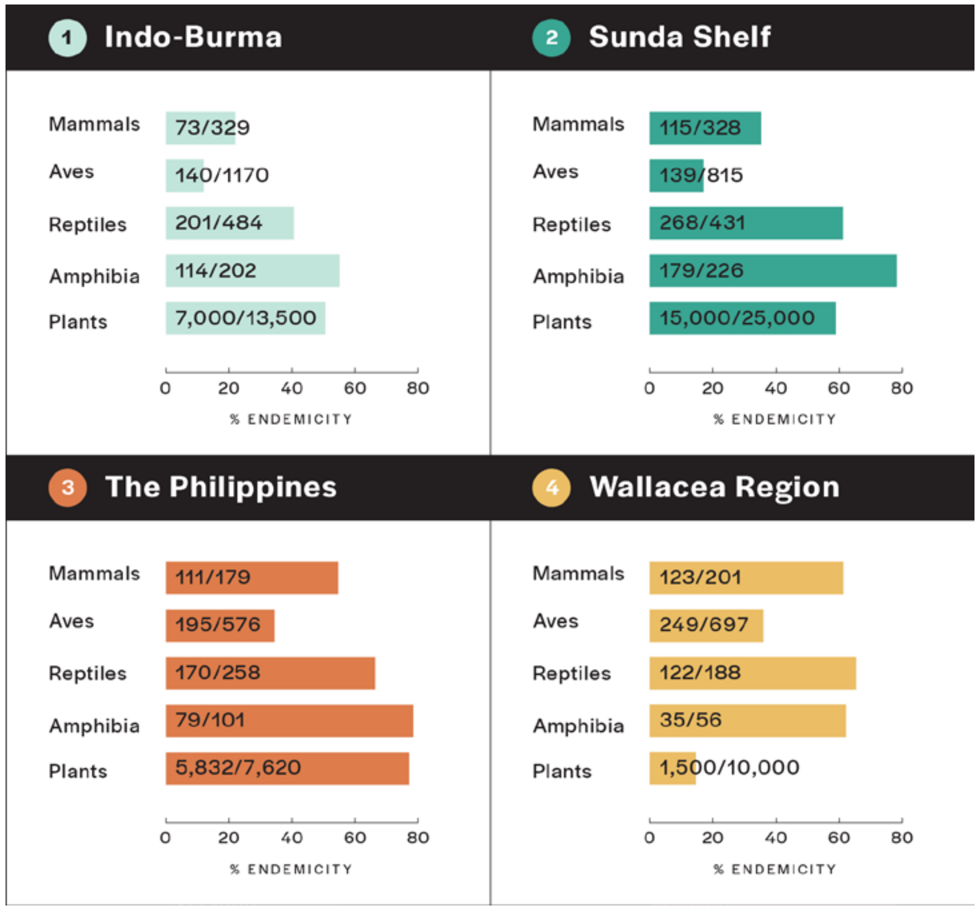
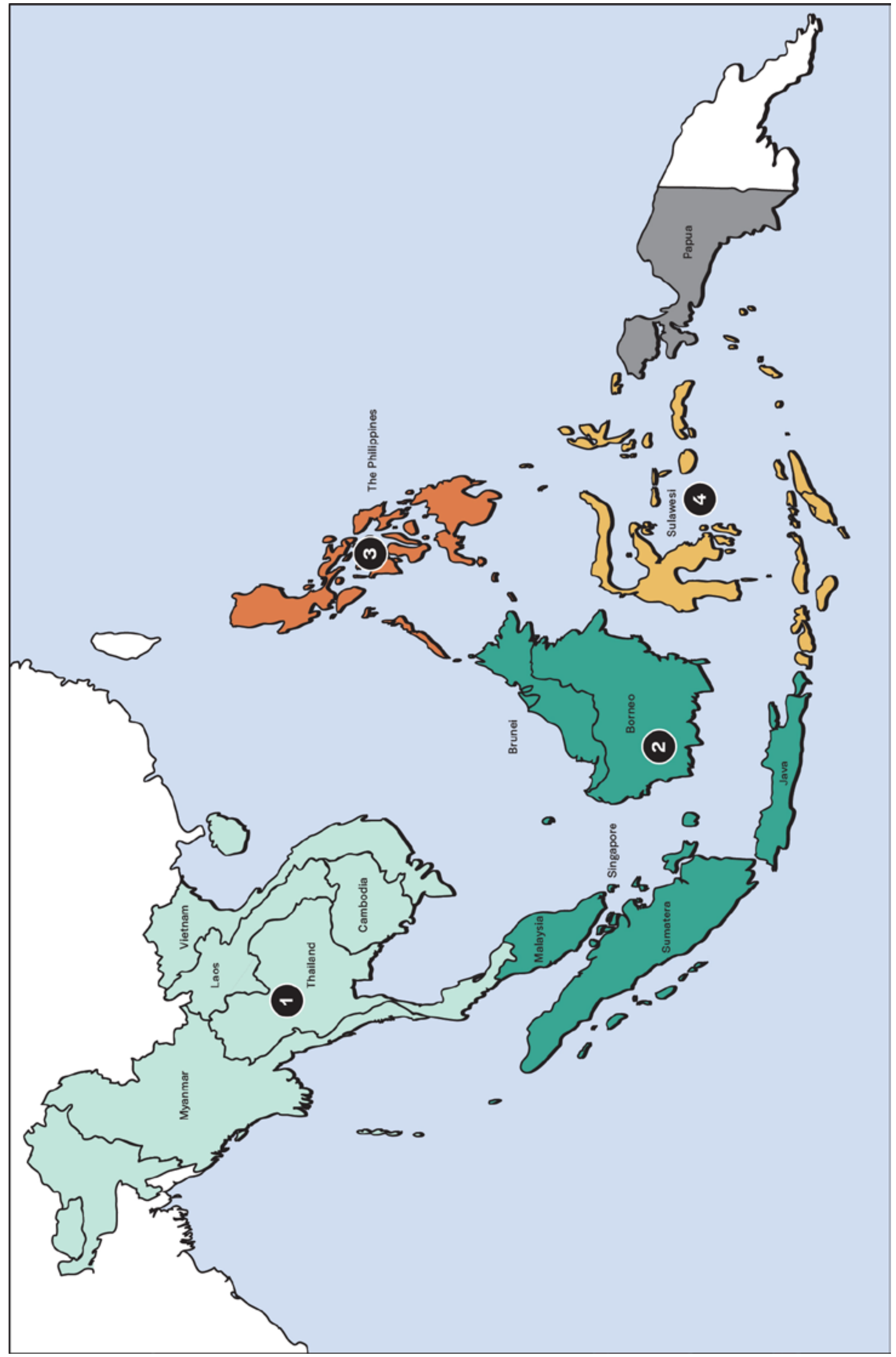


Figure 2.8 *The pattern of endemicity and species richness in Southeast Asia. The X axis shows the percentage of endemicity, Y axis shows the types of species, while the numbers e.g mammals 73/329 in Indo-Burma mean that out of 329 mammals in Indo-Burma, 73 are endemic to the area, i.e 22.18% as indicated by the length of the horizantal bar on the numbers (modified from Sodhi et al. 2004).*



Marine Biodiversity and Inland Water Ecosystems

Many researchers complain that, although Indonesia's marine biodiversity is suspected to be as rich as its terrestrial biodiversity, it is not sufficiently documented. Actually, how rich is the biodiversity of Indonesian waters? If it is really rich, how much do the various kinds of ecosystems in the sea, coast, and open waters contribute to the richness of aquatic biodiversity? Is the endemicity of Indonesian waters as unique as its land creatures—or even more odd? What is the pattern of distribution of these living beings who seem to face fewer geographical boundaries? Is there a process of isolation for marine species? If so, how to determine biogeographic areas in the vast ocean?

Indonesia as the Center of World Marine Biodiversity

The waters and the coast of Indonesia and its surroundings (Indo-Pacific Coral Triangle) are recognized as a center of world biodiversity. The high level of biodiversity in Indonesian waters not only refers to the number of genera and different types of marine biota. It also reflects a complex and astonishing natural history.

Is the source of endemicity for marine species different from terrestrial species? How can biodiversity be centered only at one particular point? Why, for example, out of about 300 million km^2 of the world's oceans, do fish prefer to settle on the coral reefs of Indonesian waters? While the area with coral reefs cover only 0.1% of the ocean floor, the Coral Triangle region has 2,700 fish species and 600 coral species whose habitats include the Philippines, eastern Indonesia, Papua, and the Solomon Islands (Asaad *et al.* 2018). The diversity and richness of marine biodiversity in Indonesian and surrounding waters makes this region a "world coral triangle", together with the Caribbean Sea sharing a reputation as a biodiversity hotspot. The fish population of this coral triangle covers one third of all the world's fish species.

Biodiversity hotspots are not only where species are formed, but also where biodiversity accumulates from surrounding habitats, and these hotspots are is increasingly threatened by human activity.

Physical isolation is not the only cause of formation of speciation, since many species change according to ecological boundaries. Although speciation in terrestrial and marine ecosystems follows a similar process, the possibilities for geographical isolation in the ocean are smaller than on land, so that speciation is more likely to be caused by ecological boundaries.

The Indo-Malay Archipelago consists mostly of large lands such as Sumatra, the Thai-Malay Peninsula, Kalimantan and the Greater Sunda Islands. During the last maximum glacial period (LGM), these islands united to form a large land mass known as the Sunda shelf. In spite of its similar geological origins, the population structure of the flora and fauna of these islands is not homogeneous. Many studies have revealed a sharp genetic breakthrough across the Java Sea, which divides populations into the north (Pacific) and south (the Indies).

Gene flow can be driven by various factors, such as ocean currents and the geological history of a location. Geographical history, such as the appearance of the Sunda Shelf during the Pleistocene period, is probably the main factor responsible for the historically limited gene flow between the Indian Ocean and the Pacific Ocean, which in turn may have triggered lineage deviations in both oceans. In eastern Indonesia, the Halmahera Eddy (Halmahera current) and the Indonesian Throughflow are likely candidates that formed biogeographic barriers between eastern and western Indonesia. As another example, water circulation and eddies at the southern tip of Sumatra plays a role in maintaining the genetic structure of the mangrove species *Rhizophora mucronata Lam.* in the Malay Peninsula and Sumatra.

The coral triangle region has a long history of accumulation of species that can be traced back to the Miocene (20-12 million years ago), which continues into the Pleistocene and through the present.

Three models are offered to explain the biodiversity richness of the coral triangles: the center of speciation, the center of accumulation, and the center of overlap. There is also the feedback model, which proposes a biodiversity center that experiences the three models above (Bowen *et al*. 2013). It should be noted that there are many combinations of boundaries and ecological differences that affect the richness of biodiversity, referred to as sharp, faint, or those which appear occasionally (ocean currents, water masses, land masses in the glacial period).

The center of speciation model proposes that a center of tropical biodiversity is an exporter of species, which is most likely due to various complex geological events and habitat heterogeneity, coupled with a fierce competition for resources. In contrast to the center of speciation, the center of accumulation theory states that the high number of species in the area of the coral triangle is the result of speciation from surrounding locations and that new taxon continue to gather in the area of the coral triangle. The center of overlap model is different again. According to this model, the coral triangle's biodiversity richness is due to the convergence of fauna typical of the Indian Ocean and of the Pacific Ocean.

The Indo-Pacific Barrier, which separated the Indian Ocean and the Pacific Ocean when the sea level fell during the isolation period has caused fauna from both oceans spread. Although the exact location of the Indo-Pacific Barrier boundary is debated, many species show strong genetic differentiation between Indian and Pacific Ocean populations, including plant species such as the mangrove forests of the genera *Ceriops* and *Gymnorrhiza bruguiera* (Urashi *et al*. 2013; Huang *et al*. 2008). Similar genetic differentiation between populations of the two oceans has also been demonstrated in a variety of marine animals including reef fish, the marine gastropods of Nerita albicilla, and the starfish crown of thorns *Acanthaster planci* (Thresher & Brothers 1985; Gaither *et al*. 2009; Crandall *et al*. 2008; Vogler *et al*. 2008; Yasuda *et al*. 2009). Although there are a growing number of phylogenetic studies on the Indian and Pacific Oceans, few are trying to identify the specific elements of the Indo-Malay Islands that have

been responsible for building and maintaining the Indo-Pacific Barrier.

The three models described may not adequately explain the richness of the biodiversity of the coral triangle waters. The central accumulation model proposes that the high number of species in the coral triangle area is the result of speciation in peripheral locations caused by isolation in these peripheral habitats, followed by the spread of new taxon into the coral triangle area due to current and wind patterns. The overlapping center model explains that high species diversity in the area of the coral triangle is partly due to the overlapping of different fauna of the Indian Ocean and the Pacific Ocean. This hypothesis is based on the premise that there exists an Indo-Pacific Barrier isolation mechanism, which separates the Indian Ocean and the Pacific Ocean during low sea levels, causing these marine fauna to deviate during the period of isolation. The center of speciation model proposes that the coral triangle area is the species exporting region, possibly driven by population fractures resulting from geological complexity and habitat heterogeneity coupled with intense competition. These three models are hypotheses that need continued study.

The feedback model states that all three models help to create a biodiversity hotspot. The distribution of reef fish is in line with this model, given the large amount of biodiversity in the islands surrounding the coral triangle region in the central Indo-Pacific. Kinetic energy arises from constant retention of sea surface may also be a factor that shapes the pattern of marine species richness (Sanciangco *et al*. 2013).

While a marine biodiversity area is indeed a source of species, the remote islands, marginal seas and barren coastal areas also contribute to the overall wealth of biodiversity. Finally, the vastness of shallow waters and the length of the coastline in the Indo-Pacific region are manifestations of a long geological history, which coincided with tectonic collisions in this region—this geographical complexity certainly contributed to species diversification.

These tectonic events not only formed large shallow water habitats over different periods, but also maintained them. Other biota forming habitats

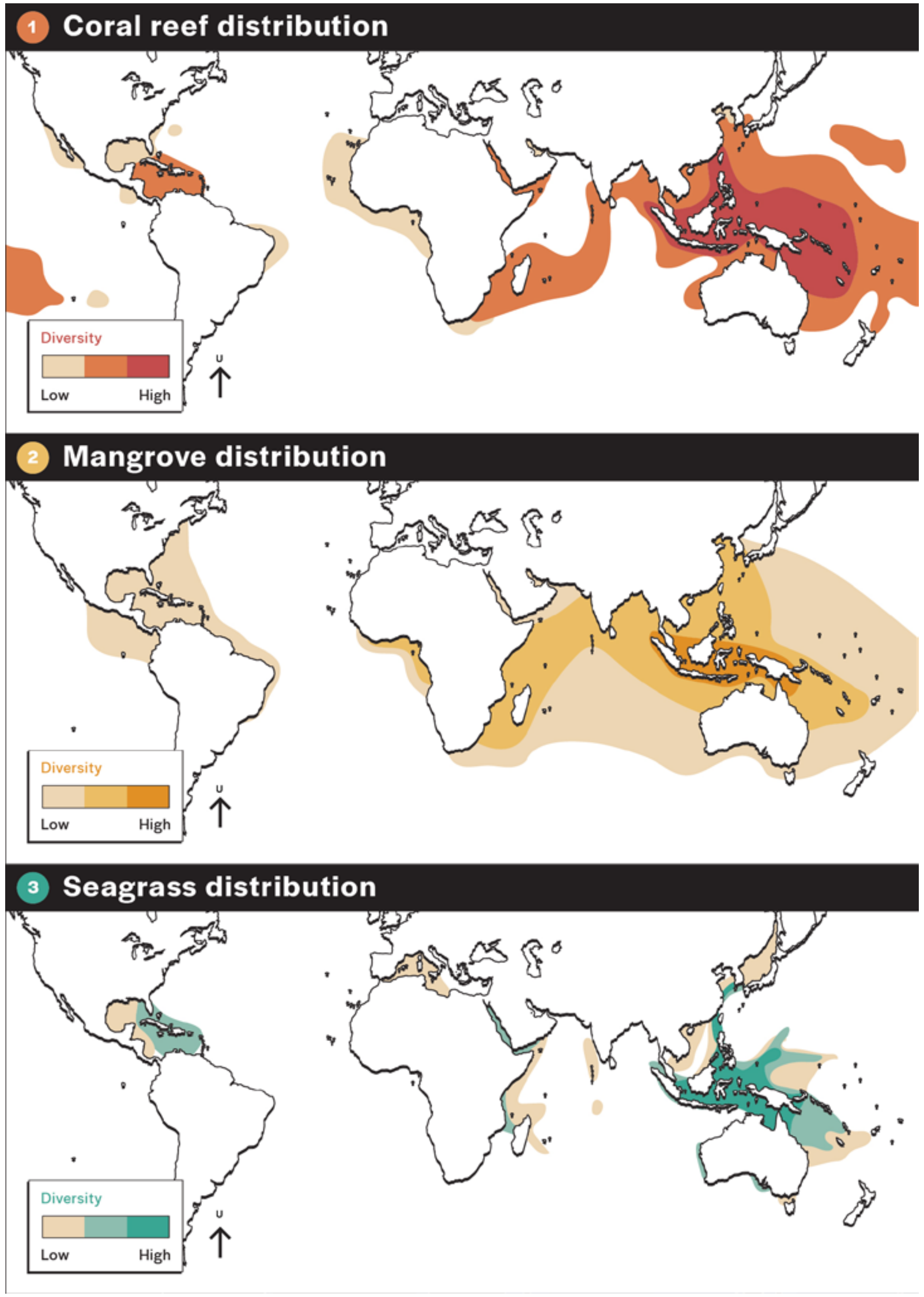


Figure 2.9 *Global distribution and biodiversity level of three key ecosystems in coastal and marine areas, namely coral reef ecosystems, mangrove forests, and seagrass beds. Indonesian waters have the highest biodiversity in the world for these three ecosystems (UNEP-WCMC (2001). United Nations Environment World Conservation Monitoring Center. Annual report).*

such as seagrass beds and mangrove forests are also very high in biodiversity in this region. Together with coral reefs and seagrass beds, mangroves play an important role in supporting the survival of many species and forming complex ecosystems.

Ecosystem triad is the nickname for three key ecosystems: seagrass beds, coral reefs and mangrove forests (see Figure 2.9). The biodiversity of the coral triangle region rests on these three ecosystems, which are not only home to fish and endangered species, but also serve as a protector of the beach and an important place for carbon storage.

Of these three ecosystems, the least studied are seagrass beds. Yet it is in the area of the coral triangle that seagrasses grow the most and expansively, crossing geographical boundaries and being able to live with many other species. The area of Indonesia's seagrass is the greatest among Southeast Asian countries, more than 150 thousand hectares, and it is home to a quarter of the world's seagrass species—some 60 species. Seagrass is the only flowering plant that is able to live immersed in the sea, but it can also grow on various types of substrates in shallow sea waters.

Mangrove is no less unique. Mangroves combine the characteristics of land and sea plants, tolerant of salt, and can adapt to oxygen-poor conditions. With their system of breathing roots, mangroves can even metabolize in anaerobic conditions. Mangroves are scattered throughout tropical and subtropical waters, and they grow only on beaches that are protected from waves. When the beach is frequently eroded by waves, mangrove seeds are not able to grow properly and plant their roots.

Mangrove forests in Indonesia grow and spread almost along all the coasts, concentrated in the coastal areas of the big islands, namely Sumatra, Kalimantan, Sulawesi, Halmahera, Java, and Papua. On large islands there are large river flows; deltas generally form at river mouths that contribute to the growth and development of mangrove forests. This does not happen to small islands or island groups, such as the Tanimbar Islands, Aru Islands, Kei Islands, Natuna Islands, or Riau

Islands. Mangrove forests on a small island are only thin groves with simple structures, often even in the form of a single stand (Pramudji 2004).

Indonesia has the largest mangrove forest cover, 26-29% of global mangrove cover, which is widely distributed in Kalimantan and Sumatra. In total, 202 species of mangrove plants have been recorded in Indonesia, including 89 tree species, 5 palm species, 19 climbing species, 44 herbaceous land species, 44 types of epiphytes, and 1 fern species. Of these types of mangroves, as many as 43 species are true mangroves, the rest are other mangrove associates.

Mangrove ecosystems have enormous benefits for the whole life-cycle of the coastal area, including serving as a place for rearing young, hunting for food, and breeding for several species of animals. Mangroves are also effective as a barrier to coastal erosion and waves. And they fertilize the land, produce wood and non-timber products, and serve as sites for education and recreation.

Biodiversity in Freshwater Areas

With 17 thousand islands, Indonesia has a variety of freshwater ecosystems, including lakes, rivers and swamps. Although there is no exact data, the number of rivers and swamps in Indonesia is estimated at hundreds, even thousands. And the Indonesian freshwater area is estimated as 13.85 million hectares.

Indonesia has the highest density of freshwater fish in the world, namely 0.6 species per 1,000 km^2, more than Brazil (0.37 species/1,000 km^2) and the Democratic Republic of Congo (0.48 species/1,000 km^2) (Hubert *et al*. 2015). Like its human population, Java is densely settled by freshwater fish species, with 1.7 species/1,000 km^2, more than Kalimantan at 1.2 species/1,000 km^2. In the Sundaland biodiversity hotspots, there are 899 species of freshwater fish, nearly half of them (430) are endemics. For endemicity, Sulawesi dominates with 50% (56 species) of endemic freshwater fish (Dahruddin *et al*. 2016).

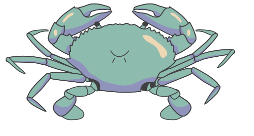
Thus, Sulawesi is not only odd in the sea and land, but also in its freshwater areas. Ancient lakes and younger lakes compete with each other in showing off their unique endemicity. Likewise for its rivers, both rivers connecting ancient lakes, and rivers on islands around Sulawesi.

Fish species in the Malili Lake System bear only a little resemblance to fish species in Lake Poso, which is 80 km away. The Malili Lake System has more endemic species because even though its five lakes are interconnected, each is unique, with different species radiations in each lake. The Malili Lake System has 33 endemic species (out of 36 species) while Lake Poso has 9 endemic species out of 10 species. The isolation of the Malili Lake System from other freshwater areas also encourages the high endemicity of fish there.

Kalimantan is a different story. It does not have ancient lakes, but Kalimantan has several sea lakes, a body of water on land that retains its marine character through narrow underwater lanes. These sea lakes are still young, being 7,000-12,000 years old, and there are only about 200 such lakes in the world, spread mainly in Vietnam, Palau, and Indonesia.

Lake Kakaban and Lake Maratua in East Kalimantan are well-known for their unique species. Kakaban is the largest sea lake with an area of 5 km^2, with a 50-meter high coral wall that traps sea water to create a lake, and it is the most isolated lake in Indonesia. Its genetic diversity is very high and not found anywhere else in the world. The unique species in Kakaban are not even found in the surrounding lakes that are only 6 km away, proving that Lake Kakaban is isolated not only physically, but also biologically (Becking *et al*. 2013).

Indonesia's marine lakes have a high diversity of flora and fauna, with a high level of endemicity. These lakes provide a very clear spatio-temporal context for research on ecology and ocean evolution.



III

THE ECONOMICS OF INDONESIA’S BIODIVERSITY

There is no Plan B because we do not have a Planet B
– Ban Ki-Moon

Indonesia's biodiversity has great potential for our future economic development. A variety of species have a high economic value for uses that range from food, medicine and cosmetics to bioenergy and ecotourism.

The relationship between biodiversity and the economy can be seen from an example. Small-scale coffee plantations around Lore Lindu National Park, Central Sulawesi, demonstrate the economic value of pollination and pollination services. The productive relationship between bees and coffee farming is made possible by the forest ecosystem in this area. There is a relationship between forest distance, the diversity of pollinator bees and Arabica coffee fruit yields. It is estimated that forests provide pollination services averaging 46 euros per hectare, although the value can reach 470 euros per hectare. The ongoing forest conversion decreases these pollination services, resulting in a real financial loss to small farmers. Currently, pollination services continue to fall, resulting in a decline in coffee yields of up to 18%; the net income of coffee farmers has dropped by 14% per hectare.

On Natural Resources, the Economy Rests

The potential of any biologically-based economy rests heavily on the balance of the surrounding ecosystems. The quality and quantity of a crop, coffee for example, is very much determined by the conditions of the surrounding environment. A balance in the natural system is needed to produce coffee in a quantity and quality that is economically profitable.

Pollination is very important for a large number of plants and has been proven to improve the yield and quality of food crop production (see Klein *et al*. 2007). Pollination can be accomplished through the intermediary of animals such as birds, bats, or insects, but bees are the dominant pollinators. The level and quality of pollination of agricultural crops, which in turn

Climate Change: A Cup of Bitter Coffee

In the past, Indonesia was an important producer of coffee for the world. Starting from the 17th century, precisely in 1696, the first Arabica coffee seeds brought by the Dutch began to be planted in Java. *Tempo Magazine* (May 2018) mentioned that just 15 years after planting, Cianjur Regent Aria Wira Tanu sent approximately four quintals (400 kilograms) of coffee to Amsterdam. This coffee soon became the primadonna of exports. From that time on, coffee from Java became popularly known as Java coffee; and "java" even became a common nickname for coffee itself. As seedlings, these superior coffee plants spread to France, the Caribbean, Suriname, and even to the colonies of European countries in Central America.

Unfortunately, the superiority of Javanese coffee did not last. Its glory faded after 1880, when a leaf rust disease caused by the fungus *Hemileia vastatrix* killed the coffee plants. Java lost the potential to export thousands tons of coffee. The world market was shaken.

Now coffees from various regions in Indonesia, especially the Arabica type, have captured back their fans, even in foreign countries. Gayo coffee, Toraja coffee, Malabar coffee, and the list may still increase. But the bitter past history of coffee can repeat.

The vulnerability of coffee plantations to natural phenomena is a reality that cannot be ruled out. An article in *Time* magazine (June 2018), titled *"Your Morning Cup of Coffee is in Danger. Can the Industry Adapt in Time?"*, reminds us how climate change threatens the sustainability of coffee plantations.

determine the yield and quality of agricultural production, is made possible by the diversity of the pollinators-and this diversity is the result of the ecosystem services from forests (Richards 2001). The greater the distance between forest or natural habitat and agricultural land, the less the number and diversity of species of pollinator bees that stop at flowering plants (Steffan-Dewenter and Tscharntke 1999; Ricketts *et al.* 2008).

The economic value of ecosystems and biodiversity caused by the benefits of pollination (ecosystem services) arising from forest ecosystems (structure, processes, and functions of ecosystems), depends on the presence of various bees (species diversity), which have an impact on the economy of coffee farmers. Pollination is just one example of the ecosystem services that result from the biodiversity in an ecosystem.

Determining the economic value of biodiversity and ecosystems is not as simple as calculating the economic value of a plantation or agricultural land. To understand how ecosystem values are calculated, an understanding of the concept of an ecosystem in all of its aspects is needed.

An ecosystem is a community of living organisms together with the non-living components in the environment, including the air, water, and soil minerals that interact as one system. All of the organisms in one ecosystem, as a whole, are referred to as its biodiversity, broadly including the number, abundance, genetic composition, population, functional groups, and richness of "spatial" patterns in its habitat and landscape mosaics (Diaz *et al* 2006).

All aspects of the ecosystem play an important role and interact to produce a variety of functions, whether physical such as water infiltration; chemical such as oxidation processes; or biological such as photosynthesis. These functions create direct or indirect ecosystem services that contribute to human well-being (TEEB 2010). Some researchers define ecosystem services as "contributions of nature to humans" (Pascual *et al.* 2017). Biodiversity, in this regard, affects the capacity for producing ecosystem services. Ecosystem services can be grouped into the following typologies, namely supply

Typology of ecosystem services with examples

Provisioning services	
	Food; water availability; raw materials, fuel and energy; fertilizer, genetic material; medicine and pharmaceuticals; models and organisms for testing (organism tests); fashion, decorative, handicraft materials.
Regulating services	
	Gas and air regulation; climate (including carbon sequestration); protection against storms and floods; prevention of dryness and the provision of natural irrigation; clean water; erosion prevention; maintenance of productive land; pollination; biological control; disease and epidemic control.
Habitat/supporting services	
	Seed planting; maintenance of biodiversity.
Cultural services	
	Panorama; recreation and tourism; inspiration for art; cultural heritage; use for religious and spiritual purposes; science and education.

Figure 3.1 *Typology of ecosystem services with examples of various services related to provision, regulation, support, and culture (extracted from Constanza et al. 1997 and De Groot et al. 2012).*

services, regulatory services, support services, and cultural services (see Figure 3.1).

The condition of an ecosystem is very dependent on biodiversity. The character of each species and its distribution and abundance will affect the ecosystem. Because the species within an ecosystem complement each other, the more diverse the species that inhabit an ecosystem, the more productive the ecosystem. For example, crop production depends on the diversity of species that live in the soil. Crop production benefits from an increased release of nutrients from decomposition by microorganisms (Van der Heijden *et al*. 2006). Conversely, plant diversity can increase soil fertility and microbial richness (Balvanera *et al*. 2006). Plant diversity will also reduce the number, life force, fertility, and diversity of invasive species. In turn, this will reduce the risk of crop damage due to outbreaks of diseases.

Marine ecosystems also show a similar tendency. The more diverse the species in it, the more productive the ecosystem is. Biodiversity even plays a significant role in the workings of the deep-sea ecosystem. These roles include the ability to use the main production of the photic zone, which is a zone of sea water that can be penetrated by sunlight; to utilize and recycle organic compounds stored on the seabed; and to direct marine waste to organisms at higher trophic levels in the food chain (Danovaro *et al*. 2008).

An understanding of the factors related to ecosystems and biodiversity, as well as of the ecosystem services they produce, enables us to link them their impact on human welfare—including the economic benefits. This is schematically illustrated in Figure 3.2.

The theoretical approach shown in Figure 3.2 emphasizes that biodiversity itself is not an ecosystem service, but rather that this service depends on the structure and processes of the ecosystems produced by living things and their interactions with abiotic material or inanimate objects (Heines-Young and Potschin 2010). It should be emphasized that the effort

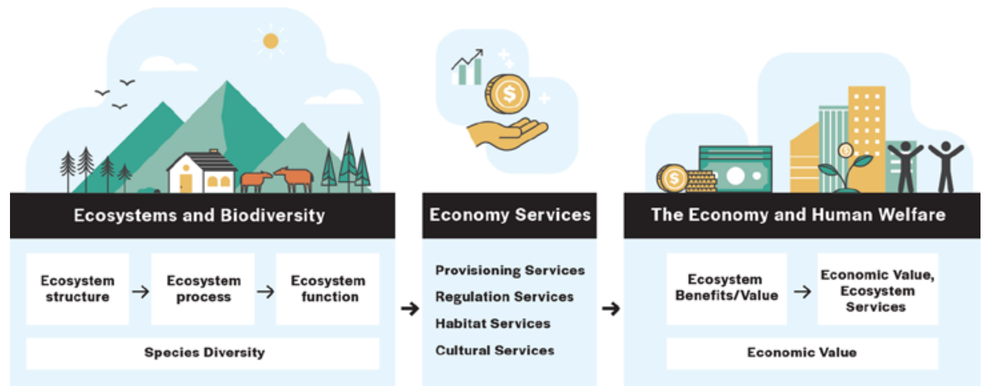


Figure 3.2 *Biodiversity in ecosystem and economic integration (Adaptated from Heines-Young and Potschin (2010) and TEEB (2011) with modifications and additions).*

to precisely quantitate the links between ecosystems, biodiversity, and the economy and is limited by a number of complex issues.

First, biodiversity is a multidimensional concept, so that its manifestations and measurements can take various forms. Second, quantitative measurements of biodiversity can be designed for different specific purposes, such as biodiversity scale differentiation (global or local), and different goals produce different numbers and results. Third, although ecosystem services often increase with increasing biodiversity, the strength and shape of the relationship between ecosystem services and biodiversity, as well as the best predictor of the size and quality of an ecosystem service, may be different depending on the ecosystem service studied.

1
Fish biodiversity in
the Sikakap Strait, Mentawai, West Sumatra

ECONOMIC VALUE:
USD 4.7 million
This economic value includes 14 types of pelagic and demersal fish, such as *baracuang* (*Sphyraena jello*), anchovies (*Stolephorus commersonii*), red snapper (*Lutjanus Campechanus*).

ECONOMIC VALUATION METHODS:
The benefit transfer approach and contingent valuation method use secondary data (Rizal and Dewanti, 2017).

2
Biodiversity in
The karst region, Maros, Sulawesi Selatan

ECONOMIC VALUE:
IDR 639 billion
based on direct use value in the form of expenditure for tourism (IDR 133.8 billion) and indirect use value from existing forests, water supply, flood control, maintaining the presence of karst (in the amount of IDR 639.5 billion), according to a study conducted in Bantimurung, Pattunuang, and Karaenta.

ECONOMIC VALUATION METHODS:
Willingness to pay using a survey of households, businesses, and visitors (Waluyo et al, 2002).

3
The value of water drought in
Ruteng, Manggarai, Nusa Tenggara Timur

ECONOMIC VALUE OF PREVENTING:
IDR 230 million/year
This includes data from nine sub-districts in the buffer zone, most of whose citizens are farming households that depend on water resources in the forest area in the Ruteng watershed.

ECONOMIC VALUATION METHODS:
Willingness to Pay Method by Contingent Valuation (Pattanayak and Kramer, 2001).

4
The value of anoa together with biodiversity & ecosystem services in
Lore Lindu National Park, Central Sulawesi

It includes the economic value of the increase in the number of anoa, together with scenarios for reducing the distance of the rattan location, decreasing the length of time of water shortages, and decreasing the level of cacao shading.
IDR 1.6 billion/year

ECONOMIC VALUATION METHODS:
The stated preference method uses choice modeling (Barkmann, 2007).

5
Whale shark tourism in
Cendrawasih Bay, Papua

ECONOMIC VALUE:
IDR 35.5 trillion
This national park covers land area on the island plus sea water area around it. The economic valuation includes ecotourism services, the value of national parks, small-scale fisheries, marine resource rents, and tour service management.

ECONOMIC VALUATION METHODS:
A combination of travel cost method, contingent valuation method, productivity approach / market value, and secondary data analysis and interviews on market prices (Anna and Saputra, 2017).

Figure 3.3 *Examples of economic values in several regions in Indonesia.*

In general, the economic benefits of biodiversity economics may not be recognized much by the Indonesian people, even though the economic value is very high (see Figure 3.3). The agriculture, forestry and fisheries sectors account for only 11% of Indonesia's gross domestic product (GDP). However, if examined in more depth, the three economic sectors are the basis of livelihood for the majority of the poor in Indonesia, whose numbers reach 99 million (Figure 3.4). Studies conducted in Kalimantan and Sumatra on the relationship between community economics and ecosystems in the form of cash and non-cash income show a fairly high level of dependence of the household economy on services provided by the ecosystem (Angelsen *et al.* 2014; Fitriani and Mumbunan 2018)

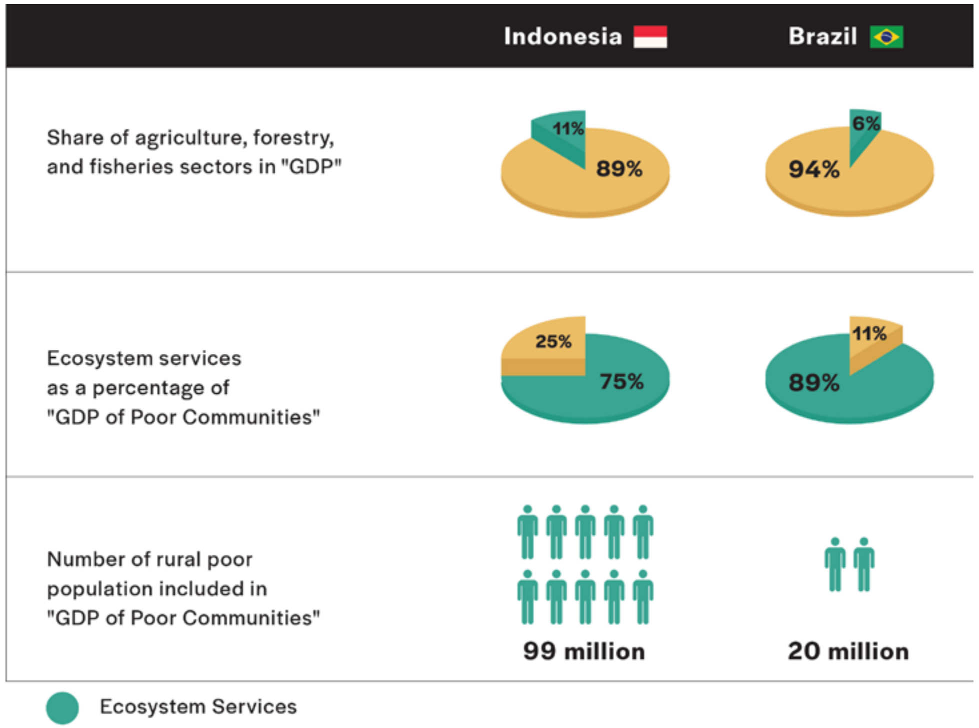
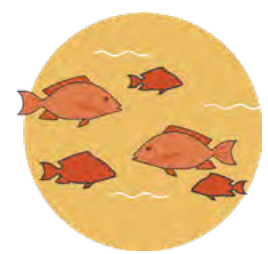


Figure 3.4 *The economic dependence on ecosystem services in Indonesia and Brazil: Sectoral contributions to the economy, the economic share of the poor, and the number of poor people who depend on ecosystem services (source: TEEB (2010), modified figure).*

Table 3.1 shows the distribution of values for various ecosystem services in Gunung Leuser National Park, according to selected scenarios in the form of deforestation, conservation, and limited and selected use of forest resources. Value is stated in million US dollars (2000-2030). From this Table it can be seen that a conservation scenario in Gunung Leuser National Park yields the greatest economic value, with the value of ecosystem services exceding the economic value determined for a selected use of forest resources and —to an even larger extent—that for deforestation.

For the above park, the highest economic value for the ecosystem services created by a conservation scenario comes from water supplies —around one quarter of value of the total ecosystem services assessed. This is followed by agriculture, flood prevention, hydroelectric power, and tourism. It is understandable that in the conservation scenario, the economic value of agriculture will be far less than the economic value of the deforestation scenario (36% of the total economic value). In addition, the economic value of non-timber forest products (NTFP) is smaller than what is manifested in the scenario of using limited and selected forest resources. In short, conservation has higher economic value.

It can be seen from the above figures how important biodiversity is in supporting the Indonesian economy. But, at the same time, real changes in biodiversity conditions are being caused by human activities, and they are closely related to ecosystem processes and the way humans use natural resources.



	Deforestation		Conservation		Selected uses	
	Value	Proportion (%)	Value	Proportion (%)	Value	Proportion (%)
Water supply	699	10	2419	25	2005	25
Fisheries	557	8	659	7	674	7
Flood control	1223	18	1591	17	1396	17
Agriculture	2499	36	1642	17	1016	17
Hydroelectric power plants	252	4	898	9	696	9
Tourism	171	2	828	9	407	9
Biodiversity	56	1	200	2	125	2
Carbon absorption	53	1	200	2	125	2
Fire prevention	30	0	715	7	643	7
NTFP	235	3	94	1	1222	1
Wood	1184	17	0	0	825	0
Total	**6958**	**100**	**9538**	**100**	**9100**	**100**

***Table 3.1** Comparison of the effects of deforestation, conservation and selected uses on the Gunung Leuser National Park ecosystem. (Source: van Beukering et al. 2003).*

Circular Economy

Efforts are clearly needed to find a wiser way to use natural resources, including biodiversity, in a sustainable manner. Development, after all, must be in accordance with the carrying capacity of the Earth. The current situation necessitates an urgent call to change the linear economic approach, which relies on the exploitation of nature for short-term interests that often harm the ecosystem, into a circular economy, which balances economic interests with ecology.

A circular economy is an economic system in which products and services are traded through a closed cycle, characterized by a regenerative design, with the main objective of maintaining as much value as possible of from a product, its parts, or its materials. The goal is to create a system that allows products and materials to last a long time—providing for their optimal reuse, replenishment/addition, reproduction and recycling.

Related to a circular economy is the concept of "green buildings" which are environmentally friendly buildings, also known as Leadership in Energy and Environmental Design, or LEDD buildings. The sustainable or green building is the result of a design philosophy that focuses on increasing the efficient use of resources, including energy, water, and materials, while reducing the impact of development on human health and the environment. In this concept all of the materials used in buildings are materials that are not for once-only use—and thus can be reused, renewed, and recycled (Buys & Hurbissoon 2011).

This philosophy and circular approach make it possible to strike a balance between economic interests and ecological interests.

Biodiversity Potential for Economic Development

The link between biodiversity and basic human needs is hard to deny. This applies everywhere, but especially in Indonesia. As a tropical country, where a great many types of plants grow on its land, Indonesia needs to learn in more depth the role and usefulness of these plants for human life in various fields. This unlimited natural resource is a great opportunity for those in our communities to open a business, whatever its type. Examples are the tourism industry (ecotourism), the food industry, the drug industry, and energy.

Ecotourism

Who has not heard about our Komodo dragons and orangutans? As icons of Indonesia's ecotourism, the fame of these two animals is undoubted. However, Indonesia has many other such "ambassadors" who can boost the interest of tourists for visiting to enjoy the natural beauty of Indonesia. There are many exotic animals in Indonesia, such as the anoa, maleo birds, and birds of paradise. These are strong candidates for becoming tourism ambassadors for Indonesia, along with our endemic flora.

Ecotourism combines tourism with a commitment to nature and social responsibility. As a manifestation of sustainable development, ecotourism gives proportionate attention to environmental, social and economic aspects. Recently this type of tourism has become popular throughout the world. Nature tourism can be in the form of trips to see wild life, for adventure, or just to enjoy nature. Unlike these older forms of tourism, which emphasize recreational activities, ecotourism puts an emphasis on conservation and its benefits to the communities in the areas visited (Brandon 1996).

Numbers can speak louder than words. The number of tourists in various national parks in the United States reach more than 2.5 billion people and in China more than 1 billion people. When added together, tourists visiting conservation areas

around the world amount to more than 8 billion people. The business value of ecotourism activity reaches 600 billion US dollars per year. This category of tourism has become a giant industry, estimated to represent 10% of the world economy (Supriatna 2014).

Ecotourism can contribute greatly to biodiversity conservation. Initially, thanks to direct income from tourists in the form of payment of entrance fees, taxes, etc., this activity can be a source of conservation funds. For communities around conservation areas, it can also provide an alternative income. Environmentalists and the government have good reasons for their efforts, namely conserving biodiversity and the sustainable development of the region. In addition, businesses involved in conservation carry out economic activities in conservation areas (Honey 1999).

On a global scale, and especially in developing countries like Indonesia, ecotourism can be used to overcome problems in conservation efforts. The use of tourism as a means of achieving conservation management goals is increasingly accepted in various countries. This can be seen from the increase in interest for visiting natural tourism areas (Hulme and Murphee 2001). In Rwanda, for example, watching gorillas in the wild is an ecotourism activity that is a source of foreign exchange. Rates per day to see mountain gorillas are 120 to 150 US dollars per tourist. When expenses for hotels, transportation, guides, food and souvenirs are added, each tourist can spend thousands of dollars (Vedder & Weber 1990).

In Indonesia, wildlife tourism is still very limited despite our 54 national parks being found, such as those in Tanjung Puting National Park, Komodo National Park, and West Bali National Park. It is not clear how much it costs per day to see orangutans, Komodo dragons, and Bali starlings.

Guidelines regarding appropriate entrance fees to conservation areas and their derivatives were only published in 2014 by Government Regulation No. 12 of 2014 concerning Types and Rates of Non-Tax State Revenues Applicable to the Ministry of Forestry. This regulation is also complemented by Government Regulation No. 46 of 2017 on Economic Instruments of the Environment, which can be used as a reference for the development of ecotourism prices.

As a country with 50 ecosystems, including forests and beaches where turtles lay eggs, as well as wildlife migration routes, Indonesia is an area that is very suitable for wildlife ecotourism. The main attraction of this type of tourism is its ability to be a substitute for lost profits from hunting activities and, at the same time, to contribute to wildlife conservation efforts. Other benefits include the emergence of development in tourist areas, education and environmental awareness, maintenance of cultural identity, and potential opportunities to improve the lives of local residents, while protecting wildlife and natural habitats.

In several areas where turtles land ashore, including Meru Betiri National Park, Derawan Islands, Tanjung Benoa and southern Sukabumi, wildlife-based tourism has been developed. Unfortunately, none of these sites has satisfactorily succeeded in integrating these activities with ecology. In fact, if managed properly, wildlife-based tourism can be a source of income for the region and the country. In Costa Rica, for example, almost 10% of the country's income comes from wildlife tourism revenues (Fennel 2007).

The Tamar-Ibama project in Brazil is another example of successful marine wildlife conservation. Here wildlife-based nature tourism is used as a substitute for hunting marine wildlife. This project is successful thanks to the participation of local communities in educational activities, tour guide training, and festivals. In addition, former wildlife poachers are employed as members of the patrol team that protects wildlife nests. The methods adopted make wildlife-based nature tourism a useful activity that brings in revenue to replace poaching, while also providing communities with ways to maintain their sustainability through marine wildlife conservation.

Indonesia clearly has a huge potential for the ecotourism industry, especially that related to its natural scenery and wildlife. In a survey of foreign tourists visiting Indonesia,

Great Barrier Reef: The Value of a Coral Treasure

Australia is fortunate to be blessed with the coral reefs called the Great Barrier Reef. In addition to its important ecological value, this Reef's economic value is very high. The Financial Advisory Service, Deloitte Access Economics, in 2017 calculated that the economic value of the Great Barrier Reef at 56 billion Australian dollars, playing a very large role in supporting the economic activities of our neighboring country. The calculation is based on the "economic, social and iconic value" of the famous coral reef group. According to Deloitte, the Great Barrier Reef contributes 6.4 billion Australian dollars to the Australian economy and produces 64,000 jobs. The assessment took place over 6 months, and it was based on research and the use of various economic sources supplemented by a survey of 1,500 people from 11 countries.

The Deloitte report uses economic modeling to estimate that the Great Barrier Reef is worth 29 billion Australian dollars for tourism and 3.2 billion Australian dollars for recreational purposes, such as recreational diving.

There is also an "indirect" value of 23.8 billion Australian dollars for what is called "brand value". This "brand value" reflects the fact that, although many Australians have not yet had the opportunity to visit this cluster of corals, they believe in the region's high value. The Deloitte report states that the total economic value of the Great Barrier Reef is 12 times greater than the Sydney Opera House, the performing arts building that is the pride of Australia.

However, Deloitte's report also states that, to maintain the high economic value, greater conservation efforts are needed for these coral reefs. In recent years, this region has experienced bleaching threats related to rising water temperatures and reduced algae in the region. As one of the richest and most complex natural ecosystems in the world, the Great Barrier Reef is indeed of immeasurable and irreplaceable value. The Australian government and the Australian community are intensively projecting an image of "invaluable and irreplaceable icon" for the Great Barrier Reef.

Indonesia, in the heart of the world's coral triangle, has a cluster of coral reefs of no lesser value than the Great Barrier Reef. These include Raja Ampat, Bunaken, Wakatobi, Takabonerate, and many more. The reef fish species in Indonesia far exceed those in Australia and the Caribbean. The potential of ecotourism in the form of coral treasures needs to be worked on seriously with the support of science and technology for their sustainable management and use.

nearly 60% expressed interest in Indonesia's natural beauty (Supriatna 2014). But no attention has yet been focused on developing wildlife tourism by governments, developers, non-governmental organizations, and tourism experts. In fact, ecotourism has the ability to build environmentally friendly and sustainable public tourism. Community involvement is very important because local people will often have knowledge about the nature, culture, and best attractions for tourists in their regions. Community engagement should be carried out from the planning level to the management level, as has been done in the Gunung Halimun-Salak National Park, West Java.

Food Bioeconomics

The increasing rate of population growth creates one inevitable consequence: a high demand for food, clothing and shelter. Indonesia is a country that is rapidly growing in population and is at the same time fortunate to have unparalleled biodiversity. The diversity of food sources that Indonesia possesses can be seen from the great diversity of staple foods in Indonesia. There are about 370 vegetable-producing plants, 400 fruit-producing plants, and 55 spice-producing plants spread throughout the archipelago.

The supreme importance of biodiversity for food and nutrition security is emphasized by the UN agency, the Food and Agriculture Organization (FAO). The diversity represented by the millions of relationships between species is an irreplaceable factor in ecosystems, on which food production throughout the world depends. Any decrease in biodiversity will trouble humans; our ability to adapt to ecosystems and face new challenges, such as an increasing population and climate change, will decline. Both our diversity of food sources and our food security depend on maintaining biodiversity.

Often agriculture and biodiversity are considered separate domains. Although biodiversity underlies most modern agriculture, the development of contemporary production systems results in a massive land conversion that causes a loss of biodiversity. An innovative and acceptable way of integrating biodiversity conservation with food production is needed to meet the world's demand for an increased food supply.

In industry, only certain commodities are developed on a large scale. On the other hand, maintaining a variety of local food variants is essential for building food security and sovereignty. This diversity can maintain and increase soil fertility, while also reducing the impact of pests and diseases. Food diversity that is based on many varieties of agricultural systems provides nutrition and better health opportunities, with the added benefit of improving productivity and human life. No less strategic is the fact that biodiversity can play a role in overcoming the effects of climate change—thus strengthening ecosystem resilience. The benefits of agricultural biodiversity are manifested on different ecological scales and human groups. Thus, to bridge across disparate views and political affiliations, a cross-sectoral approach will be needed to reassess the role of agricultural biodiversity in sustainable and safe food production (Frison *et al*. 2011).

The Search for Drugs

Plants, animals, and microorganisms contain giant libraries of chemical compounds that can be used for developing drugs. In the United States, as much as 50% of drugs come from plants, animals, and microorganisms, and 80 percent of the world's population depends on medicines derived from nature (Chivian 2008). Indonesia's opportunities to utilize its biodiversity to excel in the field of medicine are enormous. This effort can start by utilizing community knowledge about medicinal plants (ethnobotany) that has been passed from generation to generation.

Medication using herbs is an example. This cultural heritage can be found in various regions, but the tradition of herbal medicine is especially central to Javanese culture. Javanese people have been using herbal medicine since the Ancient Mataram period, approximately 12 centuries ago. Its main ingredients are passed down from generation to generation, mainly through oral tradition.

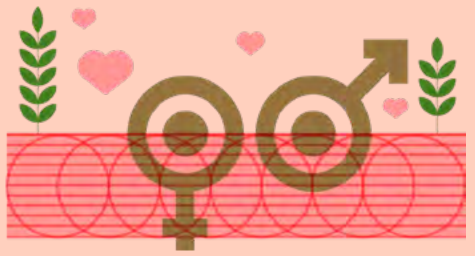
An initial documentation of herbal medicine was produced by Jacobus Bontius (1592-1631), a Dutch doctor who worked in Batavia at the beginning of the 17th century. Shortly afterwards, Georg Eberhard Rumphius documented more comprehensively the traditional herbal-based medicines in Ambon in the 17th century.

Some of the knowledge about medicinal plants in our archipelago is viewed as an open secret. For example, the plants that have been believed for a long time to have an aphrodisiac effect, increasing sexual desire and ability, include *pasak bumi* or *purwaceng* in Java, and *sanrego* wood in South Sulawesi. Some of these plants have been processed into herbs or supplements and have a large market potential.

The first Indonesian to pay serious attention to medicinal plants was RM Santoso Soerjokoesumo. At the beginning of the period of Indonesian independence, he began his Garden of Collection of Medicinal Plants (in Tawangmangu, Central Java) that aims to preserve, cultivate, and develop traditional Indonesian medicinal plants. In 1948 he handed over his collection of medicinal plants to the State. This collection was then managed by the Eijkman Institute and named Hortus Medicus Tawangmangu. The Ministry of Health took over its management since 1963, and its current name is the Center for Research and Development of Medicinal Plants and Traditional Medicines (*Balai Besar Penelitian dan Pengembangan Tanaman Obat dan Obat Tradisional*).

Since 2010, the Indonesian government has been pushing for the modernization of traditional medicines; an example is its scientification of herbal medicine program with more than 32 thousand herbal ingredients from 2,848 species

Seduction of Archipelagic Aphrodisiac: for a Stronger Economy



What worries men more than underperforming in bed? From a violent warlord, a ruler of a large tribe, to a commoner with a pitiful looking face in a room under a shabby mosquito net, sexual prowess is source of pride, as well as being one of the keys to a lasting and healthy relationship.

Long before we knew about Viagra or the blue pill, Javanese kings were consistent users of herbal medicines to maintain sexual arousal to be able to fulfill their obligations and satisfy their wives and concubines—whose numbers could not be counted on the fingers of both hands. This fertile archipelago is blessed with various types of plants (and animals) that are believed to be able to boost sexual desire, known as aphrodisiacs.

Plants such as *purwaceng* (*Pimpinella pruatjan*) in Java, *pasak bumi* or *tongkat ali* (*Eurycoma longifolia*) in Sumatra and Kalimantan, and *sanrego* (*Lunasia amara*) in South Sulawesi, are examples of well-known plants that have long been believed to be aphrodisiacs. More generally, Asia has long been known as a continent rich in aphrodisiac material.

Several ancient manuscripts as well as oral traditions in various ethnic groups in Indonesia have recorded various plants and parts of animals that were processed to increase sexual desire. The *Serat Centhini* from Java, *Lontara Pabbura*, and *Lontara Assikalaibineng* from Bugis are a few examples. If in the past the herbs were processed in a complicated traditional way, now the packaging and appearance are increasingly attractive and practical, in the form of herbs or pills. The economic benefits of the herbal medicine industry, including herbal enhancers of sexual desire, are very significant. According to the Ministry of Industry, Indonesia ranks 4th as a producer of herbal medicine in the world after China, India, and South Korea.

The economic advantage of aphrodisiacs is no joke. Its market share is large, and as long as sex is still performed by humans, demands for it will be forever.

For example, in the twenty years since it was marketed the demand for Viagra has never been sluggish. Pfizer, the manufacturer of Viagra—which is actually a heart medicine consisting of sildenafil citrate—reported that the revenues earned through this powerful drug averaged USD 2 billion per year (for 2010-2012). Its main competitor, Cialis (tadalafil), is even more impressive, with revenues of USD 2.3 billion in 2015.

Wouldn't Indonesia, whose natural environment is endowed with plants that are the raw materials of drugs for enhancing sexual desire, drool with these fantastic figures—not to mention the large number of workers employed, as well as research related to sexology that is increasingly gaining ground? With science and technology being the vanguard, herbs that increase sexual desire can be upgraded to become science-based herbal medicines.

The use of the latest science and technology should also enable the discovery of active substances that have an aphrodisiac effect from *purwaceng*, *pasak bumi*, and *sanrego*.

The late Hugh Hefner at the age of 84 dubbed Viagra—which he consumed regularly before making love—as "God's little helper". Why don't we create "God's little helper" specific for this archipelago? Not only does sexual passion continue to burn, but Indonesia's economy will also perform much stronger.

of medicinal plants (Ristoja Report, Ministry of Health 2017). Seven herbs have been reported to have passed the randomized control trial phase and are being used in clinics managed by the Ministry of Health. This is an important first step, providing an example of the success of a modernization of traditional medicine integrated with health services, as an integrated effort from upstream to downstream. Success certainly requires investments in modern science and technology, so that Indonesia can produce products using modern medical principles that demand quality assurance—including safety, standardized dose, and so on. The resulting products are expected to have commercial potential and can compete in the global market.

This type of modernization is not the only endeavor required. In the opportunity to identify the active compounds contained in traditional herbal ingredients and develop them into a phytopharmacy for modern medicine, it must be recognized that most traditional medicines work because of an interaction and synergy of several compounds. This

differs from today's medicine based on drugs produceds as single active compounds. This is where a great challenge for converting traditional medicine into modern medicine lies. The development of a traditional herbal medicine must choose between isolating the active compounds and making it traditional medicine within the rules of modern medicine, or directing its development to become a commercial health supplement. Early indications are needed, in order to decide on which direction to take for a traditional medicine as soon as possible.

The market potential for traditional medicines is large and the demand for them at the global level continues to increase. The majority of the population in many countries in Asia and Africa still depend on traditional methods of treatment. A 2013 WHO report states that the market potential in China alone was estimated to reach USD 83.1 trillion in 2012. In Korea, spending on traditional medicine was around USD 4.4 trillion in 2004 and rose to USD 7.4 trillion in 2009. The same report also revealed that in the United States personal expenses for traditional medicine in 2008 reached USD14.8 trillion. How much is this trade in traditional medicine in our land of herbs and spices? It is only IDR 3 trillion. This actually provides an opportunity, as well as a challenge, to encourage the development of our traditional medicine into a health supplement industry or even into modern medicine. But to realize this goal, Indonesia cannot work alone. An abundant knowledge of medicines and traditional treatment systems is not enough. The modern medicine industry is more advanced in highly developed countries. Thus, cooperation is needed between developing and developed countries to explore and optimize the benefits of traditional medicines. The development of traditional medicine can be approached at several levels, ranging from herbal medicine, to scientific herbal medicine, to standardized herbal medicine, to a phytopharmacy, to the isolation of pure active components. Each successive level requires a greater investment, but the returns are not small (Figure 3.5).

Another challenge to keep in mind is that the development of traditional medicine into modern medicine requires sophisticated mass screening technologies to find the beneficial compounds. The success ratio of finding molecules that can be developed into medicine is only 1: 10,000, not unlike finding a needle in a haystack.

In addition, the quality of our environment must be maintained to obtain quality medicinal ingredients. Environmental pollution and climate change are major challenges causing a decline in biodiversity. In addition, the number of speakers of oral tradition expert in the traditional medicines in various ethnic groups in Indonesia is declining.

China is one of the countries famous for its traditional medicine. In 2017, revenues from sales of traditional medicines in China reached USD 34 trillion, with an industry total of 1,368 units. The rapid pace of the traditional Chinese medicine industry is attributed to the investment and government policies in the health service sector, a high incidence of chronic diseases, other applications of traditional medicine, and changes in people's perceptions about traditional Chinese medicine (Equity Research 2016).

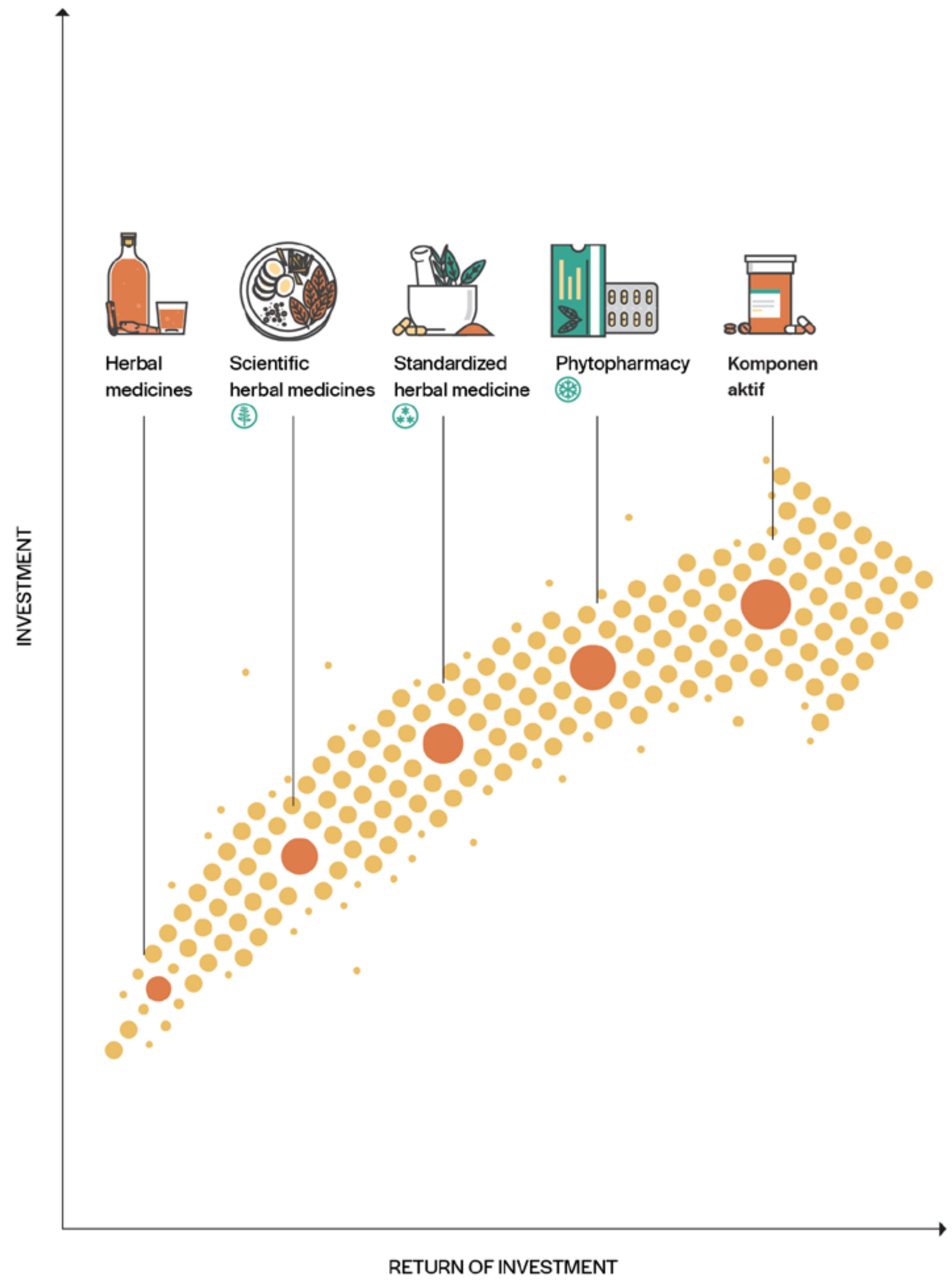


Figure 3.5 *Comparison between investment needs and revenue from biodiversity utilization for medicines.*

Tu Youyou's Nobel Prize Potion

In 2015, the Nobel Committee awarded the Nobel Prize in Medicine to Professor Tu Youyou. This scientist from China, the Bamboo Curtain country was considered to be worthy of the prize for the discovery of artemisinin, an antimalarial substance derived from the sweet wormwood plant (*Artemisia annua*). In China, artemisinin is known locally as *qinghao*.

"Traditional (Chinese) medicine is a rich resource, but it needs deep thinking for exploration and improvisation," Tu Youyou said in her Nobel Award acceptance speech. This 2015 speech not only opened Tu's achievements to an international audience, but also conveyed the story of a long, tireless search for the health of humanity—a search carried out in the giant "library" of traditional Chinese medicine.

Tu's discovery could not be separated from the events of the war that tore Vietnam apart in the 1960s. At that time the Vietnamese army was facing onslaughts of US troops. However, there was another attack that was no less fierce: malaria. The disease transmitted through mosquito bites was found to be the biggest cause of death of Vietnamese soldiers, more than that inflicted by the United States army attacks.

In 1964, the communist-leaning North Vietnamese government approached the Chinese leader, Mao Zedong, and asked China's help to fight malaria. Mao replied, "Solving your problem is the same as solving our own problem."

In 1969, the Chinese government then launched Project 523, a covert operation led by Tu Youyou, a female medical researcher who at that time was not yet 40 years old. Tu Youyou did not need to travel far from her native country to get the materials needed. She collected and searched for efficacious ingredients from thousands of recipes of Chinese herbal ingredients that were more than 1,700 years old. Tu Youyou had to discover a new drug, because the malaria parasite that infected the Vietnamese army at that time was resistant to chloroquine. Tu Youyou's search bore fruit when she extracted artemisinin from sweet wormwood, a herb used for more than 2,000 years to treat fever in China.

Since its discovery in 1972, artemisinin and a drug made from this substance, dihydroartemisinin, have saved and improved the lives of millions of people. "Professor Tu's group began by looking for prescriptions that had been used to treat fevers. They searched for more than 2,000 prescriptions and collected 640 prescriptions for further evaluation within three months. They then looked at the name of each plant with a high frequency of appearances in the prescriptions." (Su & Miller 2015).

The discovery of artemisinin is an example of utilizing traditional knowledge about the properties of drugs from natural sources as an important starting point in the discovery of new drugs. Therefore, it is important to explore ancient manuscripts as well as local knowledge and local wisdom as guides. In addition, a massive documentation of medical traditions in various ethnic groups in Indonesia needs to be done before these traditions become extinct.
It is not impossible that cures for infectious diseases, for diseases related to lifestyle, and for degenerative diseases can be found after persistent examination of the archipelago's ancient lontar manuscripts.

Alternative Energy

In addition to playing an important role in meeting the needs for clean water, food, and medicine, biodiversity also plays a role in the supply of renewable energy sources. This is an absolute necessity considering that the supply of fossil energy sources is being increasingly depleted, including in Indonesia as one of the producers of petroleum. The use of petroleum, coal and gas energy is also not environmentally sound, being a source of greenhouse gas emissions that fails to support climate change mitigation. Alternative renewable and environmentally friendly energy sources need to be found and employed very soon. Fundamental strategic research investments are needed immediately to develop renewable energy sources that can strengthen energy security. Bioenergy will provide one of the solutions, in addition to solar energy, geothermal and wind energy.

With abundant natural resources, Indonesia has the potential to not only meet its own energy needs, but to become the world's leading bioenergy center. Various efforts have been made to produce biofuel-based fuels. As the largest vegetable oil-producing country in the world, Indonesia has a wide range of biodiesel raw materials: fatty acids from palm oil, *Jatropha curcas*, coconut, soursop, sweetsop, kapok, and algae. However, not all efforts have been successful, partly due to the issue of land transfer and a competition with agriculture and food plantations.

If the issue is limited land, algae can be an alternative source of renewable energy because it can produce biodiesel very efficiently. Algae also do not need agricultural land, so they do not compete with food production. In addition to algae, Indonesia has a variety of microbes that have the potential to be developed into a producer of renewable fuels. Examples are the cyanobacteria, a bacterial phylum that is able to convert solar energy into bio-fuels or electrical energy through photosynthesis. The challenge is how to harness photosynthesis in a way that is effective, economical, and provides a sustainable supply. There is promise for the future development of an artificial photosynthesis. The hope is that the rich diversity of species having a unique structure of photosynthesis systems (because they grow in different or extreme environments) can inspire a solar cell technology that is able to capture and store light energy more efficiently and effectively.

The residues of living things and garbage that is usually burned can

also be considered as alternative local energy sources, and are denoted as biomass biological material. Various types of organic waste and agro-industrial waste are potential raw materials for the production of biomass and biogas using anaerobic technology—a microbiological decomposition process without oxygen. The products are methane gas and organic fertilizer. Methane gas, which is environmentally friendly because it can burn completely, is of high economic value and can be used for various purposes, from household kitchens to powering turbine engines.

More interestingly, biomass can be processed into biocarbon, a fuel with high calorific value that can be used for daily needs. Similarly charcoal, in the form of briquettes, can be produced from oil palm shells to meet industrial needs. For household energy needs, several regions and community groups have promoted a program to convert waste into biomass, as well as the implementation of a circular economy. The energy sources we develop should not produce carbon emissions that worsen global warming. Engineered microorganisms such as microalgae can even become a energy source with a positive effect on climate, reducing carbon emissions in the atmosphere.

IV

THREATS, CHALLENGES, AND CONSERVATION EFFORTS

If we pollute the air, water and soil that keep us alive and well, and destroy the biodiversity that allows natural systems to function, no amount of money will save us. – David Suzuki

In order for biodiversity's support for human life to last, biodiversity must always be maintained, guarded and preserved. Science is needed to face the challenges and threats to biodiversity, which are getting more serious. The destruction and extinction of biodiversity, on land and at sea, is an increasingly real threat. This threat arises due to habitat destruction caused by human actions, such as deforestation, over-exploitation of resources, pollution, invasions of alien species, and climate change. Many economic activities aimed at fulfilling the needs of human life and industry are overly focused on short-term interests.

Extinction will not only occur in large animals, such as elephants or tigers, but can also afflict the microorganisms, insects, and plants that play a fundamental role in ecosystem services. Without these services, human survival is threatened. With the current rate of destruction, modification and conversion of environmental functions, especially in the tropical forests that are home to half the world's biodiversity, biological-ecological poverty and a threat to our survival are certain. Human health and the availability of food and water sources are the most affected by biodiversity damage. Holistic conservation efforts and cross-sectoral management are needed.

There is also a need to strengthen the science needed to fundamentally understand the present phenomena, as a vanguard for their control. For example, the science of restoration ecology and conservation biology; science of environmental management; science of bioremediation, science to find alternative materials to plastics to overcome plastic pollution; science to increase the capacity of cultivation to overcome over-exploitation; science to fundamentally understand the impact of invasion of alien species on an ecosystem; and science to overcome zoonoses. These sciences are a prerequisite for preventing further damage, and they are also absolutely necessary to mitigate the impacts that may occur. Whatever policies are chosen should be based on valid evidence that can best be derived from science that places human health, environmental health, and the carrying capacity of the Earth at the center of its concerns.

Looking at the Condition of Biodiversity in the IPBES Report

The Global Assessment Report on Biodiversity and Ecosystem Services published by the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) has become a point of discussion everywhere. Based on this report, for which a draft was published in 2019, about 1 in 4 species of animals and plants are currently threatened with extinction. This means that about 1 million species are at risk of extinction unless effective action is taken to reduce the intensity of the loss of biodiversity. Especially in the last 50 years, the impacts of humans on the environment have caused biodiversity on the planet to drastically plummet. This has never happened before in human history.

According to this comprehensive report, the direct drivers of natural change with the biggest impacts globally are, changes in land and sea use; direct exploitation of organisms; climate change; pollution; and the invasion of alien species. For terrestrial and freshwater ecosystems, land use change has the most negative impact, while for marine ecosystems, exploitation of organisms, especially fisheries, has the most negative impact among these direct drivers. The direct drivers are in turn triggered by a group of indirect drivers that include production and consumption patterns; the dynamics and tendencies of the human population; commerce; technological innovation; and global governance. The risk from this situation is fairly high. As illustrations, according to this report, land degradation reduces the productivity of global terrestrial areas by 23%, and the risks to global food crop yields are between USD 235 billion to 577 billion due to the loss of pollinators. In addition, the loss of coastal and coral reef habitats increases the risk of loss of protection to life and property due to floods and storms. There are 100 to 300 million people living in these coastal zones.

IPBES is an inter-governmental organization that was established to bridge science and policy related to issues of biodiversity and ecosystem services. IPBES is often compared to IPCC, a similar panel focused on the issue of climate change. IPBES was founded based on the resolution of the 2010 United Nations General Assembly which asked UNEP (United Nations Environment Program) to establish IPBES. The Global Assessment Report on Biodiversity and Ecosystem Services published by IPBES was approved by the IPBES Plenary Meeting in 2019 in Paris, France. It consists of six chapters and one summary for policy makers, designed to provide as a scientific basis for making enlightened political and social decisions related to biodiversity policies. The report was written collaboratively by writers in various fields of science and cross-sciences from 50 countries with more than 300 contributors over three years, after examining more than 15 thousand scientific publications and reports.

Challenges to Biodiversity

Life in this world is interconnected. Anyone and anything are directly and indirectly related to the support of a healthy environment. Nevertheless, damage to the environment continues to occur.

As the population of the Earth reaches 8 billion, all will need food, clothing, and a decent shelter that depend on what nature provides. Ironically, efforts to meet these needs will cause environmental damage, threaten human health, and in the long and medium term be economically detrimental. That is why a new approach based on science and technology, supported by strong political will, is needed to harmonize the fulfillment of development and human needs, while maintaining the sustainability of the environment (circular economy).

Deforestation without Control

The conversion of primary forests into plantations and agricultural lands, settlements, and mining areas are serious challenges to Indonesia's biodiversity. Any such transfer of functions should be measured properly, with calculations based on science, so that forests can still be used sustainably. Ecosystem services are indeed something one cannot see directly, but they are irreplaceable and their economic value is high.

The Ministry of the Environment and Forestry in 2016 stated that the rate of deforestation had reached 600-700 thousand hectares per year. Forest Watch Indonesia (2016) has a different total, which is 1.13 million hectares per year; almost double the government's figure. By any estimate, the destruction of forests in our country is a disturbing fact. According to the Riau Forest Rescue Network, there are only 1.7 million hectares of natural forest left in Indonesia, or 19% of our total land area. Naturally one may believe that other regions experience more or less the same thing. In the medium and long term, this trend will harm all parties.

The extinction of various species that are part of biodiversity in Indonesia is an inevitable result of the loss of habitats related to massive deforestation. One of the main drivers of Indonesia's deforestation comes from oil palm plantations (Austin *et al*. 2019). The economic and social impacts of oil palm plantations are the biggest contributors to Indonesia's current economic development, including economic growth, income generation, poverty alleviation, and job creation. What is needed is a middle way that produces sustainable oil palm plantations, for example oil palm plantations on our degraded land that totals 30 million hectares (Austin *et al*. 2017), a reduced extensification, and an increased intensification. Education for palm oil farmers is needed to improve the quality of oil palm plantations and prevent further oil palm extensification.

Data released by the International Union for Conservation of Nature in December 2013 stated that Indonesia was ranked fourth among countries with the highest number of species threatened with extinction. According to this data, 1,206 of our species are at risk of extinction.

This condition needs to be responded to seriously. Biodiversity is at the core of ecosystems and natural balance, and is also a provider of human needs food, clothing, shelter, medicines, and more. Threats to biodiversity should be a topic to be discussed by all parties. Sustainable programs related to conservation must always be developed and include long-term programs. One way to reduce the adverse effects of deforestation is by reconnecting forests (Van Oosten 2013). This requires a fundamental understanding of forest connectivity and a minimum area of forest cover. The health of the forest and the various ecosystems within it (or those that depend on it) are prerequisites in creating a productive environment for agriculture and plantations. The irreplaceable and high-value forest ecosystem services need to be understood for successful long-term economic development.

Over-exploitation

When renewable resources are used to the point of no return, that's when what is called over-exploitation happens. The term is used whenever a population is utilized at an unsustainable rate due to a large difference between its reproductive capacity and its rate of utilization or its death.

It is true that all organisms need resources to live. Humans are no exception. In the past the human population was still relatively small, and the use of resources for survival was low. As the human population multiplies, the demand for resources, including the use of organisms, exceeds the limits for their survival. A growing market scale and easy access, as well as the development of resource utilization techniques, have contributed to worsening the situation. Threats to biodiversity, the extinction of a population and even an entire species, will be unavoidable if over-exploitation keeps continuing.

Over-exploitation occurs on land and at sea. On land, for example, there is excessive extraction of *kayu ulin*—often referred to as *bulian* or ironwood. This typical Kalimantan wood is very strong, so it is widely used as building material, such as for houses, bridges, and boats. The problem is, *ulin* grows very slowly. The average growth of ironwood is only 0.058 cm in diameter per year. Compare this with the average growth of the diameter of *meranti* trees, for example, which reaches about 1 cm per year, even 2 cm with special treatment. In addition to ironwood, *kayu gaharu* (agarwood) in Papua—which is used as an ingredient in making perfumes, cosmetics, and medicines—suffers a similar fate. There are many other species that are likewise being overexploited.

At sea, overexploitation can take the form of overfishing without regard to the ecological balance of the sea. Fishing in ways that are not environmentally friendly also damages the ecosystem. For example, the use of poisons and explosives can damage coral reefs, as well as the use of trawlers or a type of small hollow net that causes small fish that are still in the growing stage to die in it. Science is needed to understand more deeply the conservation biology of species on land and at sea in an effort to overcome this over-exploitation. No less important, is the necessity to strengthen research focused on over-exploitation, and the dissemination of its results widely to stakeholders, policy makers and the general public.

An Increasingly Polluted Environment

The increase in population and changes in land use related to human activities—such as settlements, agriculture, and industry—are common factors triggering environmental pollution in Indonesia. Land use changes and increased pollutant loads, including organic waste and sediments in rivers, cause pollution of land and sea waters.

In general, there are five types of pollutants that are often associated with human activities, namely sediments, heavy metals, fertilizers and pesticides, plastics, and organic waste (eutrophication). Severe pollution occurs in 75% of our rivers (Witono 2017). Based on the status of the quality of river water during the 2007-2014 period, rivers in 17 provinces have been heavily polluted, including most of the rivers in Java (BPS - Central Bureau of Statistics, 2017). Pollution in the Java Sea, for example, mostly comes from household and agricultural activities and industrial waste. Sedimentation and solid waste are the main sources of pollutants that hit the coastal areas. Land-based sources also play an important role there.

The Special Territory of Jakarta (DKI Jakarta) can be cited as an extreme example. This province started to be developed intensively in the 1970s, and it soon experienced rapid urbanization and growth. The population increased 93% during the 1971-2005 period, to 8.86 million people (BPS 2017). The continuous increase in population has an impact on changes in land use. Satellite images from 1971 and 2004 show about 80% of land use in the nation's capital has changed, from vegetation areas into urban areas. One example of the degree of pollution resulting from this can be seen in the five-fold increase in nitrate concentrations in the Jakarta Bay (Arifin 2005). Sedimentation in the same area increased non-stop, from the 1970s and 1980s, due to port dredging, sand exploration, and conversion of mangrove forests by land reclamation to become residential areas (UNESCO 2006). The burden of sediment that flushes from the rivers also changes the environment in estuaries and coastal areas, even affecting the coral reef ecosystem in the Kepulauan Seribu (Thousand Islands). In these islands, the area of coral cover which in the 1970s reached 70-80% shrunk drastically in 1995 to only 15-30% (UNESCO 2006).

Sources of pollution from industrial activities have contributed to worsening environmental problems in the Jakarta Bay. This can be seen from the concentration of metal chromium and zinc which had a 2 to 3-fold increase since 1965, whereas before 1960 they were considered stable (Schoemar & Wahyono 2007). An intensification pattern of chlorophyll-a concentration was found, similar to that found in coastal areas. Chlorophyll-a is a photosynthetic pigment whose existence is an indication of the phytoplankton biomass that converts inorganic substances into organic matter in aquatic ecosystems. The chlorophyll-a concentration indicates the extent to which Jakarta Bay has become a place for disposal of liquid waste, including household waste, industrial waste, agricultural waste, and urban runoff. Environmental pollution due to excessive use of fertilizers and pesticides in our agriculture also needs serious attention. It is estimated that approximately 69% of land in Indonesia is categorized as damaged due to excessive use of fertilizers and pesticides (FAO 2016). Many farmers in Indonesia apply fertilizers in large amounts to plants because they think that the more fertilizer used, the higher the yield from production. In fact what happens is that the land becomes damaged and human health is threatened.

A number of studies have shown that excessive use of fertilizers and pesticides is one of the triggering factors in the decline of insects—species with very important ecological functions—in many countries (Sanchez-Bayo & Wyckhuys 2019). Excessive use of fertilizers and pesticides also make the cost of rice production in Indonesia quite high. Based on FAO data (2017), the average cost of producing rice in Indonesia is IDR

Oceans of Plastics

Plastic waste confronts humans with complicated problems. But awareness of how serious this might be can only be raised by the realization about how plastic waste empties into its last dumping place: the sea. This is a big issue for the marine ecosystem.

In 2010, an estimated 275 million tons of plastic waste were produced in 192 coastal countries. 4.8 to 12.7 million tons of which ended in the sea. Indonesia is ranked second after China as the world's biggest producer of plastic waste. The marine plastic flakes Indonesia produces annually reach 0.48-1.29 million tons. In this ocean of plastics is hidden a great danger, namely microplastics in the food chain that are sure to return to humans, and the ability of plastics to absorb pollutants that will have an impact on food safety.

In these conditions it is important to have some kind of alarm, as a warning about how bad the sea pollution has become due to changes in water quality and changes in land use. This is when the Environmental Quality Index (IKLH, *Indeks Kualitas Lingkungan Hidup*) can be deployed. This index is a combination of three other indices, namely air quality, water quality, and forest cover. The Ministry of the Environment and Forestry has reported that Indonesia's overall IKLH in 2017 has increased to 66.46, which represents a fairly good number. However, the Jakarta Capital City index is 35.78, the nation's worst and in the "watch list" group category. In addition, the index for Yogyakarta is 49.80, so its condition is also very poor. Six other provinces fall into the fairly poor category, namely West Java (50.26), Banten (51.58), West Nusa Tenggara (56.99), East Java (57.46), Central Java (58.15), and Lampung (59.72) (KLHK 2018).

Indonesia needs to take strategic steps to tackle pollution. What must be done includes strengthening science in the field of biomaterials, to create materials to replace plastic, and in the field of bioremediation, to reduce the impact of biological resource-based pollution. But even more important is to change human behavior.

5,900 per kg, far above Vietnam which is only IDR 2,300 per kg, Australia IDR 1,800 per kg, and the United States, only IDR 900 per kg. The use of science and technology to support a soil improvement program by improving the biological characteristics of the soil is very urgent. Of course, serious efforts are also needed to enlighten and empower our farmers so that they can use fertilizers and pesticides more appropriately and wisely.

Bioremediation Science, Antidote to Pollution

Microbes are microscopic organisms, which cannot be seen with the naked eye, and they play an important role in carbon sequestration. In addition, they also play a significant role in central collective metabolic processes —including nitrogen fixation, methane metabolism, and sulphur metabolism—and in the control of global biogeochemical cycles.

Various types of microbes have the ability to recycle pollutants, such as certain bacteria, archaea, and fungi. In recycling, pollutants are broken down into harmless compounds. This natural process is known as bioremediation. The advantage of microbes is that their growth is very fast and can be manipulated, so that only desired traits are expressed. Bacteria, for example, have begun to be deployed to fertilize the soil in peat areas, so farmers do not need to burn the vegetation on that land and fires are avoided. There is still a lot of potential that can be gained from microbes. For example, microbes can be used as biological fertilizers and bioinsecticides, to prevent the contamination from chemicals that can be carried to other waters or environments and damage the balance of the ecosystem. What is needed to maximize this potential to better understanding of their basic properties.

Global Climate Change

Climate change is a threat to biodiversity. The cause of climate change in the modern era is global warming that is a consequence of an increased concentration of greenhouse gases in the atmosphere caused by human activities (IPCC 2013). In certain concentrations, greenhouse gases such as CO_2, H_2O, and methane, have supported the evolution of life on Earth. Without

Let's Clean Up the Sentiong River Using Microbes!

The government has begun to act to rehabilitate polluted rivers. An example is the initiative of the Ministry of Public Works and Public Housing (*Kementerian Pekerjaan Umum dan Perumahan Rakyat*, PUPR) which applies bioremediation technology by spreading microorganisms in the Kali Sentiong (Sentiong River)—also known as the Kali Item (Black River), Jakarta. Microorganisms are being used in bioremediation to reduce pollutants in the water, and they are working slowly to banish the unpleasant odor of Kali Sentiong.

Kali Sentiong produces unpleasant odors due to the presence of domestic waste containing organic compounds. Bioremediation utilizes biological processes to control such pollution. The microorganisms that were applied have three forms, namely solid, powder, and liquid which were applied in a number of different locations, on August 8-9, 2018.

Placement was done in stages. The first placement was of the solid form of microorganisms, as 500-600 bioblocks each weighing 2.5 kg, at the upstream part of the Sentiong River. The advantage of spreading this way is that the blocks decompose slowly so that the bacteria are released from the blocks for up to three months. However, once released into the water, the bacteria require an adaptation period of up to eight hours to become active.

The second application was in the form of powder. The third application was in the form of liquid. These microorganisms in powder and liquid form would start to work actively about one hour after scattering. The use of bioremediation is one of the options for environmentally friendly technologies that are clean, natural, and easily applied to improve water quality. Bioremediation can become part of the maintenance operations of water bodies, including rivers, reservoirs, dams, and lakes.

(Retold from https://bisnis.tempo.co/read/1116316/pupr-terapkanteknologi-bioremediasi-untuk-kali-item/full&view=ok)

greenhouse gases, Earth's average temperature would drop from 15°C average to minus 18°C, a drop of 33°C, which is not conducive to the lives of many organisms. Greenhouse gases are like a blanket that is transparent to incoming solar energy but that retains the heat. The rate of pumping CO_2 into the atmosphere since the industrialization era has increased faster than nature's ability to reabsorb it in the natural carbon cycle, thus causing warming rates that are harmful to the various species on Earth. The average global sea level temperatures have increased by 0.11°C per decade between 1971 and 2010 (IPCC 2013). The melting of the polar ice caps and a rising of sea levels of 2.8-3.6 mm/year (IPCC 2013) change the structure and distribution of coastal ecosystems, such as mangroves, seagrasses, and coral reefs.

The greenhouse gas blankets that originally made life comfortable on Earth are now too thick and backfire against biodiversity. The increase in the temperature of the Earth has great consequences, especially in the micro domain of biota on land and sea, whose tolerance range for changes in temperature is very small. This is especially true in tropical regions where the temperature range is relatively stable throughout the year. Rising sea surface temperatures can also cause vertical stratification of seawater layers, thus weakening the upwelling circulation that is instrumental in moving water masses from nutrient-rich layers to nutrient-poor layers. Indonesian waters have at least three seasonal upwelling locations (the east monsoon) namely the southern waters of Java to the Lesser Sunda Islands, Makassar, and the Banda Sea. A weakening of upwelling can reduce the supply of nutrients from the deep layers to the surface that supports the fisheries sector.

Climate change has a multi-dimensional impact. One is a change in wind patterns, which for example, can trigger changes in migration patterns of animals such as birds and the distribution of biomaterials, dust, and other nutrients. As a result, there has been a change in the distribution patterns of biota and vegetation on land and sea. Changes in wind patterns in the marine environment can cause changes in pelagic fish migration and marine biogeography at various spatial scales.

At sea, climate change causes the sea to become hot, acidic, and deoxygenated. Approximately 30% of the anthropogenic CO_2 emissions in the atmosphere are absorbed by the sea and cause a decrease in the pH of the sea known as ocean acidification. The potential impact of ocean acidification in Indonesia is very broad, and risks our position as the world's coral center, where coral and other calcareous marine biota form. In addition, rising sea temperatures increase oxygen solubility and the ocean can become deoxygenated. The increase in temperature can also reduce the concentration of chlorophyll-a in the sea, which has an impact on fish stocks in the sea. Chlorophyll-a is an indicator of primary productivity, the reduction of which will be felt up the food chain.

Climate reorganization encourages more frequent extreme weather and more intense tropical storms. Heat waves, both on land and at sea, are also increasingly common, with increasing intensity. In the last decade, heat waves have hit all the oceans of the world. In Indonesia, marine heatwaves hit the southern side of Indonesian waters in 2016, which caused massive coral death. Shifts in the rainy season can also cause the extinction of species, for instance those that have adapted their mating behavior to climate rhythms. In the long run, extreme weather and extreme climate can affect adaptation patterns or even lead to extinction. Ecological and material loss, and even loss of life underscore how climate change is a real threat, not only to biodiversity, but also to human survival.

All of these things, in the end, show that everyone must bear the risk of environmental damage. To have the ability to predict and overcome the effects of climate change on biodiversity, strengthening science is needed. Science is also needed to help understand the adaptation mechanisms of living things in the face of climate change, both temporally, spatially, and physiologically, at the individual, population, species, community, ecosystem, and biome level (Bellard 2012). Science and technology can help people determine policies objectively.

Invasive Alien Species

Invasive alien species pose a threat to biodiversity with serious ecological and economic impacts. The losses incurred can be very high.

Invasive alien species (IAS) are animals, plants or other organisms introduced by humans in areas outside their natural distribution. The presence of an IAS can change ecosystems, cause degradation and even habitat loss. The IAS can replace native species, change the structure of communities and the food chain, and even change fundamental processes, such as nutrient cycles and sedimentation (Molnar 2008). For Indonesia, which consists of several distinctive ecosystems, an IAS can not only originate from outside Indonesia's boundaries; it can also arise by moving from one ecosystem to another within our own nation —which is divided into western Indonesia (Sumatra, Kalimantan, Java, Bali), Wallacea Region and Papua.

In practice, the introduction of IAS can occur naturally or by interventions. Some introduction of IAS can occur through trade, domestic and international transportation, as well as cultivation. Since the beginning of human civilization, there have been various types of flora and fauna that entered Indonesia, which have been used as horticultural commodities, jewellery and pets. There are also species that entered Indonesia unintentionally because they were carried by trade goods or brought by visitors to Indonesia.

How many are the number of invasive species in Indonesia? In a LIPI (Indonesian Institute of Sciences) workshop in 2014 (Widjaja 2014), it was reported that there were 2,085 alien and/or invasive species. Of that number, 1,731 were alien species, 350 were invasive alien species, and the remaining four were of unknown status (Arida *et al*. 2014). The Global Invasive Species Database records only 179 invasive species in Indonesia, 72 of which are alien species. Based on the IAS list from the Ministry of the Environment and Forestry (2013), the IAS in Indonesia include 53 species in the agricultural sector, 99 species in the forestry sector, and 112 species in the maritime and fisheries sector.

The number of alien species is likely to continue to grow because many have only recently been reported. Based on the aforementioned LIPI Workshop in 2014, examples of invasive alien species in Indonesia include potato leafminers, *kutil dadap*, papaya white lice, and Japanese beetles. These have spread to several agricultural areas, in the highlands as well as the lowlands, and they are able to damage many kinds of vegetable crops.

A number of introduced alien fish have also threatened the populations of endemic or local fish (Wargasasmita 2005). For example, *mujair* fish (a type of tilapia fish) in the Selorejo Reservoir, East Java; *nila* (*Nile tilapia*) in Lake Laut Tawar, Aceh; *louhan* fish in Cirata Reservoir, West Java, and Kedungombo Reservoir, Central Java, as well as in ancient lakes such as Lake Matano and Lake Towuti in South Sulawesi. Other examples are the introduction of *oskar* fish in the Jatiluhur Reservoir, freshwater lobster in Lake Maninjau, West Sumatra, and carp in Lake Ayamaru, Papua. The introduction of new fish has been proven to exhaust native fish populations, such as *depik* fish in Lake Laut Tawar and rainbow fish (*ikan pelangi*) in Lake Ayamaru.

The way IAS disrupt and even destroy biodiversity is by forcing out the native species, preying on native species or transmitting diseases, so that the function and balance of the ecosystem is disrupted. IAS directly affect local biodiversity and they are one of the greatest threats to habitats and ecosystems (CBD 2002). Native or local species are often unable to compete, and may even become extinct. Systemic impacts on ecosystems are inevitable when species become extinct.

The problem is there is still very little understanding of IAS phenomena in various ecosystems, as well as the interaction of various species within an ecosystem. For this reason, there is generally zero anticipation of the adverse effects caused by IAS.

One of the IAS which has a very big effect on the biodiversity of natural fauna is the domestic cat, which is among the 100 worst IAS in the world (ISSG 2000). This is because cats are very generalist predators (they can prey on many types of fauna). Domestic cats have been observed preying on at least 248 distinct species, including mammals, birds, amphibians, reptiles, fish and invertebrates (Bonnaud *et al*. 2011). Predation by domestic cats can have a significant effect on native species compared to non-native species in a given region (Loss *et al*. 2013). The presence of cats greatly determines the decline in endemic fauna populations, especially mammals. It is responsible for at least 14% of the extinction of birds, mammals, and reptiles globally, and threatens at least 8% of critically endangered species (Medina *et al*. 2011).

Research on invasive microbes is still very limited compared to research on invasive flora and fauna. Invasive microbes, such as microscopic fungi, bacteria, and viruses, which also exist in many regions of the world and are generally pathogenic to other organisms, are more difficult to detect than higher organisms. Invasive microbes have a role in changing the balance of microbiome (entire population of microbes) in plant roots and also in the soil. The negative impacts happen directly on plants, even in certain agricultural areas (Coats & Rumpho 2014; Jacoby 2017). Good bacteria, which can increase the resistance of certain plants to drought, heat, and various diseases, can be adversely affected. Something similar can happen at sea, with adverse impacts on coral reefs and fish habitat.

Prevention of the entry of IAS must be carried out strategically, and it relies on fundamental knowledge about the processes or routes of IAS entry and their possible ecological and economic impacts. Cutting edge science and technology need to be developed to prevent and mitigate the impacts of IAS. One example is using acoustic and visual sensors to detect and monitor IAS, especially in remote areas (Juanes 2018). Early detection, however, is a far more efficient approach.

Threats to Health and Human Life

Damage to the environment and biodiversity due to uncontrolled population growth, over-exploitation by humans, and global climate change are all detrimental to human health and human life. Climate change, as well as the increase of chances of floods, landslides, and drought that damage sources of clean water and food, are real impacts of environmental damage that have the potential to threaten humans (Figure 4.1).

In vulnerable situations, possibilities for social conflict, forced displacement, changes in vector ecology, spread of infectious diseases, allergies, and mental disorders (related to natural disasters, conflicts, refugee status) may be inevitable. All of these can cause diseases, decreased productivity, decreased quality of life, even death. Many of the diseases caused by damage to the environment and to biodiversity are classified as chronic; thus the cost of medication and treatment would be very high.

In addition to causing the reduction or even extinction of sources of food and water, the destruction of biodiversity on land and in the ocean also eliminates the potential to develop medicines for human health. Many studies have stated that biodiversity on land and in the oceans of Indonesia has a high potential to become materials for new drugs, biomaterials and cosmetics (Chasanah 2013; Sukara 2014; Tapilatu 2015). Damaged and extinct biodiversity will hinder efforts to find new drugs, biomaterials, and cosmetics.

Another problem of environmental damage that may have the biggest impact to health is the opening up of possibilities for the spread of germs from animals to humans. This spread is known as zoonosis, which refers to a variety of infectious diseases caused by germs (bacteria, microscopic fungi, parasites, viruses) that affect humans directly or indirectly through infectious vectors from animals, especially from vertebrates (Donohoe 2013; Myers

2013). Zoonosis can trigger both the emergence of new diseases and the return of old diseases.

Forest destruction disturbs the habitat of many wild animals and forces them to approach and even enter areas of human settlement. This situation increases the chance of contact between wild animals and humans, and it increases the possibility of the transfer of germs from the body of wild animals into the body of humans, and vice versa. One of the functions of the forest is to serve as a buffer between wild animals and humans; this buffer is lost after deforestation, increasing the chance that zoonotic diseases will occur.

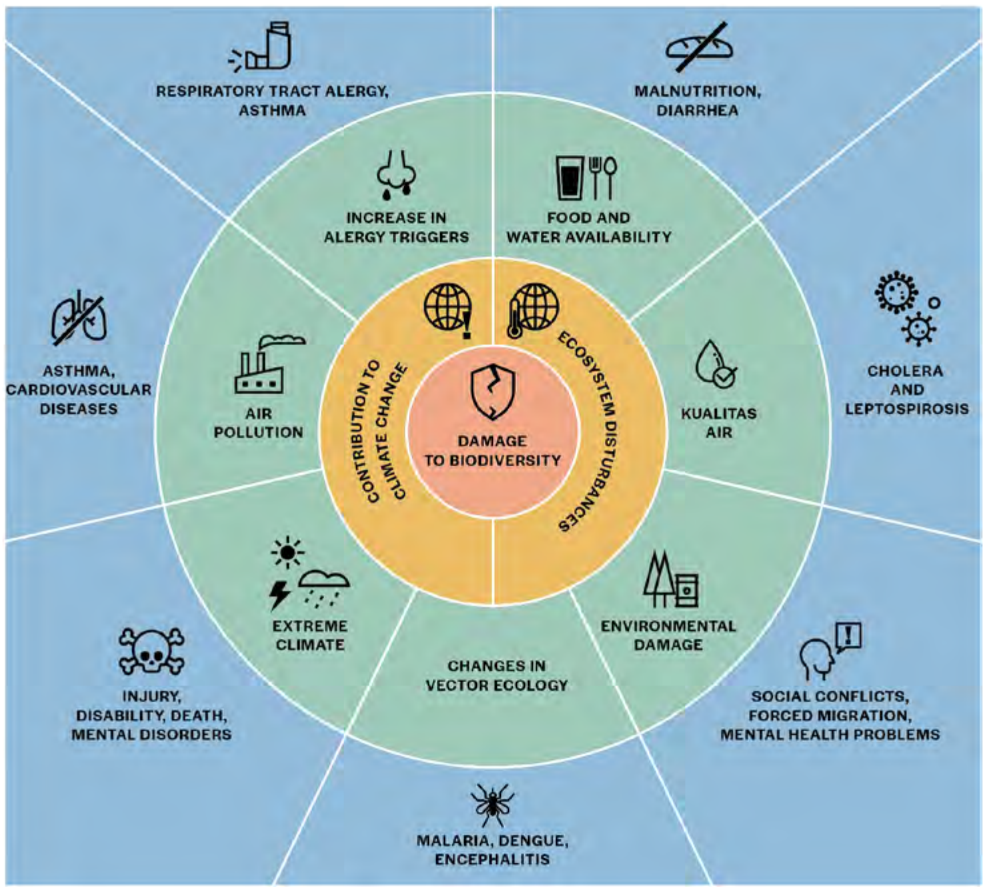


Figure 4.1 *The direct and indirect impacts of damage to biodiversity.*

One should also mention the potential of domesticated animals as a source for transmission of zoonotic diseases. Most of the viruses that cause new infectious diseases come from animals, where the high rate of mutation of viruses makes it easy for a virus to change so it can infect humans. An increased virulence, namely the ability of a pathogen to cause severe disease, accelerates subsequent human to human transmission. As has happened in other countries, in Indonesia, old zoonotic diseases such as leptospirosis, brucellosis, tuberculosis, taeniasis, anthrax, rabies, and toxoplasmosis, plus newer ones such as HIV, SARS (severe acute respiratory syndrome), avian flu, and MERS (Middle Eastern respiratory syndrome), have resulted in illness, disability, and a decreased economic productivity and quality of human life, even death (Myers 2013; Narrod 2012).

The spread of germs from animals to humans and from humans to humans has a strong possibility to increase. This is unavoidable not only due to worsening environmental damage, worsening global climate change, and the increase of globalization, but also because of increasingly high human mobility. Not surprisingly, some zoonotic diseases such as avian influenza, SARS, MERS, and HIV occur as worldwide epidemics, crossing national boundaries and becoming pandemic.

Zoonotic diseases are only a part of the diseases caused by environmental damage. Others that are very likely to arise due to floods, droughts, landslides, and other disasters are mental health diseases, such as anxiety and depression. Also unavoidable due to disasters related to ecological degradation and global warming are a decrease in the quality of life, disability, trauma, and even death (Case 2007; Measey 2010).

From floods and drought, side effects arise from a decrease in access to clean water. The consequence is an increase in waterborne infectious diseases, such as diarrhea, dysentery, cholera, typhoid fever, and leptospirosis.

Food availability and food security are also affected. Flooding and drought can cause damage to agricultural land and fisheries, as well as sickness, and even death, to fishermen and farmers. Declining productivity and the emergence of food insecurity can trigger or worsen malnutrition and infectious diseases.

Another type of disaster that is no less worrying, and has the same devastating consequences, is fire in forests and peatlands. The cause may be drought, or it may be human negligence. In addition to further damaging the environment, forest and peat fires spread smoke that has the potential to cause various respiratory and allergic diseases —even across national boundaries.

Children and the elderly are particularly susceptible to this risk.

Beyond all this, there are indirect impacts of climate change due to environmental damage, namely an increase in the spread of infectious diseases such as malaria and dengue fever through vectors. These and other diseases especially worsen the living conditions of people who are vulnerable due to poverty and who face limited access to basic needs such as clean water, food, health services, and proper education.

Biodiversity Conservation

A healthy ecosystem supports the continuation of civilization through the fulfillment of basic human needs. Healthy ecosystems and biodiversity provide a sufficient provision of clean air and water, production of food that is also healthy, and natural beauty. Conservation is not only necessary for animals or plants that are visible to the naked eye, but also for the microbes that can only be seen with the help of laboratory tools.

For human life and all living things on Earth to continue, the preservation of nature must be maintained. The necessities of life that are provided by economic activity have implications for the use of natural resources. This use requires wisdom and careful calculation, taking into account the ecological impacts and long-term economic losses. To this end, an absolute necessity is a comprehensive

and complete knowledge about important ecological areas, factoring in economic considerations and the function of these areas in regional or even national identity, both on land and at sea.

The discovery of a new orangutan species in Batang Toru, North Sumatra, provides an example. This species, which has gained world attention, exists in endangered conditions (Reese 2017). Yet at the Batang Toru River, the site of the discovery, a dam will be built to support the operation of a water-driven power plant. The problem is very clear: as currently planned, this dam in the primary forest will isolate the remaining orangutans there, with nothing to replace the ecosystem services performed by the forests and their biodiversity. The questions that must be answered are how to balance economic needs with the carrying capacity of nature. Can science can help to find a way out? Can the dam be constructed in such a way so that the link between forests and orangutan mobility can be maintained?

It must be kept in mind that biodiversity conservation efforts can not be done haphazardly. The following three basic principles should be used to guide decisions: (i) the effort is representative/ comprehensive, i.e. a protection of biodiversity that is not focused only on interesting things, but broadly represents biodiversity and involves all stakeholders, including governments, industry, and society; (ii) the effort is efficient and affordable; (iii) the effort is flexible; it can be modified according to the conditions of place, time, and the latest scientific and technological advances (Margules and Sarkar 2007).

Policies related to conservation at sea have also been implemented. These include Law Number 5/1990 (Law on Conservation), Law Number 31/2004 jo 45/2009 (Law on Fisheries), and Law Number 27/2007 and Law Number 1/2014 (Law on Management of Coastal Areas and Small Islands). However, the integration of policies and implementation of these policies need to be strengthened.

Local Wisdom and Biodiversity Maintenance

To be able to survive, indigenous peoples in various parts of the world generally are dependent on the natural environment. This closeness and dependency produce behaviors, habits, and a culture that respect nature and all its contents. This respect is manifest in that culture's knowledge, behavior, rituals, traditions and customary rules.

The respect for nature is often referred to as local wisdom. This wisdom can be physical, non-physical, literal, or symbolic. Local wisdom in protecting biodiversity and food providers is widely displayed by indigenous peoples who depend on natural resources on land and at sea for their lives (Kelbessa 2013).

In some areas in Bali, for example, a physical form of local wisdom in preserving nature and food sources is the tradition of maintaining terraced rice fields and the availability of buffer forests. Non-physical local wisdom includes the formulation of regulations on types of plants, water and planting cycles, to indigenous organizations that manage natural landscapes, as through a community organization called *subak*. A symbolic form of local wisdom takes the form of providing colored cloths for large trees that are considered sacred. This traditional symbol reminds people that these trees cannot be cut down carelessly. In addition, there are written rules (*awig-awig*) that contain the guidelines for behavior in society, including in interacting with different aspects of nature such as forests, with specific sanctions that are strictly applied (Karidewi *et al.* 2012).

Local knowledge for maintaining food resources in the forest can be witnessed in many other indigenous communities. The indigenous Baduy Dalam community in the Kanekes Village of Leuwidamar, Lebak, Banten, for example, is very serious in maintaining the balance of nature. The community has strict rules in determining forest boundaries, specifying which parts can be used for agriculture, which parts are protected, and which are strictly forbidden to be used, even just to be passed through (Iswandono *et al.* 2016). The Ammatoa indigenous people in Tana Toa Village, Kajang Subdistrict, Bulukumba District, South Sulawesi, have *pasang ri kajang* rules, concepts and ways of life that regulate, among others, how the community must wisely draw sufficient living resources from the forest, so that the lives of humans and forests are maintained (Hijjang 2014).

The Dayak Tunjung tribe in Linggang Melapeh Village, Linggang Bigung Subdistrict, West Kutai District, East Kalimantan, is different. They have a custom of shifting cultivation for 2-4 year periods, so that the land has a chance to recover. This kind of cultivation practice preserves the soil and allows the land to return to its former fertile condition. Through these and other means, the environment becomes sustainable in indigenous ways for indigenous peoples, something that is impossible if the forest is cleared (Siahaya *et al.* 2016).

The custom of planting and rotating various types of plants in gardens and fields, as carried out by many farming communities in different regions, shows conformity with the latest scientific findings on how to maintain the microbial balance and microbiome richness of the soil (Jacoby *et al.* 2017).

The *sasi* tradition in Maluku provides an example found among people whose lives depend on the sea. This tradition prohibits excessive fishing, taking *lola* shellfish, *batulaga* (a type of seashell/sea snail), or *japing* more than necessary. In *sasi*, people must not take sea products before the specified time. This is a cultural mechanism to give nature time to preserve itself so that it can provide food support to humans in a sustainable manner. Some indigenous peoples in Maluku, especially in Central Maluku, Kota Tual, Southeast Maluku and West Maluku, still practice *sasi* (Mony *et al.* in Armitage *et al.* 2017).

There are also local traditions such as *bau nyale* among the Sasak tribe in Lombok, namely various rituals performed once a year on several beaches in the area before catching sea worms. Both the activity of catching sea worms and the rituals that accompany them as a tribute to the marine environment have become an attraction for many tourists who visit Lombok. Such local traditions related to the marine environment have generated economic benefits both for the community and local government. Another use derived from local knowledge that has been carried out from generation to generation in various places in Indonesia is the use of natural dyes for Indonesian traditional textiles.

The cultural wisdom in the specific traditions of these communities is local. But all of them are based on the same basic principles, namely a respect for nature and conservation of biodiversity as a support of human life, including as a provider of food (Armitage *et al*. 2017; Kelbessa 2013; Kothari 2008). Increasing population, increasing human mobility, and increasing economic strength pose many challenges for the sustainability of local wisdom. Vanguard science is needed as a partner of local wisdom to support its existence and optimize its efforts to preserve biodiversity and the environment.

Local wisdom is a complex thing that has similarities and differences with science. One of the main differences is that local wisdom is context-bound so that it is not easily transferrable and generalized to other socio-cultural contexts. This characteristic should be taken into account if local wisdom is expected to be a "guardian" of biodiversity. In addition, it is necessary to recognize that local wisdom is not always sustainable or socially just, so we must not blindly idealize local wisdom without seeing it in a real context.

V

SCIENCE AND TECHNOLOGY AS THE VANGUARD OF INDONESIA'S BIODIVERSITY

The Nobel Prize for Medicine had "stopped by" in Indonesia in 1929. The prestigious world award was given to Christiaan Eijkman, a Dutch doctor and pathologist, for the discovery of vitamin B1 deficiency as the cause of beriberi. Although by that time Eijkman had returned to the Netherlands, the Nobel Prize that was awarded had been based on continuous research carried out for more than 25 years in the laboratory he had set up in Batavia (Jakarta). In this laboratory, Eijkman and his succsessors established the foundations of modern vitamin science. It later became known as the Eijkman Instituut, an it is now an institute for research on molecular biology and biotechnology—The Eijkman Institute for Molecular Biology.

Science and basic scientific research have indeed been strong enough to take root on the land of Indonesia. As for the discovery of the theory of evolution and the laying of the foundation of biogeography by Alfred Russel Wallace a century earlier, Indonesia's rich biodiversity inspired the birth of the science of vitamins. This science of vitamins then promoted the emergence of a vitamin industry which has very high economic value. Unfortunately, after the Eijkman era, Indonesia's social and political conditions caused us to lose a focus on strengthening science and technology.

Indonesia's rich biodiversity indeed offers many opportunities. Our megabiodiversity on land and sea is a significant comparative advantage that should provide the basic capital for developing Indonesia. The potential of our biological natural wealth is huge, and it can be exploited to support economic development.

Nature should be placed at the center of sustainable development efforts that are done in an inclusive way, involving all elements of society. New paradigms and appropriate strategies will be needed for managing and utilizing the wealth of biodiversity and its ecosystem through strong support from knowledge, science, and technology.

A good mastery of science and technology is absolutely necessary to utilize biodiversity appropriately. The Government's ability to determine priorities plays an important role. This chapter discusses the aspects of science and technology that will be needed for optimizing the management and use of Indonesia's megabiodiversity. The goal is to use biological resources for economic development through science and technological innovation, while building a strong scientific culture as part of the capital required for Indonesia to become a developed nation.

Science and Technology Priorities for Indonesia's Biodiversity

Indonesia actually has a range of choices to make biodiversity the spearhead of development. That choice is determined by our level of ambition in the effort to make Indonesia economically superior, while preserving nature and strengthening the science and technology relevant to biodiversity. The following three levels provide examples of choices, each of which has different consequences in terms of time, investment needs, knowledge created and the leverage for innovation and technological development. These range from a moderate level of ambition in the form of ecotourism development to a very high level of ambition, namely deep sea exploration (Figure 5.1).

	Ecotourism	Bioprospection	Deep Sea Exploration
Level of ambition	Moderate	High	Very high
Economic impacts	Large	Very big	Fundamental
Impact of science and technological development	Moderate	Very large—can take us to science and technological parity with the world	Fundamental

Figure 5.1 *Examples of national priorities, with their levels of ambition and impacts on the economy, as related to science and technology*

Science for Ecotourism and Conservation

The Indonesian government continues to promote efforts to conserve nature through the establishment of various conservation areas on land and at sea. The aim is of course to protect nature and the biodiversity in it, which also has an impact on human health and well-being. Creating an effective conservation area requires a design based on an analysis of alternative futures, taking into account the future development of the area, economic and social conditions, and biodiversity sustainability.

One of the strategies used to align efforts to conserve nature, conservation, and sustainable economic development is through an ecotourism approach. Ecotourism is a form of tourism that incorporates environmental insights and follows a number of rules regarding natural balance and nature conservation. According to the International Ecotourism Society, ecotourism is travel that is responsible to nature, that preserves the environment, sustains the lives of local people, and involves interpretation and education.

The education intended involves both staff and tourists. Ecotourism can prevent natural damage, such as deforestation (see Brandt and Buckey 2018). The development of an inclusive ecotourism that includes local communities can, for example, reduce illegal logging. Residents who had been cutting trees illegally can be trained and encouraged to switch professions to become tour guides or to conduct other economic activities that support tourism. Profits from this tourism can also be used to fund science that supports conservation.

Ideally, a conservation and ecotourism center needs continuous data intake as a basis for decision making. Therefore, the conservation and ecotourism center should be supported by science through ongoing strategic research. We can harness the rapid development of information and technology to strengthen conservation efforts by using the latest technology in conservation biology, data collection, analysis, and a modeling of big data that is dynamic and actual.

The uniqueness of Indonesia's biodiversity has inspired some of the world's major theories, namely the theory of evolution and the theory of biogeography and tropical botany. Our natural wealth and this history are two great potentials that should be combined in a natural historical tourism destination (eco-heritage tourism). Historical tourism that follows the footsteps of Alfred Russel Wallace and Rumphius, for example, will have a niche market of history-loving and science-loving tourists. The packaging of science tours to ancient rivers and lakes in South Sulawesi, to Wallace's trail in Ternate and the other points in Indonesia that Wallace once visited, or to the Rumphius trail in Ambon, etc. are all possibilities. We will need innovation in packaging Indonesia's tourism so that it can run sustainably and in harmony with efforts to preserve nature, while having a high economic value.

Science for Drug Discovery and Bioprospecting

"Natural products are an invaluable source of healing. Aspirin, for example, is derived from the bark of the willow tree, and the molecular basis of the anticancer chemotherapy agent, taxol, is derived from the bark of the pacific yew tree. Therefore, it makes sense to think that the contribution of ancient texts and the benefits of traditional medicine can really affect the health of modern society "—Brent Bauer, Mayo Clinic.

Nature with its plants, animals and microorganisms provides a library of millions of chemical compounds that can be used for the development of drugs. Humans have utilized the wealth of nature for medicinal ingredients since prehistoric times. The discovery of pollen deposits of 60,000 years ago at the Neanderthal burial sites in the Kurdistan region of Iraq shows that even these close relatives of modern humans knew the benefits of natural ingredients to cure various diseases (Solecki 1975).

One of the approaches being taken by world scientists today to overcome diseases such as malaria is to explore the potential of natural products (Mishra *et al*. 2017). Currently it is estimated that 25-50% of drugs on the market are sourced from natural ingredients. Natural ingredients remain the source that dominates the process of finding new drugs (Kingston 2011; Newman & Crag 2016). The dictionary of sources of natural products (DNP; http: // dnp.chemnetbase.com) lists more than 214,000 sources of natural products (Ji *et al*. 2009). The Institute of Market Research Consulting (MRC) states that the global herbal supplement market reached USD 49.1 billion in 2016 and is estimated to reach USD 86.7 billion in 2022. The magnitude of this economic opportunity opens a chance for Indonesia to compete in the global market. For this reason, human resources, facilities, funding and good national and international collaborations are needed. Some efforts have been initiated by industrial laboratories in Indonesia, such as the Dexa Laboratories of Biomolecular Sciences, Dexa Medica.

Medicines sourced from natural ingredients, organic drugs, have been generated through a long process of natural selection acing on the biological community that forms it. Plants, animals, and microorganisms live in a biological community where they interact with each other, assembling a variety of active ingredients that affect other organisms and help to create an ecological balance. The more varied the biological community, the greater the variety of potential bioactive substances that can provide candidates for drug ingredients. The active ingredients produced by one organism to fight other organisms can synergistically affect the biological processes of the surrounding species. Many active chemicals from plants have evolved to fortify themselves against plant-eating animals, for example. Humans process and utilize these active chemicals—such as in laxatives, cardiotonic drugs, and muscle relaxants (Ji *et al*. 2009).

The search for drugs from nature: the meeting between traditional knowledge and modern science

Our biological wealth is a potential economic resource for the discovery of drugs and cosmetic materials or biomaterials, for example for prosthetics. Indonesia's natural wealth contains more than 10% of the world's plants, thousands of them used for the treatment of diseases. Of these, around 900 had been studied for drugs by 2001 (Timmermans 2001).

In the midst of the challenges from the resistance of a number of infectious disease agents, as well as the attacks of various other diseases, efforts to search for drugs from Indonesia's natural environment represents a strategic investment. We can derive inspriration from the experience of China in the effort to find new anti-malarial drugs, which began by digging into ancient manuscripts and later resulted in the awarding of the Nobel Prize to Tu Youyou.

Indonesia can compete with China in having the treasures of ancient herbs. Ever since the 11th century when large kingdoms were thriving in the archipelago, Indonesia has produced a number of ancient writings in lontar palm-leaf manuscripts and books. And during the Dutch East India Company (VOC) era, Rumphius wrote *Herbarium Amboinense* that documented the properties of nearly 1,200 native species of the archipelago, published in 1741. The Rumphius documentation has been the basis for exploration of medicinal ingredients by researchers at the Mayo Clinic, United States. They took the initiative to explore ancient medical writings and history and to then employ scientific verification methods, for example to confirm the antibacterial properties of atun tree extracts that can control diarrhea-causing bacteria. Rumphius had described the efficacy of *atun* trees in his writings more than three and a half centuries ago. This work is being updated by reference to the history of medicine and ancient manuscripts, in order to aid current efforts to discover drugs.

"Our findings show that potential medicines can be identified by searches in ancient writings on herbs. Although we will never know the exact disease that was treated with the kernel of the *atun* tree, this kernel was described almost 400 years ago as a treatment for symptoms that are treated today with modern antibiotics. The current literature does not describe the use of atun trees to treat diseases similar to dysentery. By searching in historical texts for herbal medicines, we have identified potential new medicines with antibacterial properties and have restored lost knowledge about traditional medicine." (Buenz *et al*. 2006).

Now, more than three and a half centuries after the Rumphius' documentation, our nation has not yet made significant use of these initial directions. In the meantime

the rate of extinctions in the natural world increases, whether due to human activity or natural factors. The Indonesian government needs to invest strategically and more aggressively to explore this potential for the welfare of the nation and of humankind.

Jacobus Bontius, a pioneering doctor of tropical medicine in Batavia, was impressed by traditional medicine in the Dutch East Indies. He documented it in his four-volume book, *De medicina Indorum* and *Historiae naturalis et medicae Indiae orientalis*. Likewise, there are a number of ancient manuscripts from several ethnic groups in Indonesia, such as the *Lontara Pabbura* (Bugis) and *Usada Buda Kecapi* (Bali). There are also at least eight known ancient manuscripts on traditional medicines and herbs written in Sundanese, Javanese, Balinese, and Malay (Nawangningrum 2004). All of these documents can provide clues for an initiative to search for drugs strategically and systematically using a modern scientific approach. This search will also require a fundamental understanding of our megadiversity and its supporting ecosystems.

Bioprospecting

Bioprospecting is the search for, and development of new sources of medicines or other economically valuable products derived from bioactive substances of plants, animals and microorganisms. This activity involves the exploration of biodiversity for biological resources that have social and economic value to various industries, especially the pharmaceutical industry (Beattie *et al*. 2005). Interest in bioprospecting has increased as the demand for new drugs has risen to replace drugs that are available on the market.

Bacterial resistance to antibiotics is now one of the main problems in the fight against communicable diseases and in providing medical care globally. The World Health Organization (WHO) states that antibiotic resistance is one of the biggest threats to global health, food security, and development. In 2017, WHO published a global priority list of 12 antibiotic resistant bacteria. More and more diseases have evolved to become resistant to existing drugs. This condition creates a need to have a new drug supply. Through bioprospection, this need for new drugs can be met.

Whether bioprospecting activities are based on knowledge of traditional medicines or not, the development of modern medicine from natural ingredients requires the identification of useful compounds or active substances among millions of other molecules. This process can be accelerated by using a high-power mass screening approach. In the past decade, the number of molecules identified using high throughput screening has increased rapidly, as reported in the scientific literature. The biggest challenge now is to identify those targets with the greatest potential for obtaining prospective drugs (AIPI 2016).

The development of science and technology has made it possible to produce chemically synthesized drugs that are inspired by active agents found in nature by imitating their biochemical and chemical properties. Various popular drug candidates, such as capsaicin and curcumin, have come from an increased focus of research on naturally sourced agents (Ji *et al*. 2009; Ji & Zhang 2008; Corson & Crews 2007).

Genomics, metagenomics, and microbiomes

The field of genomics has developed quite rapidly since DNA sequencing technology has become much faster and the price more affordable. In the 1990s, determining the entire sequence of human genes (the human genome) required USD 3 billion in funding and more than a decade to complete the project. At present, sequencing of a human genome can be done for USD 1,000 or around IDR 15 million. In the future, the price is expected to be reduced even further to one tenth, by a gene sequencing process that takes less than an hour (Check-Hayden 2014).

This and other technological developments have helped scientists to examine biodiversity in more detail. With remote sensing and computing technology, scientists can make various observations on the scale of big data. And the combined technological breakthroughs in molecular biology, genetics, and informatics that underlie the field of genomics have enabled scientists to observe biodiversity in the form of genetic content from the individual level, even the single cell level, to the population level.

This development has triggered a boom in the field of bioinformatics that utilizes advances in computational technology and quantitative-mathematical-statistical approaches to process genome data that continues to flood from many species of organisms. The data that is produced is very diverse, containing various series and information on the interactions of molecules in organisms. There are more and more parameters that can be used to measure the diversity of organisms based on our knowledge of increasingly comprehensive characteristics.

With cheaper and easier genome sequencing, the ability to characterize genomes at the population level also begins to develop rapidly. Metagenomics is the analysis of genome content of organisms recovered directly from the environment, mapped according to where they are located in the population on an ecological scale. Metagenomics makes it possible to map biodiversity at the level of the dynamic interaction of a collection of organisms in their environment in order to understand how this interaction can affect the balance of the ecosystem. For example, there has been rapid development in the mapping of the microbial genomes in microbial ecological communities, such as those that live in the human body, in the soil, in the body of plants, and in marine ecological microbes (National Research Council 2007; Thomas *et al*. 2012). Metagenomics also allows bioprospection of potentially useful microbial genes from nature without the need to grow the organisms that contain these genes in culture.

The development of metagenomics for understanding the biodiversity of the microorganisms that grow in or on the human body is one of the potential applicative breakthroughs in the health sector currently being explored. Microbes that are in the body, especially in the digestive tract, apparently play an important role in determining one's health status. The collection of microorganisms in the body—known as the human microbiome—is even considered as the second genome of humans. Research shows that our microbiomes are as complex and perhaps nearly as influential as our own genomes, and that they have a share in causing various syndromes or diseases, such as obesity, diabetes, heart disease, and mental disorders.

The largest microbial community in the human body lives in the gut, which can contain more than 1,000 species of intestinal microbes (Wang *et al*. 2015). Food and genetic background interact with the microbes that live in our body in determining our health. The human microbiome has an important role in protecting the human body from disease-carrying microbial attacks, modulating the immune system, regulating metabolism, and even functioning collectively as an organ of hormone production. With more than 100 million nerve cells located in the gut that interact with its microbial community, microbes may even affect the way that we think (Hadhazy 2010).

Research on the microbes in our body reveals a close relationship between the composition of microbial types in the gut with mental health, with changes in the ecological community of the intestinal microbiome being associated with various neuropsychiatric diseases, such as autism and schizophrenia, in addition to immune disorders in the body (Dickerson *et al*. 2017). Thus it is hoped that increased knowledge about our microbial biodiversity will both aid efforts to improve health and lead to new biomedical innovations. The diversity of Indonesian culinary cultures will influence the human microbiome among Indonesian people, making our nation an ideal human laboratory for understanding the interaction of eating patterns with microbiomes. For example, how does the habit of fasting on Mondays and Thursdays or *mutih* practices in Javanese tradition affect the microbiome population?

Social and economic challenges in drug discovery and bioprospection

Bioprospecting is indeed very important, but it must be regulated so that we can avoid over-exploitation of natural resources, while also rewarding local knowledge. Local communities where natural resources are found must benefit economically, as well as participate actively, so that the environment is maintained.

Ideally, well-managed bioprospecting projects not only provide income for the indigenous peoples where the natural resources are located, but also incentivize efforts to preserve the natural ecology that holds them. In this way, we can have sustainable resources that promote the common good (Timmermans 2001).

Science for Deep Sea Exploration: Life in Extreme Environments

The original Snellius Expedition (1929-1930) during the era of the Dutch East Indies government and Snellius Expedition II (1989) have succeeded in mapping the topography of our seabed, particularly in Eastern Indonesia. Based on these expeditions, we know that the area between the Sunda Shelf and Sahul Shelf is a deep sea, including around the islands of Sulawesi, Halmahera, Seram, Buru, Aru, and the row of the Lesser Sunda Islands. There are at least 26 basins and troughs, the deepest being the Weber Trench with a depth of 7,440 meters.

An interesting and ironic scientific fact is that the deep sea holds great mysteries, apparently being far stranger to us than outer space, located thousands of kilometers from the Earth. Scientists have far better knowledge about the surface of Mars or the moon than about the deep sea. Deep sea exploration is still very limited; as a result, humans know only about 1% of the total wealth of organisms that live in the dark of the ocean.

Scientists do not fully understand what animals and organisms can survive in the extremely deep ocean environments—with super-thin oxygen levels, extra-low temperatures, extreme deadly pressure, high salt levels, high acidity, silence, and no light. Although the sea is eternally dark, one can still find many types of organisms, including fish.

A discovery causing much excitement is an ancient fish that was thought to be extinct, the Coelacanth (*Laminaria chalumnae*) in the Sulawesi Sea. This fish can live to a depth of 700 meters below sea level. How is this organism able to adapt to these extreme environments? Can the abilities to adapt shown by the organisms that live on the seabed help humans better understand the mechanisms of adaptation? Knowledge about life in the deep sea can give birth to new technological and industrial innovations never dreamed of previously. As an analogy, consider how knowledge about DNA polymerase enzymes gave rise to the Polymerase Chain Reaction (PCR) technology central to the extraordinary biotechnology industry.

Indonesia is located at the meeting of the Eurasian, Indo-Australian, Pacific and Philippine plates. This creates many hydrothermal fissures and several underwater volcanoes. With the existence of anaerobic deep-sea organisms that can live without light, and that are also strongly influenced by toxic hydrogen sulfate and high salt content, an understanding of the ecosystem around hydrothermal vents should provide a great deal of information about the process of adaptation to life in extreme conditions. However, only a few observations have thus far been made about this and its uses for human life.

The presence of sea mountains is also very promising for science because of the process of circulation and turbulence around them. This condition is very supportive of life and makes it rich in species of macrofauna. Exploration of the biological resources around sea mountains is very expensive and requires high technology. However, with new technological advances, the results are very promising, equivalent to the progress made when humans decided to visit the moon.

There are other potential advantages to be derived from the deep sea, such as oil and gas, electrical energy sources through Ocean Thermal Energy Conversion/OTEC, mineral reserves such as gold, tin, future mineral water reserves, and high-quality salt production. All of this is beneficial for the future economic development of the Indonesian people. But we should be careful in its management and not let the exploitation of the sea destroy nature, as has happened on land.

Developing Science and Technology to Support Indonesia's Biodiversity

Indonesia's deep sea contains enormous biological and non-biological resources. However, the lack of information and the lack of development of marine science makes developing its potential quite limited. How can we develop the ability to harness the economic potential of the deep sea?

A number of fundamental aspects will require more general support for the development of vanguard science and technology related to biodiversity and its potential for economic innovation. These include bioenergy, the potential of microbes, learning from nature through biomimicry, big data, and the strengthening of national specimen banks.

Science for Bioenergy

The environmental pollution and health threats due to burning of fossil fuels, plus a reduction in fossil energy sources accompanied by high energy needs, encourage alternative renewable energy sources that are environmentally friendly and economical. The increase in carbon dioxide (CO_2) since the Industrial Revolution is due mainly to the burning of fossil fuels (65%) and a change in land use (deforestation, 11%) (IPCC 2014). This increase of CO_2 in the atmosphere causes global warming and climate change, which threaten life on Earth. The solution is to use fuels that do not produce CO_2 emissions, and reforestation.

The geographical position and natural conditions of Indonesia are rich in the potential for producing various types of clean and renewable energy—including solar energy, wind energy, geothermal energy, and bioenergy. Bioenergy is an energy source derived from biological products, both from waste and from other sustainable biological sources such as biomass, biodiesel, bioethanol, and biogas. Bioenergy development must consider respect for natural habitat and the biodiversity within it, including the welfare of animals, land use that does not compete with or threaten food production, local use with minimal transportation, and avoiding an adverse affect on air quality.

Ideally, we need bioenergy sources that do not produce CO_2 emissions. The only type of microbes that can produce clean energy, forming waste products in the form of water and oxygen gas, are the cyanobacteria (also called blue-green algae, or microalgae) that produce energy through photosynthesis. Microalgae are an ideal source of renewable energy because some types of these cells can use water and abundant sunlight to produce oxygen and hydrogen gas (H_2), and their growth is fast. The hydrogen can be captured and used as an energy source to produce electricity with high efficiency. There is minimum pollution because the wastes produced are harmless. The utilization of microalgae is a positive climate action when used to produces carbon-neutral bio fuels such as bioH_2, biogas, bioethanol, biodiesel, and bio-oil in an efficient way that does not compete with food (Chen *et al*. 2017, Dwi Susilaningsih *et al*. 2004, Hadiyanto *et al*. 2012). However, the development of microalgae as a large-scale energy source remains confronted by a number of problems, such as a low efficiency of biomass conversion, invasion of microorganisms from outside the area, and expensive and limited nutrients needed for cultivation. One strategic solution is to combine biofuel production with waste treatment.

The development of microalgae-based technologies with photosynthetic systems that are carbon-neutral will play a significant role in future CO_2 mitigation strategies (Chen *et al*. 2017). It would require approximately 1% of global sea surface (2.3 times the size of Tasmania or 3.1 times the land area of the United Kingdom) to replace 19% of the world's current consumption of fossil fuels (Sakurai *et al*. 2015). But with engineering technology, limited land for cultivation can be overcome. Microalgae that can grow in various types of ecosystems, including in extreme ecosystems and in ecosystems with high salt levels are an advantage.

The development of bioenergy in Indonesia can reduce our dependence on imported fuel oil, support a better climate, and utilize waste, including oil palm waste. Biomass energy can be developed to meet the needs of local areas for energy self-sufficiency by utilizing organic waste. However, its use on a large scale requires large amounts of organic material and large tracts of land, which can cause deforestation. Indonesia has a great opportunity to develop clean bioenergy from microalgae.

The urgency for the need of renewable alternative energy that is environmentally friendly is a task that must be tackled in a substantial way. Energy is a primary need and a dependence on fossil fuels can lead to both economic and environmental crises, with associated impacts such as political turmoil and even war. Therefore, now is the time for Indonesia to aggressively take strategic steps to develop renewable clean energy sources. In COP21 (the 21st Session of the Conference of the Parties, Paris, 2015), the participating countries such as the United Kingdom and China (Chen *et al*. 2017) have made a commitment to significantly reduce their CO_2 emissions. Indonesia, which has the fourth largest population in the world, is also determined to contribute to the reduction of CO_2 emissions significantly.

Exploring the Economic Potential of Microbes

"Life would not long remain possible in the absence of microbes."—Louis Pasteur

Pasteur's statement clearly illustrates the vital role of microbes in sustaining human life. Microbes include bacteria, microscopic fungi, viruses, archeaes, and microalgae. Multi-celled living things, also known as macroorganisms, like humans, could theoretically live without the presence of microbes. But are they able to survive in a sterile space free of microbes? Bacteria, for example, are estimated to be five million trillion trillion on planet Earth (number five with 30 zeros behind it!) (Whitman *et al*. 1998). A fantastic number! With such abundance and diversity, microbes play a critical role in maintaining the balance of the Earth's ecosystem.

The influence of microbes on the biosphere is vital. They have a fundamental role in ecological processes, forming a major part of biogeochemical cycles, and are present across the planet, including in extreme environments. Microbes also play an important role in the food chain, in maintaining vital relationships among themselves and with multicellular organisms (Hunter-Cevera 1998), in breaking down rubbish and waste, in maintaining soil fertility, and in cleaning up oil spills offshore (bioremediation). Microbes are found everywhere, from frozen environments and acid lakes, to hydrothermal vents at the bottom of the deepest ocean; they are also found at atmospheric heights, at ocean depths, and in the human intestines.

The Indonesian inventory of microbes began in the Dutch East Indies era by a botanist named Melchior Treub (1851-1910), who also served for 30 years as Director of the Land's Plantentuin or Bogor Botanical Gardens. At that time, scientists from all over the world, especially from Europe, carried out research in Treub's laboratory on the biodiversity of the tropical Indies, including microbial diversity. Five decades later in 1959, this research activity was reopened with government support. President Sukarno's support for basic research at that time was quite significant, making it possible to reactivate microbial research. Since then the efforts of Indonesian researchers, especially at LIPI, have continued to grow. One of their most important achievements has been the establishment of a center for Indonesian culture collections called the Indonesian Culture Collection (InaCC), which was recognized by the World Federation of Culture Collection/WFCC (Sukara & Lisdiyanti 2016).

The potential of microbes including bacteria, fungi, and viruses in the archipelago to support a sustainable economy has not been much explored. There are still very many microorganisms that have not been identified and even more whose functions have not yet been understood. It is estimated that no more than 10% of microbial species are known, depending on the type of habitat studied. Our microbe-collecting activities are still mostly at the level of identification and characterization. The discovery of various new microbial species, even new genera of important microbial taxa continue to be reported by Indonesian scientists. We are most concerned about a minority of microbes that are pathogenic and dangerous to humans, whereas the majority of microbes are commensal and non-pathogenic, including those living in the human body. Are we able to utilize the diversity of microbes to improve the degree of human health and environmental health of Indonesia?

The diversity of microbes with their potential use is an asset that is often overlooked. For the sustainable use of microbes, a valuation of genetic resources is needed, including the cost of not only getting them from nature but also maintaining them. The cost for a line of microorganisms in Germany reaches 10,754 euros versus 5,042 euros in India (Overmann 2015).

The discovery of the PET (polyethylene terephthalate) plastic eating bacteria, *Ideonella sakaiensis*, in waste piles in Japan in 2016 is a significant achievement for the PET plastic recycling effort (Yoshida *et al*. 2016). A key enzyme can degrade plastics in a matter of days, instead of the hundreds of years for natural processes (Joo *et al*. 2018; Liu *et al*. 2018; Austin *et al*. 2018). The bioremediation of the Sentiong River with bacteria is another important example. The potential of microbes to change the structure of peat land so that it is no longer easily flammable also requires fundamental scientific research, giving hope that peat fires will no longer cause economic and environmental losses and threats to health.

The discovery of the key Taq polymerase enzymes used in DNA sequencing, derived from the heat resistant *Thermophilus aquaticus* microbes in extreme environments, has driven the high-economy industry of biotechnology and diagnostic medicine. Continuous and directed fundamental research to explore other bacterial properties can help to answer many future challenges and generate innovations.

The soil microbiome community provides vital services to key ecosystems that are fundamental to life on Earth, including the carbon and nutrient cycles and sustaining plant growth (Jansonn and Hormockel 2018). Advances in genome sequencing technology have mapped the genomes of various soil microbial populations and predicted their function (metagenomics). However, the biggest challenge is how to understand the function of various genes from these microbes in real conditions, no longer at the predictive level, which is known as metaphenomics. The existence of a variety of potentially beneficial soil microbes is threatened by soil degradation, poor soil management and utilization practices, and climate change (Jansonn and Hormockel 2018). It is important to know how microbes work in nature and understand their fundamental properties so that they can provide optimal benefits.

Microbes also play an important role in food preservation, both directly through the fermentation process, as well as by producing enzymes from microbes for the fermentation of food products. Food industry needs for enzymes are increasing while availability is very limited. In 2020, the world's demand for industrially used enzymes is estimated to reach USD 6 billion or around IDR 91.3 trillion. Nearly half are from the food and beverages industry (Miguel *et al*. 2013). The role of microbes is very large as producers of fermentation enzymes. The microbial diversity in ecosystems can provide a real opportunity to meet the needs of the food industry for the enzymes. Microorganisms can also be utilized in healthy products. Bacteria and fungi, for example, can provide benefits to food production, such as with probiotics and dietary fiber. Indonesia with a tropical climate has an abundance of microbes on land, sea and in extreme environments. A basic understanding of the nature and capabilities of these microbes through basic research can help find solutions to a variety of challenges, from counteracting oil spill pollution and plastic waste pollution to maintaining food security.

Biomimicry: The Whole Universe is Our Teacher —Nature's Inspiration for Technological Innovation

Nature runs on sunlight
Nature uses only the energy it needs
Nature fits form to function
Nature recycles everything
Nature rewards cooperation
Nature banks on diversity
Nature demands local expertise
Nature curbs excesses from within
Nature taps the power of limits
(Janine M. Benyus, *Biomimicry*, 1998)

Nature in itself always offers solutions to various challenges and limitations faced by humans. The physical challenges we face—the limitations of food, water, space, and shelter—are challenges that other creatures on Earth face as well. Microbes, animals and plants do what is necessary to survive, but they do it without causing damage, without petroleum that pollutes, without producing pollution, let alone by mortgaging the future of the next generation. All human innovations are available in nature in a more elegant form without damaging the Earth.

The human desire to be able to fly like a bird has led to the creation of airplanes. The sketches of the flying machine by Leonardo da Vinci (1452-1519) provides clear evidence of how humans were inspired by nature, even though the da Vinci engine had not succeeded in flying. Four centuries later, the Wright brothers (1867-1948) carefully observed the wings of an eagle and made an airplane that could allow humans to fly for the first time in 1903. Now in the next century, aircrafts can fly much faster, more stable, and more aerodynamically. Otto Schmitt was the first person to introduce the term biomimetics in 1957, as an intersection of biology and technology. Another similar term, bionics, was introduced by Jack E. Steele, a NASA scientist, in 1960. Janine M. Benyus introduced the term biomimicry in his book *Biomimicry* (1998), as a new approach to technological development that is inspired by nature. Benyus later became one of the founders of Biomimicry 3.8, a media for exchanging biomimicry ideas and concepts as well as building communication and interdisciplinary cooperation among scientists, researchers, engineers, business people, and stakeholders (Choi *et al*. 2015). Biomimicry is a directed effort to uncover the mystery of life in nature, how nature works, and then to use that inspiration for technological innovation.

Biomimicry seeks to understand the basic mechanism of nature from the macroscopic and microscopic levels to nano levels, then to adapt it as a source of inspiration for the development of science and technology. Questions from natural phenomena await answers. How do dragonflies fly better than the best maneuvers of helicopters created by humans? How do Colibri birds (hummingbirds) cross the Gulf of Mexico with less than one tenth of an ounce of fuel? How do ants carry their cargo across the forest in the hot sun?

The Industrial Revolution has brought rapid progress to humanity, extended human life, and overcome various threats of diseases. But the increase in population and life expectancy of humans also requires the fulfillment of basic needs that lead to the exploitation of nature. We have taken from nature beyond nature's capacity to replace it. This is exacerbated even more by human behavior that is unfriendly to nature.

An approach that focuses on meeting human needs and human intelligence without regard to nature has brought us to the end point of the Earth's tolerance. Environmental damage due to pollution, deforestation, overexploitation, and increase in global temperatures stare before our eyes and threaten our survival. The use and mass production of plastics far exceed the ability of nature to break them down, causing pollution that threatens life on land and at sea. Microplastics are also suspected to have entered the food chain, which can have human health consequences that we do not yet understand. This is the other side of technology that we don't want.

Many discoveries based on learning from nature have brought progress to humanity. The painless syringe created in Osaka, Japan, was inspired by the mouth structure of a blood-sucking mosquito which causes minimal nerve irritation; anti-glare was inspired by the ability of the nanostructure of the moth's eye to deflect light; insect eyes have inspired increased coverage of the camera lens; and the stickiness of shells on the rocks on beaches has inspired the discovery of a new way of sewing surgical wounds. From the African savannah, a six-meter high termite nest inspired architect Mike Pearce to build the Eastgate Center in Zimbabwe, the world's first building to use a natural cooling system (see

Hunter 2017).

The biomimicry revolution uses an approach focused on what can be learned from nature, not on what can be extracted from nature and is exploitative. The main message of biomimicry is how to create various products that follow the workings of nature more closely, and that can be decomposed after use. The threat of extinction of various species makes the natural approach through biomimicry urgent, since our making use of nature rests on biodiversity.

Biomimicry is the future of technological innovation. In Europe, Japan and the United States, interest in biomimicry is increasing rapidly, including in investments for research funding. BIOKON in Germany is a organization for biomimetic study that consists of 38 research centers. The UK has established the Biomimetics Network for Industrial Sustainability (BIONIS), a network that connects the business world to universities.

New York has established the New York State Energy Research and Development Authority (NYSERDA), which uses a biomimicry approach in finding solutions to various energy problems. Many technology companies are working with scientists to set up and design laboratories for the exploration of new technology. How can Indonesia with its mega diversity derive inspiration from its own natural environment for the benefit of the world?

Big Data for Indonesia's Biodiversity

Biodiversity science, like other branches of science, has entered the information age. The progress of this branch of science today is determined by its ability to collect, analyze and model large amounts of data called "big data". In addition to the large amount, the types of data collected and analyzed are usually varied and dynamic, involving many interactions in real time. Thus, the data modeling carried out should not only be descriptive in nature, which is useful as a reference; it also should have explanatory and predictive capabilities.

The explanations generated through such analyses of big data will generate new theories in biodiversity science. And the ability to make predictions will be very helpful for formulation of policies, including those for sustainable conservation, the use of biodiversity as a resource, and the invention of new technologies that utilize biodiversity sources.

In the development of science, the emergence of a scientific revolution usually begins with new observations. The ability to make observations in turn expands with technological advances, and these have enhanced the ability of scientists to observe large-scale biodiversity.

Large Scale Data Collection

Data collection activities in biodiversity science have long been dominated by field work, which requires scientists to be physically present in the habitats that are the objects of the research. With advances in technology, such as the ability to automate mapping through sensor innovation plus computional data processing, the number and diversity of biodiversity data have increased. This computational automation has greatly improved our ability to make observations on a large scale.

Advances in sensor technology have enabled scientists to automate observation and data collection by computer. Large-scale sensors, also known as Earth observation systems, utilize satellites (for example, Landsat, Sentinel) or camera observation platforms that are spread across various ecological localities (O'Connor *et al*. 2015; Skidmore *et al*. 2015). Biodiversity variables can be measured and monitored by various sensing techniques, such as hyperspectrum sensing that captures different frequencies of electromagnetic waves. From this spectrum we can identify various types of matter, objects, and vegetation. In addition, a Lidar scanner utilizes a laser to measure distances with high precision, combining it with a Geographic Information System so as to provide comprehensive spatial data in a three-dimensional format.

Advances in information and sensing technology for large-scale biodiversity data collection and monitoring system bring both own opportunities and challenges. One of the challenges is to analyze the huge amount of data that has been collected, especially data that requires human interpretation. A scarcity of scientists and professionals makes it difficult to monitor and analyze large-scale biodiversity variables with high resolution, especially since the biodiversity data is complex and very broad in scale.

Data modeling: integration

The big challenge in biodiversity science is to understand how various species can live together, interact with each other and live sustainably, influencing each other in an ecosystem space that is constantly undergoing dynamic evolutionary changes. The challenges in preserving and utilizing biodiversity are not only to maintain the diversity of existing species, but also to understand how the various species can live in an ecosystem in a balanced, adaptable, evolved way —especially in relation to human activities. Moreover, human life is becoming increasingly dense with increasingly complex and mounting needs.

The era of big data and the capabilities of computational technology and quantitative science provide opportunities for interventions and the implementation of innovative applications based on Indonesia's Biodiversity. The technological advances enable the integration of multidimensional components of scientific observation with the history of local wisdom, socio-cultural factors and conditions, as well as economic and governance policies. The goal is to meet the needs of a human civilization that continues to grow and change but remain in harmony with nature.

Artificial intelligence and citizen science

The challenges of the big data era have triggered the development of artificial intelligence: a computational algorithm technology that combines human observation with computational automation technology to process large scale data. The artificial intelligence algorithm starts from the human evaluation of the data processed in a statistical quantitative algorithm to determine meaningful patterns. With the increase in data supported by human observation that can be entered in an algorithm, it is expected that artificial intelligence can perform data observations and determine large-scale data patterns automatically.

An increasingly cheap and easy operation of technology, including sensor technology and information technology, provides ordinary people with the opportunity to engage in scientific activities. That is why what is known as "citizen science" (Pocock *et al*. 2017) has developed. Citizen science includes broad public involvement in the process of data collection and analysis, a process that used to be carried out collaboratively only by professional scientists.

The use of the term citizen science was first recorded in 1989. At that time 225 volunteers throughout the United States collected rain samples to help the Audubon society produce an awareness-raising campaign about acid rain (Kerson 1989). Volunteers collected samples, checked their acidity, and reported back to the organization. The information was then used to explain the phenomenon as a whole.

In the past four decades, citizen science has developed rapidly. Citizen science can be carried out by individuals, teams or volunteer networks, including partnering with professional scientists to achieve common goals. Large volunteer networks often allow scientists to complete projects that would be too expensive or time-consuming if carried out through traditional research (Silvertown 2009). Citizen science has reached a modern form in terms of access and scale of public participation. Although projects vary in the degree of collaboration between researchers and volunteers, in most projects volunteers receive training in project procedures to ensure consistency of data collection and accuracy in data analysis. If prepared carefully, citizen science can provide a breakthrough in the collection of the data and knowledge of Indonesian biodiversity that exists across our nation in the form of local wisdom in our various communities.

For example, the Global Biodiversity Information Facility (GBIF) provides access to information on world biodiversity data, including Indonesia, openly (Dooley 2002).

This digital archive has established a system to gain access to biodiversity data from various research institutions, including observations from citizen science activities. At present there are hundreds of millions of useful data, including for monitoring invasive species, modeling the effects of climate change on biodiversity, identifying areas that need to be protected, and evaluating the effectiveness of conservation programs. A number of publications document the results of citizen science actions, and they offer strategies to link research findings with management and policy making in different contexts.

Citizen science and artificial intelligence innovation are two breakthroughs of the big data era that are expected to allow more efficient tracking, data collection and biodiversity mapping through large-scale observation automation. This includes the development of software applications, such as Zooniverse, a citizen-science web portal that hosts various projects in the fields of astronomy, cell biology, humanities, ecology, and climate science. In addition, there is also the iNaturalist platform designed in 2008 by the California Academy of Sciences (Matchar 2017). iNaturalist is a platform that uses an artificial intelligence approach based on visual computing technology to automate mass observations. Merlin BirdID, designed by Cornell University, uses artificial intelligence to identify more than 750 species of birds through users' answers to a number of simple questions, including the size and color of birds seen. There is also Pl@ntNet, a similar platform to identify plants based on the type of their fruit, flowers, and other parameters (Matchar 2017).

A recent example of citizen science in the field of public health is the Eliminate Dengue Project (EDP) carried out by Gadjah Mada University, Yogyakarta, to combat dengue by releasing mosquitoes containing *Wolbachia*, a bacterium that inhibits the proliferation of dengue virus in the body of *Aedes aegypti* mosquitoes (Anders *et al*. 2018). EDP involved the citizens of Yogyakarta widely by distributing buckets containing *Aedes aegypti* mosquito eggs to be released by residents in their neighborhoods. The EDP team then collected data on fevers in these areas in collaboration with health cadres and community health centers. The aim is to assess the impact of releasing mosquitoes that contain the *Wolbachia* bacteria, as part of a global movement to eliminate dengue fever.

Biodiversity Education Through Citizen Science

Many citizen science projects have educational and socialization objectives (Osborn 2005; Brossard *et al*. 2005; Bauer *et al*. 2000). Some are designed for use in formal classes or for informal education in places like museums. The latest citizen science projects place an increased emphasis on scientific practices, with measurable goals for public education (Bonney *et al*. 2009).

The citizen science movement has achieved remarkable results for both science and education. In recent years, more than one hundred articles have been published in the scientific literature that analyze and draw significant conclusions from data collected by volunteers. Many articles and reports describing learning outcomes for participants have also been published.

Citizen science projects can have a very good impact on science education in general and on Indonesia's biodiversity science in particular. Citizen science projects can increase the participants' understanding of scientific content and their scientific capacity to deal with science issues. Citizen science projects can also complement the laboratories for science classes in Indonesia, which tend to be minimal, due for example to a lack of adequate laboratories or mentors.

For Indonesia's biodiversity science, citizen science will be able to provide a great deal of biodiversity data that previously could not be obtained because of excessive costs if done by scientists through traditional scientific research. Citizen science, for example, can document changes in plant and animal populations or variations in air and water quality. One example of a successful citizen science project is Lifepatch in Yogyakarta, through which city residents analyzed the contamination of Escherichia coli bacteria in rivers that crossed their settlements.

Designing citizen science projects is certainly not a simple process. The initiators of citizen science must be able to ensure that the project will be meaningful to all participants, that data is collected accurately and analyzed thoroughly, and that the results are widely communicated to participants and to the scientific community. This requires careful planning. But if citizen science activities can be carried out on a large scale, then Indonesian biodiversity science will experience an unprecedented rapid development.

Science for Understanding, Adapting to, and Mitigating Climate Change

The international climate change science strategy produced by the Intergovernmental Panel on Climate Change (IPCC) rests on three aspects, namely (i) understanding climate science, (ii) adapting to the effects of climate change, and (iii) mitigating greenhouse gas concentrations.

Science is needed to understand the status of climate change, the role of humans, and to make future projections through synergies between observational data, paleoclimatology, and models. The complexity of climate dynamics and oceanography in Indonesia's maritime regions requires representative observational data. For example, the rate of ocean warming and ocean acidification at upwelling locations will be different from those at other locations. Climate is weather on a long spatial and temporal scale, so understanding climate change and its human contribution requires at least several decades of data. Because such data are rarely available, studies of past climates (paleoclimates)—obtained by reading the natural archives in corals, sea sediments, and tree rings—are part of the required climate data.

Obtaining more observation and paleoclimate data will allow scientists to predict future climate change more accurately from climate models. In addition, observational data for items such as marine nutrients and pH can enhance Indonesia's role in achieving the UN Sustainable Development Goals, namely SDG 14.1 and 14.3.

Adaptation to the impacts of climate change on biodiversity will require an understanding of biota responses to multi-stressors. On land, climate change brings changes in temperature and rainfall. At sea, the combination of warming, acidification, deoxygenation and nutrients provides a complex response. Understanding the responses of the biota to climate change involves experimental studies, in situ and through modeling. Indonesia's biodiversity also has the potential to mitigate the effects of climate change; for example seagrasses can regulate the acidity of the surrounding ocean.

Such environmental services will need to be improved to minimize the impact of climate change.

Scientists have recommend a variety of natural solutions to mitigate climate change, with the greatest impact of these solutions coming from reforestation efforts and the prevention of forest conversion (Griscom *et al*. 2017). Holding the rate of global warming below 2°C is only likely to be achieved if these natural solutions can be implemented in a cost-effective manner, since geoengineering solutions have not shown optimal results. Commitment to achieving this target ultimately requires a global solution. The IPCC explained that suppressing the rate of warming in accordance with the Paris Agreement to 1.5°C above pre-industrial levels could save more than 10 million humans from the effects of rising sea levels, compared to 2°C (IPCC 2018). Every degree of temperature increase that can be suppressed will have a wide impact on life on Earth.

Documenting the Indonesia's Biodiversity Specimens: Provisions for Future Learning

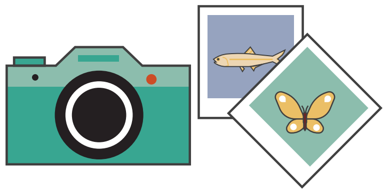
The Indonesian government ratified the Nagoya Protocol in 2013. This international agreement regulates the protection of biodiversity wealth and guarantees the distribution of benefits to the owners of genetic resources, such as Indonesia.

The high biodiversity in Indonesia is not well documented. Biodiversity exploration requires a lot of time, energy and funds, and the storage of specimens obtained from exploration is necessary. The Biodiversity Specimen Bank is a functional specimen bank that is used to collect, prepare, store and supply specimens for various scientific activities, such as actual and retrospective surveillance (Odsjo 2006).

Indonesia has three specimen storage areas, namely the Indonesian Culture Collection (InaCC), the Herbarium Bogoriense, and the Bogoriense Zoologicum Museum, all of which are located in Bogor, West Java. InaCC is a national depository center for microorganisms, such as bacteria, microscopic fungi, archaea, algae, mold, yeast, actinomycetes, and bacteriophages. At present InaCC stores 2,800 lines identified and characterized according to the World Federation of Culture Collection (WFCC) guidelines. The Herbarium Bogoriense, which was founded in 1841, has collected 900 thousand plants. The Zoologicum Bogoriense Museum, 22 years younger, currently has 3 million specimens in its collection. In addition, we also have the largest collection of wood in the world, with 185,647 specimens stored in Xylarium Bogoriense, Bogor.

Storing live microbial specimens can bring benefits in terms of economic and scientific development, including greatly increasing the efficiency of research time. Users, namely scientists and industries, can easily obtain the required microorganisms without the need to travel back into the forest to isolate them in nature. Such organisms registered

for patents can be an advantage for inventors, institutions and users. All documented organisms can be easily accessed by all domestic and international communities.
The challenge in managing Indonesian biodiversity specimens is to collect all of the specimens that have been studied by researchers from various institutions and universities, especially from research funded by the government. Another challenge is informing all stakeholders, especially scientists and industries, regarding the existence of specimen banks and their regulations. There is a need for strong national facilities with specimen storage and utilization systems that can be easily accessed.



VI

STRATEGIC POLICY: MAINSTREAMING SCIENCE FOR INDONESIA'S BIODIVERSITY

Science for biodiversity is the main tool for the efforts to maintain and optimize the benefits of biodiversity. Mainstreaming it is a must.

Indonesia has a great opportunity to take advantage of its megadiversity, making it the main driver of Indonesia's economic development. In Indonesia's natural environment there are many opportunities with high potential in the field of ecotourism, bioprospecting for drugs and energy, and in the deep sea. The wealth of megabiodiversity provides a basic capital to make the transition from an economy based on natural resources (natural resources-based economy) to an economy that relies on knowledge (knowledge-based economy). But this will require high-quality human resources and the creation of new knowledge. The exclusion of science and technology from national policies for decades has caused Indonesia to lag behind, even though efforts to catch up have begun to be carried out intensively in recent years.

Our megabiodiversity can be a stepping stone for making Indonesia a developed country. But it will require a strong national commitment and strong political support to make science and technology the key player in innovative economic development. A number of empowering efforts and new breakthroughs with long-term vision in the field of science and technology infrastructure must be accomplished. These efforts include establishing a new autonomous, permanent research funding system, strengthening innovative basic research in various tertiary institutions through the development of research universities, strengthening international cooperation, and removing various regulatory obstacles that currently hinder the progress of science and technology. In short, mainstreaming of science for biodiversity is needed.

Indonesia's Policy in the Efforts to Mainstreaming Biodiversity

Efforts to mainstream science for biodiversity into public policy began in the early 1990s, through the preparation, adoption and publication of the Indonesian Biodiversity Action Plan, IBAP). This was converted to Indonesian Biodiversity Strategy and Action Plan/IBSAP) in 2003, in order to give a greater role to the regions, in accordance with the Law on Regional Autonomy. In 2015, this strategy and action plan was again updated to IBSAP 2015-2020. But until 2019, IBSAP 2015-2020 did not yet have a strong legal basis, nor it did have clear technical guidelines to enable its implementation, and had not become a reference for researches related to biodiversity.

The momentum to integrate IBSAP 2015-2020 into the planning and activities of all development sectors came from the Sustainable Development Goals (SDGs) agreed upon by 193 countries on October 21, 2015 as a joint development ambition for 2030. This sustainable development agenda for the benefit of humanity and of planet Earth has 17 goals and 169 measurable achievements, designed to answer the demands for confronting poverty, inequality and climate change through concrete actions. The SDGs set targets that can be applied universally and can be measured in balancing the three dimensions of sustainable development—namely social, economic, and environmental.

With this sustainable development approach, the mindset for mainstreaming policies related to all human activities towards biodiversity, both positive and negative, needs to be changed from a triple bottom line approach to a nested logic approach (see Figure 6.1)

Mainstreaming Biodiversity in Public Policy

Indonesia was one of the first countries to draw up a biodiversity action plan. This Indonesian Biodiversity Action Plan (IBAP) was adopted in 1991 and published in 1993. In 2014, Indonesia also endorsed the United Nations Convention on Biological Diversity (UNCBD) in the form of Law Number 5 of 1994. However, the commitment needed to implement these laws is still lacking. The Action Plan also tends to focus on conservation of protected areas and species conservation, and only a few action plans relate to other aspects of biodiversity management.

In 2001, the Indonesian government decided to review the successes and weaknesses of IBAP and evaluate the effectiveness of our national policies and institutional conditions for biodiversity conservation. The government tried to identify barriers to biodiversity protection and options for conservation and define strategies appropriate to the new social and economic realities facing Indonesia. In 2003, the Indonesian Biodiversity Strategy and Action Plan (IBSAP) was developed. IBSAP 2003 made important changes in the form of providing wider opportunities for stakeholder participation and greater responsibility for biodiversity management at the provincial and community levels. In addition, the Law on Regional Autonomy and Decentralization in 1999 also gave the provincial and district governments roles, tasks and responsibilities in the planning, implementation and management of natural resources. Under this law, the management and conservation of biodiversity is very dependent on the seriousness of the local governments. In a later development, Law Number 23 of 2014 concerning Regional Government withdrew some of the responsibilities of the districts, and it now assigns the management of forests to the provinces.

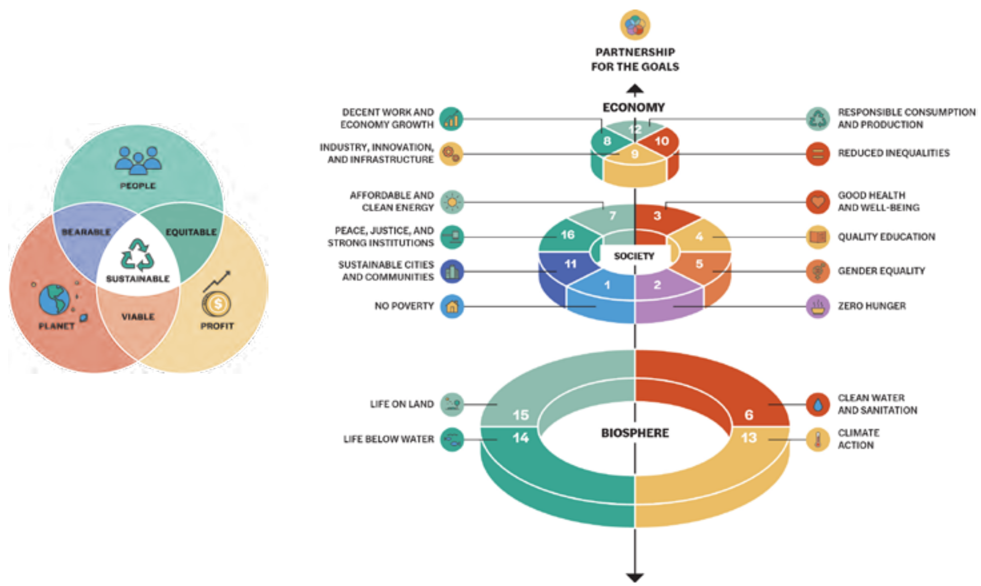
Subsequently on 22 April 2015, Indonesia introduced a new and revised Indonesian Biodiversity Strategy and Action Plan or IBSAP 2015-2020. The Indonesian government has also designed a five-year sectoral strategy (2015-2019) with a priority for reforming forest management, conserving biodiversity, and strengthening the rights of local communities who depend on forests and law enforcement.

The Nagoya Protocol on access to genetic resources and the fair and equitable sharing of benefits also has a strong legal basis through Law No. 11 of 2013 concerning the Ratification of the Nagoya Protocol on Access to Genetic Resources and the Fair and Equitable Sharing of Benefits Arising from their Utilization to the Convention on Biological Diversity.

IBSAP 2015-2020 contains a national strategy and action plan for managing Indonesia's biodiversity that covers aspects relevant to biodiversity issues and national development priority agenda for the next few years. IBSAP 2015-2020 is intended for all stakeholders so that it can be a guide for policy formulation, conservation planning and utilization in the field of biodiversity, as well as being a reference for the implementation of programs and activities in other development fields, both in the government, private sector, and civil society organizations at the central and regional level.

IBSAP 2015-2020 does not yet have a strong legal basis nor clear technical instructions for its implementation. It has not become a national guideline for managing biodiversity, in as much as Rencana Induk Riset Nasional (RIRN, the National Research Master Plan that should support biodiversity research) does not use IBSAP 2015-2020 as a reference. This is counterproductive. For comparison, the Strategic Plan for Biodiversity 2011-2020 and the Aichi Biodiversity Targets have been adopted under the Convention on Biological Diversity (CBD), which has been accepted as a global framework for the preparation of priority actions related to biodiversity.

A "triple bottom line" approach dichotomously puts economic and ecological interests in conflict, while a nested logic approach sees the need for a balance between economic and ecological interests. Although findings in the field of sustainability science increasingly show strong relationships between social, economic, and environmental dimensions, in practice, our development paradigm continues to view these three dimensions separately (Figure 6.1-a). As a result, short-term economic growth is maximized with the impact on biodiversity and the environment neglected. To implement IBSAP 2015-2020 and achieve the SDG's target by 2030, an approach that moves towards nested logic is needed, as illustrated by Figure 6.1-b.



(a) (b)

Figure 6.1 *Changes in management patterns from triple bottom line (a) to nested logic (b)*

Although the triple bottom line concept considers aspects of economic benefits, environmental quality, and social justice (Elkington 1998), with the three circles representing social, economic, and environmental dimensions interconnected through layers, they are essentially separate. The nested logic approach reflects the realization

that economics and society are part of the biosphere (Folke *et al*. 2016, Rockström & Sukhdev 2016). Therefore, socio-economic growth must grow within the limits of the ability of the biosphere to accommodate it. A loss of biodiversity will reduce the integrity of the biosphere, resulting in the biosphere being unable to provide ecosystem services. The economy is part of the society, and both are part of the biosphere. In other words, meeting economic and social needs can only be done within the limits of planet Earth.

The nested logic approach will also enable the achievement of the Aichi Biodiversity Targets, which are global targets to reduce the rate of biodiversity loss agreed upon by 196 countries. The Aichi Biodiversity Targets, which contain 20 biodiversity targets announced in 2010, are those agreed by the states at the 10th Conference of the Parties (CoP) Convention on Biological Diversity held in Nagoya, Aichi Prefecture, Japan. Among these targets are that, by 2020 at the latest, the community will be aware of the value of biodiversity and take steps to conserve and use biodiversity sustainably.

Evidence-based Policy

Mainstreaming biodiversity into policy is closely related to the formulation and implementation of evidence-based policies. There are many examples of the importance of evidence-based policies relating to biodiversity conservation. For example, the main drivers of mangrove deforestation in the last decade in Southeast Asia, including Indonesia, are aquaculture and rice cultivation, as well as oil palm plantations (Richards & Friess 2015). Mangroves offer a number of ecosystem services, including their important role in long-term carbon storage that is useful for mitigating climate change (Murdiyarso *et al.* 2015). These types of scientific finding can be the basis for public policies formulated and undertaken with respect to land use.

Another example is the development of a remote sampling analysis method to accommodate data from camera traps (Howe *et al*. 2017) allows the analysis of changes in the number of species. With a combination of satellite and terrestrial data, researchers succeeded in mapping several indicators for distribution of monkeys, including zones of human activity (Bush *et al*. 2017). Such mapping can reveal the responses of species to environmental changes, both those that occur naturally and those that occur after human intervention, which can then be considered by relevant policy makers.

The examples above illustrate evidence-based policies for specific and sectoral contexts.

In the context of cross-sectoral national development planning, the Indonesian government has explored the use of evidence-based policy for the formulation of a medium-term development plan (RPJMN) 2020-2024. This effort is a partial realization of regulations that require development planning documents for the Strategic Environmental Assessment (KLHS). For the first time in Indonesia's history, policy interventions in various fields of development for the RPJMN will be tested against the supporting capacity and carrying capacity of the environment and resources, including the supporting capacity and carrying capacity of biodiversity. This effort will of course depend on the availability and quality of biodiversity data and science, both at the national level and at the ecoregional level throughout the country.

Indonesia is Heading towards One Biodiversity Database

Satu Data Indonesia (One Data Indonesia) is an Indonesian government initiative to improve the interoperability and use of government data. Utilization of government data is not limited to internal use between agencies, but also for meeting the community's need for public data. Through One Data, the Indonesian government supports and makes a full effort to reform Indonesian government data. The data is being made available in an open and easy-to-use format with the aim of increasing government transparency and accountability, while increasing community participation in monitoring development.

Indonesia's biodiversity database integrated in One Data will be a major breakthrough in biodiversity management. At present, the initial biodiversity data used in IBSAP 2015-2020 is data on flora, fauna, and microbial types originating from the Pusat Penelitian Biologi, LIPI (Indonesian Biodiversity Information System/IBIS). This data is then combined with data from overseas herbaria and museums, as well as other data from the Global Biodiversity Information Facility (GBIF), the National Herbarium of the Netherlands (NHN), and the Fish Database. But there are many more biodiversity data that are not recorded in IBSAP 2015-2020. For microbes, for example, there are at least 16 Indonesian microbial culture collections in addition to the LIPI microbial collection at InaCC, namely the Balitvet Culture Collection, Biofarma Culture Collection, Biogen Culture Collection, BPPT Culture Collection, and ITB Culture Collection. If this biodiversity data can be incorporated, especially if combined with economic utilization data and local wisdom related to biodiversity, then the One Data on Indonesian biodiversity will become major capital for the sustainable development of the nation. With the right policies and management, Indonesia's biodiversity, which has long been a comparative advantage for the Indonesian people, can gradually become a unique, national competitive advantage.

Sustainable Funding for Science for Indonesia's Biodiversity

In terms of funding, it is necessary to distinguish between funding for biodiversity conservation and funding for science for biodiversity, even though science for biodiversity in the form of research activities can be an element of biodiversity conservation activities. This is where there are many challenges. In general, the information and analysis for both biodiversity conservation funding and funding for science of biodiversity in Indonesia are inadequate. Even at the global level, the financial costs needed to stop the pace of biodiversity extinction and to maintain important biodiversity sites, are not yet known with certainty, although efforts to estimate these financial costs have begun.

Indonesia's Policy in Financing Environmental and Biodiversity Conservation

For the Indonesian context, a preliminary study on public sector funding for the environment found that spending in the environmental sector was mostly not for environmentally-related activities, and that funding for many environmentally-related activities was found in other sectors (Vincent *et al*. 2002). This study also showed that, compared to ASEAN countries that were also experiencing the economic crisis of 1998, Indonesia's expenditure on the environment had fallen far more steeply, both in terms of budget size and proportion to GDP.

A more recent study has examined biodiversity financing using non-government financing data, specifically loans/debts and grants (Ekayana 2017). The funding came from multilateral and bilateral donor agencies plus other institutions outside this category. From 2006 to 2016, the Indonesian government had received a total loan/debt of USD 252.8 million and a grant totaling of USD 43 million to finance projects related to biodiversity. This shows that loans/debt constitute the largest share of our non-government financing (85%). See table 6.1 for further details.

Multilateral loans were the largest type of loan, followed by bilateral and commercial loans which proportionately were not very different. Funding in the form of grants came from bilateral and multilateral schemes, as well as from corporations and NGOs. Most of the financing, both debts and grants, were related to the management and maintenance of biodiversity. Funding related to biodiversity research and science—especially that in the IBSAP action plan for research, data management, and biodiversity documentation—was very limited.

In countries such as Thailand and Malaysia, public expenditure on the environment is structured into four expenditure groups, namely environmental quality control, pollution control, natural resource management, and environmental research projects (Vincent *et al*. 2002). In general, this same structure applies to the public financing system in Indonesia, including for research related to biodiversity conservation, especially terrestrial biodiversity research.

The government prepared IBSAP 2015-2020 to fund various biodiversity activities, and it proposed three steps for funding biodiversity. First, should be guided by IBSAP 2015-2020 and action plans. Second, the development of mechanisms, criteria and indicators of cooperation for activities and funding; and third, the establishment of biodiversity financing institutions. While Government Regulation No. 46 of 2017 concerning Economic Instruments for the Environment provides an important regulatory framework for biodiversity financing measures, the operationalization of further steps is needed for funding science for Indonesia's biodiversity.

LOANS

NOMINAL

USD 252.80 MILLION

PERCENTAGE

85.45%

Multilateral

NOMINAL **USD 98.01 Million**

PERCENTAGE **38.77%**

LOAN PROVIDERS

Asian Development Bank; IBRD; IDA

ADB loans to the Ministry of Maritime Affairs and Fisheries (*Kementerian Kelautan dan Perikanan* -KKP) of USD 27.7 million (realized value) for the Coral Reef Rehabilitation and Management Program -Coral Triangle Initiative (COREMAP-CTI) project and USD 20.4 million (realized value) for the Sustainable Aquaculture Development for Food Security and Poverty Reduction project.

Bilateral

NOMINAL **USD 84.01 Million**

PERCENTAGE **33.23%**

LOAN PROVIDERS

Agence Francaise de Development (AFD) France; Spanish Government; United States Government

A number of projects in the Ministry of Maritime Affairs and Fisheries and the Ministry of the Environment and Forestry for financing biodiversity are financed by bilateral loans from AFD, the Spanish Government and the US Department of the Treasury.

Commercial

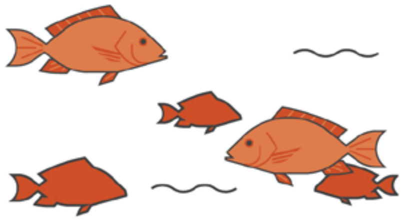
NOMINAL **USD 70.78 Million**

PERSENTASE **27.99%**

LOAN PROVIDERS

Deutsche Bank Madrid; Natexis Banques; PT BNI-Singapore

Marine aquaculture in Batam, training in fisheries development, and the Fishery Inspection Boat System (SKIPI) are examples of projects with commercial financing.



GRANTS

NOMINAL

USD 43.03 MILLION

PERCENTAGE

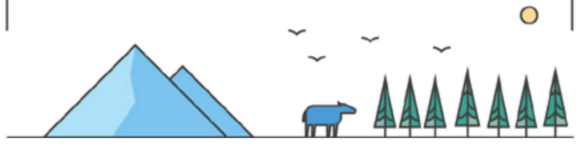
14.55%

Bilateral & Multilateral

GRANTS PROVIDERS

ACIAR, GIZ, KfW, ADB, ITTO, UN Institutions, etc.

For different time periods, bilateral grants from various institutions (USD 43 million realized) for the management and use of biodiversity: The Australian Center for International Agricultural Research (ACIAR) provides a grant of USD 0.78 million to develop biodiversity benefits; a grant from Gesellschaft fur Internationale Zusammenarbeit (GIZ) provides up to USD 6.62 million; bilateral grant from Kreditanstalt fur Wiederaufbau (KfW) for the Gunung Leuser ecosystem recovery program worth up to USD 7.10 million; Multilateral grants worth USD 24.72 million come from various institutions such as ADB, ITTO, and UN Agencies.



Corporations

GRANTS PROVIDERS

Sumitomo, Japan

KLHK (*Ministry of the Environment and Forestry*) received a corporate grant of USD 0.59 million for the maintenance and management of the Mount Bromo National Park.

NGOs

GRANTS PROVIDERS

Yayasan Kehati, TNC, WRI, WWF, etc.

Yayasan KEHATI (Indonesian Biodiversity Foundation) in the amount of IDR 91 billion for all action plans in IBSAP (2014-2015); The Nature Conservancy Indonesia (TNC) of IDR 243 billion (2012-2015) for forestry, marine and fisheries sector programs; World Resources Institute (WRI) Indonesia supports research, data management and documentation of biodiversity, and capacity building for biodiversity management, particularly in relation to forest and landscape restoration (2015-2017); World Wildlife Fund (WWF) supports all action plans listed in IBSAP (2015-2016).

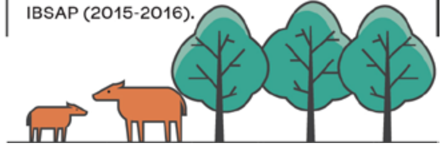


***Table 6.1** Non-government expenditure (loans and grants) relating to biodiversity, 2006-2016*

Source: Excerpted from Ekayana (2017) with the data from Ministry of Finance. Table by S. Mumbunan.

Funding for Science for Indonesia's Biodiversity

To create a strong Indonesian economy that relies on biodiversity science, one of the fundamental needs that requires a major breakthrough and strong political support is investment in a new financial investment infrastructure. This should take the form of an autonomous, sustainable and flexible research funding system in the state budget cycle, one that enables multi-year research grants to fund strategic, vanguard scientific research. Outstanding basic research creates new knowledge that can drive the growth of innovative industries. In addition to a low amount of investment of government funds in research, the absence of a good national funding system is a main cause of the low productivity of Indonesian scientists, both in terms of the number and quality of publications as well as patents (Brodjonegoro & Greene 2012). Indonesian scientists are shackled by a bureaucratization of science that inhibits their creativity, because any grant funds they receive are managed through a complex system that damages the Indonesian scientists who have the potential to contribute substantively to the creation of knowledge for an innovative economy.

Although there have been a number of improvements recently, a major breakthrough is still needed so that Indonesian scientists can stand at the same level as world scientists, which is needed to build our confidence as a dignified nation. This basic need has been ignored for much too long, and it results in the weakness of scientific culture in our universities. Major breakthroughs and strong political support are needed to reverse this situation.

Funding of collaborations between foreign research partners and domestic researchers needs to be encouraged, especially for large-scale and multi-year researches, which are expected to have a major impact on the advancement of science for Indonesia's biodiversity. An example is the Deutsche Forschungs Gemeinschaft (DFG) funding for collaborative research between Goettingen University and the Bogor Institute of Agriculture and Tadulako University, Central Sulawesi. This collaboration studies changes in biodiversity patterns in the tropical regions of Sulawesi, which are happening for a number of plants, arthropods and vertebrates. The biodiversity communities studied include rattan, briophytes, insects, herbivores, ants, parasitoids, spiders, bees, beetles, butterflies, birds, amphibians, reptiles, and mice, as well as the socio-economic implications of landscape change for this community (see Clough *et al*. 2010). Mobilization of co-funding for large-scale and multi-year collaborative research activities will be increasingly relevant to sustain strategic and high-cost studies, which include biodiversity studies in extreme environments such as the deep sea.

International or regional initiatives in biodiversity conservation can be used as capital for mobilizing funding for biodiversity research activities, in addition to their biodiversity conservation activities. However, it should be noted that being part of such initiatives does not necessarily guarantee the mobilization of funding for the research and conservation activities. The mobilization of funding takes time, requiring the enabling conditions become available.

The Heart of Borneo (HoB) initiative that covers high conservation value areas in Kalimantan can be used as an example (Van Paddenburg 2012). The increase in direct spending in the forestry sector of the districts that are part of HoB is not yet significant. At the local level, the financing of public sector on terrestrial biodiversity conservation activities is typically limited for the forest sector, and being a part of the HoB initiative has not affected the amount of a district's spending on forest sector within the Heart of Borneo region. This kind of funding can limit the ability to carry out or support biodiversity research activities at the local scale.

Research Universities

"Most of tomorrow's economy is being born today in university research laboratories."—European Molecular Biology Organization (EMBO) Report, 2007.

A research university can be defined as a university whose main activity is conducting world-class research. This research is characterized by a large number of graduate students, collaboration with international scientists on a substantive scale, and practices excellence in its various lines of activities. In developed countries, research universities gather the best talents from around the world to develop the ideas and concepts of frontiers of science.

Research universities are vital national assets for determining the future of a nation, and one of the main pillars of a science-based economy (NSF 2012). Research universities are the main source of the high-quality expertise needed for effective development, as well as the engines that create science to respond to various challenges, community needs and the uncertainties of the future.

To support biodiversity research and innovation in order to gain competitive advantage, Indonesia requires highly educated human resources. In a rapidly changing world, research universities are a fundamental part of the education infrastructure for meeting such needs.

Research universities have a unique and irreplaceable role in the educational landscape. In addition to producing research and providing scholarships that create human capital, research universities also carry out economic development and technical assistance to the community, the country and the nation. While other institutions might address these needs individually, research universities address these needs together in an effective, efficient, and in as economical a way as possible.

Research universities carry out innovative fundamental research that drives scientific and technological discoveries. Research universities produce qualified human resources, have a strong analytical power and are adaptive and creative to change. Research universities at the same time also strengthen the scientific culture in higher education. They educate and train future highly skilled workers and prepare teachers for schools. They equip the next generation of leaders with the knowledge, skills and empathy needed to lead in the context of the 21st century. Finally, most importantly, research universities are stewards and repositories of human knowledge.

Wageningen University and Research (WUR) in the Netherlands is an example of a research university with a strong focus and attention on the environment, agriculture, forestry, and marine sciences.

WUR has become a world-class environmental-related research center, where researchers from many countries conduct research on various aspects of the environment, develop interdisciplinary research on the environment, and utilize frontline science for environmental preservation and utilization. These include the development of studies on the circular economy that is needed to balance ecological, social and economic interests. The Netherlands Institute of Ecology (NIOO) is another institution in the field of environmental studies within the scope of WUR. NIOO has not only become a leading research institute; it has also developed a pilot institution based on a circular economic approach where no material is wasted, all being reprocessed into energy. WUR and NIOO in the Netherlands have inspired many people in in the country and internationally—clearly demonstrating cutting edge, interdisciplinary research in the environmental field useful for the development of science and society.

How America Transformed Itself into Becoming and Economic Super Power?

"... without scientific progress no amount of achievement in other directions can insure our health, prosperity, and security as a nation in the modern world."—Vannevar Bush, *Science. The Endless Frontier*, 1945.

In 1944, one year before World War II ended, President Roosevelt asked for recommendations from Dr. Vannevar Bush, then Director of the Office of Scientific Research and Development, on how to transform the superiority of war science and technology into a postwar tool for the progress of the United States in peace time. President Roosevelt's letter posed four important questions, namely: 1. What can be done, consistent with military security, and with the prior approval of the military authorities, to make known to the world as soon as possible the contributions which have been made during our war effort to scientific knowledge?; 2. With particular reference to the war of science against disease, what can be done now to organize a program for continuing in the future the work which has been done in medicine and related sciences?; 3. What can the Government do now and in the future to aid research activities by public and private organizations? The proper roles of public and of private research, and their interrelation, should be carefully considered.; and 4. Can an effective program be proposed for discovering and developing scientific talent in American youth so that the continuing future of scientific research in this country may be assured on a level comparable to what has been done during the war?

Dr. Bush's response was contained in a document entitled *Science. The Endless Frontier—A Report to the President,' by Vannevar Bush, Director of the Office of Scientific Research and Development*, July 1945, which can be summarized as follows:
1. War against disease. To continue to maintain progress in the field of medicine, the government needs to provide financial support for basic medical research in various medical facilities and universities.
2. National security. Continue military science and technology research in peaceful times with the involvement and control of civilian scientists through organizations that work closely with the US Army and Navy, but are funded by Congress and have clear power to initiate research that will help strengthen the military.
3. Create welfare for the public good. To create jobs, the formation of various companies and industries that produce better products at affordable prices must be encouraged. For this purpose, fundamental scientific research is needed as scientific capital, producing a trained workforce in the field of science as the main motor for the creation of new knowledge and its application for various practical purposes. Strengthen basic research centers, especially in universities and research institutions that are devoted to research to expand the frontiers of science, creating a system conducive to the creation of new knowledge and lessen the pressure to produce something tangible in a short period of time. The most important way for the government to be able to promote industrial research is to increase the flow of new knowledge through supporting basic research, and fostering new talents in the world of science. New institutions are needed to support long-term research programs with stable funding. These institutions must respect the freedom of thought and the policies on internal control, personnel and methods, and the scope of the research must be left to the institutions where the researches are carried out. These institutions are fully responsible directly to the president; and through the president, and the programs are accountable to Congress.

This is the forerunner for the birth of the many institutions in the United States funded to do basic research.

These have laid the foundation for the continued progress of science and technology in that country.
In 1862, more than eight decades earlier in the midst of a civil war, the American Congress had issued a strategic policy that proved to be a major breakthrough supporting a partnership among the federal government, the States, higher education institutions, and industries. It created universities that relied on education and research to meet practical needs that have driven the United States to become a world leader in agriculture and industry. The results of this major decision include the Green Revolution in agriculture that provides food to the world's population and a manufacturing industry that became the engine of the United States economy in the 20th century. This has led the United States democracy to create an educated middle class that has transformed it into one of the most powerful countries in the world.

The model for the research university in the story actually dates back to the Prussian Reformation of 1809. A Prussian educational politician, Wilhelm von Humboldt, founded the first research university in the world, now called the Humboldt University of Berlin, with the support of King Friedrich Wilhelm III. This university conducted intensive scientific research and integrated the main principles of teaching and research in the activities of its academic staff. This research university later became a model for similar universities throughout Europe and the United States.

After World War II was over, as described above, the US Congress again created a major breakthrough in the form of strategic policies to strengthen partnerships. It invested heavily in basic research and research-based postgraduate education to build the world's leading research universities, supply educated graduates, and strengthen science and technology innovation. This wide research partnership enabled the United States to win the Cold War, place human footprints for the first time on the moon, and lead a scientific and technological revolution in exploration into the human body in the form of the complete sequencing of the human genome—which has led to many advances in the field of medicine and public health. In addition, new technologies that include computers, internet, GPS, medical procedures, and pharmaceuticals have contributed significantly to the progress and welfare of the people of the United States and the world (National Research Council 2012).

Policy breakthroughs in creating research universities and tools for research infrastructure such as autonomous institutions that fund research are national assets which have made the United States a country with an economy driven by innovation. It excels in the arena of ideas and concepts, products, and processes for producing new industries and jobs.

Research universities have also made US universities a meeting point for the world's best scientific talents, a reputation built on great strategic design.

Research universities are national assets, home to the creation of knowledge and capabilities as well as the qualified human resources that are the foundation of the business world, government, and the general public for facing uncertainties in the future.

To a different extent, the Mahidol University in Thailand and the Australian National University in Canberra, Australia, are research universities that were established initially with programs of postgraduate studies focused on research. Indonesia should be able to learn from these countries, preparing itself to make an economic transition by making biodiversity and natural wealth the main capital for an economic development based on science, technology and innovation—thereby transforming Indonesia into a developed country.

International Collaboration and Benefit Sharing

Not a single laboratory or research group in even developed countries is sophisticated enough to cover all aspects of a complex biodiversity research topic. Research collaboration is a necessity in modern science. For Indonesia, which is rich in biodiversity but relatively poor in science and technology, international cooperation is inevitable. Through international cooperation, the transfer of science and technology and the strengthening of a scientific culture in Indonesia can be accelerated.

On one hand, the strong role of the Indonesian government in the conservation and exploitation of natural resources is stipulated in Article 33 (3) of the Constitution, which states that "the Earth, water and natural resources contained therein are controlled by the state and be used for the great prosperity of the people". The strong role of the state is also reflected in a number of supporting laws and implementing regulations to ensure protection of our biodiversity, such as genetic resources (Table 6.2).

Table 6.2. *Supporting laws and implementing regulations relating to genetic resources..*

Basically, the government is tasked with finding, collecting, using and conserving Indonesia's plant genetic resources. However, Indonesian citizens or business entities can be licensed for the search and collection of these resources. The search and collection of genetic resources is only permitted for the purpose of plant breeding, and it can be carried out by foreign parties only in the context of research collaboration with Indonesian partners. Export of genetic resources is only allowed for certain species and for the purposes of research in plant breeding, where the exchange of such resources is considered. The access for foreign researchers and institutions depends on research permits and their contents.

A good balance between national interests and the common progress of humankind is definitely needed. Regulatory instruments should encourage the growth of cross-sectoral cooperation on an international scale to respond jointly to various global challenges, such as ecosystem damage, the threat of extinction of various species, climate uncertainty, and so on. To take advantage of Indonesia's megabiodiversity, basic research that is accelerated with the cooperation of international scientists is absolutely necessary. The search for valuable and commercially profitable compounds is a mutually beneficial trans-national activity. This activity often involves institutions from countries rich in genetic resources collaborating with institutions from technology-rich countries that have the ability to commercialize genetic resources.

Access and Benefit Sharing (ABS) should be structured to ensure equality between various parties who work together in researching and utilizing biodiversity. The United Nations Convention on Biological Diversity (UNCBD) adopted in 1992 was the first international instrument that not only had the goal of conservation and sustainable use of biodiversity, but also of insuring a fair and equitable distribution of benefits from the use of biodiversity. Indonesia adopted the UNCBD in 1994 in the form of Law No. 5 of 1994. And through Law No. 11 of 2013 concerning Ratification of the Nagoya Protocol on Access to Genetic Resources and the Fair and Equitable Sharing of Benefits Arising from

Their Utilization to the Convention on Biological Diversity, Indonesia ensures that ABS on genetic resources and fair and balanced benefit sharing has a strong legal basis.

The practice of implementing ABS is far from simple. In bioprospecting, which is biodiversity exploration to obtain genetic and biochemical resources of commercial value, the traditional knowledge possessed by indigenous peoples and local communities provides information that give clues to the genetic sources that can be potentially commercialized. ABS is a tool to promote justice at the international level; however, the role of traditional knowledge requires that there also be regulations at local and central government levels. The indigenous peoples and local communities who possess valuable knowledge reside within a country, and their rights, although subject to international human rights norms, are governed by national laws.

There are national regulations that affect implementation, prior informed consent, and benefit-sharing procedures; these are designed to ensure transparency, stakeholder participation, and fair benefit sharing. However, Indonesian law involves relatively long and complicated procedures. The precautionary principle as reflected in the rules is indeed necessary, but too many overlapping rules hamper international collaborative efforts in conducting research related to biodiversity. This makes Indonesia less competitive compared to neighboring countries, because collaborators (in this case developed countries with advanced science and technology) will prefer to invest in countries whose regulations are relatively "uncomplicated". We need to balance the aspect of prudence with the need to support international collaboration in developing research on our biodiversity.

Although the absolute need for international collaboration in biodiversity research has been fully understood, many complaints are voiced by both Indonesian scientists and international partners about the difficulty of establishing cooperation. Frequent complaints include an excessive bureaucratization to obtain research permits that involve a large number of central and regional government institutions and offices; the difficulty of finding equal partners because many Indonesian scientists are shackled by administrative burdens which take so much of their time that they lag behind in the development of the latest knowledge; and the fact that many studies are not carried out simply because they are considered too sensitive (Shetty *et al*. 2014).

Clearing Houses

The natural environment, including Indonesia's biodiversity, can be viewed as public goods-part of a global ecosystem. In this view, our biodiversity should be managed and utilized to create prosperity for the whole of humanity.

Because the issue of megadiversity is very complex, a cross-sectoral approach to managing and utilizing biodiversity is a must. But both the research and management of Indonesian biodiversity are often carried out by various parties separately, in a fragmented way that is not yet integrated. At a conceptual level, biodiversity tends to be approached, organized, and structured as its own sector, even though biodiversity is cross-sectoral. At a procedural level, the existing mechanisms limit information sharing and exchange. The barriers can be found in many places, including among ministries/institutions, among universities, among research institutions, and among civil society groups who are engaged in biodiversity issues or even between parties within one institution. This problem significantly impedes the efforts to mainstreaming Indonesia's biodiversity, research implementation, and its management.

One of the breakthrough mechanisms for bridging such barriers is through an informal mechanism created by "clearing houses". The structures and processes of a clearing house are determined by the need to address biodiversity issues in an integrated manner, and they result from the values of the participants based on a shared consensus.

A clearing house has no formal regulations, but its structures and processes are such that vertical and horizontal exchanges of information occur regardless of the origin of the institutions, echelons, or hierarchies—including both public and private institutions. A clearing house displays institutional fit (Young 2002), in as much as the clearing house arrangements are commensurate with the problem to be solved (in this case the handling of Indonesia's biodiversity without borders) and are cross-sectoral and cross-party. Such clearing houses are more likely to be able to transcend institutional boundaries—including mandates and jurisdictions and internal power struggles—than are current formal processes and mechanisms. As such, a clearing house can act as a connecting node for knowledge, as well as a means of breaking down stagnancies caused by processes and mechanisms that are too formal.

The functions that may be played by a clearing house, among others, are the sharing of knowledge across the natural, social, and humanities disciplines (both intra- and inter-disciplinary sharing); the exchange of information and data through a flow that is not rigid and formal; discussion of the design and formulation of policies (future and existing) related to Indonesian biodiversity, both on land and at sea; encouragement for the accumulation of knowledge, for example through evidence summits or calls for evidence of Indonesian biodiversity —as well as contributions to the birth and management of journals that provide a place for gray literature on biodiversity in Indonesia; giving birth to future champions who have the ability to appreciate the complexity and significance of Indonesia's biodiversity; bridging the funding process and barriers for collaborative research and handling of Indonesian biodiversity—including facilitation of international collaborations, considering that Indonesia's biodiversity is a global public property.

A very important element is that a clearing house needs to be facilitated by a group of people or parties respected by the participants because of their high integrity and dedication to Indonesian biodiversity, both in terms of knowledge and action. Furthermore, this group must be considered neutral by the participants and able to embrace as many parties as possible, so that they can become facilitators for all relevant participants. This kind of leadership is the key to the success of any clearing house.

To some degree, there has been a start on producing clearing houses in Indonesia. For example, during the initial preparation of the IBSAP documents, the process succeeded in bringing together more than 100 biodiversity-related organizations. We have also had a National Biology Institute, especially before this institution was restructured to become what it is today. We are also witnessing the large organizations that are engaged in environmental conservation and resource management in Indonesia coming together in the Indonesian Conservation Communication Forum, which is exploring the possibility of exchanging information and data among these organizations. This type of modality serve as lesson sharing and as a reference point for the participating members and all those working for the creation of a clearing house for Indonesian biodiversity.

VII

RECOMMENDATIONS

Look deep into nature, and then you will understand everything better.
—Albert Einstein

The rich Indonesia paradigm which only emphasizes the richness of natural wealth, including biodiversity, can trick us and lead to exploitation of natural resources for short-term economic gain. In the midst of this abunandce, we are poor in knowledge, backward in technology, and have minimal social capital so that our natural wealth and biodiversity have not been optimally utilized for the welfare of the people and the progress of the nation. It is time for us to take strategic steps with a new paradigm based on science and technology to manage biodiversity more intelligently, productively and sustainably.

National Investment Priorities in the Utilization and Management of Biodiversity

"In the area of the environment and biodiversity, where should the government invest?" That's the important question we need to answer. Different national investment priorities have different levels of challenges and investment needs that reflect the ambitions and political commitments of policy makers. There are three main activities that can be prioritized for national investment based on biological resources, namely ecotourism, bioprospecting for drug discovery and bioenergy, as well as deep-sea exploration. These three investment priorities have different potential economic impacts, i.e. medium, big, and very big.

1. Science-based Ecotourism Development

The development of ecotourism has been initiated by the government, but with the support of science and technology it can produce a greater and more sustainable economic impact. Indonesia has many endemic and charismatic species that can be managed as a world ecotourism package. In addition to the Komodo dragons and orangutans, we also have babirusa and many kinds of

birds specific to Indonesia. Maleo birds, for example, have a biological uniqueness that can be packaged attractively. This bird's eggs are up to five times the size of chicken eggs and can hatch in a pile of sand without being incubated. The characteristics of the maleo bird and the efforts to conserve this and other charismatic species with science and technology approach can attract a special segment of tourists who are science and environment lovers.

Our ecotourism potential is huge and should be managed more optimally, just like China which successfully develops and introduces pandas to the world. China successfully uses its panda conservation efforts to create an ecotourism package. We can also do the same for our unique species. The conservation of endemic and charismatic species such as the Komodo dragons, anoa, babirusa, and various species of birds can be packaged to create an ecotourism industry. An interesting presentation that includes various scientific approaches in the effort to conserve charismatic species can be an attraction for tourists with special interests and high purchasing power. The number of tourists of this type is increasing, especially from developed countries. A comprehensive approach that combines ecotourism with conservation efforts and biodiversity research centers can promote awareness, respect and care for nature, heritage values and local culture (eco-heritage). In addition to bringing prosperity to the local community, this effort can simultaneously strengthen Indonesian science, technology and scientific culture.

Indonesia also has great potential for the development of an eco-heritage tourism based on past events. The wealth of Indonesia's megabiodiversity has inspired the birth of major scientific breakthroughs in the world. Many legendary scientists produced their magnum opus and left valuable footprints in Indonesia. In the 19^{th} century, Alfred Russel Wallace gave birth to the theory of evolution and modern biogeography, Franz Junghuhn pioneered plant acclimation efforts, and Eugene Dubois discovered *Homo erectus* fossils in Sangiran. And back in the 17^{th} century, Rumphius pioneered the birth of taxonomy and tropical botany from Ambon. Their legacies can be revived and managed as high value economic tourism assets, no less than the Galapagos ecotourism industry that relies on the footsteps of Charles Darwin.

For ecotourism, the coordination between government support for universities and environmental research institutions (both central and regional), the private sector, and the local communities will be very important. Therefore, it is urgent that the potential of ecotourism be strategically mapped, including the relevant institutions with their strengths and weaknesses, the needed coordination among them, as well as the potential and constraints for funding ecotourism development.

2. Bioprospection for Drug Discovery and Energy

Indonesia has more than 30,000 medicinal plants, 4,000 of which have a long historical track record as ingredients for herbal medicine. But in producing medicine, almost all raw materials are still imported. Indonesia is also blessed with a diversity of microorganisms that can convert solar energy into alternative energy sources. Investments in bioprospection can boost the economy through the discovery of drugs and bioenergy sources.

Indonesia's natural wealth contains more than 10% of the world's plants which can be the main source of medicines. The traditional medicine market is growing quite rapidly (Ministry of Industry 2018). Scientification of herbal medicine as a modernization effort to increase economic value has been regulated by the Ministry of Health as an attempt to provide scientific evidence through research integration with health care service.

Utilization of the latest science and technology, combined with knowledge from ancient manuscripts, can pave the way for the development of standardized herbal medicines (phytopharmacy) and to the discovery of active substances for new drugs. This second step led to the awarding of the Nobel Prize in Medicine to Chinese scientist Tu Youyou in 2015 for the discovery of artemisinin as an antimalaria drug. Her study began with the collection and search of thousands of 1,700-year-old herbal concoctions to trace substances that have the potential to have antimalarial properties.

The development of data science and information technology can accelerate efforts to find new drugs from old manuscripts. As an example, the Mayo Clinic in the United States has utilized Rumphius' great work, *Herbarium Amboniense*, to discover antibacterial properties from the extract produced by the *atun* tree (*Atuna racemosa*). This book, written by Rumphius in the 17th century, records the traditional medicinal plants in Ambon and their properties.

Systematic and continuous data collection on a national scale from ancient manuscripts and the oral tradition of the Indonesian archipelago has the potential to become a source of early knowledge about the traditional medical system of various ethnic groups in Indonesia. Local knowledge and wisdom in the form of oral traditions need to be documented before they become extinct. Efforts to find new drugs through this approach will be enhanced by new developments in science and technology, such as artificial intelligence. An increased Indonesian capacity for screening and classification of medicinal plants will need to be supported by qualified capabilities in the fields of phytochemistry, molecular pharmacology, preclinical and clinical testing, as well as translation of study results into medicine. Pharmacogenetic and pharmacogenomic studies of Indonesian people from various ethnic groups will also be needed to determine their bodies' response to drugs in relation to drug effectiveness and safety. Among the health challenges we face are the emergence of modified disease agents that are resistant to existing drugs, the emergence of new germs and diseases, and various metabolic diseases related to lifestyle. All of these challenges will continue to demand the search for new alternative medicines.

In the energy sector, Indonesia and several other countries in Southeast Asia have tried to develop biodiesel and bioethanol-based bioenergy. However, studies have shown that the effort withered before it could be developed due to uncompetitive pricing, competition with agriculture for food, and the issue of land-use change. Ideally, we need renewable energy sources that are climate positive, producing energy while reducing the amount of carbon from the atmosphere. Indonesia as the largest archipelagic country in the world has the potential to develop bioenergy from microalgae photosynthesis, so as to use solar energy to produce biomass, bioethanol, or even carbon-negative hydrogen. In addition, improving the efficiency and performance of photosynthesis is a major challenge. However, developments in science now make it possible to redesign photosynthesis in a substantial way.

An integrated system of stakeholders —including government agencies, local and global communities, research institutions, legal institutions, health organizations, and industry—will be needed for success in Indonesia's bioprospection for bioenergy. This is the same type of integration as is needed to optimize efforts for exploiting the economic potential of Indonesia's biodiversity in tracking new sources of medicines and energy, while maintaining biodiversity conservation.

3. Deep Sea Exploration

The depth of oceans holds many mysteries that have yet to be solved. Yet 90% of Indonesia's seas are deep seas. This is a living space without sunlight with extreme temperatures and extreme high pressure. In this environment, various living things can actually survive and prosper, even though it is difficult for the human mind to comprehend. Some have no eyes, some are just glows of light, some are living in the cracks of volcanoes under the ocean. Not to mention the various micro-organisms that live and interact there. Understanding the life mechanisms of these unique and astonishing creatures can lead us to new knowledge that was unthinkable before. The seabed also contains treasures such as precious minerals.

This mysterious world is much closer to us than outer space. But we have more knowledge about outer space than about the deep sea. Deep sea exploration is a momentum that requires giant endeavors. The challenge is indeed big, but it promises extraordinary rewards. Deep sea exploration will contribute to new knowledge, technological innovation, and the potential for enormous economic benefits—as happened in space exploration in the 1960s spearheaded by the United States. Deep sea exploration is also comparable to the exploration into the human body that totally described the genetic information through the Human Genome Project. This project produced a huge leap in the world of science and medical and health sciences, along with enormous economic benefits from the prevention, diagnostic and treatment technologies resulting from many breakthroughs derived from it. Deep sea exploration similarly has the potential to generate new knowledge, innovation and technology that will drive new chemical, pharmaceutical and energy industries. And on this planet, no other country is blessed with seas as rich as Indonesia's.

Mapping the strengths and weaknesses of Indonesia's human resources, institutions and funding potential to support this great endeavor is very much needed. Strengthening our human resources by encouraging more Indonesian young people to study the deep sea through doctoral level and to become involved in international research is also important.

Developing Science and Technology for Indonesia's Biodiversity

Indonesia must invest in basic science and technology if it is to be able to sustainably manage its biodiversity and obtain maximum economic benefits from it. In addition, it will be necessary to enhance various supporting factors such as the research ecosystem, institutions, and human resources.

Develop Science and Technology to Understand the Basic Characteristics of Indonesian Megabiodiversity

1. Carry out More Comprehensive Research through Developing Proper Observation and Modeling

To achieve a deeper understanding of the basic characteristics of Indonesia's megabiodiversity requires a comprehensive effort. Basic characteristics such as how various species exist together, interact with and influence one another in a dynamic ecosystem, will require careful and continuous monitoring at both upstream and downstream levels.

At the upstream level, the development of an integrated monitoring system should include the development of micro satellite sensors and field stations, both on land and at sea. At sea for example, monitoring can be based on offshore or other floating platforms. Monitoring and sampling on land and sea, such as regular expeditions in various forest ecosystems, periodic research voyages at rich and sensitive locations—such as upwelling waters and coral reefs—as well as with unmanned technology, are urgently needed. At the downstream level, the data collected from these monitoring efforts requires continued processing based on spatial grid (horizontal and vertical) at several data levels.

A single data management system will be needed that is focused on developing big data and services for research purposes. This system should allow integrated monitoring systems and field data compilation centers to be assimilated with high-level numerical modeling. The aim is to understand biodiversity and model future change scenarios on Indonesia's Maritime Earth—climate variability, sea processes, land changes, and hydrological systems.

2. Increase Understanding of Ecosystem Balance for Sustainably Protecting Endemic and/or Endangered Species

One aspect of Indonesia's unique biodiversity is its high level of endemicity, which reflects a large number of species that can only be found in Indonesia. The pattern of the spread of endemicity is different in different bio-geographic areas. Each region has a different variety of species, which are often endangered. That is why studies on the role of ecosystem balance need to be carried out in these different bio-geographic areas.

In terms of endemicity, for example, Indonesia has the highest number of limited-range (<50,000 km^2) roaming bird species in the world. For these types of birds, the Sunda Shelf has high biodiversity but low

endemicity; the Wallacea region has low biodiversity but high endemicity; while the Sahul Shelf has high biodiversity with moderate endemicity. These different levels of endemicity indicate the need for prioritization in determining the areas in which researches will be carried out, since resources are limited. Data bias also occurs for endangered species. Most of the data comes from terrestrial fauna and flora, because more studies are conducted on terrestrial organisms. More intensive explorations are needed for organisms in aquatic habitats that may also be threatened with extinction.

3. Understanding Biodiversity Adaptation Patterns on Global Developments and Climate Change

Adaptation is a process of change in the body or parts of it that can be passed down to the next generation which occur in living things so that they are able to survive and adapt to changes in the environment. This process is unique and involves various factors which until now have not been fully understood. Research to understand adaptation patterns, both at the level of organisms, populations, and ecosystems, is urgent so that we will be better able to preserve various organisms faced with the rapid environmental changes that have been happening in the last few decades. Research can be prioritized in a variety of extreme as well as dynamic environments, such as in the deep sea or volcanoes.

4. Strengthening the Indonesian Biodiversity Specimen Bank

Specimens that represent Indonesian biodiversity have enormous economic value. A depository of specimens collected, including microorganisms, plants and animals, according to international standards (a biobank) is required to store these assets properly. Biobanks like this should also store selected clinical specimens from humans such as tissue/cell residues, biopsies residues, stem cells, etc., to create genetic resources that can be analyzed genomically/metagenomically, proteomically, transcriptomically, metabolomically, etc.

The serious efforts that need to be made include:

a. Strengthening Indonesia's biodiversity specimen database in a way that is effective and easily accessible.

b. Institutional strengthening by improving the quality of human resources and the providing the budget for the management of storage areas.
c. Strengthening the networks linking institutions that manage specimen banks, linking creators and users, so that specimen collections continue to increase and specimen use is higher, both for scientific development and for commercialization purposes (thus increasing the number of patents).
d. Improving the dissemination of information on the existence of the Biodiversity Specimen Banks among researchers, academics, industry and the general public.

Increasing Community Participation in Efforts to Manage Productive and Sustainable Biodiversity

1. Raising Public Awareness of the Importance of Biodiversity

Indonesian biodiversity fulfills all criteria as a basis for the survival and comparative advantage of the nation. Ironically, public awareness about biodiversity is still very low. Community support is very important for making biodiversity a mainstream issue in public policy. Therefore, strategic communication to garner public support for all measures that support the management and use of biodiversity should be a priority. The first step that needs to be taken is to campaign for the concept of biodiversity in general, of Indonesian biodiversity and its economic potential. For the younger generation, information related to biodiversity must be conveyed in an interesting manner. Training teachers in primary and secondary schools to be able to instill interest and curiosity about biodiversity in general and Indonesian biodiversity and its benefits, is also of primary need.

2. Develop Local Wisdom

Indigenous peoples in various parts of the world, including in Indonesia, generally are dependent and close to nature to be able to survive. This is what produces behavior, habits, and a culture of respect for nature and all its aspects, both on land and at sea. The respect manifests itself in various forms of knowledge, wisdom, attitudes, rituals, traditions—and/or a set of customary rules as products of culture, physical or non-physical, literal or symbolic.

Various cultures and wisdom in the traditions of the community are local. But the meaning and implication of cultural products reflect the same basic principles, namely respect for nature and the preservation of biodiversity in support of life, including as a provider of food and medicine. The increase of population, the increase of human mobility, and a high desire to exploit nature for maximum economic benefits is a challenge for local wisdom to survive. Specific conditions and strategies are needed to maintain and use it as a guard to biodiversity. And local wisdom must always be reviewed in an ever changing world.

3. Develop Citizen Science and Computational Data

The era of big data, computational technology, and quantitative science opens opportunities for intervention and implementation of innovative applications, especially through Indonesia's biodiversity with its rich potential. How to integrate the multidimensional component of scientific observation with the history of local wisdom, socio-cultural conditions, economic policies and governance, so as to meet evolving and changing human needs, but still remain in harmony with nature?

Collaborative systems, data recording, intensive computing infrastructure, integrated data sharing and analysis processes are needed. In that way, information flow can be useful for designing interventions for problems and utilizing innovative biodiversity sources. Citizen science with the support of artificial intelligence is a major breakthrough of the big data era that is expected to be developed to help more efficient tracking, data collection, and biodiversity mapping through large-scale observation and automation. This approach is expected to be built as an initial program for the innovative use of national biodiversity sources and their preservation.

To support citizen science, it will be necessary to strengthen biodiversity content in the school curriculum, which includes:

a. Cross-sectoral curriculum mapping to place the topic of biodiversity as an interdisciplinary theme in education from kindergarten to high school. The resulting matrix is expected to be deep enough and provide a broad perspective on biodiversity in all subjects integrated with character education.

b. Local action projects as a pilot of citizen science focused on biodiversity—specifically students collecting data on the local biodiversity of the particular area. Coordination of citizen science can be carried out with local universities and/or research institutions.
c. Teacher training to include biodiversity content in the subjects they are teaching. Teachers are given basic skills in collecting data or literature related to biodiversity and teaching methodologies that are adequate and easy to implement.

Increasing Utilization and Economic Value of Indonesia's Biodiversity Excellence

1. Utilization and Management of Ecosystem Services

The economic utilization and management of ecosystem services will very much depend on the preservation of natural capital, including biodiversity, which underlies ecosystems and produces ecosystem services. The utilization of ecosystem services needs to ensure that the supporting capacity and carrying capacity of the ecosystem are strong enough so as not to incur costs and burdens. For example, one needs to take into account the possible loss of income sources—cash and non-cash—from ecosystem services, as well as possible decreased food security or deteriorating health quality of the people whose lives depend on forests, rivers, or the sea. Ecosystem services that are both sustainable and of high economic value will be maximized by innovations that add value and increase efficiency.

The innovation applies to appropriate and low-impact technologies. Access to funding, fiscal incentives, and continuing certification are needed to develop ecosystem service-based products that are biodiversity-oriented. A business model integrated with landscape management for conservation or ecosystem restoration, for example of coral reefs or peatlands, can be supported through cooperatives/village business entities or Forest Management Units (*Kesatuan Pengelolaan Hutan* or KPH)/Conservation FMUs.

At a more macro-economic level, the utilization and management of the economics of ecosystem services absolutely must pay attention to the availability of and any change in ecosystem services.

2. Technological Inspiration from Nature: Developing the Science of Biomimicry

Biomimicry is an approach that uses natural systems as a model to solve problems faced by humans, especially in product design. By studying natural systems, we can better understand that nature has actually provided solutions to problems that we encounter. Interdisciplinary research needs to be done so that we can efficiently harvest the knowledge that has been provided by nature to improve humanity's well-being through a variety of products and the latest innovations.

The roof of the Esplanade Theater in Singapore that mimics durian skin is one example of biomimicry applications in the field of architecture. The thorny theater roof shaped like a durian was made not only as decoration to attract tourists, but also functions as an aluminum panel that follows the position of the sun. The thorny roof was designed to reflect back the heat of the sun, which helps maintain coolness in the theater. In this case, aspects of aesthetics, local identity, and practical functions are combined through science and art.

Nature provides many phenomena that can inspire us to develop new science and technology. As one example, some animals such as the starfish have the ability to regenerate themselves. Some types of starfish can grow a severed arm, and in some types, even the arm pieces can grow into intact starfish. Further research on this subject can lead us to new knowledge about the process of organ regeneration in starfish. This accumulation of new knowledge has the potential to drive innovation and technology in the manufacture of human organs which will be very useful for human health.

3. Sustainable Use of Deep-Sea Resources

The knowledge about marine resources will ultimately lead to their utilization for economic development. At the level of understanding, two crucial aspects are fisheries and biotechnology. With regard to fisheries, understanding of the structure and distribution of deep-sea biota might be focused on the distribution of fish in the aquatic layer around the continental slope that is rich in nutrients, due to the vertical exchange process generated by internal waves, especially at depths of 100-400 m. The next challenge is the development of fishing gear that is environmentally friendly and suitable for these continental slope conditions.

In the context of marine biotechnology, such topics as: exploration of biological resources in the deep sea; biodiversity genetics and bacteria in the water column; and sediments and hydrothermal vents; require attention and partiality, including budget allocations. Thus, the development of deep-sea biotechnology-based products can become an economic mainstay, especially relating to future medicines and advanced materials, as well as providing inspiration for the latest innovative technology.

4. Utilization of Local Biodiversity which has the Potential to Support Food Sovereignty

The main food source of Indonesian people is rice. An effort to diversify food and develop the potential of local biodiversity as a new food source is needed to support food sovereignty. The contributions of science will be needed to anticipate climate change and an increasing population.

Develop and Improve the Effectiveness of Conservation and Biodiversity Management

1. Restoration and conservation of key ecosystems: forests, mangroves, seagrass beds and coral reefs

Although the socio-economic value of key ecosystems—forests, mangroves, seagrass beds and coral reefs—in Indonesia is very high and can support national competitiveness and food security, damage to these ecosystems has not been well mitigated.

To speed up recovery, intervention is needed through the restoration of ecosystems based on the latest science and technology. Under normal conditions, by overcoming the causes of degradation, it is most likely that damaged ecosystems can recover naturally. However, with the level of damage in several areas already very severe, developing effective rehabilitation methods is very urgent.

Then, to ensure sustainability and maintain the quality of key ecosystems, it is necessary to strengthen management, utilization and conservation strategies. Effective management of conservation areas is one of the keys in ensuring the sustainability and restoration of ecosystems, as well as maintaining their rich biodiversity. For this purpose, it is necessary to strengthen science in various aspects. Conservation biology, biosocio-ecological integration, zoning, and the process of adaptation to various disturbances, both natural and anthropogenic, are aspects that must be strengthened. In addition, good coordination is needed among institutions. Effective conservation efforts can also support the development of ecotourism.

2. Interactions and impacts of alien species on local species and ecosystems

Invasions of alien species can threaten ecosystems. One effective way to stop this problem is to understand the route of entry of an alien species and what impacts it might have. Then we can design strategies to prevent and mitigate the impacts of this invasion.

Active involvement of the wider community and stakeholders is highly needed. The general public, staff in conservation areas, airports, ports, stations and terminals of other transportation modes, need to get information and training to monitor the movement of organisms, both actively and passively, especially in habitats that are vulnerable to the emergence of invasive species. The community needs to be supported to carry out intensive control efforts. As part of an integrated strategy, it may be necessary to research various biological-control options.

A controlling species from the same area can be mobilized to control an invasive alien species. In addition, the implementation of laws and regulations related to invasive alien species can be made more effective. Coordination between the mandate holders in law enforcement related to alien species invasion must be carried out and integrated nationally, as has been done in Australia.

Human Resource Development

The points above urgently require human resources that are competent and have qualified skills relating to biodiversity. Attention is especially needed in strategic areas where human resources are seriously lacking. Taxonomy, bioinformatics, big data, genetics, and other advanced technological expertise will require strengthening to support the management and utilization of Indonesia's biodiversity.

As a country with an abundance of biodiversity, we are very short of taxonomists. The expertise of a taxonomist in describing, naming, and classifying a species is very much needed. This is important both for a basic understanding of biodiversity and for efforts to conserve it. The small number of taxonomists in the world, especially in Indonesia, is believed to be the cause of the low number of new species described by scientists in the last 60-70 years. The impact is huge on conservation science. Most species will become extinct before they have even been described. As a result, we will always be left behind in knowing the total number of species in our biodiversity. Taxonomic work is also not only for academic purposes. There are economic aspects in this activity. We need to know the differences between species to find species that have economic value and what makes them so. Taxonomy will help with sustainable management and cultivation of a species. Bioinformatics resources and big data are also key in tracking, recording and tabulating biodiversity riches. It is necessary to develop more human resources in computational technology skills and quantitative science to take advantage of opportunities to apply innovative applications in the management of data on Indonesia's biodiversity sources.

These skills includes computational and informatics expertise in data storage, management, analysis, interpretation, and integration of biodiversity data.

The broad, complex and multidimensional nature of biodiversity

data requires the design of interdisciplinary integrative training programs such as biology, social sciences, computational sciences, and quantitative approaches. Along with this training, an environment conducive to the exchange of knowledge that is open and collaborative is needed in order to be able to utilize cross-disciplinary biodiversity data, where information exchange can be used optimally to support breakthrough biodiversity-based science innovations.

The genetic composition of creatures provides a fundamental tool in the effort to characterize and track biodiversity in various forms. Efforts to conserve, utilize and manage biodiversity sources depend on measuring and tracking variations in genetic elements from individual genome levels to population metagenomics. The latest technological breakthroughs in the fields of genomics and metagenomics open up wide potential for the utilization of natural biodiversity resources in the effort to find active substances/compounds for innovation in the pharmacology industry and other applied industries. Of special importance is the ability to use this technology to map the genetic diversity of the microbial community (microbiome). This field is now starting to develop rapidly and contribute to new innovations in disease treatment, sustainable agriculture, aquaculture, and environmental conservation interventions.

To master advanced technology, Indonesian human resources need to be encouraged to master the various skills above. This needs to be done at various levels, ranging from expertise to develop innovations such as bioengineering; science development that takes into account ethical and legal aspects; mainstreaming science through science communication and diplomacy; to entrepreneurship based on Indonesia's biodiversity. The use of scholarship schemes such as the LPDP scholarship (Indonesia Endwoment Fund for Education), as well as scholarships managed by various ministries/institutions to support young people undergoing postgraduate education, needs to be considered in the strategic areas above.

Institutions and Funding

1. Competitive, Autonomous and Sustainable Funding System

Biodiversity science for basic and applied research and for biodiversity conservation and restoration efforts requires adequate and sustainable funding. This funding can be justified by the potential directly provided by Indonesia's biodiversity (for example, in the form of marine and forestry resources), as well as by its support for elements of economic development and public welfare. A continuity of funding is needed to ensure that the accumulation of Indonesian biodiversity knowledge can occur. This funding should be awarded to individual group leaders through a merit-based competition to ensure that the best projects are undertaken (Brodjonegoro and Greene, AIPI 2012). What also needed is commensurate funding for institutional support.

The amount and sustainability of biodiversity science funding should be linked to development planning documents such as the Medium-Term National Development Plan (*Rencana Pembangunan Jangka Menengah Nasional*, RPJMN). This linkage is especially needed for funding of biodiversity research initiatives that will be translated into government policies, plans and programs. It should be noted that, starting from the 2020-2024 RPJMN, for the first time in Indonesia's history a strategic environmental study to assess environmental support and capacity, including biodiversity, has become embedded in our development planning documents as mandated by the Law. Biodiversity science can thus become a development priority.

It is a fundamental need that the awarding and management of research funds be carried out by an autonomous non-governmental institution, selected competitively (merit based), and provided with sustainable funding (Brodjonegoro & Greene 2012). Specific funding must be earmarked to support the advancement of science for Indonesia's biodiversity that goes beyond borders of ministries, institutions and sectors. This is of primary importance. The specific funding mechanisms can serve as basis of thematic collaborations across ministries, institutions or sectors, as an integrated approach to finance biodiversity. The involvement of non-governmental parties and innovative financing are also strongly encouraged, such as through non-government investment funds. Such funds are needed to provide alternative funding availability or to fill the gaps in areas that are lack of funding. The involvement of non-governmental parties and innovative financing is also a way to mobilize research funding for biodiversity .

Strengthening science and technology related to Indonesian biodiversity requires a number of supporting factors. Especially the existence of funding institutions that are autonomous, responsible, and devoted to biodiversity research needs. The institution should be independent, especially in making decisions related to research activities and distribution of funding, and its research grants must be multi-year and not tied to the financial cycle of the state budget (Brodjonegoro & Greene 2012). The competitive funding provided for biodiversity science activities should differ based on the level and scope of research. Thus, for example, relatively short-term funding (5-10 years) is needed for baseline research for the purposes of tracking and monitoring species or community level biodiversity status; specific and targeted funding is needed to encourage and build research capacity, such as funding masters and doctoral students from selected interdisciplinary research groups; and large-scale funding is needed for biosphere reserves, biological collections and biodiversity databases such as specimen banks, frontline and strategic research such as drug and bioenergy bioprospections, and for providing essential research infrastructure at research universities.

2. Build an Indonesian Biodiversity Clearing House

The current structure and processes related to biodiversity research and management face barriers that are triggered by narrow perspectives on biodiversity by sector. Many good ideas may become unrealized or slow to materialize, for example data exchange for interagency learning. Given this condition, it is necessary to produce informal procedures and processes through the creation of an Indonesian biodiversity clearing house, designed to break through these formal boundaries and barriers.

Clearing house participants are those who have explored and are active in research and management of Indonesian biodiversity. The processes inside the clearing house take place regardless of the background and hierarchy of the participants, and are based on consensus. The clearing house can be a place and vehicle for sharing and accumulation of knowledge, exchange of data and information, policy discussions, the birth of future biodiversity leaders, and funding and collaboration for research and management of Indonesia's biodiversity. To work and be sustainable, such a clearing house needs to be facilitated by parties or groups whose thoughts and/or actions are respected, have high integrity, and are free from conflicts of interest. As a first step, an ad hoc team is needed to initiate the establishment of an Indonesian biodiversity clearing house by involving all stakeholders, such as universities, research institutions, NGOs, government agencies, and industry.

3. International Collaboration

International collaboration is essential in current scientific activities. Not a single laboratory or research group, even in developed countries, is sophisticated enough to cover all aspects of complex biodiversity research topics. Therefore, Indonesia needs to further enhance and strengthen its international cooperation, especially with reputable universities or research institutions in fields related to biodiversity. For fundamental research, international collaboration needs to be facilitated as much as possible in order to accelerate progress. Therefore, regulations are needed that balance the need to safeguard the security of our biodiversity and the importance of facilitating international research collaboration.

4. Research Universities

To support the recommendations above, Indonesia urgently needs strong tertiary institutions and qualified human resources in the field of biodiversity. In a world that is interconnected and rapidly changing, research universities, including those focused on biodiversity and the environment, are important prerequisites for strengthening human resources in the biodiversity field. This also allows us to optimally use science and technology in managing our biodiversity.

Research universities that emphasize the field of biodiversity can simultaneously strengthen the scientific culture in that university and encourage biodiversity and environment literacies in the community. Research universities also train human resources and can produce a highly qualified workforce in the field of biodiversity. They can become partners of the government and the private sectors in developing evidence-based policies and industries related to biodiversity. A number of countries such as the United States, Germany, the Netherlands, and Australia have experiences that we can learn from and adapt for building outstanding research universities in Indonesia, including those that contain a focus on environmental issues and biodiversity.

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Glossary

Anaerobic: literally means ”without air”.

Anomaly: not as usual, an event that cannot be predicted, so that what happens will be different from usual events.

Aphrodisiac: a substance that can increase sexual desire.

Bathymetry: the study of underwater depths and the study of three-dimensional ocean or lake floors.

Bioengineering: the application of biological, physical, chemical, and computer science concepts and methods to solve problems related to living things through engineering applications and analysis.

Biogeography: a branch of biology that studies biodiversity based on time and space. This branch of science aims to reveal the life of an organism and what influences its existence and distribution.

Bioinformatics: a science that studies the application of computational techniques to manage and analyze biological information. This field includes the application of mathematical, statistical, and informatics methods to solve biological problems, especially by using DNA, RNA, and protein sequences, as well as information related to them.

Biomimicry: the science of using natural objects (living things in particular) as models to design materials and processes, imitating them through modern technologies.

Bioprospection: the efforts to search, research, collect, and select biological resources and traditional knowledge to obtain material of commercial value, mainly referring to the pharmaceutical, biotechnology, and agricultural industries.

Bioremediation science: the science of using biological agents, especially microorganisms or plants, to reduce pollutants in the environment.

Cardiovascular diseases: diseases related to the heart and blood vessels, such as ischemic heart disease, stroke, heart disease due to high blood pressure, rheumatic heart disease, congenital heart disease, and endocarditis.

Circular economy: an economic concept created to reduce the exploitation of natural resources that damages the environment, health, and the economy.

Ecosystem services: the benefits that humans derive from ecosystems.

Ethnobotany: from the word ”ethnology” - the study of culture, and ”botany”—the study of plants, is a field of study that studies the relationship between humans and plants. Ethnobotanists are tasked with documenting and explaining the complex relationship between culture and plant use with a primary focus on how plants are used, managed and perceived in various societal environments, for example as food, medicine, religious practice, cosmetics, dyes, textiles, clothing, construction, tools, currency, literature, rituals and for social life.

Genomics: studies based on the entire genetic information possessed by a cell or organism, as carried by the nucleic acids that contain that information. The term genome was introduced by Hans Winkler of the University of Hamburg, Germany, in 1920, perhaps as a combination of the words gene and chromosome, intended to express a collection of genes.

Geomorphology: the study of rocks and the outer surface of the Earth.

Hydrothermal vents: cracks on the surface of the planet that geothermally heat sea water. Hydrothermal vents are usually found near volcanically active areas, areas where tectonic plates move. This feature is found on the middle ridge of the ocean (3,000 meters deep), but some are also found in shallow seas. The temperature of water emerging from the vents ranges from 60°C to 464°C, in contrast to the approximately 2°C ambient water temperature at these depths. The hydrothermal vent ecosystem has high productivity due to the chemosynthetic activities of bacteria that live both in microbial mats and in symbiosis with other organisms such as the tube worms *Riftia pachyptila*. Chemosynthesis by the bacteria is carried out by utilizing the abundantly available H_2S. The carbohydrates produced by these bacteria then support an entire ecosystem.

Lontara Assikalaibineng: ancient manuscripts in lontara script. *Assikalaibineng* means a way of relating between husband and wife, or the guidance book for newlyweds' first night together. This book not only contains how sexual relations between husband and wife should be conducted, but also contains techniques before and after intercourse, including the prayers which have to be uttered.

Lontara Pabbura: traditional treatment of ancestors of the Bugis based on the *Lontara Bone*, which is based on an understanding about the surrounding plants, culture, and of Islamic teachings. One of the philosophies that is adhered to is that every disease must have a cure in the universe provided by God (Hamid 2008).

Magnum opus: large and important work (Latin).

Metagenomics: the study of metagenomes, which are all of the DNA genomes from a complete ecosystem, not just from one organism. For example, by reading the genetic blueprints of all species of micro-organisms (microbes) that exist in an ecosystem, one reveals the types of organisms contained in that ecosystem, as well as some of the interactions that occur within it.

Microbiome: the totality of microorganisms in our body, many of which are useful for humans.

Morphology: literally means knowledge of forms (morphos). In biology, morphology is the study of the form of organisms, especially animals and plants, including all of their parts.

Obduction: also called overthrusting, which occurs when an oceanic plate collides with a continental plate, and slides under the continental plate.

Paleontology: the discipline that studies the history of life on Earth using ancient fossil-based plants and animals.

Phylogenetics: the branch of biology that studies and determines evolutionary relationships, or the hereditary patterns of groups of organisms.

Physiology: a branch of biology that studies the functioning of living systems. Physiology uses a variety of methods to study biomolecules, cells, tissues, organs, organ systems, and organisms which as a whole carry out their physical and chemical functions to support life.

Phytopharmaceuticals: plant-derived medicine preparations that have been proven scientifically safe and efficacious by preclinical and clinical trials.

Pollination: literally the fall of pollen on the surface of the pistil. For most flowers, this event means ”fell on the head of the pistil”. Pollination is an important part of the reproduction process of seed plants.

Serat Centhini: one of the greatest literary works in New Javanese literature. *Serat Centhini* is a compilation of all kinds of Javanese science and culture and is sung in traditional form.

Spatio-temporal: a database that manages information about space and time.

Subduction: occurs due to the difference in density between two types of tectonic plates, so that the plate with greater density dips below the other plate. This subduction occurs at the boundary between oceanic and continental plates, as well as between oceanic plates. The subduction zone is one of the places of formation of volcanoes and Earthquakes.

Taxonomy: the branch of science concerned with classification, especially of organisms.

Upwelling: a phenomenon in which colder, higher density seawater moves from the seabed to the surface due to the movement of winds above it. This movement generally carries nutrients needed for the growth of phytoplankton near the sea surface, so that it enriches the biomass in the region.

Wallacea Region: the biogeographic region that includes a group of islands and archipelago in the central part of Indonesia, separated from the Asian and Australian continental shelves by deep straits. The term Wallacea is taken from the name of a naturalist, Alfred Russel Wallace, who described the biological boundaries of the zoogeographic region known as the Wallace Line. The Wallacea line extends between Bali and Lombok, between Kalimantan and Sulawesi, and between the Maluku Islands and Papua.

Appendices

APPENDIX 1

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APPENDIX 2

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ALMI
Akademi Ilmuwan Muda Indonesia

The Indonesian Young Academy of Science (ALMI) is an autonomous organization of Indonesian young scientists which is under the auspices of the Indonesian Academy of Sciences. ALMI was formally established with the signing of Republic of Indonesia Presidential Decree No.9 / 2016 concerning Revision of the AIPI Statutes and Bylaws, on 29 February 2016. The birth of ALMI began with the preparation of the book *SAINS45: Indonesian Science Agenda towards a Century of Independence* by a network of Indonesian young scientists , alumni of the AIPI Frontiers of Science initiative. ALMI membership is based on nominations and elections. At present, ALMI works on four focuses: Frontiers of Science, Science & Society, Science & Policy, and Science & Education. Professor Jamaluddin Jompa is the first President of ALMI. The current President of ALMI is Dr. Alan F. Koropitan.

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