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Marine Protected Area in Southeast Asia:
A Brief Look into the Current Landscape, Key Benefits, and Challenges

Shirlyn Tang[1]*, Hui Hui Teow[2], Pervaiz K. Ahmed[3], Mahendhiran Sanggaran Nair[4], Santha Vaithilingam[5]

[1*]*Sunway Institute for Global Strategy and Competitiveness, Sunway University, Malaysia*
[2]*Sunway Institute for Global Strategy and Competitiveness, Sunway University, Malaysia*
[3]*Sunway Institute for Global Strategy and Competitiveness, Sunway University, Malaysia*
[4]*Sunway University, Malaysia*
[5]*Sunway Institute for Global Strategy and Competitiveness, Sunway University, Malaysia*

**Corresponding author: tangshirlyn@gmail.com*

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Abstract

This paper provides a brief overview on the current landscape of marine protected areas (MPAs) in Southeast Asia (SEA). SEA is one of the most biodiverse regions in the world: with just 2.5% of the global marine surface area, the region harbours more than 30% of coral reefs, 50% of seagrass species, and possesses the highest diversity of coral reef fish. However, as a global repository of marine biodiversity and endemism, this region has also been rated as one of the most biotically threatened. To address the losses in marine biodiversity and habitats, MPAs have been increasingly adopted worldwide, including in the SEA. Nonetheless, there exist several problems in the implementation of MPAs in the region. For one, the growth of MPAs in the SEA has been moderately slow compared to other regions. In addition, the question arises as to whether the MPAs in the region are effectively addressing biodiversity needs or are mere "paper parks" piously declared but achieved minimal results in reality. To investigate this issue, the paper highlights issues affecting MPAs' success, including the lack of management effectiveness, law enforcement, and financial capacity. In addition, the relationship with local communities in SEA's MPAs is a pertinent issue, as locals play important roles in enabling the biological and socio-economic success of MPAs.

Keywords*:* Southeast Asia, marine protected area, area-based conservation measures, biodiversity, marine ecosystems

1. Marine Ecosystem in Southeast Asia

1.1 Background

The Southeast Asia (SEA) region is blessed with rich and abundant marine resources (Southeast Asian Fisheries Development Centre, 2022). Made up of 11 sovereign states – Brunei, Cambodia, Timor-Leste, Indonesia, Laos, Malaysia, Myanmar, Philippines, Singapore, Thailand, and Vietnam, the surface area of all seas in the region amounts to over 9 million km^2, representing just 2.5% of global ocean surface area (Chou, 2014) (Table 1 and Figure 1 provide the marine surface areas of SEA countries). With a marginal surface area, SEA harbors more than 30% of the world's coral reefs, almost 50% of existing seagrass species, as well as 600 of the 800 reef-building coral species, housing the highest levels of marine biodiversity on earth (Burke et al., 2002; Savage et al., 2020).

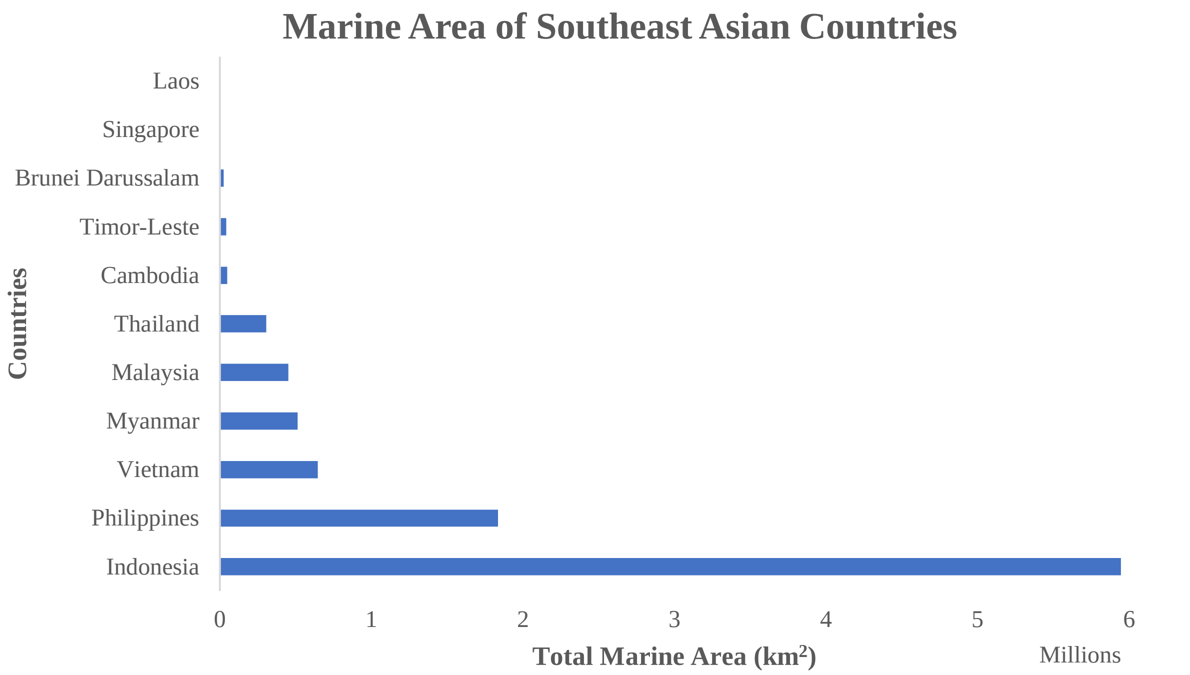
Table 1. *Marine Area of Countries in Southeast Asia*

Countries	Total Marine Area (km2)
Laos	0
Singapore	763
Brunei	25,698
Timor-Leste	42,501
Cambodia	47,967
Thailand	306,891
Malaysia	451,742
Myanmar	514,147
Vietnam	647,232
Philippines	1,835,028
Indonesia	5,947,954

Source: Protected Planet (2022)

Figure 1.

Marine Area (km²) of Countries in Southeast Asia



Source: Protected Planet (2022)

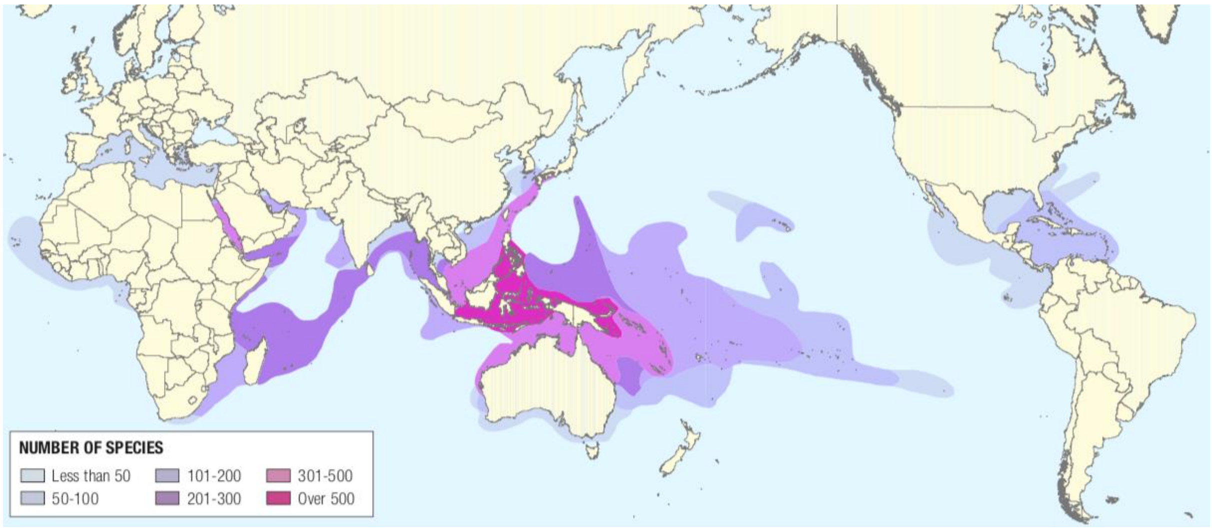
The geographic location of the SEA region is an important factor contributing to its role as a global marine biodiversity hotspot (Chou, 2014; Kamil et al., 2017). The world's two largest archipelagos, Indonesia and the Philippines, consist of more than 25,000 islands (Chou, 2014). Almost all SEA countries along the Asian continent comprise vast coastlines and various offshore islands, most of which are either volcanic or coral. The coastlines amount to approximately 92,450km, which is around 16% of the world's total coastline (Chou, 2014). Coastlines support a wide variety of coastal features, such as cliffs, coves, beaches, deltas, spits, and dunes, all of which harbor high species richness. Furthermore, the scattering locations of islands in the region facilitate the transfer of nutrient content by shifting terrestrial inputs to the marine system (Chou, 2014). The warm and humid weather year-round also contributes to the formation of distinctive natural assets (Chou, 2014; Kamil et al., 2017).

For instance, the SEA region is well known for its abundant coral reefs (Cheung et al., 2002). In particular, the region harbors approximately 34% of the world's coral reefs, which span a total of 100,000km^2, and is nominated globally as a region with the highest diversity of reef-associated fauna (Kamil et al., 2017; Savage et al., 2020). Coral reefs are animals that, in the simplest form, contain a single polyp with a tube-like body and a ring of tentacles at the top section (Burke et al., 2002). In many coral species, the single polyp forms numerous clones in condensed formations, called colonies (Burke et al., 2002). In addition to reducing the wave impacts on coasts by up to 97%, coral reefs act as a vital ecosystem for marine life (Natural History Museum, n.d.). According to the National Ocean Service (n.d.) by the United States Department of Commerce, coral reefs support most species per unit area among all marine environments. For instance, approximately one-fourth of all marine life (i.e., 4,000 fish species) are dependent on them at some point in their lifecycle (National Ocean Service, n.d.; United States Environmental Protection Agency, 2021). This is because the coral reef ecosystem provides crucial feeding, spawning, and nursery grounds for aquatic species (United States Environmental Protection Agency, 2021). In addition, coral reefs are extremely valuable as they are considered key to the creation of new medicines for numerous diseases, such as cancer, arthritis, and infections. Moreover, coral reefs are an important source of revenue for businesses through recreation and tourism activities (National Ocean Service, n.d.).

Figure 2 illustrates the high concentration of reef-building Scleractinian coral species in the region. In particular, the Scleractinian coral species are concentrated in the broad Indo-Malaysian Triangle area, which extends from the Philippines to southern Indonesia and encompasses all of East Java to New Guinea (Burke et al., 2002). Specifically, the SEA region contains over 600 of 800 Scleractinia found worldwide (Burke et al., 2002).

Figure 2.

Diversity Patterns of Reef-Building Scleractinian Corals



Source: From Burke. L., Reytar, K., Spalding, M., & Perry, A. (2011). *Reefs at risk revisited*. Copyroght 2011 by Burke.

Importantly, the marine waters enclosing Indonesia, Malaysia, and the Philippines fall within the Coral Triangle Region (CTR) (Kamil et al., 2017). Regarded as "one of the most important reef systems in the world", the CTR occupies only 1.5% of the global ocean area but constitutes 30% of global coral reefs (Gray, 2018, para. 1). It possesses the greatest coral diversity in the world, accounting for more than three-fourths of the world's known coral species (Coral Triangle Atlas, n.d.; Gray, 2018). Of the different coral species, 15 are endemic to the region (Gray, 2018). In comparison, the Caribbean, which is also famous for its coral reef ecosystem, consists of only 8% of coral species (Coral Triangle Atlas, n.d.).

As the global epicenter for coral reefs, both in terms of coverage and species diversity, it is not surprising that the CTR harbors the highest diversity of coral reef fish (Coral Triangle Atlas, n.d.). Coral reef fish are fish species that reside among or in close relation to coral reefs. Among the consensus of 5,000 to 8,000 coral fish species worldwide, the CTR is home to approximately 2230 species types (i.e., between 28% to 45%) (Coral Triangle Atlas, n.d.;

Victor, 2015). In comparison, the Hawaiian Islands have only 420 species (i.e., 5% to 8.5%) (Coral Triangle Atlas, n.d).

The mangrove forest is another marine-related ecosystem that possesses great ecological and economic importance (Burke et al., 2002; Carugati et al., 2018). In essence, mangroves are salt-tolerant plants that grow in intertidal areas of sheltered coasts around estuaries and lagoons (The Fish Site, 2009). Due to their unique – part marine, part terrestrial – composition and environment, they play vital roles in providing food, breeding grounds, as well as nurseries for terrestrial and marine biodiversity, including many commercial and juvenile reef species (Carugati et al., 2018). For instance, according to the American Museum of Natural History (n.d.), it is estimated that 75% of commercial fish either seek shelter in mangroves or are reliant on food webs linked to these coastal forests. Besides commercially-caught fish, mangroves also act as nursery sites for fish species listed on the IUCN Red List of Threatened Species, such as the "near threatened" rainbow parrotfish and "critically endangered" overexploited goliath grouper (IUCN, 2017). In addition, mangrove forests are also important sources of livelihood – for instance, an estimated 80% of small-scale fishers in many countries rely on mangrove ecosystems to support their operations (Global Mangrove Alliance, 2021). In particular, they house many commercial seafood, such as crabs, shellfish, and oysters, to sea cucumbers, sea urchins, snails, and fish, which are permanent residents that can be directly harvested from within (IUCN, 2017).

Mangroves are distributed in more than 120 countries around the globe (Gandhi & Jones, 2019). While the global estimates of mangrove coverage vary, it is generally agreed that SEA represents one-third of the global mangrove forest, with Indonesia alone housing 20% of them (see Table 2 for the mangrove coverage in the respective SEA countries) (Burke et al., 2002; Global Mangrove Alliance, 2021; The Fish Site, 2009; Richards & Friess, 2016). Five of the top 11 countries with the most mangroves are in the SEA: Indonesia, Malaysia, the Philippines, Thailand, and Vietnam (ASEAN Focus, 2021). In addition, the SEA is home to the greatest diversity of mangrove species – according to Gandhi and Jones (2019), it has 51 of the 73 known species, which is almost 70% (Burke et al., 2002; Richards & Friess, 2016). Moreover, the tropical weather in SEA enables mangrove forests to attain maximal luxuriance and development. According to a systematic review, mangrove forests in the region revealed the highest mangrove ecosystem productivity (Singh et al., 1994, as cited in Chou, 2014). This result was obtained by measuring different production parameters, such as phytoplankton production, benthic primary production, and total litter production.

Table 2. *Mangrove Habitat Extent Area of Southeast Asian Countries in 2016*

Countries	Area of mangrove habitat extent (2016)	
	km^2	ha
Singapore	5	522
Timor-Leste	9	933
Brunei	106	10,628
Cambodia	586	58,560
Vietnam	1,578	157,849
Thailand	2,247	224,687
Philippines	2,675	267,527
Myanmar	4,953	495,345
Malaysia	5,098	509,809
Indonesia	26,508	2,650,812
Total	43,767	4,376,672

Note. Square kilometers are rounded up to the closest whole number. Hectares are calculated by multiplying the respective square kilometers by 100.

Laos is excluded from the analysis due to its landlocked status.

Source: Global Mangrove Watch (2016)

1.2 Degradation of Marine Area and Habitat

Since the mid-1960s, marine ecosystems in the SEA have undergone serious degradation (Chou, 2014). This is due to rapid industrialization, strong economic development, and burgeoning human populations in the region (Chou, 2014). In particular, these factors have caused heavy anthropogenic pressure on the environment, bringing serious ramifications to the marine ecosystems in the region (Chou, 2014). The impacts of human activities on the coastal and marine ecosystem in SEA are especially relevant, given that 85% of SEA's population resides within 100km of the coasts, while the global coastal population averages at 40% (Chou, 2014).

Development activities such as harbor dredging and land reclamation directly affect coral health by damaging reef substrate and increasing sedimentation (Burke et al., 2002). For instance, Singapore has lost approximately 60% of its coral reefs because of land reclamation (Tay et al., 2018). Among six regions (i.e., Atlantic, Australia, Indian Ocean, Middle East, Pacific, and the SEA), local threats to coral reefs are the most prominent in the SEA, where nearly 95% of coral reefs are threatened, with almost half in the high and very high threat categories (Burke et al., 2011) (see Table 6). This percentage is calculated using an index that comprises four components: (i) overfishing and destructive fishing, (ii) marine-based pollution and damage, (iii) coastal development, and (iv) watershed-based pollution.

Table 3. *Integrated Threat to Coral Reefs by Regions*

Region	Coastal population within 30km of the reef (millions)	Integrated local threats (%)			
		Low	Medium	High	Very high
Australia[a]	3,509	86	13	1	<1
Pacific	7,487	52	28	15	5
Middle East	19,041	35	44	13	8
Atlantic	42,541	25	44	18	13
Indian Ocean	65,152	34	32	21	13
SEA	138,156	6	47	28	20

Notes. a. The Australia region includes the Australia territories of Christmas Island and Cocos/Keeling Islands.
Source: Burke et al. (2011)

Another coastal development that seriously impacts the marine ecosystem is mangrove deforestation. Deforestation of mangrove forests has been carried out to support the needs of growing populations (Global Mangrove Alliance, 2021). In the SEA, mangrove forests have been largely converted into aquaculture ponds to carry out rice production, oil palm plantation, fishing, shrimp farming, as well as urban areas and settlements. Another cause of mangrove deforestation involves “non-productive conversion”, a phenomenon that occurs when mangrove areas become unused lands (Global Mangrove Alliance, 2021). These include direct impacts from clearance (i.e., which is primarily done to obtain charcoal and timber), as well as indirect losses through alterations in water distribution, movement, and quality (i.e., including effects of pollution from oil, gas extraction, and nutrient runoffs). Table 4 illustrates the percentages of mangrove conversion to different usages between 2000 to 2012. In particular, aquaculture constitutes the primary usage of mangrove conversion in SEA. The next most popular usage is oil palm plantation, especially in Malaysia, Thailand, and Brunei.

Table 4. *Conversion of Deforested Mangroves to Distinct Land Uses between 2000 and 2012*

	Land Uses (%)					
	Aquaculture	Rice	Oil palm	Mangrove regrowth	Urban	Others
Brunei	29.2	0	27.7	12.5	15.9	14.8
Cambodia	27.7	1.5	8.9	9.8	4.6	47.6
Indonesia	48.6	0.1	15.7	22.6	1.9	11.2
Malaysia	14.7	0.1	38.2	17.6	12.8	16.7
Myanmar	1.6	87.6	1.1	0.5	1.6	7.6
Philippines	36.7	0.9	11.1	7.3	2.7	41.3
Singapore	0	0	0	0	0	0
Thailand	10.8	5.6	40.0	5.1	14.4	24.1
Timor-Leste	0	26.1	0	0	0	73.9[a]
Vietnam	21	10.4	0.5	0.6	62.5	4.9
Total	29.9	21.7	16.3	15.4	4.2	12.3

Note. a: The small amount of mangrove conversion in Timor-Leste is due mainly to shoreline erosion.
Source: Richards & Friess (2016)

Mangrove deforestation hotspots have been identified in Myanmar (esp. in the Rakhine state), Indonesia Sumatra, and Malaysia. On the contrary, mangrove deforestation rates are markedly lower in Thailand, Vietnam, and the Philippines (Richards & Friess, 2016). Despite the varying rates of mangrove deforestation across the region, the latest data has revealed the second-highest mangrove net losses in SEA at 6%, closely tailing the highest net loss in North and Central America and the Caribbean at 7% (Global Mangrove Alliance, 2021) (see Table 5 for the area of mangrove extent in selected regions).

Table 5. *Area of Mangrove in Selected Years from 1996 to 2016*

	Mangrove area (km^2)						
Region	1996	2007	2008	2009	2010	2015	2016
East Asia	170	169	167	165	164	170	171
Middle East	330	321	324	325	324	315	315
Pacific Islands	6,368	6,325	6,326	6,326	6,333	6,278	6,285
East & Southern Africa	7,577	7,317	7,341	7,332	7,311	7,271	7,276
South Asia	8,625	8,497	8,493	8,483	8,495	8,404	8,414
Australia & New Zealand	10,278	10,172	10,186	10,187	10,201	9,980	9,983
South America	19,512	19,105	19,146	19,145	19,127	18,907	18,943
West & Central Africa	20,016	19,913	19,933	19,930	19,916	19,807	19,767
North & Central America & the Caribbean	22,591	21,888	21,986	21,849	20,875	21,205	20,962
Southeast Asia	46,491	44,355	44,378	44,314	44,051	43,587	43,767
Total	141,957	138,064	138,279	138,054	136,798	135,925	135,882

Source: Global Mangrove Alliance (2021)

Deforestation of mangrove forests resulted in the declining population of valuable mangroves species. Examples include the *Sonneratia griffithii* and *Bruguiera hainesii*, both of which are rated as “critically endangered” on the IUCN Red List (Polidoro et al., 2010). Scattered in parts of India and SEA, a combined 80% loss of *Sonneratia griffithii* has taken place in the latter region. In the SEA, deforestation of *Sonneratia griffithii* is especially prominent in Malaysia due to mangrove clearing for aquaculture and rice farming (Polidoro et al., 2010). *Bruguiera hainesii* is an even rarer species: it is considered the rarest mangrove species to date and could only be found in several scattered locations across Indonesia, Malaysia, Thailand, Myanmar, and Singapore (Ono et al., 2016; Polidoro et al., 2010). There are approximately fewer than 250 mature individuals left, which propagations are further complicated by the species’ low germination rate (Polidoro et al., 2010).

Another major threat to SEA's marine ecosystem is overfishing (Burke et al., 2002, 2011; Cheung et al., 2002; Deridder & Nindang, 2018; The ASEAN Post, 2018; The Hornet Newspaper, 2020). Overfishing occurs when the removal of marine species happens at a rate higher than the natural breeding cycles, which may eventually lead to species depletion. The marine industry plays a critical role in the SEA's economy, as it accounts for over 20% of global marine capture production (Southeast Asian fisheries Development Center, 2022) (see Table 6 and Figure 3 for marine capture production by continent, Table 7 and Figure 4 for fisheries production of respective SEA countries in 2019).

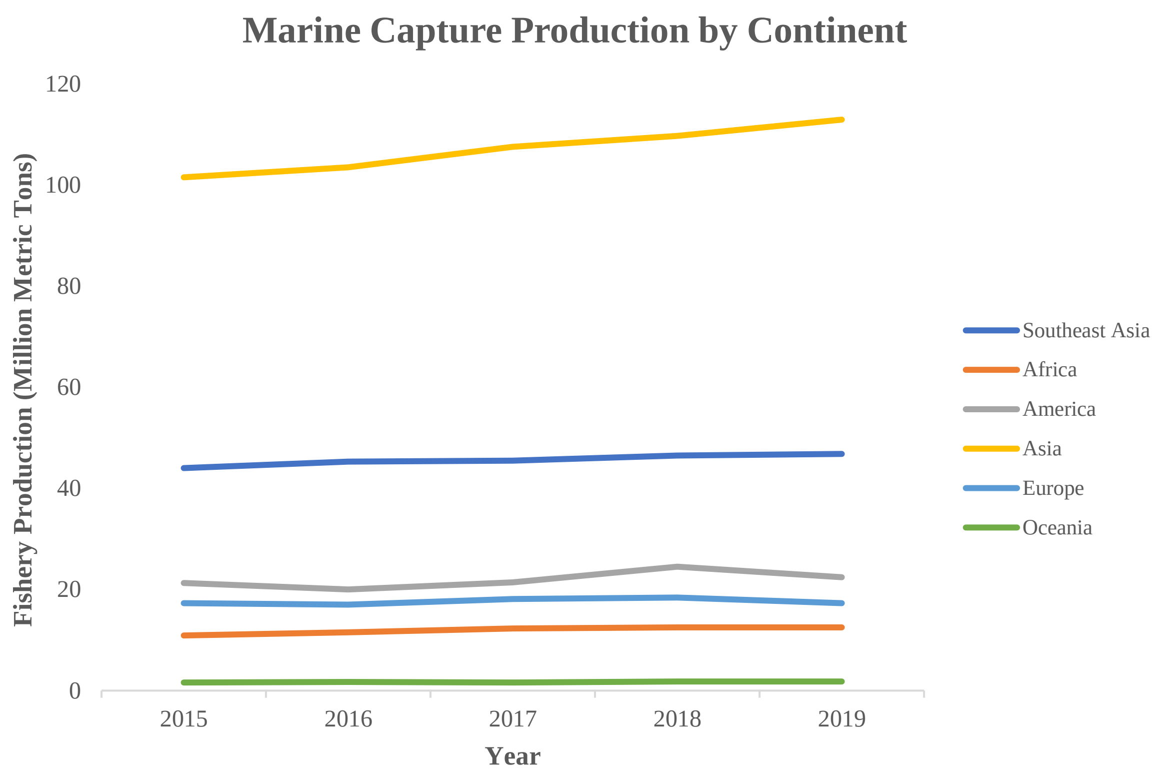
Table 6. *Total Marine Capture Production by Continent from 2015 to 2019*

	Fishery production in million metric tons (M.MT) and percentage (%)									
	2015		2016		2017		2018		2019	
	M.MT	%	M.MT	%	M.MT	%	M.MT	%	M.MT	%
SEA	44	22.4	45.3	22.8	45.5	22.0	46.5	21.8	46.8	21.9
Africa	10.9	5.5	11.5	5.8	12.3	6.0	12.5	5.9	12.5	5.8
America	21.3	10.8	20	10.1	21.4	10.4	24.5	11.5	22.4	10.5
Asia[a]	101.5	51.6	103.5	52.0	107.5	52.1	109.7	51.4	112.9	52.8
Europe	17.3	8.8	17	8.5	18.1	8.8	18.4	8.6	17.3	8.1
Oceania	1.6	0.8	1.7	0.9	1.6	0.8	1.8	0.8	1.8	0.8
World	196.6	100.0	199	100.0	206.4	100.0	213.4	100.0	213.7	100.0

Note. a. Excludes Southeast Asia
Source: Southeast Asian Fisheries Development Center (2022)

Figure 3.

Marine Capture Production by Continent from 2015 to 2019



Source: Southeast Asian Fisheries Development Center (2022)

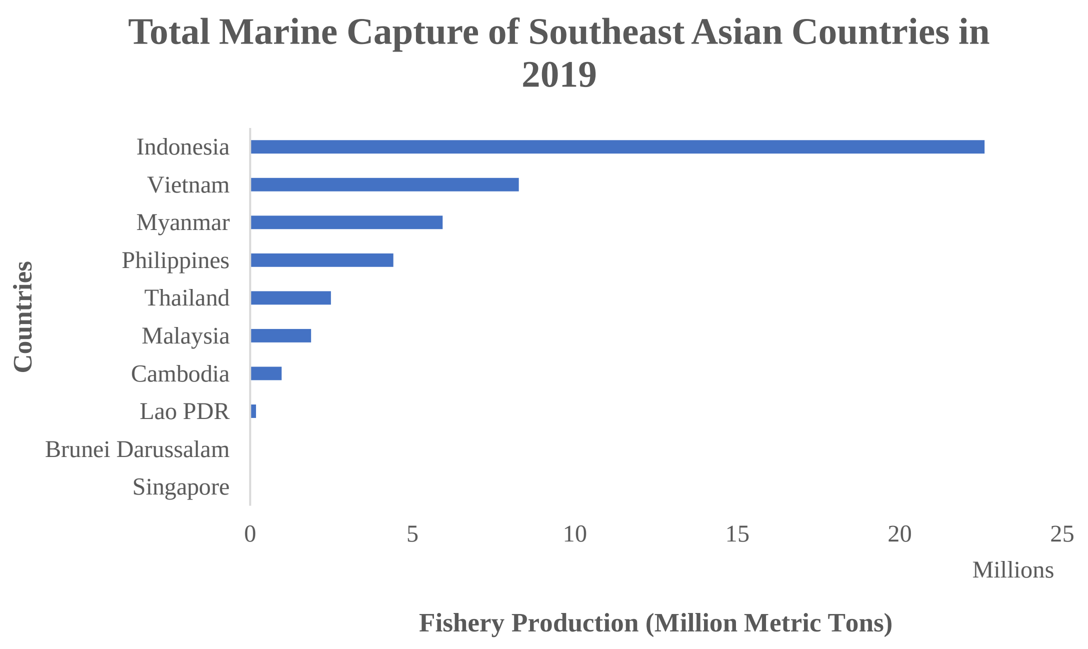
Table 7. *Breakdown of Southeast Asian Countries' Marine Production in 2019*

	Marine production in metric tons (MT)			
	Marine capture	Inland capture	Aquaculture	Total
Singapore	1,418	-	5,831	7,249
Brunei	13,725	N/A	933	14,658
Laos	-	70,900	113,000	183,900
Cambodia	137,225	524,465	307,408	969,098
Malaysia	1,455,446	5,569	411,782	1,872,797
Thailand	1,410,665	116,465	961,703	2,488,833
Philippines	1,900,210	154,681	2,358,238	4,413,129
Myanmar	3,249,700	1,600,050	1,082,065	5,931,815
Vietnam	3,583,000	194,700	4,492,500	8,270,200
Indonesia	6,416,150	649,978	15,548,467	22,614,595
Total	18,167,539	3,316,808	25,281,927	46,766,274

Notes. a. Marine capture refers to all commercial and small-scale fisheries, inland capture refers to any activity that involves catching or collecting aquatic organisms from freshwater areas, aquaculture refers to the farming of aquatic organisms in mariculture, brackishwater culture, and freshwater culture.
b. Brunei's inland capture figure is not available, while Singapore does not have inland capture.
c. Laos does not have marine capture.
Source: Southeast Asian Fisheries Development Center (2022)

Figure 4.

Southeast Asian Countries' Total Marine Capture Production in 2019



Source: Southeast Asian Fisheries Development Center (2022)

In addition, fish and seafood are the primary sources of animal protein in the region (Cheung et al., 2002; Deridder & Nindang, 2018). In particular, marine capture accounts for 60% to 70% of animal protein intake among people in the Philippines, Indonesia, and Malaysia, highlighting the importance of fishery activities as a critical source of sustenance (Cheung et al., 2002; Deridder & Nindang, 2018). Overall, 64% of fishery resources in the SEA are at a medium to high risk of being overfished, with Cambodia and the Philippines being the most significantly impacted (Deridder & Nindang, 2018).

Furthermore, studies estimated that the amount of trash fish captured (i) exceeds 60% of South China Sea's total marine production, comprises (ii) approximately 60% of total capture in the Gulf of Thailand, (iii) 30% to 80% of total fish capture in Vietnam, and (iv) 50% of trawl catches from western Malaysia (United Nations, 2004). While there are varying definitions of trash fish, it is generally referring to fish that are either juveniles, have low consumer preference, or have little to no commercial values (FAO, n.d., a). In some instances, these trash fish are directly consumed in households to avoid wastage, especially in countries such as Bangladesh (FAO, n.d., a; World Wide Fund for Nature, 2022). However, a large proportion of these fish are discarded overboard in conditions of either dying or dead (FAO, n.d., a; World Wide Fund for Nature, 2022). Besides incurring wastage, the high rates of trash fish capture can affect the sustainability of the marine ecosystem in the long run (FAO, n.d., b). This is because juvenile fish are harvested before carrying out species reproduction (FAO, n.d., b).

The degradation of vital marine ecosystems results in enormous losses in economic benefits. For instance, projections have estimated an annual diminution of US$2.2 million from mangrove loss and US$5.6 billion from coral reef loss in 2050 (ASEAN Focus, 2021). To address the degradation of marine ecosystems, recent decades have seen an increase in active management plans. One of the main measures used to protect marine areas is the establishment of MPAs (Burke et al., 2002; Our Shared Seas, 2022).

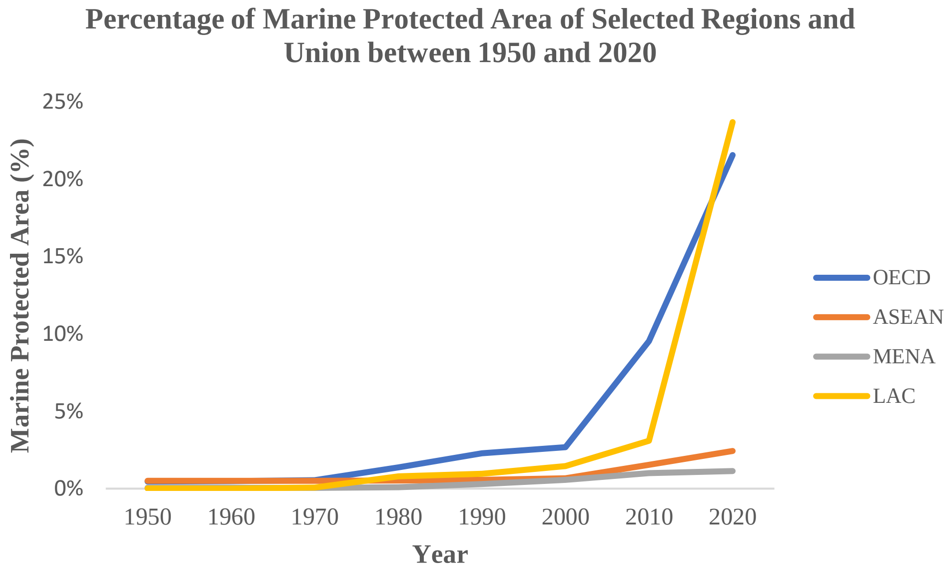
2. Marine Protected Area in Southeast Asia

2.1 Background

Area-based conservation measures offer key perspectives to achieving the post-2020 global biodiversity and sustainability goals (Hoffmann, 2021). Specifically, area-based conservation consists of protected area (PA) and other effective area-based conservation measures (OECM). According to the International Union for Conservation of Nature (IUCN) (2022a), a PA can be defined as "*a clearly defined geographical space, recognised, dedicated and managed, through legal or other effective means, to achieve the long-term conservation of nature with associated ecosystem services and cultural values*" (para. 1).

Figure 5.

The trend of Marine Protected Area Coverage of Selected Regions and Union



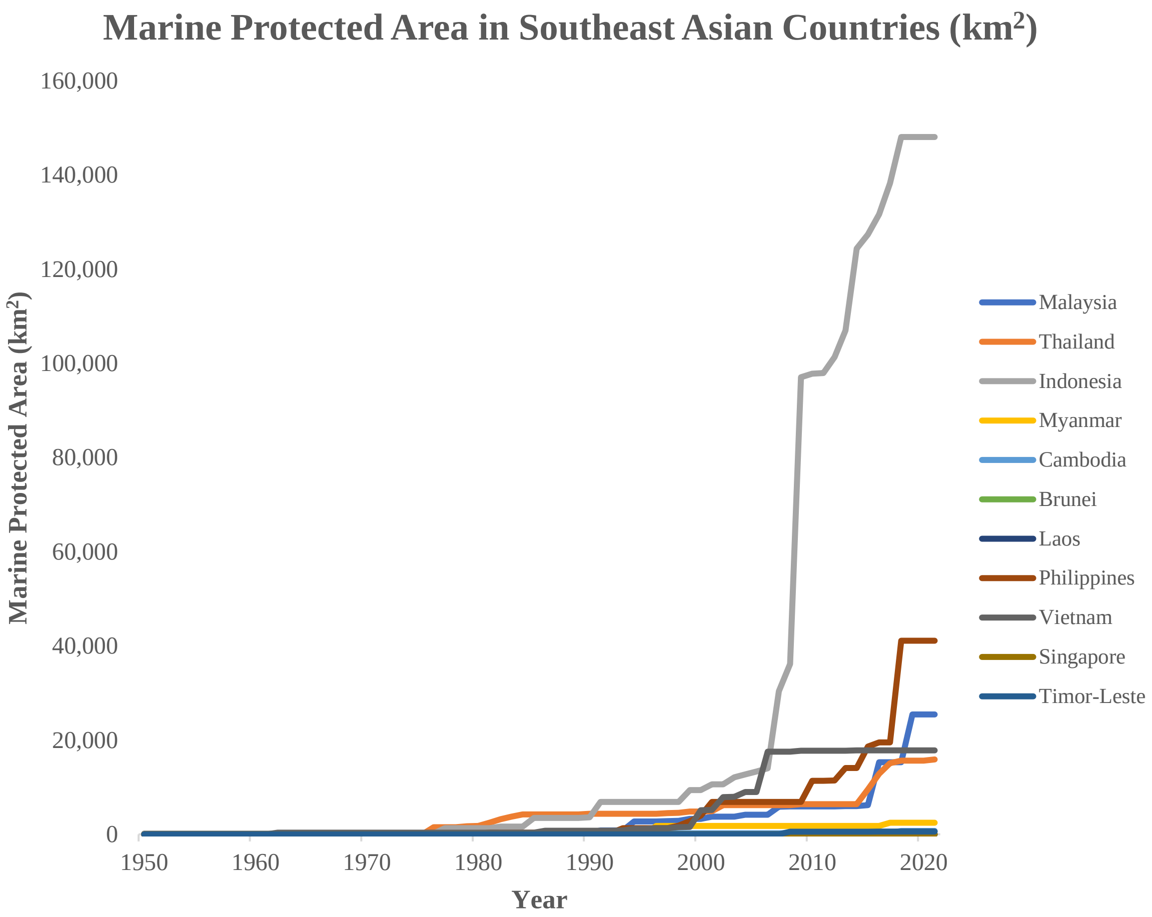
Notes. a. LAC – Latin American and Caribbean, MENA – Middle East and North America
b. The figure for ASEAN does not include Timor-Leste.
c. Percentages are derived by dividing total marine protected area by total marine area in the region/union.
Source: OECD Stat (2021)

Figure 5 presents the trend of MPA in selected global regions and union between 1950 and 2020. The Latin America and Caribbean (LAC) and Organization for Economic Cooperation and Development (OECD) recorded a significant increase in MPA coverage since 2020. In 2020, LAC had the highest MPA coverage at 23.7%, which is followed by the OECD at 21.5%. The percentages of MPA for ASEAN and Middle East and North Africa (MENA) have, on the other hand, remained relatively stagnant between 1950 to 2000. In 2020, ASEAN's MPA coverage was at 2.4%, and MENA's MPA coverage was around 1%.

Of the 11 SEA countries, Indonesia has the largest marine and coastal area, followed by the Philippines, Vietnam, Myanmar, Malaysia, Thailand, Cambodia, Timor-Leste, and Brunei. Laos is a landlocked country; hence it does not possess any marine and coastal area (Protected Planet, 2022) (refer to Figure 6 for an overview and Appendix 1 for the specific figures). While Indonesia possesses the largest marine and coastal area, it has only the third-highest percentage of MPA coverage at 3.06%, which is below Thailand at 4.44%; the country that has the highest percentage of MPA coverage is Malaysia at 5.56% (Protected Planet, 2022) (refer to Figure 7 for an overview and Appendix 1 for the specific figures). Conversely, countries with the lowest percentage of MPA coverage are Singapore (0.01%) and Brunei (0.2%). While Vietnam and Myanmar are among the countries with the biggest marine and coastal areas (second and third, respectively), they have the third and fourth lowest MPA coverage, percentage-wise, at 0.56% and 0.48%, respectively.

Figure 6.

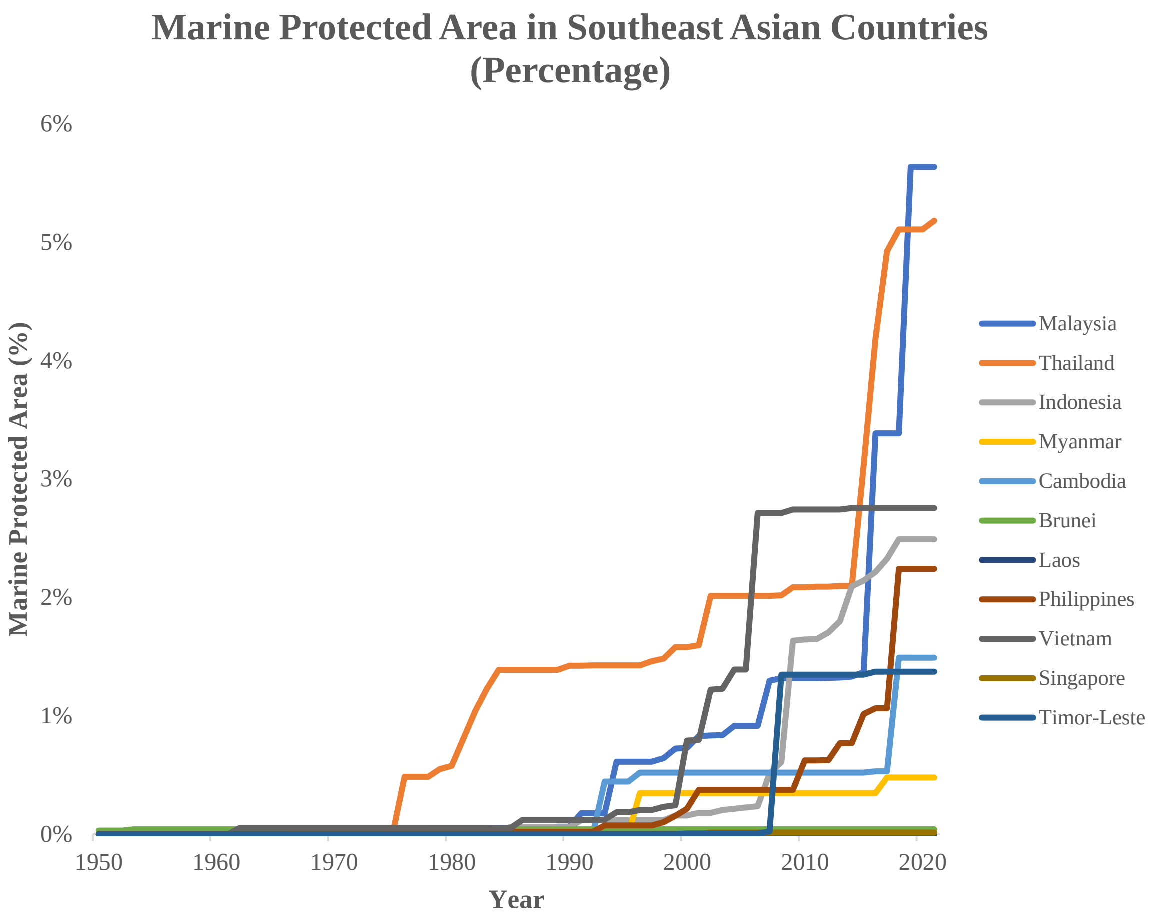
The trend of Marine Protected Areas from 1950 to 2020 in km²



Note. The figures are derived from the dataset downloaded from the Protected Planet (2022) website. Source: Protected Planet (2022)

Figure 7.

The trend of Marine Protected Areas from 1950 to 2020 in percentage



Note. The figures are derived from the dataset downloaded from the Protected Planet (2022) website.
Source: Protected Planet (2022)

These figures fall far short of the Aichi Target 11 and 30 by 30 Initiative. Aichi Target 11 and the 30 by 30 initiatives are among the ambitious biodiversity conservation targets instituted by international organizations. Specifically, the Aichi Target 11 is one of the 20 targets in the Strategic Plan for Biodiversity created by the Convention on Biological Diversity (CBD), a multilateral environmental treaty that aims to conserve biodiversity, as well as to ensure a sustainable, fair, and equitable sharing of benefits that arise from genetic resources (Bhola et al., 2021). In particular, this target calls for the conservation of "*at least 17 per cent of terrestrial and inland water, and 10 per cent of coastal and marine areas, especially areas* *of particular importance for biodiversity and ecosystem services … through effectively and equitably managed, ecologically representative and well connected systems of protected areas and other effective area-based conservation measures, and integrated into the wider landscapes and seascapes"* by 2020 (IUCN, 2022c, para. 3). As a continuation of Aichi Target 11, the High Ambition Coalition for Nature and People launched the 30 by 30 in 2020, which was later promoted at the 15th Conference of the parties to the convention (COP 15) of the CBD (Mukpo, 2021). This initiative is also supported by the Global Ocean Alliance, which is a UK-led initiative that comprises 71 members across the globe (Gov.UK, n.d.). Similar to the Aichi Target 11, the 30 by 30 initiative creates a quantitative goal for the coverage of protected areas to halt biodiversity loss (Mukpo, 2021). Specifically, this plan aims to preserve 30% of global land and sea areas by 2030 through area-based conservation methods (Mukpo, 2021). As of the end of 2021, more than 70 countries have committed to this ambition (Taylor, 2021).

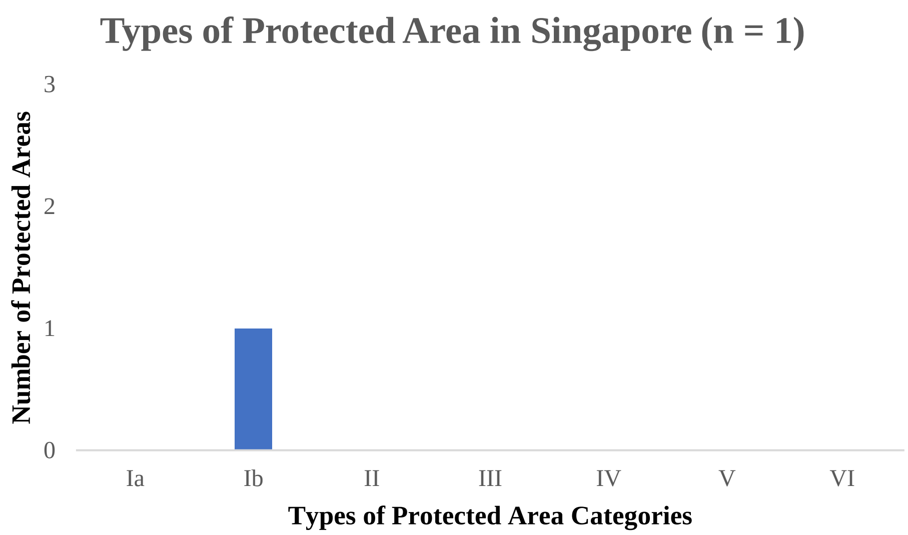
PAs are classified based on distinct management objectives. In particular, there are six categories to cater to different objectives: category I is divided into Ia: strict nature reserve and Ib: wilderness area, category II: national park, category III: natural monument or feature, category IV: habitat/species management area, category V: protected landscape/seascape, and category VI: PA with sustainable of natural resources (IUCN, 2022b) (see Appendix 2 for detailed descriptions for the different categories). Before analysing the IUCN categories of MPAs in SEA, it should be cautioned that a large proportion of IUCN categories for Brunei, Myanmar, Philippines, Timor-Leste, and Vietnam are either "not reported"[1] (NR) or "not applicable"[2] (NA) (Protected Planet, 2022; UNEP-WCMC, 2016). In particular, 67% of Brunei's MPAs, 40% of Myanmar's MPAs, 91% of Timor-Leste's MPAs, and 67% of

[1] "Not reported" applies to PAs which category is unknown and/or relevant information has yet to be provided
[2] "Not applicable" refers to PAs that do not apply to any designation type within the IUCN PA management categories, such as World Heritage Sites and UNESCO MAB Reserves.

Vietnam's MPAs are NR, whereas 66% of the Philippine's MPAs are NA (see Appendix 3 for the breakdowns for each country's MPA based on the IUCN). As a whole, 22% of SEA's MPA are NA, and 14% are NR (Protected Planet, 2022). Figure 8 to Figure 17 present clear illustrations of IUCN categories for each SEA country, though the graphs have excluded data on categories NR, NA, and "not assigned"[3] (NS). Laos' information is also excluded as it is a landlocked country.

Figure 8.

Types of Protected Areas in Singapore

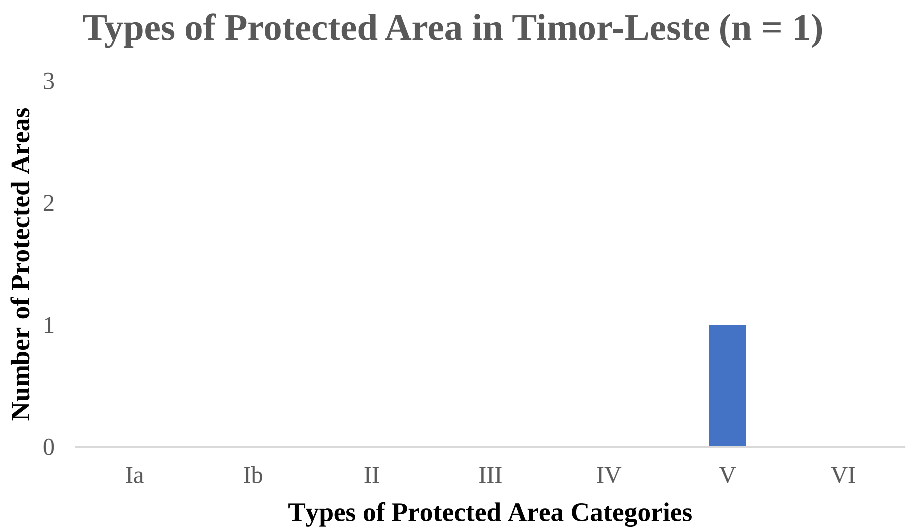


Notes. a. n = total number of marine protected area
b. Data excludes protected areas that are classified as not recognized, not applicable, and not assigned.
Source: Protected Planet (2022)

[3] "Not assigned" is applicable when the data provider opts to not utilize the IUCN PA Management Category, though the PA meets the standard definitions

Figure 9.

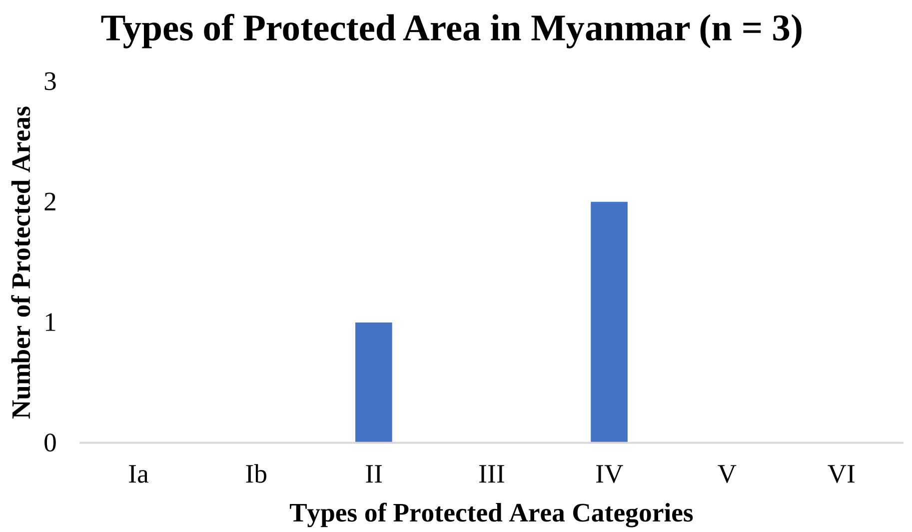
Types of Protected Areas in Timor-Leste



Notes. a. n = total number of marine protected area
b. Data excludes protected areas that are classified as not recognized, not applicable, and not assigned.
Source: Protected Planet (2022)

Figure 10.

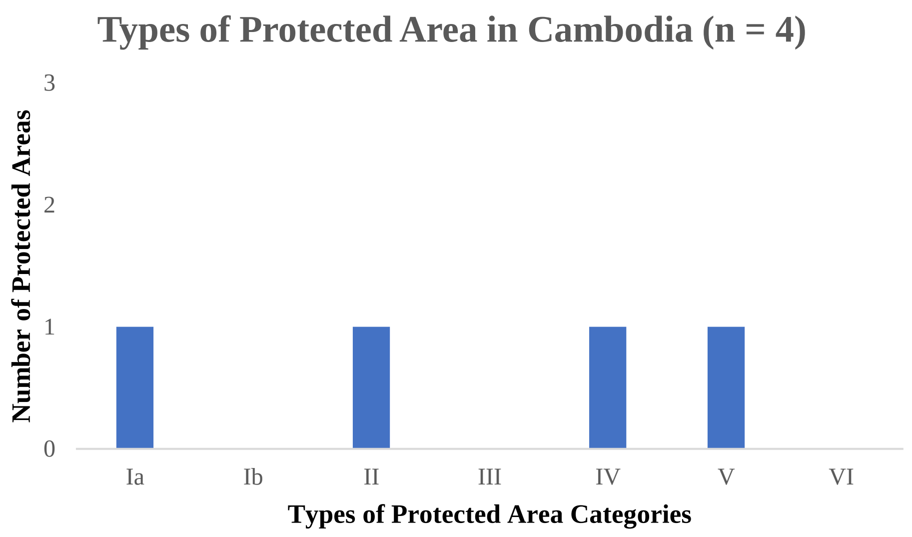
Types of Protected Areas in Myanmar



Notes. a. n = total number of marine protected area
b. Data excludes protected areas that are classified as not recognized, not applicable, and not assigned.
Source: Protected Planet (2022)

Figure 11.

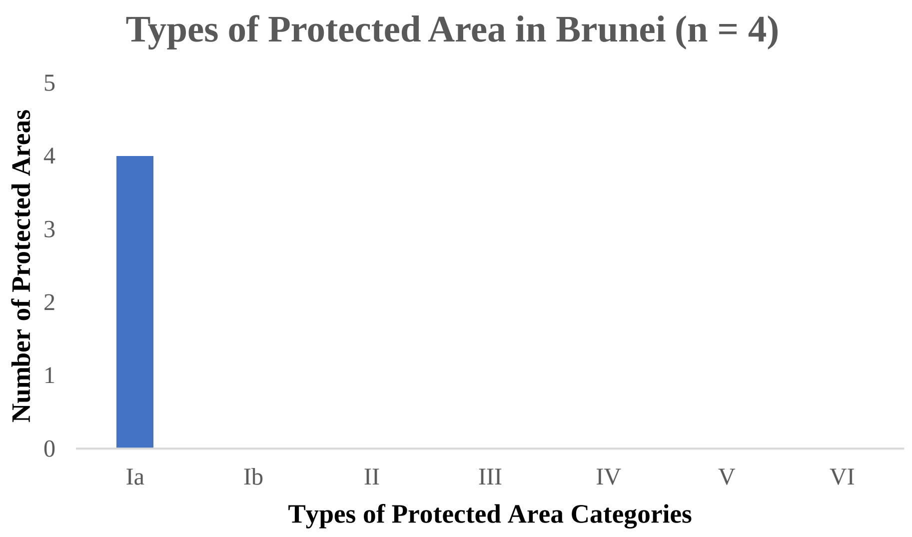
Types of Protected Areas in Cambodia



Notes. a. n = total number of marine protected area
b. Data excludes protected areas that are classified as not recognized, not applicable, and not assigned.
Source: Protected Planet (2022)

Figure 12.

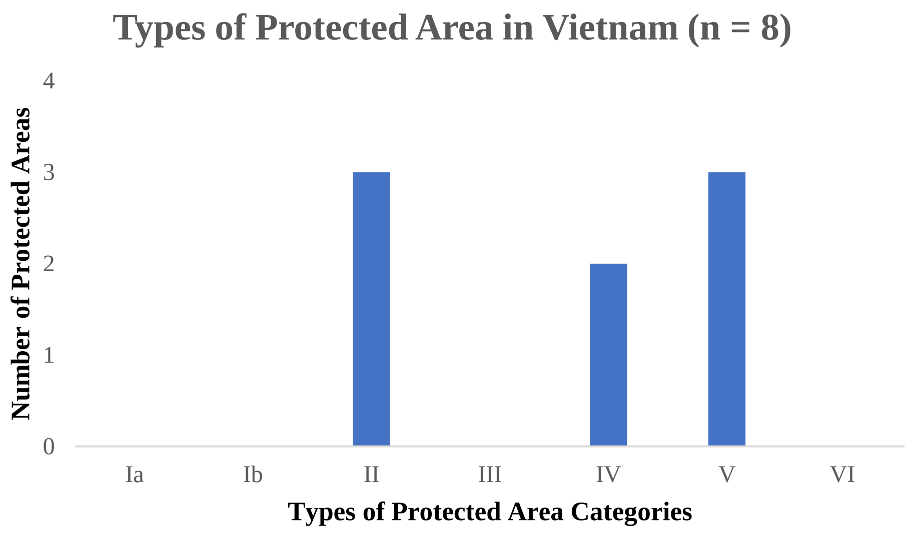
Types of Protected Areas in Brunei



Notes.a. n = total number of marine protected area
b. Data excludes protected areas that are classified as not recognized, not applicable, and not assigned.
Source: Protected Planet (2022)

Figure 13.

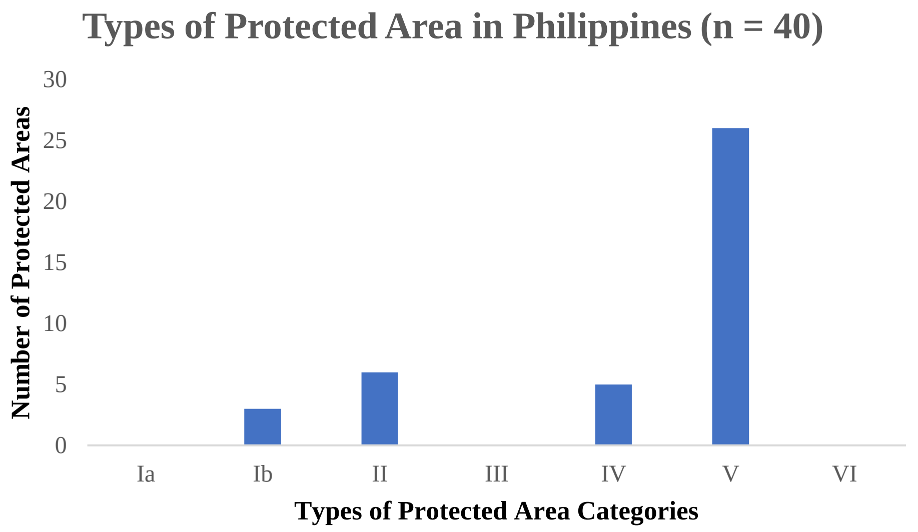
Types of Protected Areas in Vietnam



Notes.a. n = total number of marine protected area
b. Data excludes protected areas that are classified as not recognized, not applicable, and not assigned.
Source: Protected Planet (2022)

Figure 14.

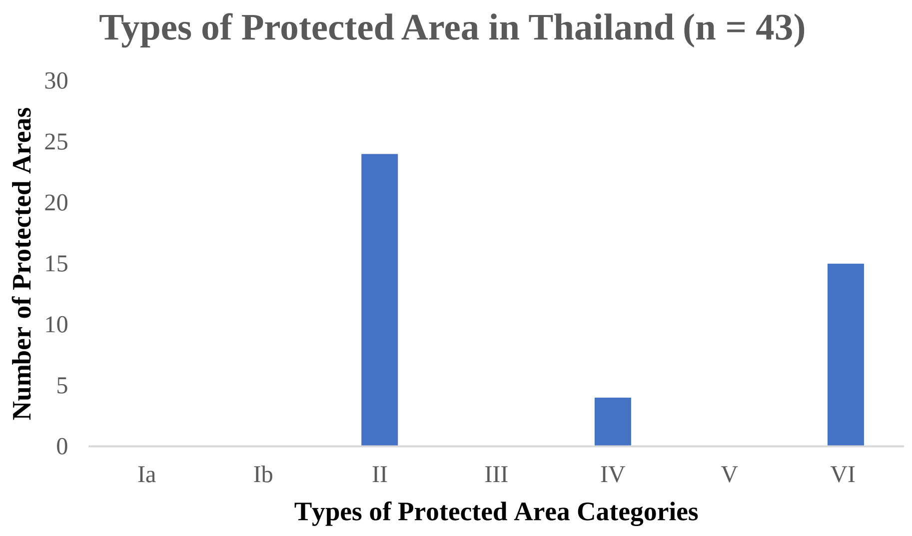
Types of Protected Areas in the Philippines



Notes. a. n = total number of marine protected area
b. Data excludes protected areas that are classified as not recognized, not applicable, and not assigned.
Source: Protected Planet (2022)

Figure 15.

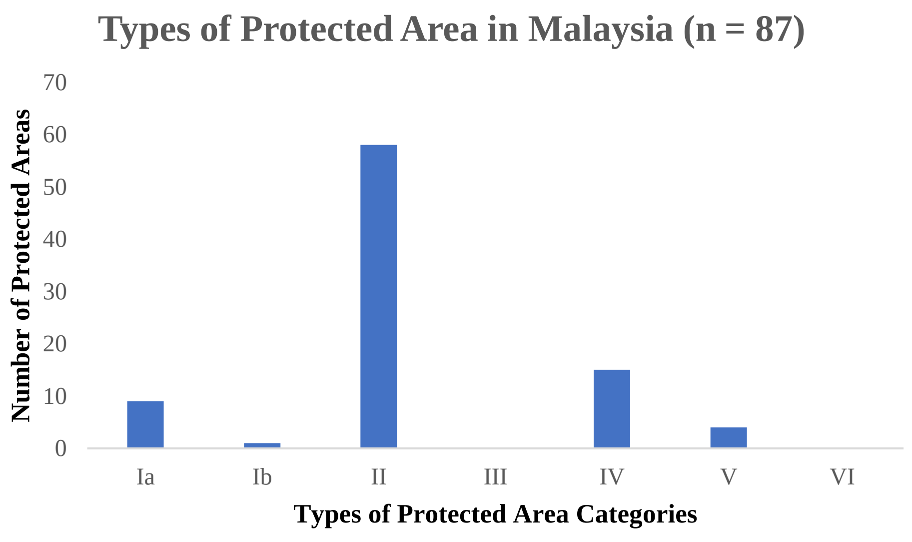
Types of Protected Areas in Thailand



Notes. a. n = total number of marine protected area
b. Data excludes protected areas that are classified as not recognized, not applicable, and not assigned.
Source: Protected Planet (2022)

Figure 16.

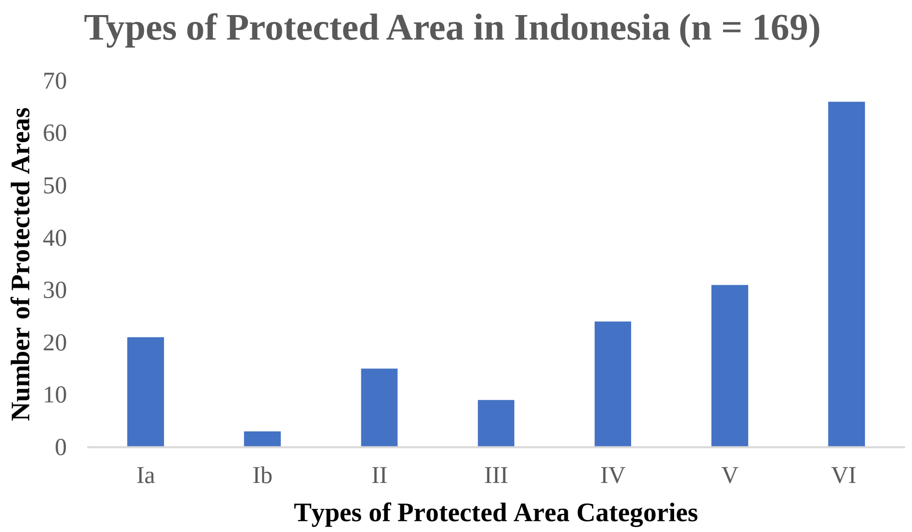
Types of Protected Areas in Malaysia



Notes. a. n = total number of marine protected area
b. Data excludes protected areas that are classified as not recognized, not applicable, and not assigned.
Source: Protected Planet (2022)

Figure 17.

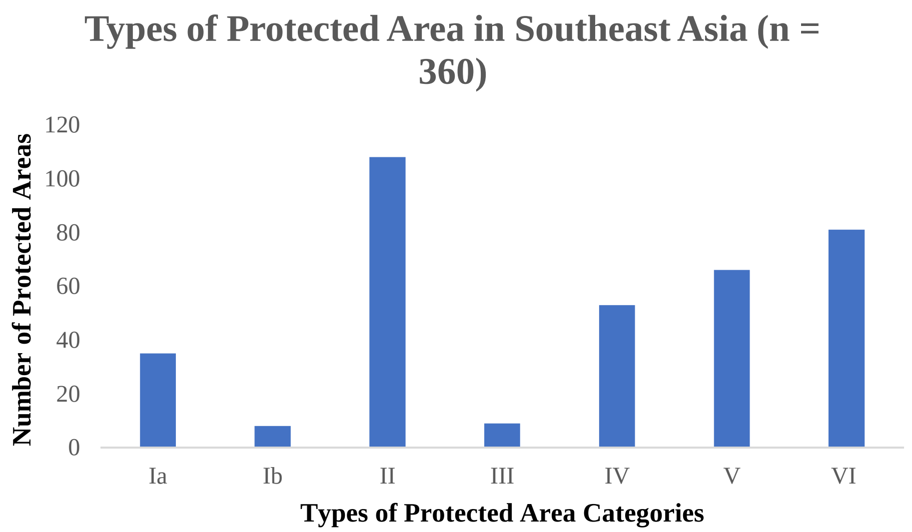
Types of Protected Areas in Indonesia



Notes. a. n = total number of marine protected area
b. Data excludes protected areas that are classified as not recognized, not applicable, and not assigned.
Source: Protected Planet (2022)

Figure 18.

Types of Protected Areas in Southeast Asia



Notes.a. n = total number of marine protected area
b. Data excludes protected areas that are classified as not recognized, not applicable, and not assigned.
Source: Protected Planet (2022)

As shown by the figures, the compositions of IUCN categories vary between countries. For instance, while Brunei has only MPAs in category Ia (i.e., 4), the Philippines does not have any MPAs in category Ia but in categories Ib, II, IV, and V. For countries that have equal to or more than 40 MPAs (i.e., Philippines, Thailand, Malaysia, and Indonesia), there are clearer preferences for specific PA management categories. In particular, there are inclinations towards category II for Thailand and Malaysia, category V for the Philippines, and category VI for Indonesia. Excluding NR, NA, and NS, the largest proportion of MPAs in the SEA are in category II, followed by categories VI, V, IV, I, and III.

According to the IUCN (2013), this categorization system is not intended to be hierarchical, as the type of PAs to utilize depends on several factors, all of which are vital considerations to maximize conservation opportunities and address conservation threats. Examples of such factors include the needs and urgency of biodiversity conservation, unique features, land ownership patterns, long-term goals, the strength of governance, and population level. For research purposes, studies have classified categories Ia, Ib, II, and III as fully PA, and classified categories IV, V, and VI as partially PA (Turnbull et al., 2021). In particular, partial PA may provide leverage in enabling certain social or targeted ecological outcomes, such as allowing traditional fishing practices or protecting certain marine species (Turnbull et al., 2021). However, studies have pointed out the marginal or insignificant biodiversity contributions of partially PA due to the inability to remove human pressures within the area, which may eventually lead to the failure to achieve desired outcomes (e.g., Sala & Glakoumi, 2018; Turnbull et al., 2021). It would be beneficial for future studies to explore this relationship between the different IUCN categories and the effectiveness of biological conservation, particularly in the context of SEA.

2.2 Key Benefits of Marine Protected Areas in Southeast Asia

Effectively managed MPA in the region has pronounced benefits on the biophysical aspects of the marine ecosystem, particularly the density and biomass of marine biodiversity (Kamil et al., 2017). For instance, in the well-managed no-take zone on the Apo Island, Philippines, the biomass of Acanthuridae and Carangidae reef fish tripled over 18 years (Russ et al., 2004). The increased fish biomass within the reserve has spillover effects on areas outside the reserve. In particular, not only was the fish biomass higher in areas near the reserve, but the catch per unit effort also increased both inside and outside the MPA (Russ et al., 2004). In addition to fish density and biomass, coral cover has recorded improvements. For example, a four-year study at the Decalve MPA, Bugor-Sand MPA, and Bintuan MPA by Garces and colleagues (2013) revealed an overall decrease in deal coral cover inside the MPA and an increase in live coral cover outside the MPA, though the changes in coral cover vary between the three MPAs.

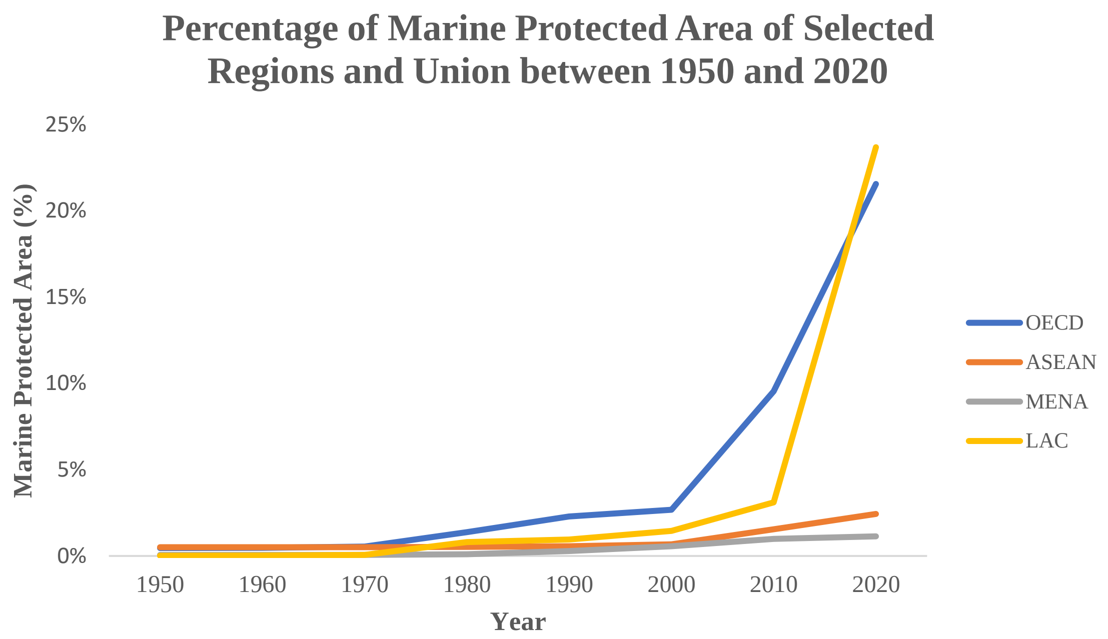
MPAs that are effectively managed also result in positive social benefits. For instance, the gazettement of Redang Island Marine Park and Tioman Island Marine Park in Malaysia has led to enhancements in community infrastructure (Mohd Salleh et al., 2011). In particular, the majority of respondents have indicated that infrastructures such as water supply, electricity, hospitals/clinics, schools, and community halls have improved since the establishment of marine parks (Mohd Salleh et al., 2011). In addition, some studies have shown that establishing MPAs has, directly and indirectly, aided in increasing the level of understanding and positive perceptions among local communities (Kamil et al., 2017). For example, the local community at Mabini in the Philippines believes that fish and coral reef conditions have improved after turning the area into an MPA (Christie, 2005, as cited in Kamil et al., 2017). A five years longitudinal study at the Raja Ampat MPA indicated that education and outreach activities successfully increased knowledge and positive attitudes among the local communities (Leisher et al., 2012). Nonetheless, not all studies on MPAs yielded positive outcomes, as there exist critical flaws in the design and management of MPAs in SEA. The following section will discuss and elaborate on these flaws that exist in SEA's MPA system.

2.3 Key Flaws or Challenges of Marine Protected Areas in Southeast Asia

As a whole, the SEA countries still lag behind developed nations in implementing MPAs. As shown in Figure 19, ASEAN has significantly lower MPA growth rates compared to the LAC region and the OECD (OECD Stat, 2021). It has a slightly higher percentage of MPA coverage as compared to the MENA region, which according to the Global Peace Index (2021), "*remains the world's least peaceful region*" (pp. 2, para. 7) and is one of the most vulnerable regions to degraded marine ecosystems (The World Bank, 2022).

Figure 19.

The trend of Marine Protected Area Coverage of Selected Regions and Union



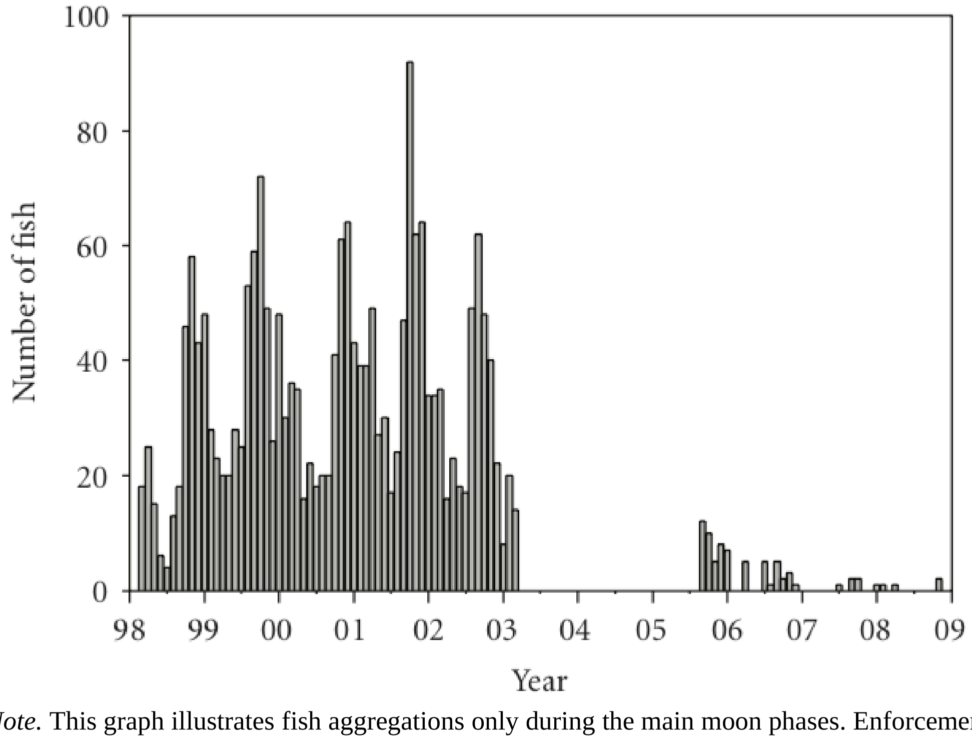
Notes. a. LAC – Latin American and Caribbean, MENA – Middle East and North America
b. The figure for ASEAN does not include Timor-Leste.
c. Percentages are derived by dividing the total marine protected area by the total marine area in the region or union.
Source: OECD Stat (2021)

In addition to the lack of MPA coverage, a major barrier hindering the realization of marine biodiversity protection is the persisting occurrence of anthropogenic activities within MPAs (e.g., Bujan & Arquiza, 2021; Yunanto et al., 2018). Such activities include overfishing, the use of destructive fishing methods, as well as infrastructure constructions. While overfishing and destructive fishing methods in MPAs are less prevalent than in non-MPAs, these activities are, nonetheless, still taking place (e.g., Bujan & Arquiza, 2021; Yunanto et al., 2019). For instance, data collected in Indonesia's MPAs between 2012 and 2014 indicated consistent overfishing in Takabonerate and Aru (Yunato et al., 2019). In addition, destructive fishing activity was still rampant in the Selayar Regency (Yunato et al., 2019). Similarly, illegal fishing is still prevalent in the waters surrounding the Koh Rong Archipelago, which is Cambodia's first MPA (Roig-Boixeda et al., 2018). Tourism activities also contribute to problems, such as the increase in waste pollution and fin and anchor damage on coral reefs (Tejero, 2014). According to Abegg (2014), most MPAs in the Coral Triangle are not managed effectively due to the lack of good enforcement and governance.

As argued by Petit and colleagues (2018), while it is important to extend the coverage of PA, the continuous extension of PA coverage without a strong support system for proper implementation has minimal effects on meeting conservation goals and targets. This results in "paper parks", which are MPA designations that lack ample enforcement and management in practice (Our Shared Seas, 2022). This is especially relevant in SEA, where the lack of effective enforcement is one of the main factors driving the persisting detrimental anthropogenic activities in MPAs. As highlighted in many studies, there are weak monitoring and law enforcement within the MPAs in SEA (Conservation International, 2016; Roig-Boixeda et al., 2018; Walton et al., 2015). For instance, the lack of monitoring and patrolling activities enabled continuous illegal fishing within the no-take zone in Komodo National Park, a marine biodiversity-rich environment within the Coral Triangle (Mangubhai et al., 2011). In the Komodo National Park, authorities prosecuted those who performed destructive fishing methods such as bomb fishing and cyanide. However, little was done to prosecute individuals who fished within no-take zones (Mangubhai et al., 2011). As a result of lapses in monitoring (especially between 2003 and 2005) in enforcement (especially between 2004 and 2005), decades would be needed to restore the populations of *Plectropomus areolatus* aggregations, one of the fish species which is known to have high economic value (Mangubhai et al., 2011) (see Figure 20).

Figure 20.

Number of Plectropomus areolatus Recorded at Fish Spawning Aggregation Sites from March 1998 to December 2009



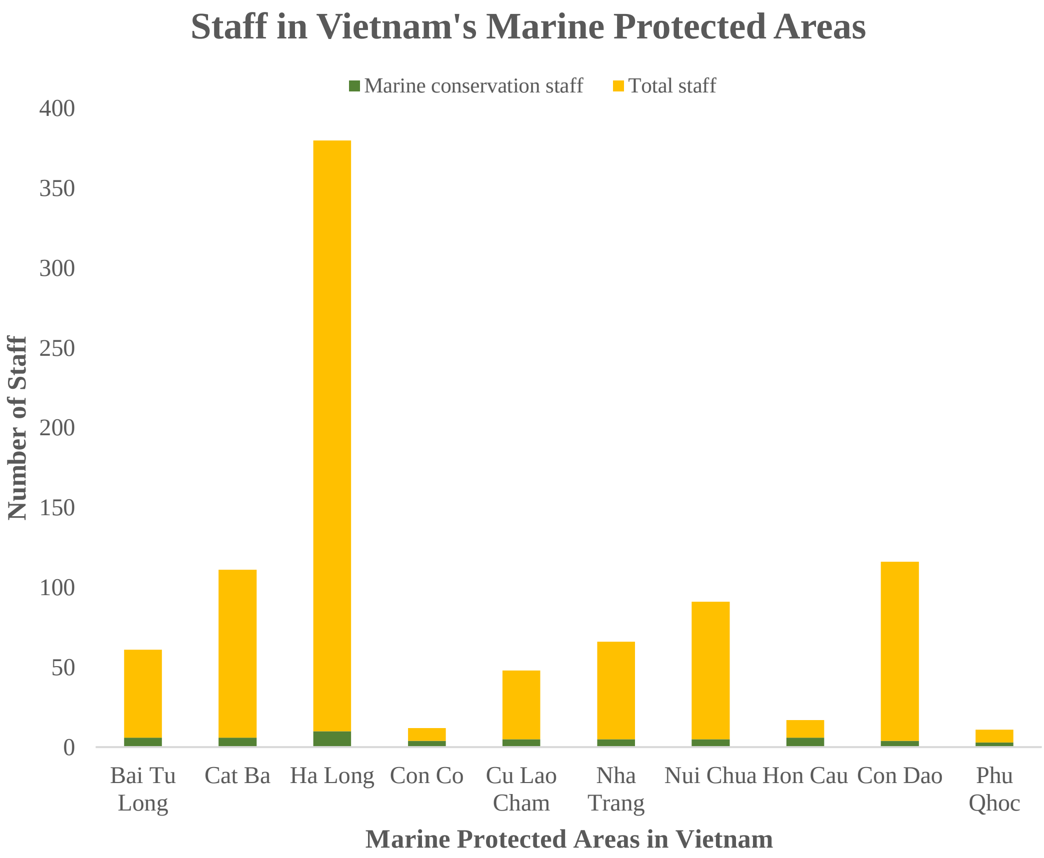
Note. This graph illustrates fish aggregations only during the main moon phases. Enforcement from 2004 to 2005 was at the lowest in a decade. No data were collected from April 2003 to August 2005.
Source: From Mangubhai, S., Saleh, M., Muljadi, A., Rhodes, K. L., & Tjandra, K. (2011). Do not stop: the importance of seamless monitoring and enforcement in an Indonesian marine protected area. *Journal of Marine Biology, 2011*, 501465. Copyright 2011 by Mangubhai

In addition, legislations gaps and inconsistencies have resulted in insufficient MPA protection. For instance, in the Verde Island Passage and Davao Gulf sites with 38 and 19 MPAs, respectively, reclamation and construction at the foreshore have persisted unabated (Bujan & Arquiza, 2021). These activities took place despite opposition from the Philippine local government units. One of the main reasons for such occurrence is the inconsistencies in foreshore governance: the licensing and monitoring of foreshore lease agreements (FLAs) by the DENR Land Management Unit are not in coordination with the local government units' land use plans. In particular, the land classification subjacent of FLAs have weak enforcement and coastal ecosystems protection rights. This enables FLAs' legal holders to continue operating in ways that are harmful to marine ecosystems (Bujan & Arquiza, 2021). Malaysia's MPA management faces a similar situation, where the dichotomy in jurisdictions between the federal and state governments has resulted in inefficient and unsustainable management of MPAs (Islam, 2014). In particular, the state government is responsible for land matters on the marine park islands, while the federal government manages the jurisdiction of water areas up to two nautical miles surrounding the island. This dichotomy in jurisdictions between the federal and state governments has resulted in inefficient and unsustainable management of MPAs (Islam, 2014).

Moreover, many MPAs within SEA lack the necessary staff capacity and funds to ensure the proper execution of essential management activities (e.g., Conservation International, 2016; Hockings et al., 2012; Tejero, 2014; Walton et al., 2015). These are serious issues, as well-resourced staffing and financial capacity are keys to executing effective administration, monitoring, enforcement, and community engagement, among other tasks (Gill et al., 2017; Our Shared Seas, 2022). For instance, the severe lack of funds for Vietnam MPAs has impeded the purchase of basic facilities and infrastructure, such as boats and diving equipment (Walton et al., 2015). The absence of these equipment pieces essential for monitoring work has led to the "non-existent" surveillance and law enforcement in these areas (Walton et al., 2015, p. 11). In addition to the amount of staff (see Figure 21), staff competence has also been severely lacking. In particular, all staff in Vietnam's MPAs do not possess professional backgrounds in marine biology, and most of them have been trained as foresters (Walton et al., 2015). Similarly, limited training opportunities combined with a paucity of formal marine conservation-related qualifications have resulted in a poorly skilled workforce among MPAs staff in Thailand (Hockings et al., 2012).

Figure 21.

Staff Capacity at Vietnam's Marine Protected Areas



Note. Marine conservation staff refers to personnel in specific marine conservation-related departments (e.g., marine research and development department and wetland conservation department). The others involve staff responsible for other aspects of MPAs, such as tourism.
Source: Walton et al. (2015)

In addition to the skills required for proper evaluation, monitoring, and marine research work, staff across many MPAs in the region lack the business and entrepreneurial skills needed to expand and diversify revenue opportunities, as well as to carry out vital business interests on an equal footing (Hockings et al., 2012). It is important to address this issue as it hinders the creation of financial sustainability for MPAs, which is critical in ensuring effective management of PAs in the long run (United Nations Environment Programme, 2014). Moreover, developing governments' allocations of conservation investment are typically lower or more difficult to acquire than those of developed countries, making it more crucial for staff in developing countries to possess business skills (Birdlife International, 2004). For instance, in many SEA countries, the major funders for MPAs are the national governments (Cripps, 2020; United Nations Development Programme, 2014). Those with fewer resources have to be more dependent on aid from international organizations, philanthropic foundations, and NGOs to fill the financial gaps (Cripps, 2020; United Nations Development Programme, 2014). Thus, possessing the know-how to foster sustainable tourism and attract additional funding sources is critical to ensuring the long-term financial sustainability of MPAs.

Finally, authorities need to reflect on their relationships with local communities, as the success of MPAs is heavily dependent on positive perceptions and engagement with the local populations (Benette & Dearden, 2014). In some instances, the establishment of MPAs has resulted in serious conflicts between the authorities and local communities, causing hindrances in achieving both biological and socio-economic goals in MPAs. For instance, the governance switch from community-based to central governance on Balicasag Island has obtained minimal support from the local community (Christie, 2004). As a result, fish populations within the no-take area recorded a drastic decline (Christie, 2004). In particular, fish populations of targeted species have declined 291% within 13 years because of the increase in poachers that were formerly supportive community members. In general, conflicts or disagreements arise as the locals feel undermined and restricted by the laws (Kamil et al., 2017). Moreover, they are also dissatisfied with the lack of job alternatives, in addition to the loss of earning opportunities because of tourism operators (Kamil et al., 2017). These circumstances are attributable to two overarching factors: (i) shortcomings in governance and communication and (ii) indirect livelihood consequences from governance.

One of the reasons for governance shortcomings is the complexity and myriad factors involved in executing optimal MPA governance (Kamil et al., 2017; Masud et al., 2022). There are several MPA management approaches: centralized (i.e., top-down), community-based (i.e., bottom-up), and collaborative management (i.e., shared power between the authorities and locals) (Kamil et al., 2017; Masud et al., 2022). According to a literature review by Kamil and colleagues (2017), there has been a transition of MPA management approaches in SEA, particularly from community-based MPA to more centralized management. However, findings and opinions on the superiority of management approaches are mixed. There are pros and cons with both approaches: bottom-up community-based management takes into consideration issues of local communities, while the top-down MPA management approach enables effective resource management and utilization, as well as ensures functional connectivity of areas (Kamil et al., 2017; Marriot et al., 2021; Masud et al., 2022). Studies have also shown support for collaborative management as it fosters both economic development and dispute management between the government and local communities. (e.g., Masud et al., 2022). However, this approach, too, has its shortcomings. In particular, effective communication and cooperation in this management approach are crucial to producing fruitful results. In addition to the respective challenges, the suitability of management approaches needs to consider a range of localized factors, such as socio-political and present socio-economic contexts. For example, while the institution of the National Integrated Protected Areas System (NIPAS) in the Philippines has reinforced several MPAs in the country, it has undermined the management of the previously successful community-based MPAs in Apo Island (Christie & White, 2007). Thus, while collaborative management is generally agreed to be the best management approach, given the complexity of executing this strategy as well as the myriad factors present in different socio-contexts, it is a challenging task to execute optimum governance that maximizes MPA development and well-being of local communities (Kamil et al., 2017; Masud et al., 2022).

Regardless of the management approach types, communication between the authorities and local communities needs to be improved, as studies have indicated a lack of effective communication between both parties in SEA's MPAs (e.g., Christie & White, 2007; Islam, 2014; Kamil et al., 2017; Masud et al., 2022). Effective communication is a two-way process: to understand local opinions when informing MPA management, but also to foster understanding of MPA management within the local communities (Trajano et al., 2018). Understanding local perceptions is the key to uncovering reasons for non-compliance in MPAs (Roig-Boxeda et al., 2018). Fostering understanding, on the other hand, is important to increase awareness and understanding of MPA's importance and benefits, as insufficient understanding may increase resistance to rules adherence, as well as in the engagement of local communities in MPA management (Trajano et al., 2018). For instance, some coastal communities in the Philippines have negative perceptions of MPAs (Yan, 2016). In particular, instead of being an important tool to conserve biodiversity, MPAs are viewed as a hindrance to their ability to carry out fishing activities in front of their homes. All in all, both understanding and fostering understanding are imperative to carrying out effective MPA management.

In addition, while several studies have indicated modestly positive socio-economic outcomes, the overall impacts of MPAs on livelihoods are mixed and heterogenous (Benette &

Dearden, 2014). In particular, while the establishment of MPAs has fostered a certain degree of livelihood diversification, especially in the tourism and hospitality industries, studies have suggested some unintended negative consequences from several MPA implementations (Haenssgen et al., 2021). For instance, conservation management efforts by community fishery organizations in Koh Sdach – a soon-to-be MPA in Cambodia – did not discernibly enhance fishing-dependent livelihoods. Instead, these efforts are said to have resulted in divided and agitated communities "locked" in a cycle of marine resource dependence (Haenssgen et al., 2021, p. 11). This phenomenon has been attributed to the lack of consideration of local social contexts, as well as the absence of support to carry out livelihood adaptation among the affected communities (Haenssgen et al., 2021). In another study measuring the perceived impacts of 17 national marine parks in Thailand, local communities perceive little employment benefits from tourism and marine parks management, except for selected elites that would gain significantly (Benette & Dearden, 2014). Furthermore, negative implications were perceived as a result of developmental lag and diminished access to social, cultural, and financial assets.

The limited contribution of tourism revenues to the local economy further contributes to the attenuation of livelihood in some MPAs (Kamil et al., 2017). For instance, a study by Yacob and colleagues (2007) indicated that tourism revenues in Malaysia Redang Marine Park scarcely contribute to the local economy. This is because only one-third of the benefits were retained in the country (and even a smaller proportion in the marine park), while the majority of revenues were "leaked" to overseas airlines and operators (Yacob et al., 2007, p. 7). A more recent study by Pham (2020) in the Vietnam Nha Trang Bay MPA has found similar findings, where tourism did not provide sufficient employment opportunities or income to the local communities. In particular, tourism investors outside of the MPA are the beneficiaries of tourism revenue, whereas the share of revenue allotted to the local community is modest (Pham, 2020).

3. Concluding Remarks

Blessed with a rich and unique marine natural heritage, SEA is recognized as one of the world's marine biodiversity hotspots. Nonetheless, with the heavy anthropogenic pressures driven by the increasing population and rapid economic growth, the marine ecosystem in SEA has embarked on a path of deterioration since the mid-1950s. To halt the continuous degradation of marine ecosystems and to achieve the post-2020 global biodiversity and sustainability goals, MPAs have been instituted and recognized as one of the vital environmental conservation measures. Currently, SEA's MPA coverage still falls far short of international targets, such as the Aichi Target 11 and 30 by 30 initiatives.

Indeed, quantitative goals present clear targets that countries need to strive to achieve. However, it is vital to ensure the presence of key enabling conditions to achieve successful MPAs in addition to achieving the quantitative targets. While successful MPAs offer significant benefits, such as improving biophysical elements of marine ecosystems and providing socio-economic benefits to local communities, critical flaws are present in the current SEA MPA system. In addition to the fundamental lack of MPA coverage, harmful anthropogenic activities still occur within the MPAs. Several reasons for this persisting condition include weak monitoring and law enforcement, gaps, and inconsistencies in current legislation, as well as funding and staff deficiencies. Finally, it is vital to address the issues concerning the local communities in MPAs, as the lack of support and understanding from the locals seriously undermines MPA development and effectiveness. In particular, the suitability and effectiveness of governance methods need to be further explored in different social contexts. Moreover, the consequences of MPA governance and establishment on locals' livelihoods need to be further examined.

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5. Appendix

Appendix 1. *Marine Protected Area in Southeast Asia.*

	Total marine & coastal area (km^2)	No. of marine protected area	No. of partial marine protected area	Marine protected area coverage	
				km^2	%
Brunei	25,698	11	1	52	0.20
Cambodia	47,967	0	4	691	1.44
Indonesia	5,947,954	97	101	181,865	3.06
Laos	0	0	0	0	0
Malaysia	451,742	69	22	25,099	5.56
Myanmar	514,147	0	5	2,457	0.48
Philippines	1,835,028	137	43	32,010	1.74
Singapore	763	1	0	0	0.01
Thailand	306,891	16	28	13,635	4.44
Timor-Leste	42,501	6	5	583	1.37
Vietnam	647,232	10	36	3,630	0.56
Total	9,819,923	347	245	260,022	0.03

Source: Protected Planet, 2022

Appendix 2. *Definitions of IUCN Protected Area Categories.*

Categories		Descriptions
Ia	Strict nature reserve	Strictly protected for biodiversity and also possibly geological/ geomorphological features, where human visitation, use and impacts are controlled and limited to ensure protection of the conservation values
Ib	Wilderness area	Usually large unmodified or slightly modified areas, retaining their natural character and influence, without permanent or significant human habitation, protected and managed to preserve their natural condition
II	National park	Large natural or near-natural areas protecting large-scale ecological processes with characteristic species and ecosystems, which also have environmentally and culturally compatible spiritual, scientific, educational, recreational and visitor opportunities
III	Natural monument or feature	Areas set aside to protect a specific natural monument, which can be a landform, sea mount, marine cavern, geological feature such as a cave, or a living feature such as an ancient grove
IV	Habitat/species management area	Areas to protect particular species or habitats, where management reflects this priority. Many will need regular, active interventions to meet the needs of particular species or habitats, but this is not a requirement of the category
V	Protected landscape/seascape	Where the interaction of people and nature over time has produced a distinct character with significant ecological, biological, cultural and scenic value: and where safeguarding the integrity of this interaction is vital to protecting and sustaining the area and its associated nature conservation and other values

VI	Protected area with sustainable use of natural resources	Areas which conserve ecosystems, together with associated cultural values and traditional natural resource management systems. Generally large, mainly in a natural condition, with a proportion under sustainable natural resource management and where low-level non-industrial natural resource use compatible with nature conservation is seen as one of the main aims

Note: The category given is based on the primary management aims, which should be applied to at least 75% of the protected area

Source: IUCN, 2013

Appendix 3. *Respective counts of IUCN Categories of Marine Protected Area in Southeast Asia.*

		Ia	Ib	II	III	IV	V	VI	Not reported	Not applicable	Not assigned	Total
Brunei	*Partial marine*	1	0	0	0	0	0	0	0	0	0	1
	Complete marine	3	0	0	0	0	0	0	8	0	0	11
	Total	4	0	0	0	0	0	0	8	0	0	12
	%	33%	0%	0%	0%	0%	0%	0%	67%	0%	0%	100%
Cambodia	*Partial marine*	1	0	1	0	1	1	0	0	0	0	4
	Complete marine	0	0	0	0	0	0	0	0	0	0	0
	Total	1	0	1	0	1	1	0	0	0	0	4
	%	25%	0%	25%	0%	25%	25%	0%	0%	0%	0%	100%
Indonesia	*Partial marine*	15	3	6	4	13	23	24	10	3	0	101
	Complete marine	6	0	9	5	11	8	42	15	1	0	97
	Total	21	3	15	9	24	31	66	25	4	0	198
	%	11%	2%	8%	5%	12%	16%	33%	13%	2%	0%	100%
Laos	*Partial marine*	0	0	0	0	0	0	0	0	0	0	0
	Complete marine	0	0	0	0	0	0	0	0	0	0	0
	Total	0	0	0	0	0	0	0	0	0	0	0
	%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Malaysia	*Partial marine*	8	0	9	0	4	1	0	0	0	0	22
	Complete marine	1	1	49	0	11	3	0	4	0	0	69

	Total	9	1	58	0	15	4	0	4	0	0	91
	%	10%	1%	64%	0%	16%	4%	0%	4%	0%	0%	100%
Myanmar	*Partial marine*	0	0	1	0	2	0	0	2	0	0	5
	Complete marine	0	0	0	0	0	0	0	0	0	0	0
	Total	0	0	1	0	2	0	0	2	0	0	5
	%	0%	0%	20%	0%	40%	0%	0%	40%	0%	0%	100%
Philippines	*Partial marine*	0	1	2	0	4	14	0	0	3	19	43
	Complete marine	0	2	4	0	1	12	0	2	115	1	137
	Total	0	3	6	0	5	26	0	2	118	20	180
	%	0%	2%	3%	0%	3%	14%	0%	1%	66%	11%	100%
Singapore	*Partial marine*	0	0	0	0	0	0	0	0	0	0	0
	Complete marine	0	1	0	0	0	0	0	0	0	0	1
	Total	0	1	0	0	0	0	0	0	0	0	1
	%	0%	100%	0%	0%	0%	0%	0%	0%	0%	0%	100%
Thailand	*Partial marine*	0	0	13	0	4	0	11	0	0	0	28
	Complete marine	0	0	11	0	0	0	4	0	1	0	16
	Total	0	0	24	0	4	0	15	0	1	0	44
	%	0%	0%	55%	0%	9%	0%	34%	0%	2%	0%	100%
Timor-Leste	*Partial marine*	0	0	0	0	0	0	0	5	0	0	5
	Complete marine	0	0	0	0	0	1	0	5	0	0	6

	Total	0	0	0	0	0	1	0	10	0	0	11
	%	0%	0%	0%	0%	0%	9%	0%	91%	0%	0%	100%
Vietnam	*Partial marine*	0	0	3	0	1	3	0	22	7	0	36
	Complete marine	0	0	0	0	1	0	0	9	0	0	10
	Total	0	0	3	0	2	3	0	31	7	0	46
	%	0%	0%	7%	0%	4%	7%	0%	67%	15%	0%	100%
Total	*Partial marine*	25	4	35	4	29	42	35	39	13	19	245
	Complete marine	10	4	73	5	24	24	46	43	117	1	347
	Total	35	8	108	9	53	66	81	82	130	20	592
	%	6%	1%	18%	2%	9%	11%	14%	14%	22%	3%	100%

Note: "Partial marine" consists of protected areas which are partially within the marine environmental (e.g., coastal), whereas "complete marine" consists of protected areas which are completely within the marine environment (e.g., ocean). Definitions can be obtained from the World Database on Protected Area's User Manual (UNEP-WCMC, 2016).

Source: Protected Planet, 2022

Terrestrial Biodiversity and Protected Areas in Southeast Asia

Hui Hui Teow[1*], Shirlyn Tang[2], Pervaiz K. Ahmed[3], Mahendhiran Sanggaran Nair[4], Santha Vaithilingam[5]

[1*]*Sunway Institute for Global Strategy and Competitiveness, Sunway University, Malaysia*
[2]*Sunway Institute for Global Strategy and Competitiveness, Sunway University, Malaysia*
[3]*Sunway Institute for Global Strategy and Competitiveness, Sunway University, Malaysia*
[4]*Sunway University, Malaysia*
[5]*Sunway Institute for Global Strategy and Competitiveness, Sunway University, Malaysia*

**Corresponding author: huihuit@sunway.edu.my*

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Abstract

This working paper aims to provide a comprehensive understanding on terrestrial biodiversity and protected areas in Southeast Asia. Southeast Asia consists of a wide array of terrestrial biomes that comprise natural ecosystems rich in biodiversity, such as lowland evergreen forests, montane evergreen forests, tropical rainforests, semi-deciduous forests, limestone karst formations, mossy forests, pine forests, heath forests, monsoon forests, and grasslands. These ecosystems are situated within the four key globally important biodiversity hotspots in Southeast Asia, namely Indo-Burma, Sundaland, the Philippines, and Wallacea, which house around 20% of the world's flora and fauna species. However, these biodiversity hotspots have already lost more than 90% of their original habitats to anthropogenic activities such as deforestation for socio-economic development and unsustainable use of natural resources. To minimize the anthropogenic impacts, terrestrial protected areas have long been designated to conserve biodiversity and protect biologically important terrestrial areas in Southeast Asia. Despite being protected, some protected areas are not efficiently managed. For example, many have failed to protect and conserve certain endemic species. Poor representation of habitats and lack of connectivity between terrestrial protected areas also serve as other problems with the current terrestrial protected area. Furthermore, some terrestrial protected areas are less effective than other unprotected areas at reducing deforestation and conserving biodiversity. As such,

remedial measures are urgently needed to address the shortfalls of these protected areas to ensure the sustainability of biodiversity and ecosystem services.

Keywords: Southeast Asia, biodiversity hotspots, biodiversity loss, terrestrial biodiversity, terrestrial protected areas

1. Terrestrial Ecosystem in Southeast Asia

1.1 Background

Covering an area of about 44.6 million km^2 and a population of over 650 million, Southeast Asia is geographically divided into Mainland Southeast Asia (also known as Indochina) and Maritime Southeast Asia (Malay Archipelago), which comprise eleven countries of rich biodiversity: Singapore, Brunei, Timor-Leste, Cambodia, Laos, Philippines, Vietnam, Malaysia, Thailand, Myanmar, and Indonesia, all of which represent 3% of the world's total land area (Yale, 2022) (see Table 1 for the respective terrestrial areas of Southeast Asia countries). Southeast Asia is situated within the tropical and subtropical climatic zones. These zones encompass four types of landforms, including mountains, hills, plateaus, and plains (Leinbach & Frederick, 2020).

Table 1. *Terrestrial Area (km^2) of Countries in Southeast Asia*

Countries	Total Terrestrial Area (km^2)
Singapore	605
Brunei	5,962
Timor-Leste	15,007
Cambodia	182,511
Laos	231,276
Philippines	298,775
Vietnam	329,880
Malaysia	331,701
Thailand	517,787
Myanmar	673,079
Indonesia	1,906,555

Source: Protected Planet (2022)

The terrestrial ecosystem is a land-based ecosystem that involves interactions between living organisms and non-living elements. It includes the taiga, tundra, grasslands, deserts, and rainforests. The types of ecosystems found in a particular terrestrial area are dependent upon the climate, type of soil, amount of soil minerals and nutrients, presence of endemic species, level of rainfall, elevation, and availability of sunlight (McHaughton, 2021). Southeast Asia consists of a wide array of terrestrial biomes that comprise natural ecosystems rich in biodiversity, such as lowland evergreen forests, montane evergreen forests, tropical rainforests, semi-deciduous forests, limestone karst formations, mossy forests, pine forests, heath forests, monsoon forests, and grasslands (CEPF, 2014; 2020). These ecosystems are situated within four key globally important biodiversity hotspots in Southeast Asia, which will be discussed in detail in the section that follows.

2. Biodiversity Hotspots in Southeast Asia

The Convention of Biological Diversity (CBD) defines biodiversity 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" (Mcgill & Magurran, 2011, p. 292). According to Myers et al. (2000, p. 853), biodiversity hotspots can be defined as "the exceptional concentrations of endemic species and the exceptional loss of habitat." Conservationists and environmentalists have long been using biodiversity hotspots to measure the richness of biodiversity and the degree of habitat loss in certain regions (Mcgill & Magurran, 2011, p. 292). Two strict criteria need to be taken into account when qualifying certain terrestrial regions as biodiversity hotspots. First, the hotspot areas must encompass more than 1,500 species of vascular plants endemic to the regions and cannot be found elsewhere. Secondly, the regions should have lost more than 70% of their original habitat (Critical Ecosystem Partnership Fund

[CEPF], 2022). To date, there are 36 biodiversity hotspots, which are rich in biodiversity but heavily threatened by habitat loss (CEPF, 2022). Of these, four biodiversity hotspots can be found in Southeast Asia: Indo-Burma, Sundaland, the Philippines, and Wallacea, which house around 20% of the world's flora and fauna species (Myers et al., 2000). These four biodiversity hotspots deserve immediate conservation efforts as they consist of a copious amount of endemic species yet have already lost more than 90% of their original habitats (Nilsson, 2019). The details of these biodiversity hotspots will be discussed in the following sections.

Figure 1a. *Indo-Burma Biodiversity Hotspot*

Source: Conservation International/Wikimedia Commons (2005a)

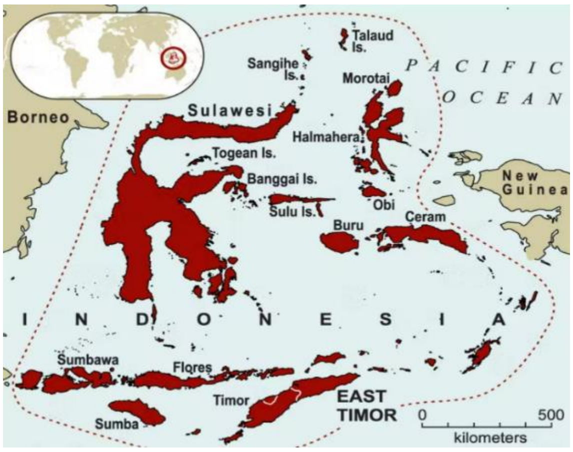
Figure 1b. *Sundaland Biodiversity Hotspot*

Source: Conservation International/Wikimedia Commons (2005)

Figure 1c. *The Philippines Biodiversity Hotspot*

Source: Conservation International/Wikimedia Commons (2005b)

Figure 1d. *The Wallacea Biodiversity Hotspot*



Source: Conservation International/Wikimedia Commons (2005d)

2.1 The Indo-Burma biodiversity hotspot

2.1.1 Terrestrial Ecosystems in the Indo-Burma Biodiversity Hotspot

As shown in Figure 1a, the Indo-Burma biodiversity hotspot covers all land regions in Thailand, Vietnam, Myanmar, Laos, Cambodia, and part of southern China (IUCN, 2020a). As the largest biodiversity hotspot, it covers a total terrestrial area of 2,308,815 km^2 and includes several mountain ranges, such as the Annamite Mountain and parts of the Himalayas. The hotspot is rich in various types of species-rich terrestrial ecosystems, including lowland evergreen forests, montane evergreen forests, semi-evergreen and mixed deciduous forests, limestone karst formations, grasslands, seasonally inundated swamp forests, and freshwater ecosystems. Specifically, lowland evergreen forests (at elevations less than 1,000m) in this hotspot can be found in the lowlands of Thailand, Myanmar, and Vietnam (Mongabay, 2012). However, a large portion of the forests has been substantially exploited due to agricultural expansion and the lucrative market of timber species in these forests (CEPF, 2020). On the other hand, montane evergreen forests (at elevations between 1,000 to 2,500m), which span the Cardamom Mountains of Cambodia, the Annamite Mountains of Laos and Vietnam, mountainous areas of Cambodia, part of southern China, and northern Thailand, are less exploited as compared to lowland forests in this hotspot (CEPF, 2020). Semi-evergreen and mixed deciduous forests, which harbour lesser flora and fauna, are situated within lowland and hill areas across the biodiversity hotspot. Deciduous dipterocarp forest, which is characterized by an open canopy with 50 – 80% canopy cover and a grassy forest floor, is the most prevalent type of forest in Indo-Burma (Rundel, 2009). Consisting primarily of calcium carbonate, limestone karsts are landforms that feature complex terrains such as fissured cliffs and caves and house a large number of unique endemic species such as cave geckos, scorpions, and blind fish (Dreybrodt & Loveridge, 2021). Nevertheless, the need for economic development has put limestone karst biodiversity in this hotspot at risk. For instance, limestone quarrying for cement production has further exacerbated the extinction rate of certain hyperendemic invertebrates, reptiles, fish, and plant species endemic to the hotspot (Lim, 2016).

The grassland ecosystem refers to large open land mainly dominated by different species of grasses with very few trees (Earth Reminder, 2020). There has been a substantial decline in the grassland ecosystem across the Indo-Burma hotspot due to conversion to agriculture, aquaculture, and forestry (CEPF, 2020). Freshwater or peat swamp forests are seasonally inundated with shallow freshwater (Rundel, 2009). This forest type is mainly distributed around the Great Lake of Tonle Sap in Cambodia and the Irrawaddy Delta in Myanmar (CEPF, 2020). Some critically endangered large waterbirds can be found in swamp forests in this ecoregion, such as the Black-Headed Ibis, the Milky Stork, and the Grey-Headed Fish Eagle (Aqua Expedition, 2021). Nonetheless, swamp forests in this hotspot have also been substantially degraded due to their optimal conditions for plantation agriculture (CEPF, 2020). On the other hand, natural freshwater ecosystems involve "the terrestrial phases of the global hydrological cycle and include permanent rivers, streams, lakes, ponds, wetlands as well as groundwaters" (Reid et al., 2020, p. 270). The Tonle Sap in Cambodia is one of the largest freshwater ecosystems in the world (Dempsey, 2014). Specifically, the lake houses 149 fish species from four families, namely Cyprinidae, Bagridae, Siluridae, and Pangasiidae. Furthermore, it is also home to 11 globally endangered species (Campbell et al., 2006). These freshwater areas are essential for communities that rely on their natural resources for livelihoods. Yet, human activities such as unsustainable fishing, overexploitation for human consumption, and hydropower dam construction have caused irreversible damage to freshwater ecosystems in the Indo-Burma hotspot (CEPF, 2020; Dempsey, 2014). Clearly, a vast land area (including freshwater systems) of the Indo-Burma biodiversity hotspot has been degraded and exploited, threatening the various ecosystems and key biodiversity areas across the region

(CEPF, 2020; Tordoff et al., 2012). In fact, only 5% of the original natural habitats are left intact in this biodiversity hotspot (Mittermeier et al., 2004).

2.1.2 Biodiversity in the Indo-Burma Hotspot

The Indo-Burma hotspot is biologically rich and threatened at the same time. It is home to more than 15,000 species of vascular plants, 470 mammal species, 1,330 bird species, 670 reptile species, 380 amphibian species, and 1,440 species of fish (CEPF, 2020). In fact, there are around 1,300 globally threatened species in the Indo-Burma hotspot, of which 17% are critically endangered, 36% are endangered, and 47% are vulnerable (CEPF, 2020) (see Table 2). To be more specific, 20% of mammal species, 8% of bird species, 20% of reptile species, 25% of the amphibian species, and 9% of the fish species in the hotspot are registered as globally endangered. Mammal species such as tiger (*Panthera tigris*), Asian elephant (*Elephas maximus*), banteng (*Bos javanicus*), and Lao leaf monkey (*T. laotum*); bird species such as white-throated wren-babbler (*Rimator pasquieri*), reptile species such as Siamese crocodile (*Crocodylus siamensis*), amphibian species such as Hoang Lien moustached toad (*Leptobrachium echinatum*), and fish species such as the Mekong giant catfish (*Pangasianodon gigas*) are some examples of globally threatened vertebrates that inhabit the Indo-Burma hotspot. On the other hand, nearly half of the plant species in the hotspot are listed as globally endangered plant species (CEPF, 2020). As can be seen, the hotspot's biodiversity is declining at an unprecedented rate, and these globally endangered species are at risk of going extinct very shortly if no further actions are taken to protect the biodiversity against deterioration.

Table 2. *Summary of Globally Threatened Species in the Indo-Burma Hotspot*

Taxonomic Group	Global Threat Status				Distribution by Country					
	Critically Endangered	Endangered	Vulnerable	Total	Cambodia	China	Lao PDR	Myanmar	Thailand	Vietnam
Mammals	18	37	42	**97**	38	49	50	47	57	60
Birds	18	32	58	**108**	34	58	31	63	70	57
Reptiles	28	42	54	**124**	24	36	30	34	38	75
Amphibians	3	42	53	**98**	11	41	17	9	8	52
Fish	25	43	66	**134**	30	27	60	21	61	38
Invertebrates	19	41	88	**148**	6	26	25	9	44	60
Plants	116	234	239	**589**	48	253	69	90	189	269
Total	**227**	**471**	**600**	**1,298**	**191**	**490**	**282**	**273**	**467**	**611**

Source: CEPF (2020, p. 43)

Key biodiversity areas (KBAs) are "sites contributing significantly to the global persistence of biodiversity in terrestrial, freshwater, and marine ecosystems" (IUCN, 2022). As of 2020, the Indo-Burma biodiversity hotspot consists of a total of 555 key biodiversity areas (covering 16% of the total area of the hotspot) with many globally threatened species. However, 44% of the KBAs are not situated within protected areas, implying a mismatch between the KBAs and protected areas in the Indo-Burma biodiversity hotspot (CEPF, 2020). As such, there is an urgent need to reassess the locations of these KBAs and identify ways to improve their practicality in conserving globally threatened species (CEPF, 2020).

Table 3. *Summary of Key Biodiversity Areas in the Indo-Burma Hotspot*

Taxonomic Group	Cambodia	China	Lao PDR	Myanmar	Thailand	Vietnam	Total
Mammals	21	25	32	59	59	78	**274**
Birds	39	55	24	82	63	59	**322**
Reptiles	24	18	20	100	32	21	**215**
Amphibians	2	20	1	0	5	13	**41**
Fish	8	2	13	2	9	5	**39**
Invertebrates	1	0	2	16	3	3	**25**
Plants	8	48	8	28	75	36	**203**
All KBAs	**43**	**90**	**47**	**142**	**117**	**116**	**555**

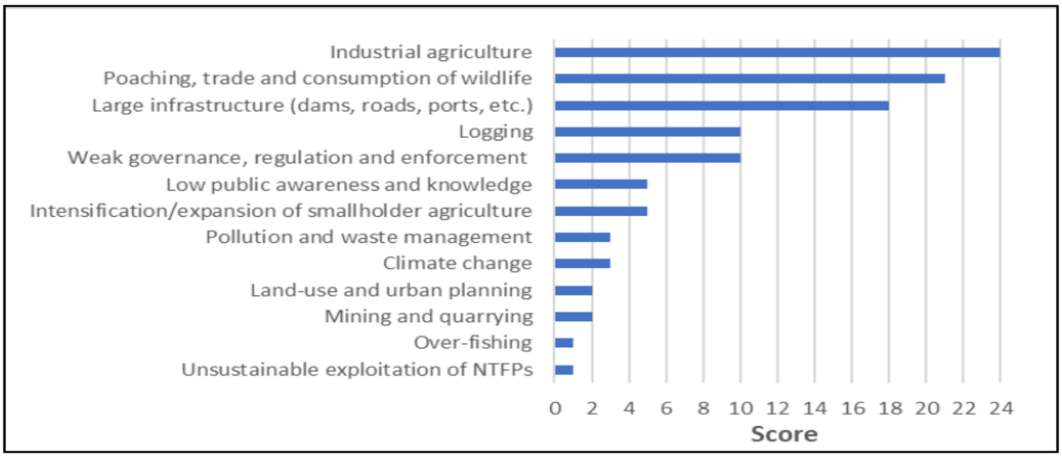
Source: CEPF (2020, p. 47)

2.1.3 Threats to Terrestrial Biodiversity Loss in the Indo-Burma Hotspot

The Indo-Burma biodiversity hotspot is threatened with severe biodiversity loss, as it has lost more than 95% of its original natural habitats (CEPF, 2020). Moreover, approximately 120,000 km^2 of forest ecosystems across the Indo-Burma hotspot were destroyed between 2000 and 2017, causing a significant reduction in biodiversity (Foley, 2020). A study conducted by CEPF (2020) reveals that industrial agriculture, poaching, and the construction of large infrastructures serve as the top three drivers of biodiversity loss in the hotspot. Refer to the figure below for other causes of biodiversity loss in the regions.

Figure 2.

Drivers of Biodiversity Loss in the Indo-Burma Hotspot



Source: CEPF (2020, p. 74)

2.2 The Sundaland Biodiversity Hotspot

2.2.1 Terrestrial Ecosystems in the Sundaland Biodiversity Hotspot

As shown in Figure 1b, the Sundaland biodiversity hotspot is dominated by the islands of the Malay Peninsula (encompasses southeastern Myanmar, southwestern Thailand, West Malaysia, and Singapore), Borneo (covers Brunei, western Indonesia, and East Malaysia), Sumatra, and Java, covering around 17,000 equatorial islands and an area of 1.6 million km^2

(CEPF, 2001; Mauldin & Karas, 2016). This hotspot is well-known for its tropical forests and contains around 15,000 endemic plant species (CEPF, 2022). Also, more than 92% of the primary natural vegetation in this biodiversity hotspot has been destroyed (Polgar & Jaafar, 2018). Various types of terrestrial ecosystems are distributed across this hotspot: lowland tropical rainforests, montane tropical rainforests, peat swamp forests, freshwater swamp forests, heath forests, limestone karsts as well as freshwater ecosystems (CEPF, 2001; WWF, 2007). Lowland tropical forests in this hotspot provide an ideal environment and climate for over 10,000 plant species, including 3,000 types of trees and 2,000 types of orchids (Sawe, 2018). Within the Sundaland, Borneo comprises the largest area of heath forest in Southeast Asia (WWF, 2007). In addition, the tropical rainforests in Borneo cover a total area of 24 million hectares, which accounts for 30% of the Borneo land area, and represent the largest contiguous forest in Southeast Asia (WWF, 2007). Although it only makes up 1% of the world's land area, Borneo harbours more than 6% of global biodiversity in its tropical forests (WWF, 2020). Nonetheless, Borneo lost around 1.9 million forest areas between 2004 – 2017 to commercial agriculture (The Borneo Post, 2021). Table 4 shows that the area of lowland forests in Borneo had decreased from 19 million hectares in 2005 to 13 million hectares in 2015. Likewise, the areas of limestone forests, heath forests, and swamp forests also reduced substantially between 2005 to 2015 (Wulffraat et al., 2016). In general, there has been a sharp decline in the area of different terrestrial ecosystems in Borneo alone from 2005 to 2015, signalling an alarming deforestation rate (Wulffraat et al., 2016).

Table 4. *The Area of Different Terrestrial Ecosystems in Borneo from 2005 to 2015*

Terrestrial Ecosystems	Area (hectares)	
	2005	**2015**
Lowland rainforest	19,338,952	13,198,700
Upland rainforest	13,118,466	12,348,000
Montane forest	6,655,131	6,461,900
Limestone forest	902,331	675,100
Heath forest	2,930,249	1,624,600
Freshwater swamp forest	1,068,219	534,600
Peat swamp forest	6,490,437	3,951,200

Source: Wulffraat et al. (2016, p. 27)

Sumatra, which covers 470,000 km^2 of land area, consists of the richest yet most threatened biodiversity in the Sundaland hotspot (CEPF, 2001). In the past decades, it has lost nearly half (approximately 12 million hectares) of its tropical forests (WWF, 2020). Similarly, as of 2010, Java comprises slightly more than 10,000 hectares of tropical rainforests. Specifically, 2,500 hectares of forests were cleared annually from 2003 to 2006 on average (Hance, 2010). In fact, more than 95% of the original habitat of this ecoregion has been demolished as the country is densely populated, making it an important biodiversity hotspot to protect (Wikramanayake et al., 2002). On the other hand, most of the remaining forests in Peninsula Malay are located in steep and mountainous areas of the ecoregion. Montane rainforests are the largest terrestrial ecosystems in the Peninsula Malay bioregion, consisting of 1.7 million hectares of land area and occupying the mountainous spine of the peninsula in Malaysia and southern Thailand (Wikramanayake, 2022; Loucks, n.d.). Yet, Peninsula Malaysia is not spared from the forest loss issue; it lost approximately 50,000 hectares of primary forests in 2019 alone (The Borneo Post, 2021). In general, it is evident that the terrestrial ecosystems in these ecoregions are severely deforested and degraded, which can result in massive biodiversity loss if further preventive and remedial measures are not implemented. In fact, the Sundaland biodiversity hotspot has lost more than 90% of its original primary vegetation, left with 125,000 km^2 as of the year 2000 (Myers et al., 2000).

2.2.2 Biodiversity in the Sundaland Hotspot

Sundaland is home to more than 25,000 vascular plant species, of which 15,000 are endemic to the hotspot. In terms of fauna, Sundaland consists of 1,800 species of terrestrial vertebrates, and 2.6% are endemic (Myers et al., 2000). Specifically, this ecoregion houses around 112 endemic mammal species and 128 bird species (Brooks et al., 2002; Eaton et al., 2016). For instance, mammals such as the Bornean orangutans and Sumatran Rhino, and bird species such as the Bali Starling and the Javanese Lapwing are classified as critically endangered animals in Sundaland (Mauldin & Karas, 2016). In Sumatra, 23% of the reptile and amphibian species and 15% of its freshwater fish species are endemic (CEPF, 2001). Besides that, less than 300 Sumatran rhinos and 400 Sumatran tigers are left in the forests (WWF, 2020). Sumatra also houses some unique mammal species, such as the proboscis monkey, clouded leopard, sun bear, and flying fox bat (WWF, 2020). In the Borneo rainforest, there are more than 15,000 plant species, of which 40% are endemic to the hotspot. Moreover, Borneo harbours approximately 222 mammal species, of which 44 are endemic; 420 bird species with 37 endemic species; 100 amphibians and 394 fish, 19 are endemic (WWF, 2020). Some of these faunas are classified as critically endangered, such as the Borneo pygmy elephant (*Elephasmaximusborneensis*), Borneo Bay cat (*Pardofelis badia*), and the Helmeted Hornbill (*Rhinoplax vigil*) (WWF, 2020).

Located in another part of the Sundaland, the Malay Peninsula also consists of a number of endangered species, such as the Malayan tapir (*Tapirus indicus*), the Asian elephant (*Elephas maximus*), and the gaur (*Bos gaurus*) (WWF, 2022). Besides that, as one of the most actively volcanic islands in the world, the Java rainforests also contain moderately rich biodiversity (WWF, 2022). Specifically, there are more than 100 mammal species in this ecoregion, including five endemic species such as the *Rhinolophus canuti* and the *Otomops formosus.* Some critically endangered mammal species include Javan rhinoceros (*Rhinoceros sondaicus*) and Javan gibbon (*Hylobates moloch*) (IUCN, 2000). In addition, the Java ecoregion also houses more than 350 bird species, of which nine are endemic [e.g., Javan hawk-eagle (*Spizaetus bartelsi*), Javan white-eye (*Zosterops flavus*), Grey-cheeked tit-babbler (*Macronous flavicollis*), etc.]. Also, more than 3,800 plant species can be found here, including the giant Rafflesia species such as *Rafflesia rochussenii* and *Rafflesia padma* (Whitten et al., 1996).

A study discovered that human activities had extensively degraded 70.6% of the Sundaland hotspot, surpassing the global average of 30% due to its high-density population (Jones et al., 2018). Moreover, approximately 63% of the key biodiversity areas in Sundaland were not located within any protected areas of Categories I to IV (Verma et al., 2020). However, the overlapping between key biodiversity and protected areas in the Sundaland increased from 20% in 1993 to 30% in 2009 (Verma et al., 2020). In Sumatra, 54% of the 34 Important Bird Areas (IBA) remain outside protected areas, while 18% are situated in critically threatened lowland forests (CEPF, 2001). As shown in Table 5, except for the montane forest, less than 50% of other terrestrial ecosystems in Borneo are situated within protected areas, respectively. Conversely, more than half of Borneo's montane forest (53.3%) is still protected as these mountainous areas are relatively difficult to access and less attractive for agricultural development (Wulffraat et al., 2016).

Table 5. *Percentage of Borneo's Terrestrial Ecosystem Protected*

Ecosystem	% of extent protected
Lowland rainforest	16.2
Upland rainforest	36.0
Montane forest	53.3
Limestone forest	28.5
Heath forest	14.0
Peat swamp forest	38.5
Freshwater swamp forest	30.3

Source: Wulffraat et al. (2016)

2.2.3 Threats to Terrestrial Biodiversity Loss in the Sundaland Hotspot

Deforestation and forest degradation are the major factors contributing to terrestrial biodiversity loss in the Sundaland hotspot. The original habitat of the hotspot has been reduced from 1.6 million km^2 to 125,000 km^2 as of the year 2000 (Polgar & Jaafar, 2018). Further, it lost approximately 773,000 km^2 of tropical lowland forests by 2010, accounting for around 70% of its total area of lowland forests (Wilcove et al., 2013). In fact, Sundaland's tropical forests face the highest deforestation rate in the world (Hansen et al., 2013), which was mainly driven by rapid agricultural expansion, unsustainable logging activities, and road construction (CEPF, 2001; Wilcove et al., 2013). For instance, palm oil plantations were liable for nearly 40% of deforestation in Sumatra and Borneo, respectively, between the 1980s and 2010s (Guindon, 2021). Moreover, the rapid construction of roads has also catalyzed the deforestation rate in Sumatra (Nilsson, 2019). Although the construction of new logging roads in the Sumatran forests may lead to easier access for settlers and trucks, it can also have negative consequences, such as habitat loss and a decline in biodiversity (Jong, 2021). Other anthropogenic disturbances, such as illegal hunting and wildlife trade, are exacerbating biodiversity loss in the Sundaland hotspot (CEPF, 2001; Haas & Ferreira, 2016). For example, there are currently only approximately 500 critically endangered Sumatran tigers left in Indonesia, with a mere 33 of them residing in North Sumatra. This alarming decline in population is primarily due to habitat loss, illegal hunting, and poaching for commercial gain (Gunawan, 2020; Mangunjaya, 2018).

2.3 The Wallacea Biodiversity Hotspot

2.3.1 Terrestrial Ecosystems in the Wallacea Biodiversity Hotspot

The Wallacea biodiversity hotspot is located within the central islands of Sulawesi in Indonesia and Timor-Leste, particularly sitting between Maluku, Lesser Sundas, and Sulawesi. As a result of tectonic activities, the land area of this hotspot is fragmented into 1,680 islands (which cover a total terrestrial area of 347,000 km^2) separated by oceanic trenches (CEPF, 2014; Lohman et al., 2011). Nearly half of the land area of the Wallacea hotspot is covered with forests (17.7 million hectares), which are home to more than 1,500 endemic plant species and comprise around 560 globally threatened species (including critically endangered, endangered, and vulnerable categories (CEPF, 2014). Natural habitats in the lowland areas of Maluku & Sulawesi are made up of evergreen and semi-evergreen forests, while monsoon forest is the main type of forest found in Lesser Sundas (CEPF, 2014). Specifically, 56% of the Wallacea's forests are located in Sulawesi, 24% in Maluku, 19% in Lesser Sundas, and 4% in Timor-Leste. Several types of terrestrial ecosystems can be found in the Wallacea hotspot, including lowland tropical forests, lowland monsoon forests, montane forests, heath forests, grassland, karsts, swamp forests, and as well as freshwater rivers and lakes, all of which serve as important terrestrial ecosystems (CEPF, 2014). Lowland tropical forests are primarily distributed across Maluku and Sulawesi and are dominated by trees of the *Dipterocarpaceae*. Monsoon forests are characterized by a dry period of several months and can be found mainly in regions with seasonal climates. However, a large area of the monsoon forests in this hotspot had been deforested for mining and agriculture expansion. Heath forests are primarily situated in areas with acidic and nutrient-deficient soil, which are covered with drought-tolerant trees, whereas there are relatively lesser tree species in the karst regions due to infertile soil. Swamp forests, such as freshwater swamp forests or peat swamp forests, can be found mainly in Sulawesi (CEPF, 2014). As can be seen, the Wallacea biodiversity hotspot is rich in forested areas. However, mining activities and forest clearing for industrial agriculture are the major threats to these terrestrial ecosystems in the Wallacea hotspot (Gaveau et al., 2021). A study has found that socio-economic development has resulted in 10,231 km^2 of forest loss between 2000 and 2018, and a further 49,570 km^2 of the forest is projected to be cleared by 2053 (Voigt et al., 2021), signalling an alarming deforestation rate.

Like terrestrial ecosystems, freshwater systems (rivers and lakes) located on land areas in the Wallacea hotspot also play significant roles in supporting livelihoods and contributing to socio-economic development. Rivers in the region are generally steep, while the lakes are deep and isolated due to the plate tectonic revolution and volcanic activity (CEPF, 2014). The Malili Lake system, located on Sulawesi Island, formed due to volcanic activity 1.5 million years ago (Haffner et al., 2001; Russell et al., 2016). As the only hydrologically connected ancient lake system in the world (Vaillant et al., 2011), it consists of five interconnected lakes: Lake Matano, Lake Mahalona, Lake Towuti, Lake Lontoa, and Lake Masapi, as well as rivers that connect one lake to another in the system, such as Petea River, Tominanga River, and Larona River (von Rintelen & Cai, 2009). The Maliki Lake system is rich in freshwater biodiversity, yet it has been constantly threatened by human activities (e.g., agricultural expansion, mining, illegal logging, etc.) that degraded and polluted the freshwater environment, causing a severe biodiversity loss in the region (IUCN, 2022). Overall, it is clear that the terrestrial ecosystems (forests and freshwater systems) in the Wallacea hotspot are deteriorating at a rate that warrants urgent attention from environmentalists and conservationists, hence the establishment of the “Wallacea biodiversity hotspot”.

2.3.2 Biodiversity in the Wallacea Hotspot

The Wallacea hotspot comprises relatively lesser flora and fauna species than other biodiversity hotspots in Southeast Asia due to the fragmented terrestrial areas resulting from the subduction and volcanic activities (CEPF, 2014). Yet, this unique geographical environment has allowed the occurrence of highly endemic species that can only be found in some of the islands in the Wallacea hotspot (Supriatna, 2017). As evidence, Table 6 shows that 57% of the mammal species, 39% of the bird species, 44% of the reptile species, 50% of birdwing butterflies, 68% of the amphibian species, and 20% of the freshwater fish species are endemic to the Wallacea hotspot. Of the total number of species in this hotspot, a considerable proportion is regarded as globally threatened (see Table 7). For example, mammals species such as the Sunda Pangolin (*Manis javanica*) and Javan Langur (*Trachypithecus auratus*), bird species such as the Timor imperial pigeon (*Ducula cineracea*) and Wetar ground-dove (*Gallicolumba hoedtii*), reptile species such as the Banda Island dtella (*Gehyra barea*) and the Sulawesian tortoise (*Indotestudo forstenii*), amphibian species such as the Djikoro wart frog (*Limnonectes arathooni*) and the Lombok cross frog (*Oreophryne monticola*), and freshwater fishes such as Duckbilled Bunting (*Adrianichthys kruyt*) and Poso Bungu (*Weberogobius amad*) are some of the endangered species inhabiting the Wallacea biodiversity hotspot. In terms of flora, only 1% of the plant species are classified as threatened species, including species of economic value such as sandalwood (*Santalum album*) and eaglewood (*Aquilaria cumingiana*) (CEPF, 2014). As shown in Table 7, of 336 globally threatened terrestrial species in the hotspot, 28 are classified as critically endangered, 61 are endangered, and 157 are vulnerable.

Table 6. *Summary of Terrestrial Species Diversity and Endemism in the Wallacea Biodiversity Hotspot*

Taxonomic Group	Total No. of Species	No. of endemic species (%)	# of threatened species (%)
Plants	10,000	>1,500 (15)	66 (1)
Mammals	222	127 (57)	64 (29)
Birds	711	274 (39)	61 (9)
Reptiles	222	99 (44)	10 (5)
Amphibians	48	33 (68)	8 (17)
Freshwater fishes	250	50 (20)	37 (15)

Source: CEPF (2014, p. 21)

Table 7. *Summary of Globally Threatened Terrestrial Species in the Wallacea*

Taxonomic Group	Global Threat Status				Species Distribution by Bioregion		
	Critically Endangered	Endangered	Vulnerable	Total	Sulawesi	Maluku	Lesser Sundas
Plants	5	7	54	66	36	23	18
Mammals	5	23	36	64	40	13	15
Birds	12	20	29	61	28	16	20
Reptiles	2	3	5	10	6	2	7
Amphibians	0	4	4	8	6	1	1
Freshwater fishes	4	4	29	37	37	0	0
Total	**28**	**61**	**157**	**336**	**153**	**199**	**61**

Source: CEPF (2014, p. 32)

The Wallacea hotspot consists of a total of 251 terrestrial key biodiversity areas (KBAs), which are situated within the three biogeographic regions and cover a total land area of 9.5 million hectares (see Table 8). In Indonesia, 88% of the terrestrial KBAs are situated within the national forest estate. However, only 31% of the terrestrial KBAs are within legally protected areas such as national parks, strict nature reserves, wildlife reserves, and other conservation reserves, while the remaining 69% of the KBAs are outside the protected area network (CEPF, 2014). However, a more recent study claims that there are 227 terrestrial KBAs in the Wallacea, of which around 45% are partially protected, 6.2% are completely protected, and 37% are not protected at all (Voigt et al., 2021). In Timor-Leste, 12 terrestrial KBAs are designated as protected areas, of which 11 are Important Bird Areas (IBAs). As can be seen, these statistics show that a large area of the terrestrial KBAs in the Wallacea hotspot remains outside the protected area network. In fact, less than 6% of the Wallacea biodiversity hotspot is within protected areas (Hernani, 2018).

Table 8. *Summary of the Number of Terrestrial KBAs in the Wallacea Hotspot*

	Terrestrial Key Biodiversity Areas	
	Total	**Area (ha)**
Sulawesi	95	5,266,204
Maluku	51	2,146,217
Lesser Sundas	105	2,098,638
Total	**251**	**9,511,059**

Source: CEPF (2014)

2.3.3 Threats to Terrestrial Biodiversity Loss in the Wallacea Hotspot

Some of the major threats to terrestrial biodiversity loss in the Wallacea include overexploitation of natural resources (e.g., unsustainable logging and hunting for commercial purposes) and large-scale deforestation for the expansion of agriculture, mining, urbanization, and infrastructure development (CBD, 2022; CEPF, 2014; Voigt et al., 2021). The top driver of terrestrial biodiversity loss in the Wallacea hotspot is the conversion of lowland forests for oil palm plantations (CBD, 2022; CEPF, 2014). As part of the Wallacea hotspot, Indonesia supplied nearly half of the global palm oil between 2010 and 2011, making it a profitable business (CEPF, 2014). The table below shows that the oil palm plantation size has increased tremendously from 9.6 million hectares in 2012 to 11.8 million hectares in 2016, generating USD 18.6 billion for Indonesia in 2016 (Indonesia Investment, 2017). Although oil palm plantation is the key industry to the country's economy, it has further exacerbated the loss of terrestrial biodiversity in the Wallacea hotspot (CBD, 2022; CEPF, 2014; Voigt, 2021).

Table 9. *Indonesian Palm Oil Production and Export Statistics from 2012 to 2016*

	2012	2013	2014	2015	2016
Production (million tons)	26.5	30.0	31.5	32.5	32.0
Export (USD billion)	21.6	20.6	21.1	18.6	18.6
Plantation size (million hectares)	9.6	10.5	10.7	11.4	11.8

Source: Indonesia Investment (2017)

2.4 The Philippines Biodiversity Hotspot

2.4.1 Terrestrial Ecosystems in the Philippines Biodiversity Hotspot

As a country of more than 7,000 islands that amount to 300,780 km^2 of terrestrial area, the Philippines is another vital biodiversity hotspot in Southeast Asia, with more than 6,500 endemic plant species and 700 threatened species (Convention on Biological Diversity, n.d.; Goldman, 2010). In fact, the Philippines has lost more than 93% of its original vegetation since the 1900s (Biodiversity Management Bureau [BMB] - Department of Environment and Natural Resources [DENR], 2016). Despite its species richness, the Philippines is severely threatened with biodiversity loss due to anthropogenic activities, making it a biodiversity hotspot that requires intensive conservation efforts (CEPF, 2001; Mona, 2016). Covering almost 24% of the total land area, the terrestrial ecosystems in the Philippines are mainly dominated by tropical evergreen rainforests, montane rainforests, ultramafic forests, limestone karsts, and freshwater swamp forests (CEPF, 2001; Convention on Biological Diversity, n.d.). Several biodiversity corridors can be found in the Philippines, of which the Sierra Madre Corridor, Palawan Corridor, and the Eastern Mindanao Corridor cover most of the terrestrial ecosystems and hold more than 70% of plant species in the Philippines (CEPF, 2001). Biodiversity corridors involve areas of vegetation that connect fragmented habitats, enabling species to move from one patch of forest to another and enhancing biodiversity (ForestrySA, 2022). In particular, the Sierra Madre covers 1.8 million hectares of land area in ten provinces, including Batanes, Cagayan, Isabela, Nueva Vizcaya, Quirino, Nueva Ecija, Aurora, Bulacan, Rizal, and Quezon. Furthermore, this corridor covers 40% of the country's primary forests and encompasses the most terrestrial protected areas, such as natural parks, forest reserves, and natural monuments. The largest protected area in the Philippines, namely the Northern Sierra Madre Natural Park, can be found in the northern range of the Sierra Madre mountains (CEPF, 2001). Several types of terrestrial forests can be found in the Sierra Madre Corridor, including tropical evergreen rainforests, montane rainforests, limestone forests, and ultramafic forests (CEPF, 2001). Being the largest province in the Philippines, the Pahlawan Corridor is covered with approximately 690,000 hectares of terrestrial forest, which involves a variety of forests similar to those in the Sierra Madre Corridor, such as tropical lowland evergreen forests, moist deciduous forests, and upper montane rainforests (CEPF, 2001; WWF, 2022). On the other hand, the Eastern Mindanao Corridor covers 2 million hectares of land, and nearly half of the areas are covered with forests (Philippine Eagle Foundation, 2008). The terrestrial ecosystems in the corridor are mainly dominated by lowland forests (63%), while the remaining comprises montane forests, with Mount Kampalili (2,499 m) as the highest peak in the region (Philippine Eagle Foundation, 2008). Nevertheless, anthropogenic causes such as commercial logging and mining activities have resulted in habitat degradation and biodiversity loss in the region (CEPF, 2001; Paz et al., 2013).

2.4.2 Biodiversity in the Philippines Hotspot

The Philippines is home to more than 53,000 species, of which nearly 50% of its terrestrial vertebrates and around 60% of its vascular plants are endemic to the hotspot (Mona, 2016; Smith, 2017). Being one of the mega-diverse countries, it comprises more than 60% of the world's biodiversity and around 80% of the flora and fauna in the world (Convention on

Biological Diversity, n.d.). Specifically, the Philippines harbours around 1,500 terrestrial vertebrate species, including more than 200 mammal species, 690 bird species, 419 reptile species, and 120 amphibian species, of which nearly half of the terrestrial species are endemic to the region (BMB, 2016). In addition, 42 terrestrial mammal species, 127 bird species, 24 reptile species, and 14 amphibian species are classified as endangered in the Philippines (CBD, n.d.). For example, the Philippine eagle (*Pithecophaga jefferyi*), Philippine cockatoo (*Cacatua haematuropygia*), Tamaraw (*Bubalus mindorensis*), and the Philippine tarsier (*Tarsius syrichta*) are some examples of threatened species in the Philippines (BMB-DENR, 2016). There are a number of endemic species residing within the Sierra Madre Corridor, including 12 amphibian species, 21 mammal species, and 16 reptile species (CEPF, 2001). In another part of the Philippines, the Palawan Corridor hosts 11 amphibian species, 18 mammal species, 24 reptile species, and 25 bird species endemic to the Philippines. Moreover, more than 60% of the threatened species identified in the corridor are endemic (CEPF, 2001). A large proportion of the Philippines' flora and fauna can also be found in the Eastern Mindanao Corridor. Specifically, it encompasses more than 2,300 plant species, accounting for 31% of the Philippines' total number of plant species. The Eastern Mindanao Corridor also houses more than 370 vertebrate species, of which 180 are endemic to the Philippines (Philippine Eagle Foundation, 2008). In addition, 69 globally threatened flora and fauna are found in the corridor. For example, the Philippine eagle, the Philippine cockatoo, and the Philippine crocodile are some of the critically endangered species residing in the Eastern Mindanao Corridor (Philippine Eagle Foundation, 2008).

Key biodiversity areas (KBAs) also play a significant role in protecting and conserving biodiversity in the Philippines. This biodiversity hotspot comprises 228 key biodiversity areas, 101 of which are terrestrial KBAs, 77 are marine KBAs, and the remaining 50 are a combination of terrestrial and marine KBAs (BMB-DENR, 2016). These KBAs harbor more than 850 species of plants and animals, of which 196 are categorized as globally threatened species (Ambal et al., 2012). Nevertheless, less than 40% of the KBAs are situated within protected areas (see Table 10). Specifically, only 22% of the KBAs are completely protected, and 18% are partially protected, implying that more appropriate conservation initiatives are needed to preserve the KBAs in the Philippines.

Table 10. *Key Biodiversity Areas in the Philippines*

KBAs by Ecosystem Coverage	Area (km^2)	No. of KBAs	% of KBAs	No. of KBAs Protected	No. of KBAs Partially Protected
Terrestrial	51,249	101	44	27	25
Marine	19,601	77	34	8	6
Terrestrial + Marine	35,702	50	22	15	10
Total	106,552	228	100	50	41

Source: BMB-DENR (2016, p.35)

2.4.3 Threats to Terrestrial Biodiversity Loss in the Philippines Hotspot

Similar to other biodiversity hotspots in Southeast Asia, there has been a significant decline in biodiversity in the Philippines. Habitat loss and degradation, overexploitation, the introduction of invasive alien species, and rapid urbanization are the main pressures leading to biodiversity loss in the Philippines (Antonio et al., 2013; BMB-DENR, 2016). Habitat loss due to deforestation is not uncommon, especially within a biodiversity hotspot rich in tropical forests. In fact, the Philippines lost approximately 1.3 million hectares of tree cover to deforestation between 2001 to 2020, resulting in 753 metric tons of carbon dioxide emissions (Global Forest Watch, 2021). Terrestrial biodiversity loss in the Philippines is also caused by rapid urbanization due to the burgeoning human population in the region. In this sense, forest areas are cleared for socio-economic development involving agricultural expansion, plantations, forest products extraction, and infrastructure expansion (Antonio et al., 2013;

BMB-DENR, 2016; CBD, n.d.). Furthermore, mining is another key factor causing habitat loss and degradation in the region (BMB-DENR, 2016). The Philippines is rich in metallic minerals, such as nickel, copper, and gold, yet many of the mineral reserves are located within key biodiversity areas (BMB-DENR, 2016; Philippine Council for Industry, Energy, and Emerging Technology Research and Development [PCIEERD], 2017). Although the mining industry has contributed significantly to the economic development of the Philippines, it has led to irreversible environmental impacts (PCIEERD, 2017). For instance, a large area of forests in Mindanao has been cleared for mining purposes, resulting in forest fragmentation and severe habitat loss (PCIEERD, 2017). Overexploitation is another anthropogenic cause of biodiversity loss in the Philippines. As evidence, the bird population (e.g., hornbills, parrots, cockatoos, etc.) in the Philippines forests, especially Mindanao and Palawan, is threatened by overhunting and illegal wildlife trading (BMB-DENR, 2016; Mayuga, 2021). Socio-economic development is inevitable, but humans are exploiting natural resources in an unsustainable manner, causing irrevocable damage to the terrestrial ecosystems and biodiversity in the Philippines.

3. Main Anthropogenic Causes Of Biodiversity Loss in Southeast Asia Terrestrial Areas

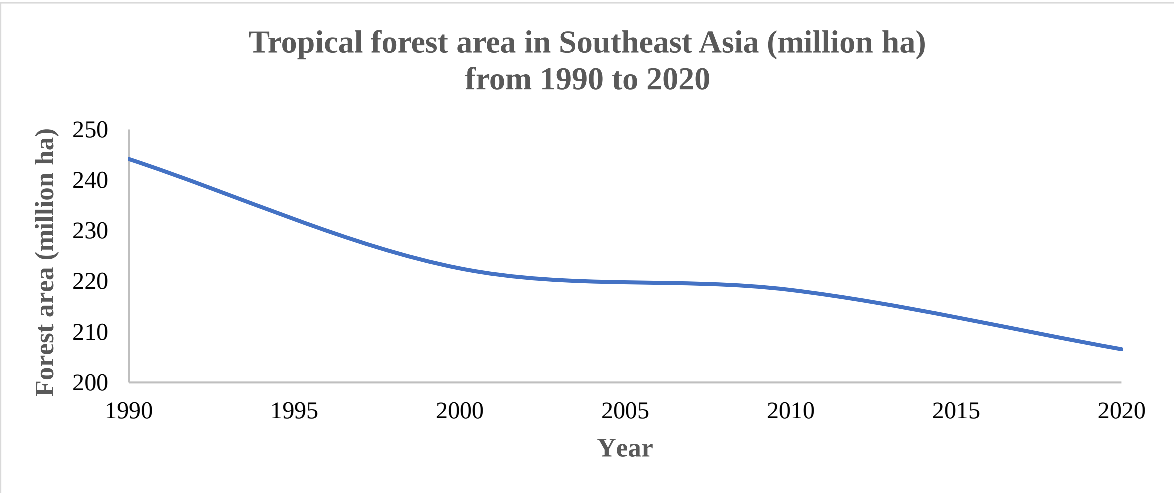
In Southeast Asia, the four main biodiversity hotspots mentioned above are in danger of losing more biodiversity if no further actions are taken to preserve and protect the biodiversity in the region. Correspondingly, research has discovered that Southeast Asia is severely threatened with biodiversity loss (Sodhi et al., 2010). Furthermore, the region is at risk of losing around 40% of its biodiversity by 2100 (Sodhi et al., 2004). Biodiversity loss in terrestrial areas in Southeast Asia is mainly driven by anthropogenic activities such as deforestation for socio-economic development and unsustainable use of natural resources (e.g., Burkmar & Bell, 2015; Convention on Biological Diversity, 2020b; Slingenberg et al., 2009). The details of each anthropogenic factor will be discussed in the following sections.

3.1 Deforestation

In addition to protecting natural habitats and conserving biodiversity, tropical forests in Southeast Asia also contribute to local communities' livelihoods and socio-economic development. 15% of the world's tropical forests are situated in Southeast Asia (Stibig et al., 2014), consisting of 207.5 million hectares of forest area. Of these forest areas, 92% were covered by natural forests, and the remaining areas were covered by plantation forests (FAO, 2020). However, Southeast Asia has the highest deforestation rate compared to other regions in the world (Russell, 2020). As evidence, the United Nations Food and Agriculture Organization (FAO) (2022) reported that Southeast Asia registered a loss of approximately 37 million hectares of tropical forest area from 1990 to 2020 (refer to Figure 3). Moreover, research purports that Southeast Asia will lose more than 70% of its tropical forests by 2100 if the rate of deforestation remains high (Achard et al., 2002).

Figure 3.

Tropical Forest Area in Southeast Asia from 1990 to 2020



Source: FAO (2020)

Of the Southeast Asia countries, Indonesia and Myanmar face the largest magnitude of deforestation, losing about 26 million ha and 10 million ha of forests within 30 years (1990 – 2020) (FAO, 2022). In other countries, such as Brunei, Timor Leste, and the Philippines, the areas of forest loss are comparatively small. On the other hand, encouragingly, some Southeast Asia countries have made tremendous efforts to expand their forest areas, such as Singapore, Vietnam, and Thailand (see Table 11) (FAO, 2022). Deforestation in Southeast Asia has been largely driven by urbanization, agriculture (e.g., oil palm plantations), wildfire, forestry, and logging (Russell, 2020). The reasons for deforestation vary among different countries. For example, in Indonesia, the main drivers of deforestation involve oil palm plantation, timber plantation, conversion of forests to grasslands, mining activities, and commercial logging. Of which, oil palm plantation is the main driver of deforestation in Indonesia, resulting in 2.08 million hectares of forest loss, accounting for a quarter of deforestation nationwide between 2001 to 2016 (Austin et al., 2019). In fact, Indonesia is the largest exporter of palm oil in the world, with an export volume of around 28 million metric tons in 2021 (Shahbandeh, 2022). Despite being a profitable industry, it has resulted in severe deforestation and habitat destruction, damaging the health of the natural ecosystems and causing biodiversity loss in Indonesia (Rifin, 2020). Furthermore, clearing forests for grasslands was another culprit of deforestation in Indonesia, which has led to 1.8 million hectares of forest loss (Austin et al., 2019). In other countries, such as Myanmar and Laos, the primary causes of deforestation include the expansion of agriculture, mining activities, illegal logging, and infrastructure development (Cook, 2018; Ministry of Natural Resources and Environmental Conservation Myanmar, 2020). In contrast to the results shown in Table 11, another study discovers no significant gain in the Philippines' forest area despite the implementation of the National Greening Program, which aims to reforest the degraded forestlands in the Philippines from 2011 to 2016 (Perez et al., 2020). Specifically, there has been a decline in forest loss from 2011 to 2015, yet immense deforestation continued from 2016 to 2018. Consequently, deforestation offsets the reforestation efforts, resulting in no significant gain from the National Greening Program (Perez et al., 2020). To achieve more remarkable reforestation outcomes, efforts to curtail deforestation should also be executed simultaneously to complement the effective restoration of forests in the Philippines.

Table 11. *Forest Area in Southeast Asia Countries from 1990 to 2020*

	Forest area (hectares)	
Countries	**1990**	**2020**
Singapore	14,830	15,570
Brunei	413,000	380,000
Timor Leste	963,000	921,100
Philippines	7,778,810	7,188,590
Vietnam	9,375,900	14,643,090
Cambodia	11,004,790	8,068,370
Laos	17,843,000	16,595,500
Thailand	19,361,000	19,873,000
Malaysia	20,618,000	19,114,040
Myanmar	39,218,480	28,543,890
Indonesia	118,545,000	92,133,200

Source: FAO (2022)

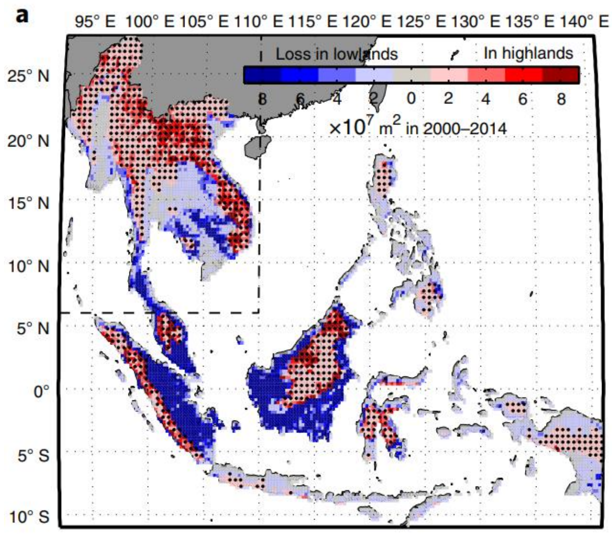
3.1.1 Deforestation of Mountains

Studies have suggested that tropical deforestation usually occurs in lowland areas and is rarely observed in mountainous areas with relatively richer biodiversity and higher carbon stocks (Aide et al., 2019; Song et al., 2018; Zeng et al., 2018a). However, forest loss is gradually shifting to higher elevations and steeper slopes due to rapid croplands expansion and plantations over the past decade (Feng et al., 2021; Zeng et al., 2018b). Specifically, the average altitude of deforestation has escalated by 150 m over the past decade (Cross, 2021). For instance, a case study in Nan Province in Thailand shows that due to the lucrative market of corn, deforestation has begun to move upwards into mountainous areas since 2012 due to forest clearing for cornfields (Zeng et al., 2018b). In fact, approximately 18 million hectares of highland forests have been cleared for agricultural expansion since 2000 (Cowan, 2021). Deforestation in mountainous areas has accounted for around 30% of the total forest loss in Southeast Asia (Cross, 2021). Likewise, another research found that Southeast Asia had lost around 3.22 million hectares annually from 2001 to 2019, of which 31% took place in mountainous areas, which have been converted into croplands and farms (Feng et al., 2021).

More worryingly, the rate of deforestation in highlands across Southeast Asia demonstrated an upward trend, increasing from 24% (the ratio of mountain forest-loss area to total forest-loss area) in 2001 to 42% in 2019 (Feng et al., 2021). As shown in Figure 4, considerable forest loss in highlands is primarily observed in mainland Southeast Asia (Cambodia, Thailand, Myanmar, Laos, and Vietnam), while deforestation of lowland forests is detected mainly in maritime Southeast Asia (Brunei, Timor-Leste, Malaysia, Singapore, Indonesia, and the Philippines), although small patches of forest loss are also evident in highlands (Zeng et al., 2018a). In line with the findings, another study reveals that rubber plantations have gradually expanded into the highland areas across Southeast Asia, including Cambodia, Laos, Vietnam, Thailand, and Myanmar, indicating the occurrence of large-scale deforestation in mountainous areas (Fox et al., 2018). As aforementioned, highland forests in Southeast Asia generally store more carbon than lowland forests. In fact, forest loss in highland areas has accounted for more than 30% of Southeast Asia's total annual forest carbon loss (Cowan, 2021). Many species of mammals, birds, and amphibians that inhabit the mountains are at risk of going extinct if deforestation continues to accelerate in mountainous areas across Southeast Asia (Cowan, 2021). Hence, forest loss at higher altitudes in mountainous areas across Southeast Asia is a major issue, given these regions are incredibly rich in biodiversity and carbon stocks.

Figure 4.

Spatial Pattern of Forest Loss in Southeast Asia between 2000 – 2014



Source: Zeng et al. (2018, p. 558)

3.1.2 Consequences of Deforestation on Terrestrial Ecosystem and Biodiversity

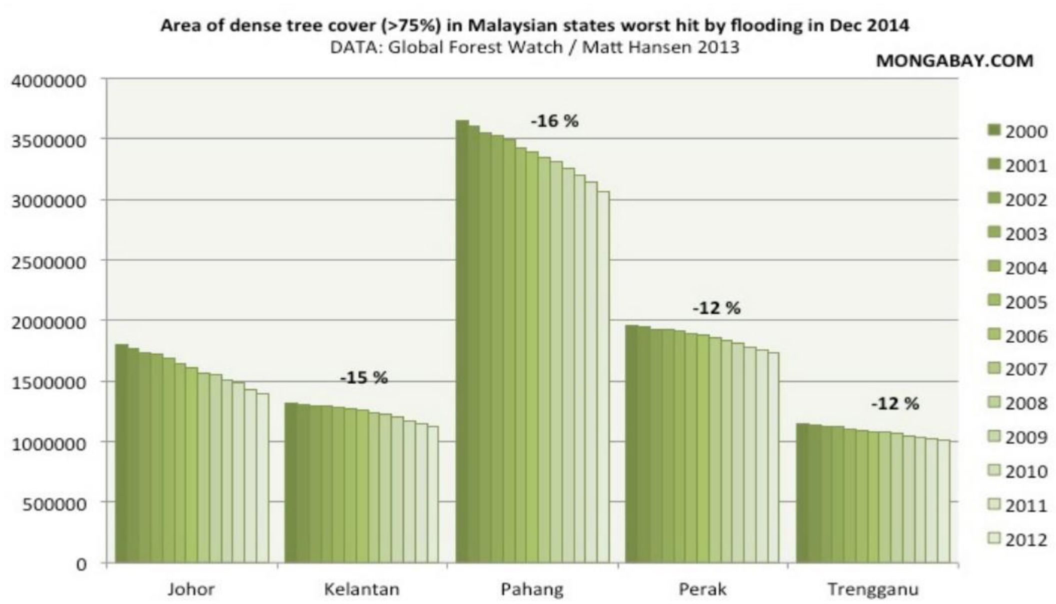
Deforestation in Southeast Asia has compromised the tropical rain forests' capacity to store carbon and reduce carbon emissions, leading to 424 million metric tons of carbon emission annually, resulting in accelerated global warming (Cross, 2021). In fact, Southeast Asia contributed the most carbon emissions from deforestation and forest degradation (Pearson et al., 2017). It is not surprising that Indonesia and Myanmar are the countries that emit the most carbon into the atmosphere as a result of their large-scale deforestation (Sasaki et al., 2021). On the other hand, Vietnam and Thailand had the highest amount of carbon sequestered annually by their terrestrial ecosystems between 2000 and 2020 (Sasaki et al., 2021), which is on par with the increase in their forest areas (see Table 11). Worryingly, Southeast Asia is at heightened risk of losing USD 28 trillion in economic value over the next 50 years if no actions are taken to reduce carbon emissions in the region (Deloitte, 2021). However, if the countries act quickly to limit carbon dioxide emissions, Southeast Asia can gain USD 12.5 trillion, with an average GDP growth rate of 3.5% annually over the next 50 years (Deloitte, 2021). Failing to do so may result in accelerated global warming with an increase in temperature by more than 3ºC by 2070, eventually leading to extreme floods and droughts devastating to the well-being of the planet and human beings (Deloitte, 2021).

Deforestation and degradation of tropical forests in Southeast Asia have also resulted in significant biodiversity loss and the extinction of critically endangered endemic species, such as Indochinese tigers, Asian elephants, and Bornean orangutans (Cross, 2021). It is likely that Southeast Asia may lose more than 50% of endemic species if large-scale deforestation continues to expand in the next century (Koh & Sodhi, 2010). In fact, around 85% of species will go extinct by the end of this century if the deforestation rate in Southeast Asia remains high (Sodhi & Brook, 2006). For example, deforestation on the Indonesian island of Sulawesi has resulted in dramatic declines in primate habitats in the past decade. This is partly a result of habitat fragmentation caused by extensive deforestation in the region (Supriatna et al., 2020). Despite being classified as critically endangered species, the Bornean and Sumatran Orangutans are losing their habitats because of deforestation for palm oil plantations in Indonesia and Malaysia (Orangutan Conservancy, 2021). Without drastic interventions to reduce the deforestation rate in the region, experts believe that Orangutans may face complete extinction in the next ten years (Johnston, 2019). Moreover, habitat destruction resulting from deforestation has also led to a sharp decline in the tiger population in Malaysia (Perera, 2019). Specifically, the tiger populations in Malaysia have declined by more than 88% within 50 years – from more than 3000 in the 1950s to around 340 in the 2000s (Perera, 2019). Similarly, in Indonesia, the IUCN declared the Balinese tigers (*Panthera tigris balica*) and Javan tigers (*Panthera tigris virgata*) as extinct species in 2003 due to rapid deforestation and habitat fragmentation (Mongabay, 2017). As can be seen, deforestation and forest degradation are evidently threatening the survival of species in Southeast Asia, especially the endangered species on the verge of extinction.

In addition to exerting adverse impacts on wildlife, deforestation can also cause harm to human beings. Floods and landslides are typical examples of calamities caused by massive deforestation (Campion, 2021). Specifically, logging activities cause soil erosion and lower forests' water retention capacity, resulting in increased flash floods in lowland areas (Butler, 2015). As evidence, in recent years, several Malaysian states, namely Selangor, Pahang, Kelantan, Johor, and Terengganu, have suffered serious floods because of the large-scale illegal logging activities in forest areas (Free Malaysia Today, 2021; Haroon, 2022), causing a total loss of RM 6.1 billion (Bedi, 2022). A similar tragedy happened in 2014 when Johor, Kelantan, Pahang, Perak, and Terengganu were hard hit by floods. On average, these states have lost more than 10% of their tree cover within 12 years (from 2000 to 2012) (see Figure 5). Without doubts, forest loss is a critical factor leading to floods in these Malaysian states (Butler, 2015).

Figure 5.

Area of Tree Cover in the Malaysian States between 2000 and 2012



Source: Butler (2015)

In 2014, illegal land clearing for agricultural expansion led to a devastating landslide in Cameron Highland (situated in Pahang, Malaysia). Consequently, this disaster caused five deaths and displaced dozens of households (The Sun Daily, 2014). Correspondingly, Kalimantan was also struck by massive floods and landslides in 2021 due to immense deforestation for oil palm plantations (Campion, 2021). Unfortunately, 21 individuals were found dead, and more than 70,000 people were displaced by the floods. Simultaneously, damages to the infrastructure and buildings caused by the floods cost Kalimantan a total economic loss of USD 96.1 million (Campion, 2021). Evidently, massive floods and landslides can cause serious damage to physical properties, create unnecessary financial burdens, and endanger human lives. Therefore, it is crucial to take urgent measures to reduce deforestation in Southeast Asia.

3.2 Overexploitation of Wildlife

Southeast Asia is one of the global hotspots for wildlife hunting and trading due to its rich biodiversity. Thus, overexploitation of wildlife remains a key threat to biodiversity in the region, which has led to a sharp decline in animal populations across Southeast Asia since the 1980s (Harrison et al., 2016; Hughes, 2017). Animals of more than one kg have greatly decreased in numbers (Harrison et al., 2016), such as the Indochinese tiger, the Burmese star tortoise, and the Javan rhinoceros (Brook et al., 2014; New Straits Times, 2020; Rostro-Garcia et al., 2014). Addressing the overexploitation issue can be more difficult when hunting and trade are conducted illegally. A research study discovered that 48% of amphibian and reptile species traded in Indonesia are listed as endangered, and 17% are fully protected (Natusch & Lyons, 2012). These figures clearly show that wildlife hunting and trading in the region are not properly monitored and reinforced with strict law enforcement, which may eventually result in irreversible biodiversity loss across Southeast Asia (Natusch & Lyons, 2012). In fact, illegal hunting in Southeast Asia is a more severe and immediate threat to biodiversity loss as compared to deforestation and habitat fragmentation (The ASEAN Post, 2019). Shockingly, illegal wildlife trading in Southeast Asia is worth more than USD 20 billion a year, making it one of the most profitable criminal trafficking enterprises in the region (The ASEAN Post, 2019). Furthermore, the Covid-19 pandemic has increasingly moved the illegal trading of wildlife online in recent years. The use of online platforms to facilitate wildlife trading has amplified the poaching issue as traffickers can better protect their identities using virtual private networks (VPNs) and fake accounts that are often not traceable (Fallin, 2021).

The burgeoning demand for traditional Chinese medicinal products, wild meats, and wild animals as pets in Southeast Asia is one of the primary reasons animal species are threatened with extinction (Hall, 2019; Harrison et al., 2016; Natusch & Lyons, 2012). For example, bear bile has been used in traditional Chinese medicine for thousands of years. Dealers usually acquire bear bile by killing the bears and extracting bile juice from their gallbladders (Hall, 2019). According to a report by the United Nations Office on Drugs and Crime [UNODC] (2013), the estimated prices for bear gallbladders were between USD 50 (in Myanmar) and USD 2,000 (in Hong Kong). Undeniably, the lucrative market of bear bile has further exacerbated the issue of wildlife poaching. Moreover, most of the traditional Chinese medicine shops in Malaysia often sell bear bile openly, which is a prohibited item in the country, further putting the bear species at risk of extinction (Koshy, 2020). As a result of overexploitation and trafficking, the Malayan Sun bears and Asian black bears are listed as Vulnerable to Extinction by the IUCN (Asher, 2016). On the other hand, the presence of Asian elephants has made Indonesia, Vietnam, and Thailand the largest markets for the illegal trade of elephant ivory in Southeast Asia (Indraswari et al., 2020; WWF, 2015). As evidence, the Thai government seized and destroyed two tonnes of illegal elephant ivory at a solemn ceremony in Bangkok in 2015 (WWF, 2015). Besides that, a study indicates that 8,508 products made from elephant ivories involving elephant tusks, pieces of jewellery, and decorative items were found offered for sale on various social media platforms within just a month across Indonesia, Thailand, and Vietnam (Indraswari et al., 2020).

Figure 6.

Harvested Elephant Ivory

Source: Svetlana Foote/Shutterstock.com

Figure 7.

Bracelet Made with Ivory

Source: Roman Tsymbal/Shutterstock.com

Besides being highly valued in the pet markets, Burmese Star Tortoises in Myanmar were also extensively harvested for food, shells, and medicinal purposes in China (Aung, 2018). Over 15 million turtles and tortoises are illegally hunted and traded yearly in Myanmar (Aung, 2018).

As a result, this species of tortoise is nearly depleted, eventually being classified as critically endangered by the IUCN (Platt et al., 2011).

Figure 8.

Burmese Star Tortoise

Source: Thanakarn Singto/Shutterstock.com

In addition, the wildlife trade between Myanmar and China has significantly endangered the pangolin species. Over one million pangolins have been trafficked in the past ten years, making it one of the world's most trafficked mammals (Castagnino, 2021). Although listed as a critically endangered species by the IUCN, the Sunda pangolins are still threatened with poaching for their meats and scales that are believed to have medicinal value (IUCN SSC Pangolin, n.d.). In China, one pangolin was found to be sold for around USD 1,550 in 2007, amounting to more than USD 176 million annually (UNODC, 2013), making it a highly remunerative wildlife crime.

Figure 9.

Pangolin

Source: Vickey Chauhan/Shutterstock.com

Malaysia is also one of the popular hubs of the illegal wildlife trade due to its rich biodiversity (Koshy, 2020). As shown in the figure below, around 3,300 pig-nosed turtles and 29.8 tonnes of pangolin products were seized by relevant authorities in Malaysia (The ASEAN Post, 2019). Furthermore, in 2019 alone, the Thai authorities seized around 2,730 rats, snakes, cobras, four tiger bones, and 1,666 pieces of bear claws, whereas a total of 25.6 tonnes of pangolin scales were confiscated by the Singapore government (see Figure 10) (The ASEAN Post, 2019). These statistics demonstrate that illegal hunting and trade are occurring at an alarming rate, which can result in species extinction across Southeast Asia.

Figure 10.

Wildlife Trafficking Seizures in Southeast Asia

Source: The ASEAN Post (2019)

As can be seen, illegal hunting and trading have caused a substantial decline in the fauna biodiversity in Southeast Asia, putting many unique species into the critically endangered category. Undoubtedly, the trade parties involved in illegal hunting and wildlife trafficking need to come together to collectively and effectively address illegal wildlife hunting and trading in Southeast Asia (Esmail et al., 2020).

Taken together, it is evident that deforestation, forest degradation, and unsustainable hunting serve as the main anthropogenic activities causing deleterious impacts on terrestrial biodiversity and the ecosystems in Southeast Asia. To minimize the anthropogenic impacts, terrestrial protected areas have long been designated to conserve biodiversity and protect biologically important terrestrial areas in Southeast Asia. Despite being protected, some protected areas are not efficiently managed, resulting in even worse outcomes as compared to non-protected areas. Detailed explanations of terrestrial protected areas are outlined in the sections that follow.

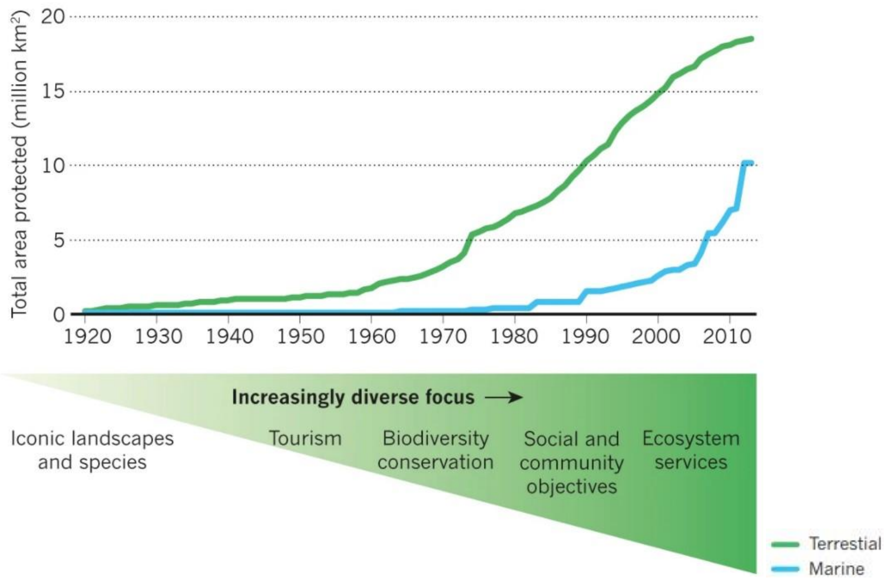
4. Terrestrial Protected Areas in Southeast Asia

4.1 Background

The protected area, one of the area-based measures, plays significant roles in protecting the environment, conserving biodiversity, minimizing habitat loss, and lowering the rate of species extinctions (Gray et al., 2016; Geldmann et al., 2014; Joppa et al., 2008). IUCN defines a protected area as "a clearly defined geographical space, recognized, dedicated, and managed, through legal or other effective means, to achieve the long-term conservation of nature with associated ecosystem services and cultural values" (Dudley, 2008). While conserving and minimizing the loss of biodiversity, protected areas also contribute to people's livelihoods, which depend upon nature for sources of food, clean water supply, and protection against natural disasters (Dudley, 2008; Gray et al., 2016). According to a research study, the first official protected area in the world – Yosemite National Park in the United States, was established in 1864 to promote eco-tourism while conserving natural ecosystems (Watson et al., 2014). In later years, protected areas have been designated for increasingly diverse purposes, which include but are not limited to serving social and community objectives (e.g., contributing to the socio-economic development of local communities), and preserving ecosystem services (e.g., food security, clean water supply, climate regulation) essential for human beings (Watson et al., 2014).

Figure 11.

Historical Growth of the Modern Terrestrial and Marine Protected Area



Source: Watson et al. (2014, p. 68)

There are two main types of protected areas, namely terrestrial protected areas and marine protected areas. This paper focuses primarily on the former, which involves land areas comprising at least 1,000 hectares of completely or partially protected areas. Specifically, these areas have been selected to serve as scientific and nature reserves in which public access may be restricted partially or completely, protected landscapes, national monuments, national parks, wildlife sanctuaries, and areas that are designated for sustainable use of natural resources (The World Bank, 2022). In addition to government agencies, these protected areas are also managed by non-governmental organizations, private sectors, and local communities (Emerton et al., 2006). Globally, there has been a significant increase in terrestrial protected areas from 10% in 2000 to 15% in 2020 (Convention on Biological Diversity, 2020b). This conservation approach (e.g., the establishment of protected areas) has greatly reduced the extinctions of mammals and birds in the past decade (Convention on Biological Diversity, 2020b).

4.2 Different IUCN Categories

To efficiently manage protected areas, IUCN has identified six categories of protected areas, such as Category 1a: Strict Nature Reserve, where human visitation is strictly controlled to preserve ecosystems and conserve biodiversity; Category 1b: Wilderness Area, which involves undisturbed or slightly modified areas that allow a certain extent of human access, with the objectives of preserving the ecological integrity of certain natural areas; Category 2: National Park, which involves natural areas set aside to protect ecosystems and the supporting ecological processes, and to contribute to educational and recreational purposes; Category 3: Natural Monument or Feature, which aims to protect specific natural sites and their cultural values; Category 4: Habitat/Species Management Area, where active management interventions are needed to protect particular species and reinstate habitats; Category 5: Protected Landscape/Seascape, which is managed mainly for biodiversity conservation and recreation purposes, where there is a balanced interaction between human and nature; and Category 6: Protected Area with Sustainable Use of Natural Resources, where biodiversity conservation and sustainable use of natural resources occur simultaneously, which is also vital in promoting socio-economic development of local communities.

Essentially, these six categories of protected areas serve different objectives with respect to particular situations, with the ultimate goal of conserving and protecting biodiversity and natural ecosystems while simultaneously safeguarding human welfare (Dudley, 2008). Refer to Table 12 for the different management objectives of each IUCN protected area management category. Specifically, every category of protected areas has both primary and secondary management objectives (IUCN, 2000). See Table 13 for the number of terrestrial protected areas in each IUCN protected area category in Southeast Asia to date. The IUCN categories are not compulsorily applied uniformly across countries (Dudley, 2008). As shown in the table, different countries have taken different approaches to protect their terrestrial ecosystem. For instance, Malaysia, Indonesia, and Thailand have relatively more terrestrial protected areas placed in category 1a - the strict nature reserves. Bidu-Bidu, Kelawat, and Mount Cochrane are examples of the IUCN category 1a terrestrial protected areas in Malaysia (Protected Planet, 2022). In contrast, little emphasis has been placed on establishing category 1b – wilderness areas across Southeast Asia countries (see Table 13). Based on statistics, Malaysia, Singapore, and the Philippines are the only countries that have established terrestrial protected areas of category 1a (Protected Planet, 2022). A research study has found that protected areas with minimal human footprints are more effective at conserving biodiversity (Gray et al., 2016). Yet, there is no relationship between the strictness of protected areas and species richness and abundance. This indicates that more restrictive protected areas do not imply higher species richness or biodiversity (Gray et al., 2016). Nonetheless, another study found that more strictly protected areas are more effective at conserving larger and threatened mammals (Ferreira et al., 2020). Although the strictness of protected areas varies by country and protection level, these protected areas serve the common goal of preserving biodiversity and the ecosystems in Southeast Asia.

Table 12. *Management Objectives of Each IUCN Protected Area Management Category*

Management objectives	IUCN protected area management categories						
	Ia	Ib	II	III	IV	V	VI
Scientific research	***	*	**	**	**	**	*
Wilderness protection	**	***	**	*	*	-	**
Preservation of species and genetic diversity	***	**	***	***	***	**	***
Maintenance of environmental services	**	***	***	-	***	**	***
Protection of specific natural and cultural features	-	-	**	*	*	***	*
Tourism and recreation	-	**	***	***	*	***	*
Education	-	**	**	**	*	-	-
Sustainable use of resources from natural ecosystems	-	*	*	-	**	**	***
Maintenance of cultural and traditional attributes	-	-	-	-	-	***	**

Source: IUCN (2000, p. 10)

Notes. *** Primary objective; ** Secondary objective; * Potentially applicable objective; - Not applicable

Table 13: *IUCN Terrestrial Protected Area Categories in Southeast Asia Countries in 2021*

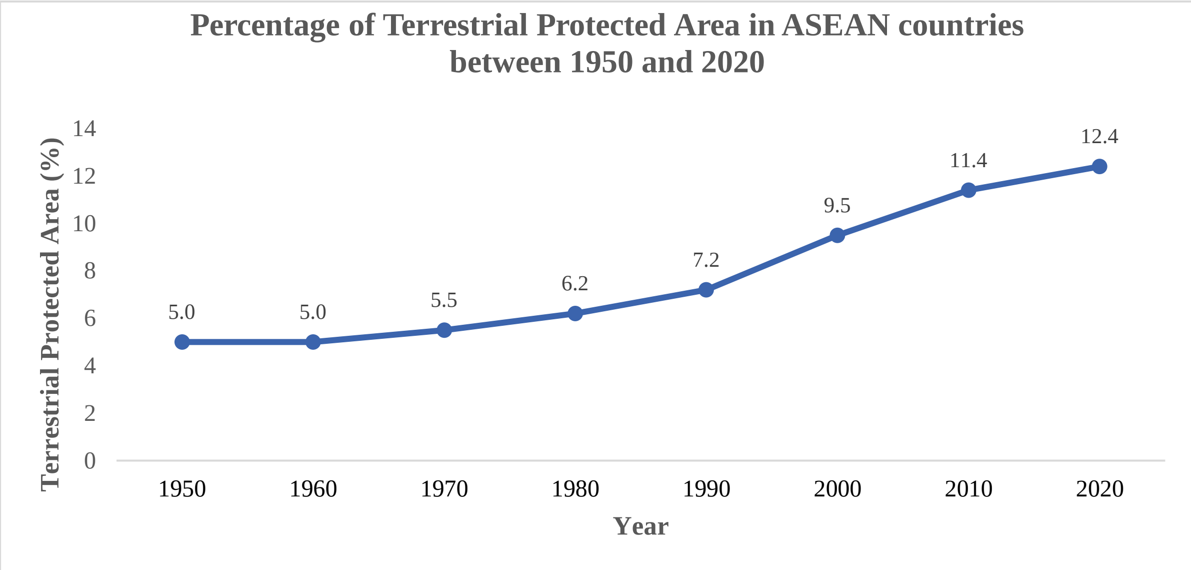
Countries	Terrestrial Protected Area Categories (no.)									
	Ia	**Ib**	**II**	**III**	**IV**	**V**	**VI**	**Not reported**	**Not applicable**	**Not assigned**
Malaysia	170	38	60	1	26	32	103	4	3	0
Singapore	-	3	-	-	-	-	-	-	-	-
Vietnam	-	-	23	-	32	23	-	81	4	-
Cambodia	5	-	11	2	18	14	14	-	1	-
Laos	-	-	3	-	1	-	20	7	-	-
Indonesia	136	-	39	61	56	90	41	105	7	-
Philippines	-	2	27	5	9	36	6	4	6	116
Thailand	58	-	121	12	-	-	1	5	5	-
Brunei	22	-	3	-	-	7	-	12	-	-
Myanmar	1	-	7	2	30	1	-	5	2	-

Source: UN Environment Program-World Conservation Monitoring Centre [UNEP-WCMC] (2022)

4.3 Current Trends of Marine Protected Areas in Southeast Asia

Figure 12.

Percentage of Terrestrial Protected Areas of Southeast Asia Region between 1950 and 2020



Source: OECD Stat (2021)

Table 14. *Terrestrial Protected Area (%) in Southeast Asia Countries in 2021*

Countries	Total Land Area	Terrestrial Protected Area	
	km²	km²	%
Malaysia	331,701	44,205	13.33
Singapore	605	34	5.55
Brunei	5,962	2,794	46.87
Cambodia	182,511	72,527	39.74
Indonesia	1,906,555	231,946	12.17
Laos	231,276	43,220	18.69
Myanmar	673,079	44,289	6.58
Philippines	298,775	47,412	15.87
Thailand	517,787	96,038	18.55
Vietnam	329,880	24,994	7.58
Timor-Leste	15,007	2,401	16
TOTAL	**4,493,138**	**609,860**	**13.57**

Source: Protected Planet (2022)

As shown in Figure 12, terrestrial protected areas in the Southeast Asia region have more than doubled since 1950, increasing from 5% in 1950 to 12.4% in 2020, indicating a positive sign of conservation efforts (OECD Stats, 2021). The current pattern of terrestrial protected areas in each Southeast Asia country is shown in Table 14. Specifically, Southeast Asia's terrestrial protected areas cover 609,860 km^2, accounting for only 13.57% of the total terrestrial realm in Southeast Asia. As shown in Table 14, although Brunei has the highest percentage of terrestrial protected areas (46.87%) among the Southeast Asia countries, it has relatively small total land areas. In contrast, Indonesia has the largest total land area among the Southeast Asia countries, yet only 12.17% are designated as terrestrial protected areas (UNEP-WCMC, 2021). As can be seen, the ratios of total land areas and protected areas in these countries vary greatly. Based on the percentage of terrestrial protected areas, nearly half of the Southeast Asia countries, namely Brunei (46.86%), Cambodia (39.74%), Laos (18.69%), Thailand (18.55%), Timor-Leste (16%), and the Philippines (15.87%), are meeting or have already exceeded the Aichi Biodiversity Target 11. In short, this target calls for at least 17% of the terrestrial areas vital for biodiversity and ecosystem services to be optimally preserved and effectively protected through active conservation efforts (Convention on Biological Diversity [CBD], 2020a).

4.4 The 30 x 30 Initiative

Environmentalists have advocated for the protection of 30% of land and ocean areas by 2030 (30 x 30 initiative) using protected areas and other effective area-based conservation measures, with the aims of conserving biodiversity and maintaining ecosystem services while simultaneously preserving the welfare of local communities (IUCN, 2021). However, although Southeast Asia countries are rich in biodiversity (containing almost 20% of the world's biodiversity), Cambodia is the only Southeast Asia country participating in the 30 x 30 initiative, implying a lack of conservation efforts in other Southeast Asia countries (Taylor, 2021). The reluctance of other Southeast Asia countries to join the 30 x 30 initiative is probably because conservation initiatives are still regarded as a stumbling block to rapid economic development in these Southeast Asia countries (Taylor, 2021). According to the Southeast Asia Centre for Biodiversity (2017), Southeast Asia countries risk losing 70 to 90 percent of natural habitats as well as 13 – 42 percent of flora and fauna species by the year 2100 if no further preventive measures are taken to protect the biodiversity in the region. Furthermore, the recent outbreak of COVID-19 has hindered conservation efforts in Southeast Asia countries. This is mainly due to the restriction of non-essential economic activities, which include biodiversity conservation initiatives (Athira, 2020; Lawler et al., 2021). Consequently, this could substantially disrupt conservation efforts in the future.

5. Analysis of Terrestrial Protected Areas in Southeast Asia

5.1 Key Benefits of Terrestrial Protected Areas in the Southeast Asia Region

The establishment of the Southeast Asia heritage parks, which have been defined as "protected areas of high conservation importance, preserving in total a complete spectrum of representative ecosystems of the Southeast Asia region" (Southeast Asia Centre for Biodiversity, 2015), is one of the collective conservation initiatives among the Southeast Asia countries in protecting biological diversity and recognizing the values of these protected areas. Fifty protected areas have been designated as Southeast Asia Heritage Parks as of 2021 (The Phuket News, 2021). For instance, there are nine Southeast Asia Heritage Parks in the Philippines alone, two of which are also gazetted as UNESCO World Heritage Sites, namely

Tubbataha Reefs Natural Park and Mt. Hamiguitan Range Natural Park (The Philippine Clearing House Mechanism, n.d.). Likewise, Myanmar consists of eight Southeast Asia Heritage Parks, such as Inle Lake Wildlife Sanctuary, Alaungdaw Kathapa National Park, Hkakaborazi National Park, etc. (Southeast Asia Centre for Biodiversity, 2015). In essence, these Southeast Asia Heritage Parks were established to conserve a wide array of ecosystems in the region and generate greater public awareness of the importance of preserving Southeast Asia's rich biodiversity for a sustainable future (Southeast Asia Centre for Biodiversity, 2015).

Effectively managed terrestrial protected areas play an essential role in curtailing the loss of biodiversity, preserving habitats and natural resources, maintaining ecosystem services that serve basic human needs, protecting against natural disasters, and improving climate resilience (Asamoah et al., 2021; Watson et al., 2014). Besides that, they also help reduce the poverty rate, promote eco-tourism, contribute to socio-economic development, and positively impact human well-being (Convention on Biological Diversity, 2008; Naidoo et al., 2019). For example, the Mount Kitanglad Range Natural Park (MKRNP), considered the most well-managed protected area in the Philippines, has contributed to ecosystem services, such as supplying clean water and hydroelectric to the surrounding communities (La Viña et al., 2010). Besides that, MKRNP also provides sustainable livelihood opportunities to the local communities and indigenous people through the eco-tourism industry (BIMP–EAGA, 2017). As another Southeast Asia heritage park, the Khakaborazi National Park, which is situated in northern Myanmar, is also a popular eco-tourism destination for foreign tourists and local travellers, contributing to environmental protection and economic development (Global New Light of Myanmar, 2021). Similarly, serving as the first ecosystem restoration concession in Indonesia, Hutan Harapan Initiative aims to reinstate Indonesia's biodiversity and ecosystem functions while providing the Batin Sembilan community with income-generating opportunities through sustainable use of natural resources in Hutan Harapan (Hutan Harapan, 2018). As a result, these initiatives have led to an increase in the percentage of terrestrial protected areas and reduced natural habitat loss in the Southeast Asia region over time (BIMP–EAGA, 2017).

In another instance, Taman Negara Pahang National Park, the first and oldest terrestrial protected area in Malaysia, also contributes substantially to biodiversity conservation and ecosystem services in the region. This 4,343-hectare national park spreads across Pahang, Kelantan, and Terengganu in Malaysia, with an approximate height of 2,187 meters above sea level (Southeast Asia Centre for Biodiversity, n.d.). It comprises rich biodiversity, housing more than 180,000 fauna, 250 bird species, 50 reptile species, 50 amphibian species, and 100 fish species. Besides serving as the natural habitat for the various species, the establishment of this national park has also promoted eco-tourism activities in the region, including river cruises, jungle trekking, bird watching, canoeing, and visitation to the Orang Asli settlement (Southeast Asia Centre for Biodiversity, n.d.). In addition, the Department of Wildlife and National Parks has taken steps to involve the local communities in preserving and managing the national park. As a result, the majority of indigenous people – the Orang Asli – engage in eco-tourism activities that reconcile the conservation of biological diversity with economic development. In other words, it helps improve the livelihoods of the indigenous people and protect the natural habitats simultaneously. Moreover, the indigenous knowledge of medicinal plants is useful for pharmaceutical companies searching for new drugs vital to public health (Bakar, 2018). As can be seen, terrestrial protected areas such as national parks are beneficial for both biodiversity conservation and the socio-economic development of local communities.

5.2 Shortfalls of Terrestrial Protected Areas in the Southeast Asia Region

Prior to the COVID-19 pandemic, there were already many challenges associated with managing terrestrial protected areas in the Southeast Asia region. There is no rose without a thorn. Despite the increasing number of terrestrial protected areas in the Southeast Asia region and their encouraging biodiversity outcomes mentioned earlier, there are some controversial issues with these terrestrial protected areas. In fact, 70% of terrestrial protected areas in Southeast Asia are under intense human pressure, signifying that the degree of protection provided by these terrestrial protected areas is not up to expectation (Jones et al., 2018). In particular, terrestrial protected areas under intense human pressure have increased by 55.2 % from 1993 to 2009 (Verma et al., 2020). Moreover, some of these protected areas are not effectively managed to safeguard the natural habitats and species residing in these areas (WWF, 2020). For example, Indonesia has more than 220,000 km^2 of terrestrial protected areas, yet 10% of the regions have been degraded. In addition, there was a significant reduction in the forest cover in most of Indonesia's terrestrial national parks between 2012 and 2017 due to rapid infrastructure development, land transformation, and the increasing human population in these regions (Dwiyahreni et al., 2021). In fact, the rate of deforestation in the terrestrial protected areas in Sumatra (one of the largest islands in Indonesia) is similar to that in other production forest areas in Indonesia, overthrowing the conservation purpose of the terrestrial protected areas (Dwiyahreni et al., 2021). More worryingly, deforestation within the terrestrial protected areas in Indonesia, especially the Sebangau National Park, has also contributed to tons of carbon emissions annually, exacerbating global warming (Benji, 2017). Realizing the detrimental impacts of carbon emissions, the Krombacher Climate Protection Project was established by WWF to reduce carbon emissions and curtail forest degradation in Sebangau National Park (WWF Deutschland, 2019).

Besides that, while there are a considerable number of terrestrial protected areas in Southeast Asian countries, many have failed to protect and conserve certain endemic species. For example, Sumatran primates and tigers residing in the terrestrial protected areas in Indonesia have declined significantly due to the high deforestation rates (Supriatna et al., 2017; Wibisono & Pusparini, 2010). These endemic species are less likely to survive in highly fragmented and disturbed habitats where illegal logging, hunting, land conversion, and other human activities occur frequently. A study discovered that a species of the Sumatran primates, namely *Macaca Tonkeana*, had lost 4% of their forest habitats in terrestrial protected areas to deforestation between 2000 and 2017 (Supriatna et al., 2020). Other than that, illegal hunting in terrestrial protected areas has also put Sumatran tigers' lives in danger. As evidence, recent news reported that three Sumatran tigers were found dead in a protected area in Banda Aceh (a province in Indonesia) as a result of poaching activities (Daniel, 2021). Although tiger poaching is punishable with hefty fines and imprisonment in Indonesia, many are still involved in poaching activities to make money by selling the Sumatran tigers or their parts to wildlife traffickers (WWF, 2011). In fact, tiger poaching for commercial trade is an extremely lucrative business in Indonesia. Tiger bones are allegedly high in medical value and are usually exported to neighbouring countries at sky-high prices to supply the demand for traditional Chinese medicine (Wibisono & Pusparini, 2010). Additionally, Bornean banteng (*Bos javanicus lowi*), a critically endangered wild bovid in Sabah, is also at risk of extinction due to continuous habitat loss, forest fragmentation, and intense poaching within the terrestrial protected areas (Kristy, 2017; Lim et al., 2019). As of 2021, there are only 320 Bornean bantengs left in the forest in Sabah (Paul, 2021). To protect these critically endangered species against extinction, well-trained forest guards are needed to prevent further poaching and illegal logging activities within the terrestrial protected areas.

Poor representation of habitats also serves as another problem with the current terrestrial protected area. In particular, the Southeast Asia region's terrestrial protected areas are mainly located in mountainous areas. As a result, some of the key biodiversity areas are left unprotected as they are primarily located in biologically diverse lowland forests (Verma et al., 2020). The placement of protected areas at high altitudes is largely due to the low economic value of the less-accessible mountainous areas (Singh et al., 2021). For instance, the majority of terrestrial protected areas in Thailand are in areas of high altitudes, which are less likely to cover a good range of altitudes to preserve a wide array of endemic species (Singh et al., 2021). Correspondingly, some of the key natural habitats remain outside the terrestrial protected areas in Indonesia (Supriatna et al., 2017). Sumatra endemic primates, such as the Pagai langur (*Presbytis potenziani*) and the Pagai macaque (*Macaca pagensis*), reside in lowland forests, which are not represented in any of the terrestrial protected areas and national parks in Indonesia. Clearly, there is an apparent discrepancy between the government-declared terrestrial protected areas and the areas that environmentalists have designated for biodiversity conservation. Nevertheless, these biodiversity conservation issues have been largely ignored by the government and the private sector (Supriatna et al., 2017). This may be due to the fact that Indonesia's Government still sees biodiversity conservation as impeding economic development (Dwiyahreni et al., 2021). Analogous to Indonesia, the Philippines' terrestrial protected areas fail to achieve the requirements of the Aichi Target 11 established by the Convention on Biological Diversity (CBD), which urges Southeast Asia nations to conserve and effectively manage land areas that are of utmost importance for biodiversity and ecosystem services (Mallari et al., 2016). As shown in Figure 2, although the Philippines is reaching the Aichi Target 11, 64% of its key biodiversity areas in the Philippines are still not covered in the system of protected areas such as national parks and reserves (Mallari et al., 2016). For example, most of the endemic bird areas in the Philippines are not located within the terrestrial protected areas (Mallari et al., 2016). As can be seen, many of the terrestrial protected areas in the Philippines are not appropriately located to protect sites essential for biodiversity conservation, signifying a mismatch between key biodiversity distribution and terrestrial protected areas in the Philippines.

Some terrestrial protected areas are less effective than other unprotected areas at reducing deforestation and conserving biodiversity. For example, there has been a substantial forest loss (97,007 hectares) within the terrestrial protected areas in the Philippines in recent decades (Apan et al., 2017), which has resulted in immense forest fragmentation and biodiversity loss (Estoque et al., 2018). Moreover, poorly implemented environmental legislation has driven illegal logging even within the protected areas in the Philippines. Yet, the government authorities turn a blind eye to these logging activities as the surrounding poor rural villagers rely heavily on timber revenue for their sources of income (Ploeg et al., 2011). Infuriatingly, illegal logging activities have persisted in Sierra Madre Mountain Range, the largest terrestrial protected area in the Philippines, despite the COVID-19 pandemic in recent years (Jonathan, 2020). Furthermore, almost half of the terrestrial protected areas in the Philippines lack proper management systems and capacities, which are vital for biodiversity conservation (Mallari et al., 2016). In particular, only 15% of the terrestrial protected areas have finalized management plans approved by the Protected Area Management Boards. The shortage of budget, staffing, and research activities is another critical issue leading to poor biodiversity conservation management in the Philippines' terrestrial protected areas (Mallari et al., 2016). Terrestrial protected areas in Indonesia are also faced with deforestation issues. For instance, the Tesso Nilo National Park, the largest lowland rainforest in Sumatra, experienced substantial habitat loss due to illegal logging and rapid road construction within the protected areas. In fact, a study found that the level of human footprint within Category 1a terrestrial protected areas (strict nature reserve) is significantly higher than other categories of protected areas within the Southeast Asia region (Verma et al., 2020). This finding contrasts the main objectives of IUCN Category 1a protected areas, which insinuates that the protected areas are strictly set aside for biodiversity conservation and where human activities are strictly limited (Dudley, 2008). For instance, one of the strict nature reserves in Indonesia suffers from higher deforestation rates than other logging concessions, suggesting that logging concessions provide a higher success rate of halting deforestation compared to terrestrial protected areas in Category 1a (Brun et al., 2015). If deforestation and degradation persist in these terrestrial protected areas, it can eventually result in the extinction of endangered endemic species that inhabit the forest and accelerate climate change (Poor et al., 2019). The ineffective management of these protected areas might be due to the low budget allocated for biodiversity management. Based on calculations of funding requirements, Indonesia lacks approximately USD 522 million of conservation funding per year from 2010 through 2020 (Ministry of National Development Planning of the Republic of Indonesia, 2016 – see Table 16).

Table 16. *Conservation Fund Deficiency for Protected Area Management in Indonesia between 2010 to 2020*

Description	Value
Lack of conservation cost per hectare	USD 1,352
Lack of conservation cost	USD 521, 930

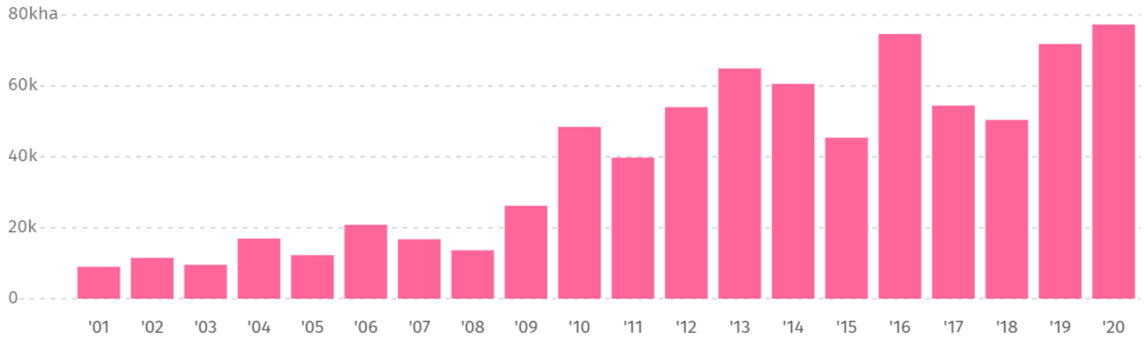
Source: Ministry of National Development Planning of the Republic of Indonesia (2016)

Clearly, expanding terrestrial protected areas alone is not enough to address biodiversity loss; sufficient funding and proper law enforcement are much needed to address the shortcomings of these poorly managed terrestrial protected areas. Besides that, community engagement and the involvement of local communities in the terrestrial protected areas management are also necessary to protect the forest areas against all forms of exploitation (Poor et al., 2019).

In another example, Cambodia lost approximately 770,000 hectares of tree cover in the protected areas between 2001 and 2020, representing a 14% loss of tree cover since 2001 (see Figure 12). In particular, there has been a significant increase in tree cover loss since 2010 throughout 2020. The bulk of tree cover loss has led to 480 metric tons of carbon emissions in Cambodia within these 20 years (Global Forest Watch, 2020). Moreover, one of the protected areas has been de-gazetted due to substantial deforestation, leaving a devastating impact on the socio-economic development of the indigenous people and local communities who primarily depend on the forest resources for their livelihoods (Global Initiative Against Transnational Organized Crime [GIATOC], 2021).

Figure 12.

Tree Cover Loss in Protected Areas in Cambodia from 2001 to 2020



Source: Krasek (2019)

Paradoxically, some government-sanctioned territorial concessions, including economic and social land concessions, are placed within the protected areas in Cambodia. As of 2012, 113 economic land concessions inside protected areas have been approved by the Cambodia Ministry of Environment (GIATOC, 2021). Alarmingly, illegal logging also occurs outside the logging concessions boundary within the protected areas. However, government officials' negligence and lack of action have further allowed logging companies (e.g., Think Biotech, Angkor Plywood, etc.) to carry out large-scale deforestation in the protected areas with assistance from local communities. In particular, these companies outsourced the logging tasks to local communities and stayed aloof from the actual task of logging itself. Moreover, the logging companies also involved local communities in selling resin trees, allowing them to reap benefits from the deals (GIATOC, 2021). For instance, tonnes of trees in some of the wildlife sanctuaries in Cambodia (e.g., Prey Lang, Prey Preah Roka, etc.) have been extensively harvested and traded illegally (GIATOC, 2021). As can be seen, the rate of deforestation in the protected areas is comparable to other unprotected areas nationwide, creating controversial issues with the protected area approach (Theilade & De Kok, 2015).

Another major obstacle to effective protected area management is the lack of connectivity between terrestrial protected areas (Convention on Biological Diversity, 2020a; WWF, 2020). Some countries fail to take into account the structural connectivity between terrestrial protected areas when expanding their terrestrial protected area networks (Ward et al., 2020). In fact, only 9.7% of global terrestrial protected areas are structurally linked, and on average, around 11% of each country's protected areas are connected (Ward et al., 2020). Furthermore, none of the terrestrial protected areas is found interconnected in some Southeast Asia countries, such as Thailand, Myanmar, Vietnam, and Laos, indicating a severe shortfall in the protected area management (Ward et al., 2020). Structurally connected landscapes are crucial in enabling seasonal animal migrations and enhancing ecosystem resilience (Lundberg & Moberg, 2003; Tucker et al., 2018). Some species tend to migrate to other landscapes seasonally to look for food and water, as well as more favourable living and breeding conditions. Climate change has also prompted some temperature-sensitive species to move away from their ancestral lands and seek new habitats in areas with more suitable temperatures (Heller & Zavaleta, 2009; Ward et al., 2020). Nonetheless, the fragmentation of terrestrial protected areas has limited the possibility of animal migration, which can result in species extinctions due to their inability to adapt to climate change (Heller & Zavaleta, 2009). Besides that, species extinctions often occur in small, fragmented habitats rather than large connected habitats. This is because some large animal species, such as bears and big cats (e.g., lions, tigers, leopards, etc.), require larger areas of natural habitat for food hunting and reproduction (WWF, 2020). For example, studies state that the survival of critically endangered species such as saola (*Pseudoryx nghetinhensis*) and Indochinese tigers (*Panthera tigris Linnaeus*) is heavily dependent upon the structural connectivity between terrestrial protected areas in Southeast Asia

(Lynam, 2010; Stone, 2006). Undoubtedly, a high level of connectivity between terrestrial protected areas is one of the key solutions to ensure effective conservation and the survival of many species, especially under anthropogenic climate change in the 21st century (Convention on Biological Diversity, 2020b; Ward et al., 2020). Thus, more corridors between the terrestrial protected areas must be established to enable the movement of species from one protected habitat to another, which is also vital in enhancing biodiversity conservation.

6. Moving Forward

Although Southeast Asia countries have devised and implemented strategic plans to manage their terrestrial protected areas, there are many challenges halting the effective management of these protected areas. Therefore, remedial measures are urgently needed to address the shortfalls of these protected areas to ensure the sustainability of biodiversity and ecosystem services. Several preventive and restorative measures that can help monitor and ensure the effectiveness of terrestrial areas in the Southeast Asia region are discussed in the following paragraphs.

6.1 Inclusion of Local Communities in the Protected Area Management

Government and NGOs such as WWF should encourage indigenous people and local communities to actively involve themselves in the protected area decision-making process. Indigenous peoples hold primary responsibilities for managing natural habitats and protecting 80% of biodiversity worldwide (Gleb, 2018). They inhabit at least 38 million km^2 of land that spans 87 countries and overlap with 40% of all terrestrial protected areas (Garnett et al., 2018). Local indigenous knowledge and practices are essential in contributing to sustainable ecosystem management and simultaneously safeguarding the livelihoods of local communities

(UNEP, 2020). Furthermore, it is relatively easier to enforce conservation policies and implement sound initiatives when the knowledge and opinions of local communities are regularly taken into consideration in protected area management (Andrade & Rhodes, 2012). The inclusion may promote a sense of ownership, which encourages the local communities to jointly protect their homelands against exploitation and sustainably utilize natural resources (Andrade & Rhodes, 2012). Moreover, studies have shown that indigenous lands are more successful in halting deforestation and conserving biodiversity than protected areas (Barrow et al., 2016; Tauli-Corpuz et al., 2020). Indigenous people are more adept at utilizing traditional conservation strategies and systems to protect the lands in a sustainable manner, owing partly to the traditions and spiritual beliefs that these sacred lands and forests are where the natural gods/spirits belong (Chunhabunyatip et al., 2018). For example, the Lua people, who were the first colonizers in Chiang Mai (Thailand) 1,300 years ago, tend to manage and preserve natural resources based on their beliefs in the spirits of the forests. As a result, they have demonstrated the ability to protect essential natural resources and sustain ecosystem services in ways that contribute to biodiversity conservation and the livelihoods of local communities (Chunhabunyatip et al., 2018). Success stories involving the inclusion of indigenous communities in protected area management also happened in the Jawa Bali bioregion in Indonesia. Jawa Bali successfully maintained and even gained forest cover despite the highest human footprint within and outside its terrestrial protected areas. This is because the Balinese believe that cutting trees on a daily basis is taboo. Instead, they adhere strictly to the Brubuh system, a traditional seasonal logging practice that only allows communities to cut down trees on a seasonal basis. As a result, these cultural customs have contributed significantly to forest preservation and biodiversity conservation (Dwiyahreni et al., 2021). As such, policymakers and conservationists are encouraged to actively engage indigenous communities in protecting and managing terrestrial protected areas in the Southeast Asia region – for instance, involving them in forest patrolling to combat illegal activities (e.g., illegal logging, poaching, timber smuggling, etc.) in the protected areas. Incentives such as income and recognition are crucial to encourage indigenous communities to be involved in managing terrestrial protected areas. In fact, this remedial measure is in line with the Aichi Target 18 set by the CBD, which asserts that local and traditional knowledge, innovations, and practices should be incorporated into biodiversity conservation and ecosystem management, alongside the active participation of indigenous and local communities, by 2020 (CDB, 2020).

6.2 Reforestation and Afforestation within Protected Areas

As aforementioned, some terrestrial protected areas suffer from higher deforestation rates than logging concessions and other unprotected areas, compromising the effectiveness of protected areas in conserving biodiversity (Brun et al., 2015; Verma et al., 2020). Thus, reforestation and afforestation within protected areas are urgently needed to restore biodiversity and ecosystem services in the long run. For example, Vietnam has successfully increased its forest coverage from 32% in 1998 to 39.5% in 2010 through the Five Million Hectare Reforestation Program (5MHRP). In this project, local communities such as upland farmers were subsidized to afforest and reforest the mountainous areas. Moreover, 5MHRP has also helped create ample employment opportunities and improved the livelihoods of local communities (OECD, 2018). Likewise, AstraZeneca has recently launched the AZ Forest Programme in Indonesia, pledging to plant 20 million trees by 2025. The first 1.5 million trees were planted in Tanjung Puting National Park, Kalimantan, while another 600,000 trees were planted in the Citarum River Basin, West Java, in 2020. This program will likely contribute to various sustainability benefits: species biodiversity enrichment, natural habitat maintenance, rainforest restoration, forest fires prevention, more effective flood management systems, climate change mitigation, job opportunities, and greater socio-economic development (AstraZeneca, 2020). To further ramp up reforestation and afforestation efforts, the Southeast Asia Green Initiative, a region-wide conservation initiative established by Southeast Asia, was introduced in 2021 with the goal of planting at least 10 million native trees within ten years (Joyce Ann, 2021). This greening project takes a whole-of-society approach through collaborative efforts among Southeast Asia countries to reinstate degraded lands and curb biodiversity loss for a sustainable future (Joyce Ann, 2021). Clearly, reforestation and afforestation play significant roles in restoring the ecosystem and biodiversity. As such, urgent actions are needed to reforest and afforest certain terrestrial protected areas where rapid deforestation and fragmentation occur to reinstate biodiversity and the ecosystem.

6.3 Other Effective Measures in Improving the Effectiveness of Terrestrial Protected Areas in Southeast Asia

In addition to reforestation and the involvement of local communities in protected area management, long-term maintenance of protected areas relies heavily on sustainable revenue streams from diverse sources (Emerton et al., 2006; Watson et al., 2014). In fact, terrestrial protected areas regularly suffer from inadequate budgets and investments from the public and private sectors, leading to ineffective management (IUCN, 2020c). A large proportion of the public funding often goes into supporting other development objectives, such as education, public health, and infrastructure development, leaving only a small budget to enhance the effectiveness of the country's protected areas (IUCN, 2000). Furthermore, in recent years, governments have reallocated funding to health-related services and industries to help curb the spread of Covid-19, leading to a further reduction in the funding set aside for biodiversity conservation (Lawler et al., 2021). Some protected areas have been closed to tourists and visitors in response to the Covid-19 pandemic, causing a substantial decline in the revenues generated from eco-tourism, which also plays an essential role in sustaining the effective management of protected areas (Gokkon, 2020; IUCN, 2020b). Undeniably, adequate financial resources are tremendously important, especially in recruiting and training management staff (e.g., site maintenance managers, anti-poacher patrols, park rangers, etc.), purchasing necessary equipment, and building infrastructures essential to effectively managing and protecting terrestrial protected areas (O'Flynn et al., 2021). In addition, with sustainable funding sources, conservationists can better plan and design the expansion of terrestrial protected area networks in Southeast Asia (Bruner et al., 2004; Watson et al., 2014). Therefore, conservationists should actively seek diversified and sustainable financing resources to sustainably support the effective management of these protected areas.

Other than that, Southeast Asia countries should also continue expanding their terrestrial protected area networks to achieve the Aichi Target 11, which calls for at least 17% of terrestrial areas of particular importance for biodiversity and ecosystem services to be effectively protected and managed (CBD, 2020). As shown in Table 14, nearly half of the countries in Southeast Asia are far from achieving the Aichi Biodiversity Target 11, including Malaysia, Singapore, Indonesia, Myanmar, and Vietnam. Hence, these countries need to ramp up their efforts to expand their terrestrial protected areas to achieve the Aichi Biodiversity Target 11, which is essential in preserving biodiversity in Southeast Asia. Furthermore, it is also crucial to take into account the structural connectivity between protected areas (Ward et al., 2020), the representation of different species within proposed protected areas (Arabian et al., 2019), and the costs of protected areas expansion and management when deciding whether to expand the protected area networks (Watson et al., 2014). Lastly, the extent to which the expansion of terrestrial protected areas in Southeast Asia countries achieves other biodiversity targets (e.g., Aichi Target 5 – reduce habitat loss, Aichi Target 12 – reduce species extinctions, Aichi Target 14 – safeguard ecosystem services, etc.) should also be considered when expanding terrestrial protected area networks in order to achieve synergies between different biodiversity targets and subsequently enhance management effectiveness of terrestrial protected areas (Di Marco et al., 2016).

7. References

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Unveiling the Significance of A*STAR's Contributions to Singapore's National Development Plan

Hui Hui Teow[1*], Pervaiz K. Ahmed[2], Mahendhiran Sanggaran Nair[3], Santha Vaithilingam[4]

[1]Sunway Institute for Global Strategy and Competitiveness, Sunway University, Malaysia*
[2]Sunway Institute for Global Strategy and Competitiveness, Sunway University, Malaysia
[3]Sunway University, Malaysia
[4]Sunway Institute for Global Strategy and Competitiveness, Sunway University, Malaysia

**Corresponding author: huihuit@sunway.edu.my*

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Abstract

This paper explores the multifaceted role of the Agency for Science, Technology, and Research (A*STAR) in creating value for Singapore through its comprehensive approach to research, development, innovation, commercialization, and economic development. As the major driver of Singapore's national Research, Innovation and Enterprise (RIE) plan, A*STAR actively contributes to Singapore's development across four key domains: manufacturing, trade and connectivity (MTC); human health and potential (HHP); urban solutions and sustainability (USS); and smart nation and digital economy (SNDE). With its strategic initiatives, expertise, state-of-the-art technologies, and robust collaborative networks involving industry players, universities, and research institutes, A*STAR plays a pivotal role in spearheading and shaping Singapore's research and development trajectory. Furthermore, by fostering a strong ecosystem of scientific excellence and industry partnerships, A*STAR accelerates the translation of research outcomes into practical applications, enhancing Singapore's economic competitiveness and strengthening its position as an innovation-driven, knowledge-based economy. This paper provides insights into A*STAR's contributions and highlights the importance of its endeavours in driving Singapore's research, development, innovation, commercialization, and economic growth.

Keywords: A*STAR, research and development, innovation, commercialization

1. National Priorities of Singapore

Covering an area of 646 square kilometers, Singapore is a wealthy island country located in the southern region of the Malay Peninsula in Southeast Asia (Asia Biz, 2021). As a high-income nation, Singapore's economy is ranked top three in competitiveness in 2022 (IMD World Competitiveness Center, 2022). The whole country has rapidly developed since its independence from Malaysia on 9th August 1965 (The World Bank, 2019). In the late 1960s, after its independence, Singapore was confronted with severe unemployment and poverty issues (Zhou, 2019). Furthermore, due to the lack of natural resources in Singapore, the nation has to rely on external sources for natural resources and basic necessities such as water, food, and energy (The World Bank, 2019). As a result, human capital development became crucial in developing and sustaining Singapore's economy (Zhou, 2019). Since its independence, the Government of Singapore shifted its focus from an import substitution strategy to an export-led industrialization approach, aiming to attract foreign investors and create more job opportunities for its citizens. This has contributed directly to Singapore's rapid industrial growth (Monetary Authority of Singapore [MAS], 2015). In fact, Singapore is strategically located at the heart of Southeast Asia, which is in an advantageous position that connects the world's major trade routes, providing a great extent of global connectivity (Economic Development Board [EDB], 2022). Specifically, Singapore's transportation hub is connected to 600 ports in 123 countries (EDB, 2022). As a result, the strategic location and established port system have successfully attracted a large inflow of foreign investments and brought about the rapid development of the manufacturing sector in Singapore (MAS, 2015; Zhou, 2019).

In the early 1970s, both the United States and Japan were major investors in Singapore's manufacturing firms. Due to Singapore's conducive investment environment, the country experienced rapid GDP growth from 1965 to 1972 (Zhou, 2019). In the 1980s and 1990s, the rapid expansion in manufacturing industries, such as electronics, petrochemicals, component and precision engineering, and pharmaceuticals, helped attract even more foreign investments to Singapore (Soon & Tan, 1993). Over this period, Singapore owes its GDP growth mainly to the manufacturing sectors (Soon & Tan, 1993). Increasingly, modern service sectors, particularly the information and communications industries, as well as the finance and insurance industries, began to play important roles in ramping up Singapore's GDP (Soon & Tan, 1993). Manufacturing sectors, particularly the construction, shipbuilding, pharmaceuticals, chemicals, electronics, and precision engineering sectors, contribute to more than 30% of Singapore's Gross Domestic Product (GDP) value (Asia Biz, 2021). From the 1990s onwards, the modern service sectors began to constitute a larger share of GDP than the manufacturing sectors in Singapore (Soon & Tan, 1993). To date, the manufacturing and services sectors remain the two pillars of economic growth in Singapore, which simultaneously features the government's efforts in recruiting and developing human capital, specifically the "Professional, Managerial, Executive, and Technical (PMET) workforce" (Matthew, 2020; Tan, 2019). For instance, the Ministry of Manpower Singapore has taken steps to adjust immigration policies to attract, recruit, and retain foreign workers who play important roles in the manufacturing and services sectors in Singapore (The Hindu, 2022). Singapore's GDP is expected to reach 425 USD Billion by the end of 2022, mainly contributed by the aforementioned two important sectors (Asia Fund Managers, 2022). Intriguingly, with these development efforts, Singapore has grown from a small nation lacking natural resources to one of the world's leading economies (Santhi & Saravanakumar, 2020).

Alongside human capital, science and technology (S&T) are fundamental enablers of Singapore's economy, particularly in the manufacturing and services sectors (National Research Foundation, 2021). In fact, Singapore's S&T efforts can be witnessed through its investments in research and development (R&D) activities. The establishment of the National Science and Technology Board in 1991 and the launch of the first five-year National Technology Plan in 1995 marked the beginning of Singapore's research and development journey. The objective was to develop S&T professionals who could contribute to the nation's economic development (National Research Foundation, 2021). As the nation's economy became more sophisticated, the government's investment in S&T began focusing on other areas, particularly biomedical sciences, biotechnology, computer science, and cybersecurity (SG Innovate, 2020). Since 1985, Singapore has spent approximately USD 44 billion to expand its research capacities, develop highly-skilled S&T talent, and build cutting-edge research institutions. For instance, the Agency for Science and Technology Research (A*STAR), a public research organization, was established to drive and lead S&T development in Singapore. Complementing that, several technological research entities were established in a number of Singapore's tertiary institutions, such as the National University of Singapore and the Nanyang Technological University. To drive and enable the Science, Technology, and Innovation (STI) ecosystem, joint research collaborations between government agencies, tertiary institutes, and private sector players in Singapore were nurtured, with the main objective of developing research capabilities and driving economic growth (SG Innovate, 2020).

In 2010, Singapore's R&D strategy has been extended across research, innovation, and enterprise (RIE), aiming to streamline research capacities, innovation, and commercialization, which can add to the economic development in Singapore (National Research Foundation, 2021). Under the RIE plans (2015 - 2020), the Government of Singapore has invested more than US$ 30 billion to build the nation's competitive advantage in Advanced Manufacturing and Engineering, Health and Biomedical Sciences, Urban Solutions and Sustainability, and Services and Digital Economy. Activities in these four strategic technology domains are supported by three value-adding programs: Academic Research, Manpower, and Innovation and Enterprise (I&E). Essentially, these programs are crucial in supporting enterprises and industries to convert research and development into novel products and services, which are then available in the market (Research, Innovation, and Enterprise [RIE], 2020). As a result of these national R&D plans and platforms, some top-notch technology corporations, such as Facebook and Google, decided to establish their presence in Singapore. Furthermore, many local small and medium-sized enterprises and start-ups have established RIE partnerships to build stronger research capacities and gain access to a bigger pool of talent and networks, facilitating them to produce and offer novel products and services to the market (National Research Foundation, 2021).

The latest RIE 2025 Plan was launched in December 2020 with a massive budget of USD 25 billion, which is the biggest budget ever devoted to Singapore's R&D (A*STAR, 2021a). This investment sum clearly reflects Singapore's sustained dedication to improving its R&D. Along with prior objectives, the RIE 2025 Plan aims to build and gain more value from previous RIE investments. First, under the RIE 2025, the Government of Singapore envisions addressing a wider range of national needs. In other words, RIE investments will be integrated with national initiatives to transform industries and drive economic growth (National Research Foundation, 2021). Secondly, RIE 2025 aims to build a stronger research base, create a healthy research ecosystem, and reinforce interdisciplinary research to tackle a broader spectrum of issues in new and emerging areas (National Research Foundation, 2021). The third objective of the RIE Plan is to strengthen the I&E platforms, hoping to reach out to more local enterprises and facilitate them in technology translation and commercialization (National Research Foundation, 2021). Moreover, these I&E platforms also serve as a central hub connecting key stakeholders across the research and development communities, as well as public and private sector players, so as to facilitate the exchange of ideas, expertise, and technologies (National Research Foundation, 2021). With such objectives and efforts, Singapore is strongly committed to bringing the whole nation to greater heights through its research and development clusters. In fact, A*STAR, an important public sector R&D agency in Singapore, is the biggest driver of the RIE efforts. Further insights, background on A*STAR, and its importance to Singapore's economic development are outlined in the section that follows.

2. About A*Star

As the national driver of scientific research, the Agency for Science, Technology and Research (A*STAR) is a public research organization founded in Singapore on 11th January 1991 (A*STAR, 2022a). Originally, the research institute, formerly known as the Science Council of Singapore, was established to provide support and advice to the Government of Singapore in research and development in 1967 (Moasi, 2019). In the late 1960s, the research council mainly worked with tertiary institutions and government agencies to drive research and development in Singapore. In the 1980s, it played a significant role in raising awareness for the adoption of science and technology in Singapore, organizing research seminars, and building networks with international research communities (Moasi, 2019). Subsequently, the council shifted its role from an advisor to being directly involved in navigating Singapore's research and development industry, meeting the nation's goal of driving high-tech research and development. In 1990, the council was upgraded to the National Science and Technology Board (NSTB), holding primary responsibilities for science and technology policies, building talent in essential industry sectors, and developing facilities crucial for research and development activities (Moasi, 2019). In 1991, the NSTB formulated Singapore's first five-year National Technology Plan, primarily focusing on developing research capacities in nine sectors, including medical sciences; biotechnology; energy, water, environment and resources;

manufacturing technology; materials technology; information technology; food and agrotechnology; microelectronics; and electronic systems (Moasi, 2019).

In the 2000s, the research institute was officially divided into two primary research bodies, involving the biomedical field as well as the physical sciences & engineering field (Moasi, 2019). Subsequently, NSTB was renamed the Agency for Science, Technology and Research, or A*STAR, in January 2002 (A*STAR, 2022a). Serving as a statutory board under the Ministry of Trade and Industry of Singapore, the current goal of A*STAR is to enhance and develop the knowledge-intensive biomedical sciences, physical sciences & engineering fields, which contribute substantially to socioeconomic development and improve the overall quality of life (A*STAR, 2022b). Importantly, A*STAR encompasses two broad research arms: i) The Biomedical Research Council (BMRC); ii) the Science and Engineering Research Council (SERC) (A*STAR, 2022a). Specifically, the biomedical research entities are mainly situated at Biopolis, while the physical sciences & engineering research centers are situated at Fusionopolis, both of which are located at one-north in Buona Vista, Singapore (A*STAR, 2022c). The capabilities of these research bodies extend across a wide array of fields, including but not limited to nutrition, food security, medical technology, pharmaceuticals and biologics, immunology, advanced manufacturing, computational sciences, robotics and automation, etc. (A*STAR, 2022c). With regard to its mission, A*STAR aims to bring together academia and industry players and integrate their research capabilities, which are essential in yielding impactful outcomes for society. In terms of vision, A*STAR envisions becoming a "global leader in science, technology, and open innovation" (A*STAR, 2022b). Specifically, it establishes partnership collaborations with a variety of entities, including public and private sector players (e.g., government bodies, start-ups, small and medium-sized enterprises, and multinational corporations), with the objective of creating impacts on industry sectors and society as a whole (A*STAR, 2022b). It is also worth noting that A*STAR is the major driver of the national RIE 2025 Plan across four domains, namely: manufacturing, trade and connectivity (MTC); human health and potential (HHP); urban solutions and sustainability (USS); and Smart Nation and digital economy (SNDE) (A*STAR, 2021a). Further details on the role of A*STAR and how it creates value for its stakeholders are discussed in the sections that follow.

2.1 A*STAR's Main Research Arms

As mentioned above, the Biomedical Research Council (BMRC) and the Science and Engineering Research Council (SERC) are the two main research arms under A*STAR (Moasi, 2019). These two research arms serve different objectives in different areas. Specifically, the BMRC supports, manages, and supervises Singapore's public sector research and development activities in biomedical research. Under the BMRC, several research entities oversee and second the development of research capacities in BMRC's core research clusters, including pharmaceuticals, biotechnology and biologics, medical technology, and personal care and nutrition clusters (A*STAR, 2022b). For instance, the Institute of Bioengineering and Bioimaging (IBB), Bioprocessing Technology Institute (BTI), Genome Institute of Singapore (GIS), Bioinformatics Institute (BII), A*STAR Infectious Disease Labs (ID Labs), and the Institute of Molecular and Cell Biology (IMCB) are some of the well-established research institutes under the BMRC (A*STAR, 2022b). In addition to overseeing the development of core research capabilities in the abovementioned research clusters, BMRC also actively develops highly-skilled talent in biomedical science and promotes cross-disciplinary research, which contributes significantly to the development of Singapore's healthcare sector (A*STAR, 2022b).

The Science and Engineering Research Council (SERC), which serves as another research arm of A*STAR, promotes and oversees the public sector research and development in the physical sciences and engineering. Similar to the BMRC, SERC's research area is divided into four research clusters: engineering; electronics; chemicals, materials and energy; and info-communications, media and computing. Likewise, its' primary goals involve actively promoting multi-disciplinary research and collaborations among physical sciences and engineering industries, research institutes, and sectors; establishing a wider network of industry partners and research institutes by offering a wide variety of funding schemes and programs to enable a smooth translation of research and development into commercialization; and lastly, building and cultivating talent in physical sciences and engineering (A*STAR, 2022b). Some of the research institutes under the SERC include the Advanced Remanufacturing and Technology Centre (ARTC), Institute of Sustainability for Chemicals, Energy and Environment (ISCE^2), Institute of High-Performance Computing (IHPC), Institute for Infocomm Research (I^{2}R), Institute of Materials Research & Engineering (IMRE), etc. (A*STAR, 2022b). In general, these research institutes are responsible for leading and managing a wide range of research and development activities, from idea generation and knowledge translation to industry-led programs (A*STAR, 2022a).

2.2 The Role of A*Star in Singapore's Economic Development

As mentioned in the "National Priorities in Singapore" section, A*STAR plays an instrumental role in spearheading and navigating Singapore's research and development direction. A*STAR's primary goals align with the national Research, Innovation, and Enterprise (RIE) Plan. Specifically, the RIE plan is refreshed every five years to establish an ecosystem that accelerates the translation of research and development into innovation and commercialization (RIE, 2020). The five-year blueprint focuses on four broad strategic domains: advanced manufacturing and engineering (AME); health and biomedical sciences (HBMS); urban solutions and sustainability (USS); and Services and digital economy (SDE) (RIE, 2020). Of the RIE's budget, nearly 30% is utilized to enhance research capacities in A*STAR's research institutes and universities in Singapore, highlighting the nation's dedication to improving its research and development ecosystem (A*STAR, 2021a). In fact, each strategic domain addresses different economic issues and contributes directly to economic development. A*STAR is one of the key research institutes involved in the entire research ecosystem, from research and development activities to the innovation and commercialization phase. Further insights are discussed in the sections that follow.

2.2.1 Advanced Manufacturing and Engineering (AME)

The advanced manufacturing and engineering (AME) domain aims to "develop technological capabilities that support the growth and competitiveness of our manufacturing and engineering sectors" (RIE, 2020, p. 7). Due to its strategic location, Singapore has long been well-known for its manufacturing sector for decades (RIE, 2020). In fact, the manufacturing industry accounts for approximately 20% of Singapore's GDP and created job opportunities for more than 500,000 people (RIE, 2020). Hence, the manufacturing sector is of immeasurable value to the Government of Singapore (International Trade Administration, 2020). Research and development (R&D) are key in improving and strengthening the manufacturing and engineering sectors. This is where A*STAR comes into play to guide the R&D's direction and promote an innovation-driven, knowledge-based economy (National Research Foundation, 2021). The following section discusses some case studies of how A*STAR contributes to research and development activities in the manufacturing and engineering sectors.

2.2.1.1 Research and Development (R&D)

The Future of Manufacturing (FoM) initiative is a concrete example of how A*STAR brings value to Singapore's research and development in the manufacturing sector. Specifically, FoM was established in 2015 to empower local start-ups, SMEs, and multinational corporations to adopt smart manufacturing and automation technologies (A*STAR, 2021b). There are three public-private partnership platforms under the FoM that drive knowledge transfer and innovation, namely *Tech Access, Tech Depot,* and *Model Factories*. First, Tech Access is a platform that enables industry players or companies to gain access to A*STAR research infrastructure and expertise, such as advanced manufacturing and biotech/biomedical scientific tools, under the guidance of experts. For example, Sanwa-Intec (Asia) Pte Ltd utilized A*STAR's 3D X-Ray Computed Tomography System to scan their insert molding samples in order to address design issues, which helped improve their overall product quality (National Research Foundation, 2021). Essentially, the *Tech Access* platform allows them to explore new technologies, experiment with new applications, and prototype new products (A*STAR, 2021b). Through this platform, A*STAR also provides SMEs with its intellectual property license so that they can utilize its technologies to produce and commercialize their new ideas/solutions (Johnston, 2018). Similarly, through the *Tech Depot* platform, companies can access and adopt plug-and-play technologies. To date, more than 600 companies have utilized the *Tech Depot* platform, resulting in greater productivity improvement (National Research Foundation, 2021). The *Model Factories* platform promotes research and development activities by providing a virtual manufacturing lab, which enables simulation of process planning and production. These processes allow companies to test and prototype their novel ideas before launching them in the real-world manufacturing environment, which helps in improving production and manufacturing efficiency (A*STAR, 2021b). More than 100 companies have leveraged A*STAR's *Model Factory* platform to test and improve their new ideas and products (National Research Foundation, 2021). For instance, Abrasive Engineering Pte Ltd, which mainly produces automated blasting and shot peening machines, adopted the Industrial Internet-of-Things (IIoT) technologies through the *Model Factory* initiative to improve their machine maintenance cycles and minimize failures, aiming to boost their sales by 20% in 2021 (Seow, 2018).

The *Model Factory* initiative's contribution to Singapore's R&D can also be demonstrated through the partnership between Racer Technology (a local firm) and A*STAR's Singapore Institute of Manufacturing Technology (SIMTech). In 2006, Racer Technology leveraged A*STAR's research capabilities and expertise in engineering and technological solutions to develop and manufacture its own medical products (A*STAR, 2020). As a result, this partnership enabled Racer Technology to research and co-develop a medical device that improves the storage of blood plasma (A*STAR, 2020a). Another example involving A*STAR's *Model Factory* is the collaboration between A*STAR's SIMTech and Fong's Engineering and Manufacturing (FEM). Specifically, FEM visited A*STAR's Model Factory and discovered its Real Time Dashboard technology, which can help capture data more accurately and optimize its shopfloor connectivity (A*STAR, 2020b). The company's engineers were then trained by A*STAR's researchers to use and familiarise themselves with the technology over nine months. After adopting A*STAR's smart technology, FEM's output rose by 40%, indicating a significant improvement in their production outputs. This shows that knowledge sharing and transfer are essential for successful technology adoption. Besides its technologies, FEM also tapped into A*STAR's network of contacts that can help with the installation of the machines (A*STAR, 2020b). As can be seen, from the discussion above, the initiatives introduced by A*STAR indeed help contribute to research and development activities across industry players, private and public sector research institutes, and broader research communities in Singapore.

2.2.1.2 Innovation and Commercialization (I&C)

A*STAR also actively collaborates with industry players (e.g., local enterprises, SMEs, MNCs) to drive innovation and commercialization in Singapore. For example, STMicroelectronics, a global semiconductor company, entered into a partnership with A*STAR to establish a leading-edge R&D line in its Singapore manufacturing facility in 2020 (National Research Foundation, 2021). Through this partnership, the world's first *"Lab-in-Fab"* was jointly created to produce the piezoelectric microelectromechanical system, which is applicable in diverse market segments, such as 3D printing, healthcare devices, virtual/artificial reality applications, and smart glasses (STMicroelectronics, 2020). In fact, industry players often work with research institutes at a very theoretical level and often find it difficult to convert ideas/concepts into high-volume production. Endowed with research capacities and competencies from A*STAR and STMicroelectronics, *Lab-in-Fab* aims to address this challenge by integrating R&D and high-volume production capacities to efficiently translate new ideas/concepts into products/services (STMicroelectronics, 2022). In other words, *Lab-in-Fab* provides a platform that allows industry players to test their new ideas and products before mass production takes place (STMicroelectronics, 2020).

As another illustration, A*STAR and Sembcorp Marine, a pioneer in Singapore's offshore and marine sector, signed a Master Research Collaboration Agreement (MRCA) in 2020 to work together to seek innovation in Digital Design and Advanced Manufacturing. (Sembcorp Marine, 2020). This collaborative research project's main goal is to hasten the transition of novel offshore, marine, and renewable energy solutions from the "research and development" stage to the "commercialization" stage. Specifically, a research laboratory –

Joint Lab @ TBY, has been jointly established by Sembcorp Marine and A*STAR to provide a platform for test-bedding, which aims to facilitate and accelerate the commercialization of novel advanced manufacturing technologies in Singapore (Sembcorp Marine, 2020). Likewise, the National Additive Manufacturing Innovation Cluster (NAMIC), which is a national platform spearheaded by A*STAR, plays an important part in the innovation phase of new ideas/concepts (National Research Foundation, 2021). In the RIE 2025, NAMIC aims to provide test-bedding facilities (which include technologies that involve artificial intelligence and robotics) for research institutes and companies in the Advanced Manufacturing sectors. This effort facilitates researchers and industry players to pilot new technologies and solutions, which can efficiently and significantly help shorten the period needed to commercialize innovative solutions for the markets (National Research Foundation, 2021).

2.2.2 Health and Biomedical Sciences (HBMS)

The main objective of the health and biomedical sciences (HBMS) strategic domain is to "be a leading centre that advances human health and wellness, and creates economic value for Singapore and Singaporeans through the pursuit of excellence in research and its application" (RIE, 2020, p. 7). The key strategies of this domain involve developing new approaches to support the conversion of research ideas/concepts into healthcare solutions, better health outcomes, and greater economic value; establishing a holistic Innovation and Enterprise (I&E) ecosystem for pharmaceutical, biopharmaceutical, and medical technologies; and provide support to other health and biomedical sciences-related sectors, such as food and nutrition, as well as personal care (RIE, 2020). In fact, Singapore relies heavily on external sources for its food (more than 90% of its food is imported from more than 170 countries), and hence its food supply is vulnerably influenced by the volatile global supply chain (A*STAR, 2021c; National Research Foundation, 2021). Therefore, the Government of Singapore has established a national goal on food security, that is, to produce food locally sufficient to meet 30% of the nutritional needs in Singapore in a sustainable manner by 2030 (30 by 30 food security plan). Simultaneously, sustainable local food production will translate into greater economic opportunities for Singapore (Ministry of Sustainability and the Environment, 2021). A*STAR's Food and Consumer cluster brings together industry partners, researchers, and regulators to create innovative solutions for sustainable food production, which helps address the nation's challenges in food supply and production (A*STAR, 2021d). As can be seen, the above strategies perfectly fit into A*STAR's core research expertise, including medical technology, pharmaceuticals and biologics, food and consumer, and biomanufacturing (A*STAR, 2021e). That is to say, as the nation's largest public research institute, A*STAR holds crucial responsibilities in leading the HBMS strategic domain and addressing the aforementioned national plans. The sections below will illustrate how A*STAR contributes to the Research & Development and Innovation & Commercialization of the sectors mentioned in the HBMS strategic domain.

2.2.2.1 Research and Development (R&D)

In response to the Covid-19 pandemic, A*STAR's Infectious Diseases Labs (ID Labs) was established in April 2021 to gather a multi-disciplinary team of researchers to conduct research and develop new technologies for the detection, prevention, and elimination of the Corona Virus and other infectious diseases (A*STAR, 2021f). This initiative encouraged cross-disciplinary collaboration among industry players, clinical researchers, and public and private sector research institutes. Moreover, a wide range of cutting-edge research facilities and expertise were made readily available through ID Labs for researchers to drive translational research on infectious diseases (A*STAR, 2021f). Partnering with the National Centre for Infectious Diseases (NCID), ID Labs is also responsible for looking into the effectiveness of the Covid-19 vaccines in the Singaporean population. In addition, ID Labs also plays an important part in identifying emerging pathogens and conducting research to discover potential drugs and vaccines to protect against the transmissions of pathogens (Audrey, 2021). Other than that, the Fortitude Kit, Singapore's first ready-made Covid-19 self-test kit, was jointly researched and co-developed by A*STAR's research entities and Tan Tock Seng Hospital in Singapore (Audrey, 2021). The effectiveness and accuracy of the newly developed test kits were jointly tested and assessed by the Diagnostics Development Hub (DxD Hub) and the National Centre for Infectious Diseases before mass production took place (National Research Foundation, 2021). As a result, the Fortitude Kit was efficiently developed within a month from the idea generation to the product development phase, which is mainly attributed to the strong collaborations between researchers and the public health community (A*STAR, 2020c). Besides that, Boehringer Ingelheim (BI) signed a global licensing agreement with A*STAR to develop innovative antibodies for targeted cancer therapies. Under this agreement, BI possesses exclusive rights to research, develop, and commercialize its products by making use of A*STAR's tumor-specific antibodies for safer and more efficacious cancer treatments (ACN NewsWire, 2022). Essentially, BI conducts research, clinical trials, and commercialization of targeted cancer medicines using antibodies from A*STAR. Based on the accomplishment of the development and commercialization goals, A*STAR might receive more than EUR 100 million as compensation (ACN NewsWire, 2022). This is how A*STAR brings value to the health sector through knowledge transfer and licensing agreements.

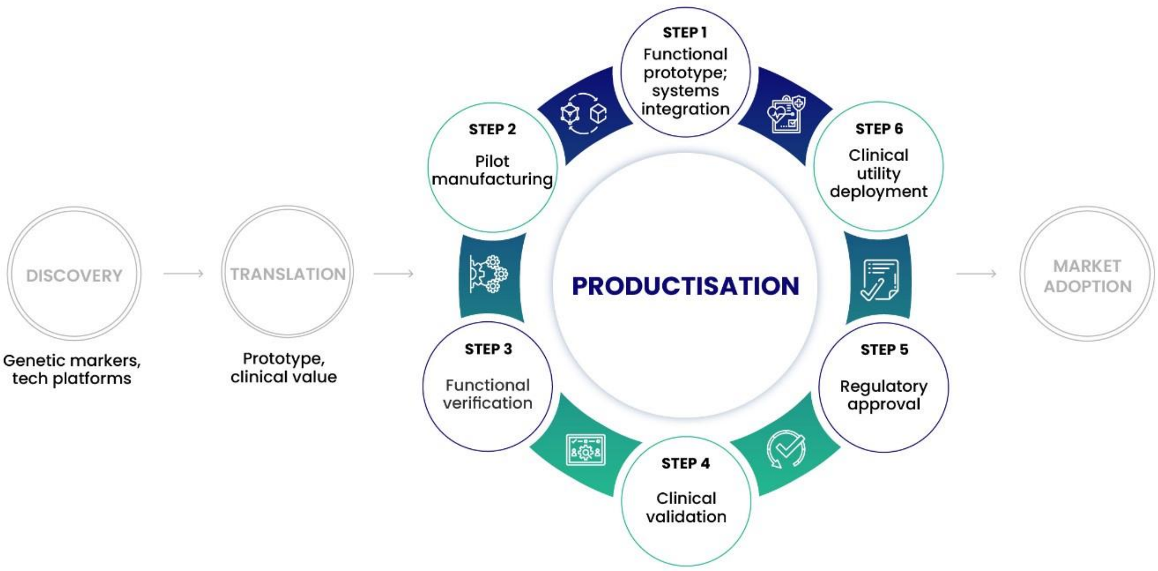
In addition to pharmaceutical and medical technology, biomedical sciences also involve the R&D of food and nutrition, which is essential in ensuring healthy living and food security in Singapore (RIE, 2020). As an example, led by A*STAR, the Singapore Institute of Food and Biotechnology Innovation (SIFBI) was established in 2020 to promote joint research collaborations on the development of innovative food solutions in Singapore (A*STAR, 2022d). Specifically, through its Taste Receptor Platform, SIFBI supports the R&D activities in local food production companies and provides innovative solutions to their food and ingredients (A*STAR, 2021g). Other than that, A*STAR also collaborates with the Singapore Food Agency (SFA) and Nanyang Technological University Singapore to jointly develop the Singapore Food Story R&D Programme, which aims to improve and strengthen food security and supply in Singapore (A*STAR, 2021h). The Future Ready Food Safety Hub (FRESH), which is a national research and support platform established under this R&D program, aims to build and enhance Singapore's food safety science and R&D capabilities, contributing to the national goal of achieving the "30 by 30" food security plan by 2030. Specifically, this platform allows the development of optimized food formulations through various laboratory experimental designs (A*STAR, 2021i). Furthermore, FRESH also aims to integrate food safety risk assessment into the research and development process to control the quality of food products for commercialization in Singapore (A*STAR, 2021i). Undeniably, A*STAR indeed serves an instrumental role in guiding and promoting the R&D activities in Singapore's food production industry.

2.2.2.2 Innovation and Commercialization (I&C)

Located in Biopolis and established in 2014, the Diagnostics Development Hub (DxD Hub) is another national initiative spearheaded by *A*ccelerate*, which is the commercialization arm of A*STAR. The DxD Hub is committed to guiding medical technology innovation through partnerships and collaborations with industry players and research institutes. Its' goal is to accelerate the translation of diagnostic-related concepts and intellectual properties into clinically approved and registered diagnostic tools, which are readily available for adoption by local start-ups, SMEs, and MNCs (A*STAR, 2021j). In fact, the process of getting novel drug discoveries to clinical trials and achieving final approval from relevant authorities can take up to ten years. However, DxD Hub steps in to shorten the cycle needed to commercialize drug discovery while assuring the quality of the newly discovered drugs (Chan, 2015). Furthermore, the development of medical technology products is closely monitored by the review panels selected by the DxD Hub, involving clinicians, venture capitalists, and other relevant industry professionals (Chan, 2015). The DxD Hub also helps local start-ups ensure that their new diagnostic products meet regulatory compliance and standard requirements. In turn, this can speed up the process of getting the products approved for sale in the global market (Chan, 2015). Figure 1 demonstrates the DxD Hub's productization process.

Figure 1.

The productization process of DxD Hub.



Source: DxD Hub (2022)

Many local enterprises, MNCs, and research institutes have partnered with A*STAR in getting their new diagnostic devices and drugs developed and commercialized. TIIM Healthcare, X-Zell, Advanced MedTech, Parkway Laboratories, Respiree, and ASEAN-NDI are some of A*STAR's partners (A*STAR, 2021k). For example, X-Zell, a global medical technology start-up specializing in cancer cell detection, signed a research collaboration agreement with A*STAR to enhance its research capacities, accelerate the product development phase, and scale up its commercialization process (X-Zell, 2018). Specifically, in phase one of the collaboration, DxD Hub will conduct stringent testing on X-Zell's novel cancer cell detection technology (X-ZELL Prostate™) for safety and quality assurance. In phase two, prospective, blinded, multi-center clinical trials will be carried out by DxD Hub to test and validate the efficacy, accuracy, and safety of X-Zell Prostate™. This is followed by the global commercialization of X-Zell's unique cancer cell detection technology (X-Zell, 2018). As can be seen, DxD Hub is strategically involved in every stage of X-Zell's productization of its cancer cell detection technology, bringing value to the entire innovation and enterprise ecosystem. As another example, following the R&D phase involving collaboration between A*STAR research entities and Tan Tock Seng Hospital, A*STAR has partnered with various biotechnology corporations (e.g., MiRXES) in Singapore to mass-produce and commercialize the Fortitude Kit to meet global demand (National Research Foundation, 2021). To date, the Fortitude Kit has been distributed to more than 45 countries worldwide as a result of the innovation and commercialization efforts among A*STAR research institutes and other industry players (MiRXES, n.d.).

Regarding food and nutrition, A*STAR established a Food Tech Innovation Centre (FTIC) with Temasek, an investment company owned by the Government of Singapore, aiming to accelerate the development and commercialization of food technologies to meet Singapore's "30 by 30" food security goal (Ovais, 2020). The main purpose of FTIC is to provide food production companies with support in the pilot manufacturing activities and food production process. FTIC offers essential facilities such as Wet Labs, Test Kitchens, and pilot-scale facilities for product testing and development. That is to say, local start-ups can utilize this platform to testbed their food products in small batches before the actual commercialization phase (Ovais, 2020). Beyond facilities and equipment, FTIC also provides a wide range of advisory support for local food start-ups to facilitate rapid commercialization. The advisory support ranges from food production based on consumer insights, product and process development, regulatory affairs, and sales and marketing support (Asia-Pacific Agri-Food Innovation Summit Singapore, 2020). These facilities and advisory supports can efficiently help shorten the innovation and commercialization process of novel food technologies or products. Essentially, A*STAR's and Temasek's research capabilities and strong network collaborations in the food and biotechnology area can definitely bring the "30 by 30" food security goal to reality by 2030, bringing value to Singapore's economic development.

2.2.3 Urban Solutions and Sustainability (USS)

The urban solutions and sustainability (USS) strategic domain aims to "develop a sustainable and liveable city through integrated solutions for Singapore and the world (RIE, 2020, p. 7). This strategic technology domain focuses on developing and strengthening five key pillars: Infrastructure, Built Environment, Clean Energy, Water & Environment, and Urban Mobility (Singapore Economic Development Board [SEDB], 2022). The Government of Singapore has invested approximately USD 220 million into national research initiatives focusing on the USS (Cheryl, 2022). Through USS, the government aims to turn Singapore into a smart and sustainable city with a robust infrastructure ecosystem that integrates developers, engineering consultancy, project financing, legal advisory services, and other professional services (SEDB, 2022). Additionally, Singapore envisions promoting smart and sustainable building solutions that can help develop and maintain infrastructures sustainably in a resource-efficient manner. It also aims to have "at least 80% of buildings (by floor area) in

Singapore to be green by 2030" through the USD 50 million Green Mark Incentive Scheme. In fact, more than 40% of buildings in Singapore received the Green Building Product Certification by 2019, signifying that the building structures and construction processes involved are resource-efficient and environmentally friendly (Jacqueline, 2020).

To address the climate change issue, Singapore's energy sector has begun focusing on clean power generation and increasing the adoption of renewable energy sources, aiming to turn Singapore into a global clean energy hub (National Research Foundation, 2021). In addition, Singapore is also taking extra steps to reduce its carbon emissions, although it only contributes around 0.10% of global carbon emissions (Ministry of Foreign Affairs Singapore, 2022). For instance, the government strongly encourages industry players to utilize low-carbon energy technologies and renewable energy sources to minimize carbon emissions, which can help address the climate change issue (National Research Foundation, 2021). Other than that, due to the lack of natural water resources, Singapore signed the 1962 Water Agreement with the Government of Malaysia, which agreed to supply 250 million gallons of water to Singapore at 3 cents per thousand gallons of raw water from the Johor River on a daily basis (Amir, 2021). To safeguard against water scarcity, Singapore has to build its capabilities and capacities in water management and treatment technologies, as well as reduce daily water consumption (SEDB, 2022). In fact, there are around 180 water companies and 26 water research centers driving the growth of the water sector in Singapore, striving to make Singapore a global hydro hub (RIE, 2020).

Regarding urban mobility, as one of the smallest and most densely populated countries, Singapore has to rely heavily on efficient transportation infrastructure to optimize its town planning and enable smart urban mobility (SEDB, 2022). Therefore, the Land Transport Master Plan (LTMP) 2040 was established by the Government of Singapore, envision creating a green and holistic transport ecosystem that enables its citizens to get around the country within 45 minutes (Daniel, 2020). As can be seen, research and development play the biggest role in optimizing transport systems in Singapore. Generally, the USS sustainability goals can be achieved through research collaborations between USS agencies, public and private sector researchers, and industry players. In turn, these research efforts are vital in creating sustainable urban solutions and bringing economic value to Singapore. Clearly, A*STAR, a government link research organization, also plays a substantial role in catalyzing the translation of R&D, deployment, commercialization of USS-related research outcomes, and promoting industry adoption.

2.2.3.1 Research and Development (R&D)

To contribute to Singapore's sustainability and climate change goals (including the Singapore Green Plan and Zero Waste Masterplan), A*STAR recently established the Institute of Sustainability for Chemicals, Energy and Environment ($ISCE^2$), focusing on R&D in areas involving low-carbon technologies, carbon capture and utilization, green materials, products, and manufacturing processes, etc. $ISCE^2$ looks to collaborate with various industry players, as well as private and public research institutes, to jointly achieve Singapore's sustainability goals (A*STAR, 2022e). For example, IHI Corporation, a multinational corporation, has entered into an agreement with A*STAR's $ISCE^2$ to establish a joint centre for research and development specializing in carbon solutions development (IHI, 2022). Specifically, this collaboration aims to research ways to recycle carbon dioxide by transforming it into methane and olefins, which can be used to produce polymers. This can substantially help reduce the emission of carbon dioxide from manufacturing plastics and protect the environment (IHI, 2021). Through joint R&D with $ISCE^2$, IHI corporation has successfully developed the catalyst, which is essential for producing olefins (IHI, 2021). Another R&D example of carbon solutions is the partnerships between A*STAR, the Singapore EDB, and the Jurong Town Corporation (JTC). This partnership involves working with 13 ecosystem partners, such as ExxonMobil, Keppel Infrastructure Holdings Pte Ltd, Nanyang Technological University, IHI Asia Pacific Pte Ltd, etc., to study the development of a Carbon Capture and Utilisation Translational Testbed (CCUTT). Located on Jurong Island, the CCUTT enables companies to speed up the test-bedding process and efficiently scale up the production of Carbon Capture and Utilization (CCU) technologies (SEDB, 2021). These CCU technologies are crucial in capturing carbon dioxide and transforming them into functional and harmless substances, such as methanol and formic acid, thereby minimizing air pollution and slowing down climate change (SEDB, 2021). Regarding water issues in Singapore, Xylem, a global water technology company, collaborates with A*STAR's Institute of High-Performance Computing (IHPC) to develop water distribution and water treatment technologies in Singapore (Xylem, 2020). Specifically, this partnership involves the combination of Xylem's expertise in water technologies and IHPC's strong capabilities in computer modelling and simulations for sustainable water technologies, aiming to develop a new computational fluid dynamics model. This model will then be used for designing and testing products/solutions that will be installed in water treatment plants and water distribution networks, improving water security issues in Singapore (Xylem, 2020).

2.2.3.2 Innovation and Commercialization (I&C)

A*STAR plays an essential role in exploring and developing smart city solutions with its stakeholders. For instance, A*STAR is teaming up with Surbana Jurong, an urban and infrastructure consultancy firm, to co-develop value-adding and cost-effective digital solutions for Sustainable Smart Cities planning. Digital capabilities in urban planning, designing and simulating buildings, and creating technologies for inspection are some of the missions under this partnership (A*STAR, 2019a). Moreover, this collaboration will help market the technologies commercialized by the SMEs under A*STAR. As a result, the SMEs in its supply chain will be able to reap benefits from this partnership, as they will be exposed to more business opportunities overseas. A*STAR also partners with ST Engineering in co-developing innovative solutions for smart cities. In fact, ST Engineering has been involved in 500 smart city projects in 70 cities, indicating that it is highly experienced in providing smart city solutions (Shamini, 2019). Building on the R&D capabilities of A*STAR's research institutes, A*STAR and ST Engineering will focus on R&D as well as the adoption and commercialization of robotics (e.g., advanced material-handling robots), smart mobility (e.g., all-weather autonomous vehicles), smart communications (e.g., satellite communications), and health tech (e.g., intelligent workflows and analytics) (Shamini, 2019). As can be seen, it can be observed that A*STAR is actively involved in the entire Research, Development, Innovation, and Commercialization (RDIC) value chain, which eventually contributes to economic development.

2.2.4 Services and Digital Economy (SNDE)

The services and digital economy (SDE) domain aims to "develop, integrate and leverage Singapore's digital innovation capabilities to meet national priorities, raise productivity and support key services, create sustainable economic opportunities and quality jobs" (RIE, 2020, p. 7). One of Singapore's national plans is to promote whole-of-nation digitalization in government agencies, industry players, and society (National Research Foundation, 2021). As such, the SNDE strategic domain strives to develop, apply, scale, and commercialize high-tech digital solutions to cater to market demands. This requires collaborations and knowledge sharing between public research institutes, enterprises, and government agencies in order to develop technology leadership to drive Singapore's Smart Nation goals (National Research Foundation, 2021). Furthermore, Singapore is on its way to installing full-fledged 5G networks, which can accelerate a new wave of Internet-of-Things (IoT) applications and better achieve the Smart Nation goals (National Research Foundation, 2021). A report by The World Economic Forum (2020) states that approximately 22 million jobs will be created in the 5G value chain worldwide, signifying that 5G can contribute substantially to global economic development. Besides that, the Government of Singapore plans to transform Singapore into a global artificial intelligence (AI) leader by 2030, with the primary objective of delivering strong economic and societal impacts for its citizens (Free Malaysia Today, 2019). Specifically, it aims to provide AI solutions to address issues and challenges in a wide spectrum of areas, including government services, logistics planning, healthcare, education, smart estates, border security, and financial services (Smart Nation Singapore, 2022). Other than that, to reinforce Singapore's position as a trusted digital innovation hub, R&D capabilities are much needed in developing digital trust, which plays an important role in safeguarding digital platforms and technologies. In addition, these technological solutions need to be commercialized immediately to benefit industry players and society. These national strategies fit well into A*STAR's R&D capabilities in info-communication technologies, which involve Artificial Intelligence (AI) and data science; digital trust (blockchain and privacy preservation technologies); cybersecurity; modeling & simulation / digital twinning; and communications and Internet-of-Things (A*STAR, 2021l). A*STAR partners with various local enterprises and SMEs to strengthen their R&D capacities in the aforementioned info-communication technologies. In fact, A*STAR's technological innovations have been commercialized and leveraged by its' industry partners and government agencies. As such, A*STAR's roles in R&D and I&C in Singapore's SNDE's strategic domain should not be neglected. Some good examples of how A*STAR contributes to R&D and I&C will be discussed in the following sections.

2.2.4.1 Research and Development (R&D)

As one of A*STAR's research arms, Artificial Intelligence Analytics & Informatics (AI3) manages and catalyzes A*STAR's R&D efforts in data science and AI technologies to address economic and societal needs in Singapore (A*STAR, 2021m). Besides utilizing its' AI capabilities to support Singapore's national AI strategies, A*STAR also offers AI solutions to help transform and expand the businesses of its' industry players (A*STAR, 2021m). For instance, A*STAR entered into a partnership with DSO National Laboratories to strengthen Singapore's defense system through co-developing R&D solutions in additive manufacturing, advanced electronics, AI, etc. (Stephen, 2020). Through this collaboration, DSO can draw on A*STAR's R&D capacities, expertise, technologies, talent, and facilities to develop technologies in defense and national security (Stephen, 2020). Similarly, SIIX-AGT, a local robotics start-up, collaborated with A*STAR's Institute for Infocomm Research (I2R) to co-create smart robotics technologies to serve market demands and enhance productivity (A*STAR, 2019b). The launch of the robotic base products, SIIX-iCUBE AGT's 200 and iCUBE 500, was made possible by the incorporation of A*STAR's AI technology into its' service robots. One of the most remarkable AI products co-researched and co-created by SIIX-AGT and A*STAR is the security patrol robot on the street for crowd control and security purposes, making a positive impact on society (A*STAR, 2019b).

In 2017, A*STAR launched an Industrial Internet of Things (IIoT) Initiative, in which an association (including 13 companies) with capabilities extending across the IIoT value was formed to bring academia and industry players together and develop IIoT solutions, such as industrial data analytics, sensors, cybersecurity, and gateways (Priyankar, 2017). This initiative involves MNCs (e.g., Rolls-Royce, Hewlett Packard Enterprise), local enterprises (e.g., Singtel, Starhub), SMEs (e.g., Concorde Security), and start-ups (e.g., Wismut Labs) (Priyankar, 2017).

Likewise, the IIoT Research Programme was established by A*STAR to promote cross-disciplinary collaboration and learning between A*STAR's research institutes, Singapore University of Technology and Design (SUTD), Nanyang Technological University (NTU), and National University of Singapore (NUS). Specifically, this program aims to drive R&D in IIoT technologies, such as advanced data analytics, industrial cyber-physical security for cognitive, and secure IIoT systems. The newly invented IIoT technologies will then be test-bedded at A*STAR's SIMTech's Model Factories and Advanced Remanufacturing and Technology Centre (ARTC). Under the RIE 2020 plan, A*STAR also established two model factories, which SMEs can use for experimenting and learning new advanced manufacturing technologies with support and guidance from A*STAR's researchers (Priyankar, 2017). As can be seen, A*STAR's efforts in Singapore's SNDE's R&D ecosystem are valuable, bringing economic value to industry players and society as a whole.

2.2.4.2 Innovation and Commercialization (I&C)

A*ccelerate, which is A*STAR's commercialization arm, helps drive innovation and commercialization of its stakeholders' research outcomes (A*STAR, 2018). In 2018, A*ccelerate entered into partnerships with investors, such as Startup-O, Hafnium Hafaway, Marvelstone, Trendlines, and Dymon Asia Ventures, to raise USD 85 million, with the main purpose of co-creating deep-tech start-ups and commercializing deep tech innovation in areas such as the IoT and AI (Ng, 2018). In addition, A*STAR's SERC's Industrial Internet-of-Things Innovation (I^3) program aims to speed up and promote the translation of Industrial Internet of Things research into industry-ready solutions that can be commercialized and adopted by SMEs, local enterprises, and MNCs (A*STAR, 2022f). For example, PTC Japan, a digital transformation corporation that offers software and industrial service solutions, has joined as a strategic member of A*STAR's I^3 program to leverage IIoT R&D and drive digital transformation initiatives (PTC, 2021). This partnership enables the exchange of IIoT knowledge and research resources between PTC and A*STAR's research institutes. Moreover, it also allows their stakeholders to grasp benefits from the entire research ecosystem, from co-development of IIoT and Industry 4.0 technologies to test-bedding research outcomes towards commercial scale-up, providing digital innovation solutions to the market. As a result, this collaboration brings substantial value and benefits to their industry partners and local enterprises, such as manufacturing optimizations, cost efficiencies, and quality assurances of their business (PTC, 2021).

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Roles of Malaysian Indigenous Communities in Biodiversity Conservation: A Case Study Approach

Hui Hui Teow[1*], Shirlyn Tang[2], Pervaiz K. Ahmed[3], Mahendhiran Sanggaran Nair[4], Santha Vaithilingam[5]

[1*]*Sunway Institute for Global Strategy and Competitiveness, Sunway University, Malaysia*
[2]*Sunway Institute for Global Strategy and Competitiveness, Sunway University, Malaysia*
[3]*Sunway Institute for Global Strategy and Competitiveness, Sunway University, Malaysia*
[4]*Sunway University, Malaysia*
[5]*Sunway Institute for Global Strategy and Competitiveness, Sunway University, Malaysia*

**Corresponding author: huihuit@sunway.edu.my*

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Abstract

This paper presents two case studies that underscore the importance of involving indigenous communities in biodiversity conservation efforts. The first case study demonstrates the criticality of acknowledging and integrating indigenous knowledge within scientific investigations pertaining to biodiversity conservation. Failing to recognize this valuable resource may result in missed opportunities for optimal preservation of biodiversity. The second case study highlights the importance of engaging indigenous communities in conserving a forest reserve through forest patrolling and monitoring alongside measures to curb illegal activities. This approach not only helps preserve biodiversity but also sustains the livelihoods of indigenous communities through the provision of monetary incentives. Furthermore, the active involvement of indigenous communities in ecotourism development allows for the integration of their traditional knowledge and practices, fostering effective management of ecotourism activities and safeguarding their territories against detrimental impacts. Moving forward, it is essential for governmental agencies and relevant authorities to identify effective strategies to promote the active involvement of indigenous communities in biodiversity conservation.

Keywords: Indigenous communities, biodiversity conservation, indigenous knowledge and practices

1. Introduction

Indigenous communities are key stewards of nature and biodiversity. Despite a meager five percent of the population worldwide, the indigenous communities oversee or hold tenure over one-quarter of the global land surface, especially land cover that provides refuge and support for 80% of the global biodiversity (Garnett et al., 2018).

Malaysia, one of the world's megadiverse countries, has over four million indigenous people, accounting for approximately 14% of its population (Convention on Biological Diversity, 2022; International Work Group for Indigenous Affairs, 2022). Malaysia is categorized into West Peninsular Malaysia and East Malaysia: West Malaysia comprises 11 states, whereas East Malaysia consists of two states, Sabah and Sarawak, which are also collectively known as the Malaysian Borneo (Gimbad, 2020). Collectively, these states have over 80 indigenous ethnic subgroups, including Kensai, Jahai, Mendriq, Cheq Wong, Temair, Iban, Bidayuh, and Dusun, just to name a few (International Work Group for Indigenous Affairs, 2022; Minority Rights Group International, 2018).

This paper utilizes the case study approach to highlight the contributions of Indigenous communities in Malaysia to biodiversity conservation. In particular, two case studies are presented. The first case study discusses a recent finding on the misclassification of tree species by Western taxonomy, knowledge which has long been known by the Iban and Dusun communities. For a broader perspective of the conservatory roles of indigenous communities, the second case study showcases the conservation roles of the Jahai and Temair people in the Belum-Temengor Rainforest, Perak. In particular, this case study highlights some of the challenges faced by the indigenous communities in the rainforest and their roles in biodiversity conservation. Following the detailed elaboration of the case studies, the paper discusses several important lessons from the case studies and provides a few suggestions based on the lessons identified.

2. Case Study A: Iban and Dusun: Accurate Identification of Bornean Tree Species

The Iban and Dusun communities are indigenous people concentrated in Sarawak and Sabah, respectively (Simonson et al., 2011). The Iban community, also known as Sea Dayaks, is the largest ethnic group in Sarawak (Kreier, 2022; Simonson et al., 2011). It accounts for 30% of Sarawak's 2.6 million population (i.e., 780,000 people) (Minority Rights Group International, 2018). Similarly, the Dusun community is part of the largest indigenous group in Sabah, known as the Kadazandusun, which constitutes approximately one-quarter of the state's 3.8 million population (i.e., 950,000 people) (Gimbad, 2020; Statista, 2021). These indigenous tribes have long histories with the lands they reside on. The settlement of the Iban community in Sarawak dates back to the 1600s, while the Dusun people have been living in Sabah since the 1500s (British North Borneo Herald, 2021; Utusan Sarawak, 2022). With long histories of direct interaction with the natural environment, indigenous communities have built deep understanding and broad knowledge of the local natural ecosystem (Sneed, 2019). The natural ecosystem is the main source of essential resources for the indigenous communities, including food, medicine, and shelter. To navigate and adapt to nature, indigenous communities have developed localized knowledge systems to inform fundamental daily decisions, such as which food is safe or nutritious to consume (Mongabay, 2020; UNESCO, 2021).

Indigenous people in tropical regions have developed extensive knowledge about plants and their services due to centuries of interactions with a wide range of plant species (Camara-Leret, 2019). Known as one of the global biodiversity hotspots, Borneo consists of over 15,000 plant species, many of which are endemic to the region (WWF, 2020). In particular, Iban

Lumok and Pingan are two endemic plant species in Malaysian Borneo, which are the equivalent to Timadang and Tonggom-Onggom to the Dusun people in Sabah. These trees are endemic to the lowland rainforests in Borneo, and bear fruits that are described as "juicy", "sweet", and "superior to jackfruits" (Garner et al., 2022; Plants for A Future, 2022, para. 1). Lumok and Pingan are differentiated by several distinct features, including the leaf, fruit, and twig sizes, as well as fruit sweetness. Lumok has larger leaves, as well as bigger, sweeter fruits, as compared to Pingan, which has tinier leaves, smaller and less-sweet fruits (Garner et al., 2022). While Lumok and Pinggan are identified as separate taxa by the Iban and Dusun communities, they are classified under a single species in the Linnaean taxonomy as the *Artocarpus odaratissimus* (Cowan, 2022; Garner et al., 2022).

After almost two centuries of discrepancy on this subject, a recent study by Garner and colleagues (2022) has confirmed that the Iban Lumok and Pingan – or the Dusun Timadang and Tonggom-Onggom – are indeed two different species. After observing that Iban field botanists were referring to the trees using two different names, Garner and colleagues (2022) decided to investigate this issue (Krier, 2022). To accurately identify the correct taxonomy, the researchers extracted DNA samples from the aforementioned trees in Malaysian Borneo, as well as obtained samples from herbarium specimens of the whole species range. Through the phylogenetic analyses and DNA microsatellite sequencing, Iban Lumok was indeed found to be genetically different from Pinggan. While these two species are closely related, the degree of their genetic and morphological distinctness is vast enough that they should be identified as separate taxonomies (Garner et al., 2022).

This case study showcases an example whereby long-standing knowledge of the Linnaean taxonomy was found to be less accurate than the indigenous classification of trees drawn from Iban's and Dusun's knowledge. With this new finding, the risks of extinction for these trees may be significantly decreased. This is because scientific nomenclature forms the basis of species conservation; hence only taxa with official names are actively evaluated and safeguarded (Gardner et al., 2022). In all, this case example highlights the significance of indigenous knowledge developed through generations of societies on the land, and the failure to appreciate and engage with indigenous knowledge may result in the loss of opportunities to achieve better biodiversity conservation outcomes.

3. Case Study B: Jahai and Temiar: Conservation of the Belum-Temengor Rainforest

Covering an area of about 290,000 hectares in Perak, Malaysia, the Belum-Temengor Rainforest is one of the largest rainforests in the world. Moreover, it has existed for more than 130,000 million years, making it one of the world's oldest rainforests (Belum Temenggor, 2021). The forest is separated into two main zones: The Royal Belum State Park, which consists of 117,500 hectares of forest, and the Temenggor Forest Reserve, where the Temenggor Lake is situated (Belum Temenggor, 2021). Remarkably, the rainforest is home to a substantial amount of flora and fauna endemic to the region, including ten species of hornbills and 80 species of mammals (UNESCO, 2017). It also houses a number of threatened plant species, such as *Cleissostoma complicatum and Dipterocarpus costatus, as well as endangered animal species, such as the Asian* elephant (*Elephas maximus maximus*), Malayan Sun Bear (*Helarctos malayanus*), and the iconic Malayan tiger (*Panthera tigris jacksoni*). Besides that, four species of the world's largest flower – *Rafflesia – can also be found in the rainforest.* Due to its rich biodiversity, the Royal Belum State Park was gazetted as a terrestrial protected area in 2007 (UNESCO, 2017). In addition to the species richness, the Belum-Temengor Rainforest also shelters two main groups of indigenous people, namely the Jahais and Temiar, who rely heavily on the rainforest's natural resources for their livelihoods (Fadzil et al., 2013). Specifically, the

Jahais reside in the northern region of the forest, whereas the Temiar tribe inhabits the southern area of the forest (Belum Rainforest Resort, 2022). These indigenous communities generally live by hunting, fishing, harvesting plants, and collecting honey and other non-timber forest products from the forest. Importantly, they also play a significant role in protecting and conserving biodiversity in the Belum-Temengor Rainforest (Belum Temenggor, 2021). However, high levels of human footprint in the forest reserve have substantially threatened biodiversity and also the livelihood of indigenous communities residing in the region (Abdullah et al., 2013). Detailed insights into the challenges faced by the indigenous communities in the forest reserve and their roles in biodiversity conservation are discussed in the sections that follow.

3.1 Challenges Faced by the Indigenous Communities in the Royal Belum Forest Reserve

As mentioned above, the Royal Belum Forest Reserve is home to two main indigenous communities: the Jahais and Temiar, who have been residing in the forest for decades (Loke et al., 2020). The Jahai tribe primarily lives along Sungai Tiang and Sungai Kejar, whereas the Temiar tribe mainly lives in the southern region of the forest reserve (Perak State Parks Corporation, 2016).

Even though the Royal Belum State Park was set up to protect nature, as a tourist attraction, it has somewhat brought about unsustainable tourism development, posing threats to the indigenous communities in the forest reserve (Abdullah et al., 2013). A number of communities were forced to leave their settlements due to the development of tourist sites (Kamarudin, 2015). Moreover, some of their settlements and villages were designated as part of tourist hotspots, which brought about trouble for the local communities (Abdullah et al., 2013). For instance, visitors and tourists often offer tokens of money and donations to the indigenous communities, indirectly promoting the culture of begging among them (Abdullah et al., 2013). Also, the development of ecotourism in the Royal Belum Forest Reserve failed to bring substantial benefits to the indigenous communities. This is because a majority of the indigenous communities are not involved in ecotourism activities due to their low levels of education; they are still primarily hunters and collectors of non-timber forest products (Abdullah et al., 2013). This demonstrates that ecotourism at the forest reserve does not contribute much to the economic development of indigenous communities.

Other than the above, the continuation of poaching activities has negatively impacted the indigenous community through reduced food sources like animals and plants (Abdullah et al., 2013). This issue has persisted due to understaffing in managing and patrolling the forest reserve. In fact, only two rangers have been put in charge of patrolling the entire forest, resulting in ineffective detection of poachers and illegal loggers (Abdullah et al., 2013). Indeed, more than 400 animals were illegally hunted in Royal Belum Forest Reserve during 2009 – 2011, including certain threatened species, such as the Asian elephant, pangolin, Malayan tiger, and Sumatran rhinoceros (Abdullah et al., 2011). In addition to poaching, the agarwood trees in the forest reserve have been illegally harvested for economic gain (Lim & Noorainie, 2010). As a result, the indigenous communities in the forest reserve have been left with insufficient natural resources to sustain their livelihoods. Other than that, over-fishing and sport fishing at Temenggor Lake have polluted the water and threatened the fishery sources, further diminishing the food sources of the indigenous communities (Abdullah et al., 2011). The invasion of Escherichia coli (E. coli) bacteria and the discharge of untreated sewage from nearby hotels and tourist attractions have also threatened the aquatic ecosystem in Temenggor Lake. These issues have caused severe water pollution and food poisoning in the indigenous communities, who often consume water from rivers and lakes without filtration (Abdullah et al., 2013). As can be seen, from these examples, indigenous communities face numerous challenges in the Royal Belum Forest Reserve.

3.2 Contributions of the Indigenous Communities in the Royal Belum Forest Reserve

Despite challenges, the indigenous community still plays a significant role in conserving biodiversity and protecting ecosystem vitality in the Royal Belum Forest Reserve (Yayasan Sime Darby, 2022). For example, local and traditional knowledge is essential in preserving the forest reserve. In fact, the Jahais and Temiar tribes believe that nature gods and spirits, such as Moyang Tapern dan Tok Samin, live in forests where supernatural powers exist in every object in the surrounding environment (Isa & Saidin, 2014). Hence, the overexploitation of natural resources is prohibited among the tribes (Likin et al., 2018). For instance, big trees in the forest are not allowed to be cut down, and only mature plants can be harvested (Likin et al., 2018). Moreover, they are not allowed to hunt and kill animals for purposes other than consumption. This is because they believe that the overexploitation of natural resources will eventually result in undesirable consequences (Yayasan Sime Darby, 2022). In fact, slaughtering and consuming certain species can create bad karma and bring about diseases. For example, among the Temiar and Jahai tribes, elephants and tigers are considered taboo animals that should not be hunted for food (Benjamin, 2014; Loke et al., 2020). As can be seen, the indigenous communities value reciprocity between humans and nature instead of perceiving nature as existing mainly for human benefit (Irvine et al., 2019; Sneed, 2019). Collectively, these beliefs and values translate into a multitude of spiritual beliefs, taboos, and traditions linked to practices or measures that may aid in preserving biodiversity, such as restrictions against over-harvesting or measures that disturb the ecological balance of forests.

As mentioned in the "challenges" section, poaching activities and illegal logging are some of the threats to the Royal Belum Forest Reserve. However, in recent years, the Perak State Park Corporation established the Menraq Patrol Unit, which includes the Jahai community and other NGOs, such as the Rimau, to collectively protect the forest from poaching, illegal hunting, and wildlife trafficking activities (Hussein, 2021). Specifically, the Jahai people, who are capable and literate, were recruited for forest-patrolling activities and were paid RM85 per day as incentives (Pearl, 2021). The formation of the Menraq Patrol Unit has allowed the Jahai indigenous community to earn at least RM2000 monthly income, contributing to their livelihoods. One of their job tasks is to help gather data related to poaching activities and wildlife information. In addition, they also actively encourage the local communities to get involved in biodiversity conservation efforts (Yayasan Sime Darby, 2022). Consequently, there has been a 90% reduction in poaching activities in the forest through joint efforts (Pearl, 2021). Four Malayan tiger cubs were recently spotted in the Royal Belum Forest Reserve. This clearly shows that the anti-poaching efforts by the Menraq Patrol Unit successfully saved the Malayan tigers from extinction (Milad, 2022).

In general, indigenous communities play important roles in safeguarding flora and fauna against illegal hunting, wildlife trade, and logging activities. They often work with law enforcement agencies or establish patrol programs to monitor the forests (Wilson-Holt, 2021). A study shows that indigenous communities are better able to guard the protected areas than rangers hired from external sources due to their knowledge and familiarity with the landscape of the entire forest (Williamson et al., 2020). Hence, indigenous communities often detect and report crimes or other illegal activities in the protected areas faster and more efficiently as compared to externally-hired patrol rangers (Hai et al., 2021; Williamson et al., 2020). In addition, a study shows that forests guarded by indigenous communities have a lower deforestation rate compared to those that are not monitored and protected by indigenous communities (Porter-Bolland et al., 2012). Essentially, involving indigenous people in patrolling the forest has helped conserve biodiversity and contribute to their livelihoods. As such, policymakers and relevant authorities need to identify ways to improve the indigenous communities' participation rate in forest patrolling and monitoring, which are discussed in the following section.

4. Way Forward

4.1 Increase Recognition and Engagement of Indigenous Knowledge

The case study of the Iban and Dusun communities showcased an example where an important finding may not have been discovered without considering or engaging with indigenous taxonomy, underscoring the significance of indigenous knowledge even when molecular phylogenetics gains ultimate precedence in modern taxonomic classifications. Historically, there has been a hierarchy between Western "scientific" knowledge and indigenous knowledge, whereby the former is often framed as more valuable than the latter (Zurba & Papadopoulos, 2021). Moving forward, it is crucial for the fundamental acknowledgment and recognition of indigenous knowledge value to be present, even when the knowledge contradicts current scientific thought.

Recent years have seen a global increase in the incorporation of indigenous knowledge into scholarly and applied research (e.g., Jessen et al., 2021; Knopp et al., 2020; Wilder et al., 2016). In fact, the integration of indigenous knowledge in scientific research has increased from 5 studies in 1990 to over 1400 studies in 2018 (Jessen et al., 2021). For example, a study by Adom and colleagues (2016) utilized the qualitative approach to analyze the impacts of the Asante indigenous knowledge on conservation issues in Abono, a village in Ghana.

Specifically, the study revealed that the Asante indigenous knowledge systems, which include cultural taboos, folklore, proverbs, and cosmological beliefs, have been used to safeguard the areas in Ghana, especially those with rich biodiversity. While indigenous knowledge is increasingly explored and applied in research, the integration of Malaysian indigenous knowledge in scientific research still has significant room for improvement (Halim et al., 2012). This should be addressed by the government and research institutions since the lack of effective engagement has led to a loss of opportunities to achieve better biodiversity conservation outcomes.

4.2 Encourage Indigenous Communities to Actively Participate in Forest Patrolling and Monitoring

Based on the Royal Belum case study, it is clear that indigenous communities play important roles in patrolling and monitoring protected areas. Poaching activities in the Royal Belum Forest Reserve were drastically reduced under the patrol and monitoring of the Menraq Patrol Unit, which involves the indigenous communities (Pearl, 2021). As such, the support and involvement of the indigenous communities in forest patrolling appear to be essential in protecting the protected areas from various illegal encounters (Wiafe, 2016). As shown in the case study, the Jahai community could earn a monthly income of RM2000 through the Menraq Patrol Unit, hence attracting the indigenous community to actively participate in the patrolling activities (Yayasan Sime Darby, 2022). Besides earning extra income, indigenous communities were able to protect their ancestral lands, which they heavily rely on for their livelihoods. Past studies have similarly shown that indigenous communities are motivated mainly by the benefits and incentives they can gain by participating in forest protection and management activities (Derkyi et al., 2021; Kacho et al., 2014; Musyoki et al., 2016). As can be seen, rewarding incentive packages are essential in promoting the indigenous communities' participation in forest patrolling and monitoring. Moving forward, policymakers, local authorities, or conservationists should offer sufficient monetary incentives to motivate indigenous communities to actively participate in forest patrolling and monitoring so that their livelihoods are well taken care of (Slough et al., 2021; Truong, 2022).

Additionally, to support and further encourage the indigenous communities to participate in forest patrolling and monitoring, the government bodies and relevant conservationists should establish training programs for indigenous communities so that they can be more confident and adept at performing their patrolling tasks (Global Forest Watch, 2021; Williamson et al., 2020). Patrolling knowledge such as keeping track of records, managing budgets for forest patrolling activities, using Smartphones and drones to detect illegal activities, Geographic Positioning Systems (GPS), and map resources are important to ensure the success of forest patrol and monitoring (Williamson et al., 2020). Indigenous patrollers should also be well-trained with the Spatial Monitoring and Reporting Tool (SMART) patrolling system. Essentially, the SMART system allows them to utilize GPS systems to collect more systematic data in the forests, optimally allocate patrolling resources to safeguard the forests against illegal activities (e.g., illegal hunting and logging), and facilitate the protection of forests in an efficient way (WWF-Malaysia, 2014). In fact, research has suggested that accessibility to forestry training programs can influence indigenous communities' level of participation in forest patrolling activities (Derkyi et al., 2021). This can be attributed to the fact that the training programs enable them to become more mindful of the detrimental consequences of illegal activities in the forests, which can enhance their motivation to protect and monitor their homeland (Derkyi et al., 2021). In all, with monetary incentives and patrolling training activities, indigenous communities are likely to be more motivated to participate in forest patrolling and monitoring, contributing to biodiversity conservation in the forest reserve.

4.3 Minimize the Negative Impacts of Ecotourism on the Forest Reserve and the Indigenous Communities

As highlighted in the Belum-Temenggor case study, ecotourism has posed severe threats to the forest reserve and indigenous communities in the area. For example, untreated sewage from the Royal Belum tourist attractions has contaminated rivers and lakes, which the indigenous communities rely on for water and food sources (Abdullah et al., 2013). Moreover, sport fishing activities (part of the ecotourism activities) at Temenggor Lake have posed threats to the fishery sources of the indigenous communities (Abdullah et al., 2011). Moving forward, one way to minimize the negative impacts of ecotourism on the forest reserve is to promote responsible tourism, which emphasizes the development of environmentally based and sustainable tourism activities, the involvement of local communities in the tourism industry, and the prevention of over-exploitation and over-consumption (Chan et al., 2021). Indigenous communities are key stakeholders of the forest reserve where ecotourism takes place; hence, by involving them as community representatives on the ecotourism board, they are more likely to share their indigenous knowledge and traditional practices, which are essential in preserving and protecting the forest from the negative impacts of ecotourism. In other words, the indigenous communities can integrate their indigenous knowledge and cultural norms into managing and planning ecotourism activities, which may help alleviate pollution, over-exploitation, and over-consumption of natural resources in the forests (Nagarjuna, 2015; Prasetyo, 2020). In essence, involving them in the planning and decision-making processes of ecotourism development is likely to lead to a more sustainable ecotourism development, which also helps to preserve their indigenous culture and improve their quality of life (Chan et al., 2021; Nagarjuna, 2015). As such, government agencies and tour operators should identify ways to actively engage them in the development of ecotourism. For example, tour operators need to collaborate with government agencies to deliver workshops on the benefits of involving indigenous communities in ecotourism development. Other than that, the indigenous communities should also be trained to become professional tourist guides in order to promote their cultural knowledge and heritage in the forest reserve. This approach enables the preservation of the uniqueness of their cultural heritage. Most importantly, it is essential to provide training sessions related to ecotourism development to the indigenous communities so that they are well-equipped with the relevant knowledge and skills needed to efficiently plan, manage, and monitor ecotourism development (Kamarudin et al., 2015). The approaches mentioned above are more likely to increase the indigenous communities' participation in ecotourism development when they are aware that these activities can provide economic benefits and improve their welfare whilst simultaneously promoting and preserving their cultural heritage in a sustainable manner (Chan et al., 2021).

Another issue associated with ecotourism at the Royal Belum Forest Reserve is that it has promoted the culture of begging among indigenous communities rather than providing them with employment opportunities (Abdullah et al., 2013). In fact, a majority of the indigenous communities remain hunters and gatherers of forest resources. This is because most of the indigenous communities in the Belum-Temenggor forest reserve have low levels of educational achievement, impeding them from getting jobs in the ecotourism industry (Abdullah et al., 2013; Rasoolimanesh et al., 2017). In general, the lack of equality and access to education has worsened poverty and unemployment issues among indigenous communities (Sawalludin et al., 2020). The low educational achievement issue is primarily due to the fact that most of the indigenous communities' settlements are located very far away from the schools in town. Poor transportation connectivity in rural areas also serves as one of the barriers that demotivated indigenous children from traveling to schools for education (Sawalludin et al., 2020). In addition, the lack of awareness among parents on the importance of education is another main reason for low levels of educational achievement among the indigenous communities (Sawalludin et al., 2020). Moving forward, government bodies and relevant authorities should hold educational awareness campaigns near settlements to share and discuss the importance of education with the indigenous communities, thereby encouraging indigenous parents to send their children to schools. Other than that, NGOs or social enterprises should also set up schools nearby the indigenous communities' settlements to ensure that every indigenous child has easy access to proper education. To address the transport connectivity issue, government agencies, private sector companies, and other NGOs must collaborate to build better roads and bridges to shorten travel time from the indigenous communities' settlements to schools. Doing so is likely to enhance the indigenous children's enthusiasm to go to school and improve their employment opportunities in the ecotourism industry in the future, which then helps in poverty alleviation among the indigenous communities.

5. Conclusion

In summary, the two case studies above showcased the importance of involving indigenous communities in biodiversity conservation efforts. One of the key takeaways from the case studies is that it is crucial to acknowledge and integrate indigenous knowledge in scientific research relevant to biodiversity conservation. The failure to engage with indigenous knowledge may risk losing opportunities to achieve better biodiversity conservation outcomes. In addition to restricting illegal activities in forest reserves, involving indigenous communities in forest patrolling and monitoring also helps contribute to their livelihoods, particularly through the provision of monetary incentives. Furthermore, it is also vital to engage indigenous communities in ecotourism development so that they can integrate their traditional knowledge and practices in managing ecotourism activities, which aids in protecting their territories from the negative impacts of ecotourism. Moving forward, government agencies and relevant authorities should identify effective ways to promote the active participation of indigenous communities in biodiversity conservation, which also improves their living standards through benefits and incentives offered in return for their efforts.

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8i Ecosystem Analysis of the Pace Setter ASEAN Country – Singapore

Hui Hui Teow[1*], Dhiviya Gopal Balakrishnan[2], Pervaiz K. Ahmed[3], Mahendhiran Sanggaran Nair[4], Santha Vaithilingam[5]

[1*]*Sunway Institute for Global Strategy and Competitiveness, Sunway University, Malaysia*
[2]*Sunway Institute for Global Strategy and Competitiveness, Sunway University, Malaysia*
[3]*Sunway Institute for Global Strategy and Competitiveness, Sunway University, Malaysia*
[4]*Sunway University, Malaysia*
[5]*Sunway Institute for Global Strategy and Competitiveness, Sunway University, Malaysia*

**Corresponding author:* huihuit@sunway.edu.my

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Abstract

This paper explores the factors contributing to Singapore's position as a major player in the global economy. Singapore, a small state in Southeast Asia, has experienced rapid economic growth since gaining independence in 1965. Its strategic location in the heart of Southeast Asia, along with a business-friendly environment, robust institutional governance system, sound economic policies, and world-class infrastructure, have played pivotal roles in driving its transformation from a developing country with a low-income economy into a high-income economy within less than five decades. Additionally, Singapore's emphasis on human capital development, exemplified by its robust education system and high literacy rates, has resulted in a highly skilled and innovative workforce. This, in turn, has enabled Singapore to establish a strong presence at the higher end of the global value chains, attracting multinational corporations and high-value foreign investments. Essentially, these factors are crucial in maintaining Singapore's economic competitiveness and strengthening its position as a global business hub. To delve into Singapore's success, this paper adopts the 8i ecosystem framework characterized by eight enablers, including institutions, interaction, integrity, infrastructure, infostructure, intellectual capital, incentives, and internationalization. Through a comprehensive examination of each enabler, this paper aims to shed light on Singapore's robust national ecosystem and its role in shaping its political, social, and economic systems.

Keywords: Singapore, the pace-setter ASEAN country, the current state of play, 8i ecosystem analysis

1. Introduction

Singapore, officially known as the Republic of Singapore, consists of the main island and around 64 smaller islands situated off the coast. These offshore islands include Sentosa, Pulau Ubin, St John's Island, and the Sisters' Islands. Covering an area of 719 km², Singapore is the smallest state in Southeast Asia, with a population of about 5.4 million people (World Data, n.d.). Since gaining independence from Malaysia in 1965, Singapore has rapidly transformed itself from a developing country with a low-income economy into a high-income nation with significant GDP growth (World Bank, 2019a). One of the key factors that has contributed to the country's success is its strategic location in the heart of Southeast Asia, which helps attract foreign investors and multinational corporations, leading to a vibrant and diverse economy (U.S. Department of State, 2022). Additionally, Singapore has emerged as a global hub for trade, finance, and tourism owing to its business-friendly environment, world-class infrastructure, and sophisticated transportation systems (World Bank, 2019a; World Economic Forum, 2019). Furthermore, the effectiveness of Singapore's governance system has enabled it to successfully combat corruption and maintain a high level of transparency in its judiciary, resulting in strong political stability. This has helped create a favorable regulatory environment for business operations and foreign investments (Economic Development Board, 2023a; U.S. Department of State, 2022). Besides that, Singapore's strong emphasis on human capital development is also pivotal to its success as a pace-setter country in the ASEAN region (Quah, 2018; World Bank, 2019a). As a result of its robust education system, Singapore has a high literacy rate of 97% and a tertiary school enrolment rate of 93%, with a high proportion of university graduates (36.3%) specializing in the fields of science, technology, engineering, and mathematics (STEM) (Buchholz, 2023; Statista, 2021). This has successfully led to the creation of a pool of highly skilled and innovative workforce, which enhances Singapore's innovation capacities and enables it to maintain its economic competitiveness in the global market (Economic Development Board, 2022a). In brief, the abovementioned efforts have expedited Singapore's socio-economic growth and strengthened its position as a major player in the global economy.

Often cited as a role model for its strength in political, social, and economic systems, Singapore's success is widely attributed to its robust and resilient national ecosystem. To examine Singapore's thriving ecosystem and how it has strengthened its position as a global hub for trade and innovation, this paper adopts an ecosystem framework characterized by eight enablers known as the "8i enablers", which are explained in detail in the section that follows.

2. Definitions of the Eight Enablers in the 8i Innovation Framework

The definitions of the eight enablers in the 8i Innovation Framework are provided below, and a summary of them is shown in Figure 1:

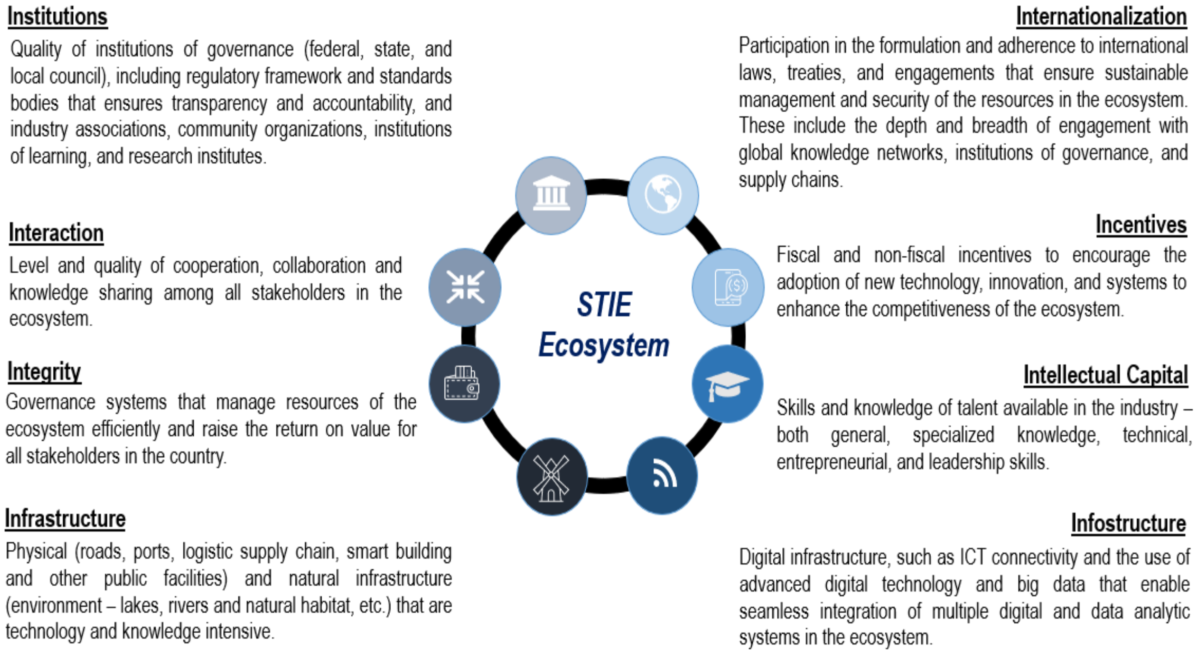
- **Institutions** refer to the quality and strength of the institutional leadership and institutions (e.g., government agencies, research institutes, higher education institutions, industry players) in managing the country's institutional governance systems. This includes the existence of effective government and strong "Champions with Clouts" in various sectors to efficiently oversee governance systems and manage the implementation of policies to enhance the country's competitiveness through the Whole-of-Nation approach.
- **Interaction** captures the state of cooperation, collaboration, and knowledge-sharing among the key stakeholders (government agencies, industry players, higher education institutions, and research institutes) in a country. These collaborations are essential to creating a knowledge- and innovation-driven economy characterized by a strong knowledge-sharing culture that fosters the adoption of best practices and innovative systems to strengthen the country's economic competitiveness.

- **Integrity** encompasses the state of the governance systems at the national, state, and local levels that ensure seamless and efficient implementation of policies, as well as regulatory frameworks that uphold transparency, accountability, and impartiality to promote political stability and socio-economic growth. This includes ensuring effective implementation and enforcement of regulations and policies, as well as establishing laws and policies conducive to business activities that promote economic competitiveness.
- **Infrastructure** captures the state of the natural infrastructure (e.g., environment - lakes, rivers, natural habitats, etc.) as well as knowledge and technology-driven physical infrastructure necessary for a country to function efficiently. Physical infrastructure encompasses both the public and private systems and services necessary for socio-economic growth and the overall well-being of the population. This includes transportation infrastructure (e.g., roads, railways, bridges, airports, seaports, etc.), energy infrastructure (e.g., physical networks of oil and natural gas pipelines, power generation, transmission, and distribution systems), water infrastructure (e.g., water supply and sanitization systems, wastewater management systems, etc.), and social infrastructure (e.g., healthcare facilities, schools, etc.).
- **Infostructure** involves the state of digital infrastructure, ICT connectivity, and the use of advanced digital technologies to promote the country's economic development and competitiveness. This includes innovative technologies such as artificial intelligence systems, big data analytics, blockchain technology, 5G technology and networks, and other digital technologies to ensure cybersecurity and drive innovation development across various industries.

- **Intellectual Capital** refers to the state of the talent stock in the country. This includes the availability and quality of the workforce with basic education and competencies, specialized knowledge, innovation capabilities, technical competencies, as well as entrepreneurial and leadership skills to enhance a country's global competitiveness by fostering a culture of creativity and innovation.
- **Incentives** incorporate the availability and quality of fiscal and non-fiscal incentives to drive the development of the country's STIE ecosystem. This includes incentives to promote knowledge sharing culture by strengthening the "quintuple innovation helix", increase local and foreign investments to nurture and develop strong local STI players, promote research and development activities, enable greater access to national research facilities, tax incentives and subsidies for STIE initiatives, as well as taxes and fines to discourage activities that are against the UN-SDG goals.
- **Internationalization** refers to the state of global outreach and international collaboration to promote technology and knowledge transfer, reduce trade barriers, increase market share, and participate in the global value chains. This includes participation in free trade agreements and economic partnerships with other countries and adhering to global standards and best practices that enable the country to move up the global value chains.

Figure 1.

The 8i Ecosystem Framework to assess Singapore's current state of play.



Adapted from Nair (2011) and Nair et al. (2022)

3.0 8i Ecosystem Analysis of Singapore

Institutions

Singapore's **strong institutional leadership** is a key factor in its political and socio-economic growth. The country has achieved the top rank among ASEAN countries for its **government effectiveness** and is highly regarded for its public service delivery and bureaucracy quality. Additionally, Singapore has **top-notch public research institutions and higher education institutions** that foster innovation and scientific research through collaborations. Its **industry players are strongly driven by R&D** and innovative partnerships. These strong institutions have contributed to a well-established Science, Technology, and Innovation ecosystem in Singapore.

Interaction

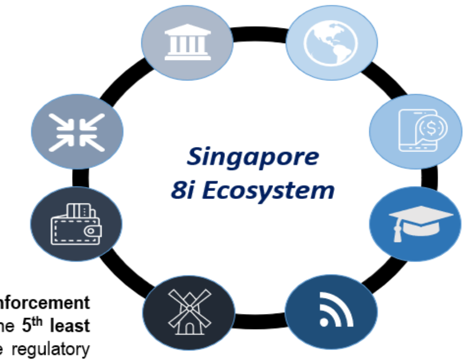
Singapore's **strong and efficient system of collaboration and cooperation** among **government bodies, industry players, academia, and research institutions** is essential for promoting political and socio-economic growth in the country. **The Research, Innovation and Enterprise (RIE) 2025 plan** by the government fosters collaboration between policymakers, universities, research institutions, and industry players, envisioning developing the country's STI ecosystem. It also **actively pursues regional and international partnerships** to establish its presence in the global market and expand its talent networks, contributing to its economic success and position as an important hub for business and innovation.

Integrity

Singapore has a **strong national integrity system** backed by **effective law enforcement** mechanisms, ensuring zero tolerance for corruption. As a result, it is ranked as the **5th least corrupt country globally** in the 2022 Corruption Perceptions Index. Its effective regulatory frameworks and **impartial legal frameworks** create a **friendly business environment** and attract foreign direct investment, and there are **no restrictions on foreign ownership** of companies in Singapore, making it one of the **easiest places to do business** in the world.

Infrastructure

The Singaporean government places **great importance on infrastructure development**, recognizing its crucial role in supporting economic growth and enhancing the quality of life for citizens. Singapore has earned **a high score for infrastructure quality**, with top-notch transportation systems and reliable power and water supplies. The government is also dedicated to **sustainable infrastructure development**, including promoting green buildings and reducing carbon footprints. Singapore is also known for **its top-notch healthcare infrastructure,** with top pharmaceutical and biotechnology companies setting up manufacturing hubs. These initiatives reflect Singapore's commitment to maintaining and improving its state-of-the-art infrastructure to drive economic growth and competitiveness..



Internationalization

Singapore's government is actively developing **regional and international partnerships** to enhance its economic growth and global competitiveness. It has signed **numerous agreements with other countries** to advance development in various areas, including trade agreements such as the **RCEP**. Moreover, Singapore has the **highest level of participation in the global value chains** among ASEAN countries, specializing in **forward linkages**, which contribute to around **42% of Singapore's GDP**. As a result, the country has been able to enhance its market presence, expand its knowledge networks, and integrate into global supply chains through its active involvement in the global value chains and the establishment of agreements with multiple countries.

Incentives

Singapore has implemented a range of fiscal and non-fiscal incentives to boost its **R&D capabilities and promote high-value economic activities**. For example, the government offers a **250% tax deduction for qualifying R&D capital expenditure** to encourage R&D activities and technology adoption by companies. Besides that, the Global Trader Program offers **tax exemptions to global trading companies**. Caregivers and persons with disabilities also benefit from **personal incentives such as the Caregivers Training Grant and Home Caregiving Grant.** These incentives demonstrate the government's commitment to promoting innovation, economic growth, and social welfare in Singapore.

Intellectual Capital

Singapore places great importance on developing its intellectual capital to maintain its competitiveness in the global market. It possesses a **highly educated and skilled workforce**, with over 30% holding a university degree and 15% possessing diplomas or professional qualifications. Moreover, its **education system aligns well with industry demand**, scoring 92.13 out of 100. Singapore's **world-class higher education institutions, including NUS and NTU,** offer initiatives focused on data science and AI, collaborating with tech companies to cultivate skilled professionals. The universities also **work closely with industry partners** to provide real-world experience to students. These efforts have built up the country's human capital and contributed to a robust research and innovation ecosystem, essential for Singapore's economic competitiveness.

Infostructure

Singapore **scores highly on the ICT Infrastructure Index**, indicating that it is one of the top achievers in ASEAN in various aspects of ICT infrastructure, such as **affordable mobile tariffs, widespread internet access, and high fixed-broadband subscription rates**. The government has also implemented various national programs and initiatives to promote research and innovation in digitalization and advanced technologies. The **Smart Nation initiative**, based on Digital Society, Digital Economy, and Digital Government pillars, aims to leverage technology to improve citizens' lives, businesses, and government. Singapore's success in digital initiatives has made it a world leader in the digital economy and transformed it into a Smart nation.

Figure 2. Summary of the 8i ecosystem analysis of Singapore

3.1 Institutions

Singapore's strong institutions of governance at the federal, state, and local levels, involving government agencies, industry players, higher education institutions, and research institutions, play critical roles in promoting political and socio-economic growth in the country. According to the World Bank's Worldwide Governance Indicators, Singapore has achieved the top rank among ASEAN countries for its government effectiveness[1], with a perfect score of 100 (see Figure 2) (World Bank, 2021). Besides that, Singapore ranks 3rd in the global ranking on government effectiveness in the Chandler Good Government Index[2] across 104 countries (Chandler Good Government Index, 2022). In other words, Singapore excels in its public service delivery, quality of bureaucracy, and government's commitment to policies. This achievement can be demonstrated through a study conducted by the Institute of Policy Studies (IPS) Social Lab, which reveals that more than 70% of respondents expressed "a great deal" or "quite a lot" of confidence across key institutions in Singapore, including the government, Parliament, courts, Singapore Police Force, Singapore Armed Forces and civil services (Ho, 2021). Moreover, Singapore scores 98 out of 100 on the Political Stability and Absence of Violence/Terrorism Index (World Bank, 2021), demonstrating a highly stable political environment.

In addition to being able to stay politically neutral regardless of political pressures, Singapore's civil servants are also highly competent in conducting and delivering public services (World Bank, 2021). In fact, Singapore is well-known for its highly efficient and

[1] The World Bank defines "government effectiveness" as the "perceptions of the quality of public services, the quality of the civil service and the degree of its independence from political pressures, the quality of policy formulation and implementation, and the credibility of the government's commitment to such policies".
[2] Chandler Good Government Index is evaluated across seven pillars, including leadership and foresight; robust laws and policies; strong institutions; financial stewardship; attractive marketplace; global influence and reputation; and helping people rise (Chandler Good Government Index, 2022).

professional public service delivery systems, in which Singaporean civil servants are appointed and evaluated based on their performance (merit-based appointments) rather than academic results and relationships (Pennington, 2017). For example, Singapore's Corrupt Practices Investigation Bureau (CPIB) is highly competent and effective in enforcing the Prevention of Corruption Act (POCA), with an 87% clearance rate and a 97% conviction rate (CPIB, 2020). In addition, the CPIB Public Perceptions Survey 2020 reveals that 80% of the respondents perceived CPIB as an effective anti-corruption agency in Singapore (CPIB, 2020). As a result, Singapore's 5th ranking among 180 countries worldwide on the Corruption Perceptions Index is a testament to the agency's outstanding performance in combating corruption (Transparency International, 2022).

As a nation with a strong focus on research and development (R&D), Singapore owns top-notch public research institutions, such as the Agency for Science, Technology and Research (A*STAR). A*STAR plays an important role in moving Singapore towards a knowledge-based economy by fostering innovation and scientific research. It often collaborates with industry partners (e.g., Racer Technology, STMicroelectronics, etc.), research institutions (e.g., RVAC Medicines, Advanced Technology Research Centre [ATREC]), and higher education institutions (e.g., National University of Singapore, Nanyang Technological University, etc.) to jointly commercialize research and develop new technologies in a wide range of areas, including but not limited to biomanufacturing, engineering, food technology, robotics and automation, etc. (A*STAR, 2020b; ATREC, 2023; Compound Semiconductor, 2021; Pharmaceutical Technology, 2022).

In addition to world-renowned research institutions, Singapore also houses world-class research-based higher education institutions (HEIs), including the National University of

Singapore (NUS) and Nanyang Technological University (NTU), which were ranked 2nd (97.4/100) and 5th (96.7/100) out of 1,500 universities in the Quacquarelli Symonds (Q.S.) ranking of Asia's universities (Q.S. Top Universities, 2023). Besides that, NUS and NTU were ranked 19th and 36th (out of 1,662 universities) in the latest Times Higher Education (THE) World University Rankings 2023 (THE, 2023). These recognitions attest to the excellent performance of these HEIs in teaching, R&D, publications, knowledge transfer, and international outlook (THE, 2023; Top Universities, 2023). For example, between 2016 – 2020, NUS published more than 46,000 journal articles, secured more than S$3.74 billion of research funding, and granted more than 500 new patents, with 125 spin-off companies based on NUS technology. These achievements demonstrate that NUS has been a pioneer in pursuing impactful research that contributes to society (NUS, 2020).

As an innovation-driven and knowledge-based economy, Singapore's industry players are strongly driven by R&D and innovative partnerships to foster knowledge-sharing between different sectors (National Research Foundation, 2021). For example, Singapore Technologies Engineering Ltd. (S.T. Engineering) is a global supplier of aerospace, electronics, and defense systems. It jointly established the Research Translation @ S.T. Engineering research collaboration platform with NUS, NTU, Singapore University of Technology and Design (SUTD), and A*STAR to work together in technological areas, such as smart traffic management, 5G and future communications, digitalization and data analytics, etc. This platform allows them to leverage the knowledge and expertise of the partners to expedite the translation of research outcomes into industrial applications (S.T. Engineering, 2021).

In brief, Singapore has a well-established Science, Technology, and Innovation (STI) ecosystem attributed to its strong institutional governance, robust STI policies, investment in

R&D initiatives, talent acquisition and development, and conducive business environment (United Nations, ESCAP, 2018). Its efficient institutional governance systems have helped enhance the country's economic competitiveness and create a stable society.

3.2 Interaction

Singapore is known for its efficient system of collaboration among government, industry, academia, and research institutions, as well as its efforts to establish partnerships both regionally and internationally to strengthen its position in the global market. This collaborative ecosystem has played a significant role in Singapore's economic success and its recognition as an important hub for business and innovation. In fact, Singapore has been acknowledged as one of the most innovative countries in the world due in part to the strong culture of collaboration and knowledge-sharing between government, industry, and academia at national, regional, and global levels (Economic Development Board, 2023b). This can be demonstrated by the establishment of the Research, Innovation and Enterprise (RIE) 2025 plan by the government to foster collaborations between policymakers, universities, research institutions, and industry players, envision developing the country's STI ecosystem to move Singapore up the economic value chain (National Research Foundation, 2021).

Some successful partnership initiatives in Singapore can be demonstrated through the following cases. To achieve Singapore's "30 by 30" goal (to produce 30% of the country's nutritional needs locally by the year 2030), the Singapore Institute of Food and Biotechnology Innovation (SIFBI), which is a research institute under A*STAR, collaborates with government agencies (e.g., Economic Development Board (EDB), Enterprise Singapore, Health Promotion Board) and institutes of higher learning (e.g., National University of Singapore, Nanyang Technological University, Singapore Polytechnic, etc.) to develop novel technologies for urban agriculture and aquaculture, as well as exploring alternative sources of protein, such as cell-cultured meat (A*STAR, 2020a). Furthermore, due to land scarcity in Singapore, the Economic Development Board, the Solar Energy Institute of Singapore, and Singapore's National Water Agency jointly developed floating solar photovoltaic systems at Tengeh Reservoir to harness solar energy for the national power grid (Ministry of Foreign Affairs Singapore, 2018). Besides that, to enhance Singapore's robotics ecosystem, the National Robotics Programme, which is a national multi-agency program, brings together public agencies (e.g., EDB, Enterprise Singapore, Smart Nation & Digital Government Office, National Research Foundation, etc.), universities and research institutes (e.g., A*STAR, National University of Singapore, Singapore Management University, etc.), as well as industry players (e.g., S.T. Engineering, Xnergy, HandPlus Robotics, Orinno technology, etc.) to collaboratively improve socio-economic impacts through applications of automation and robotics in various industries (e.g., healthcare, manufacturing, services, hospitality, education, etc.) (Ministry of Trade and Industry Singapore, 2023).

In terms of regional partnership, for example, Singapore's industry players (National University Hospital (Singapore) Pte Ltd (NUH) and CytoMed Therapeutics Pte Ltd.) have signed a Memorandum of Understanding (MoU) with Clinical Research Malaysia (CRM) to jointly develop clinical research capabilities on novel drug development (Business Today, 2019). This MoU enables clinical knowledge sharing between the partners, adding value to the healthcare ecosystems in both countries (Business Today, 2019). In addition, to further boost artificial intelligence (A.I.) innovation in the country, Singapore's Smart Nation and Digital Government Group (SNDGG) has entered into a global partnership with Google Cloud (a world-renowned technology company), envisioning co-developing A.I. solutions applicable in key sectors, such as healthcare, sustainability, and finance (Smart Nation Singapore, 2022). Specifically, Singapore can leverage Google Cloud's deep tech skills (e.g., deep A.I. and machine learning training resources and programs) and cutting-edge technologies, while Google Cloud can benefit from Singapore's rich innovation ecosystem (Smart Nation Singapore, 2022). This is Singapore's first public-private partnership in the field of A.I., which is a win-win collaborative strategy.

Overall, Singapore's comprehensive and integrated collaborative ecosystem has contributed to its economic success and position as an important hub for business and innovation. In fact, Singapore has been recognized as one of the most innovative countries in the world partly due to the strong collaborations and knowledge-sharing culture between government, industry players, and academia at the national, regional, and global levels (Economic Development Board, 2023b; Low, 2022).

3.3 Integrity

The Singaporean government has a strict approach to upholding laws and regulations, with a zero-tolerance policy towards corruption and harsh punishments for those found guilty of corrupt acts. This has helped establish a strong national integrity system that ensures ethical behavior and accountability across all sectors of society. Such a system is vital for maintaining public trust in the government and promoting a fair and just society. In fact, Singapore has put anti-corruption measures on top of its national agenda since its independence from Malaysia in 1959. As a result, the number of corruption cases in Singapore has consistently remained low for years due to all these effective anti-corruption efforts (CPIB, 2023). Moreover, Singapore's integrity system is backed by strong enforcement mechanisms. For example, the CPIB and other law enforcement agencies have a high rate of success in investigating and prosecuting corruption cases (with 87% clearance rate and 97% conviction rate) (CPIB, 2020). As a result, Singapore scores 83 and ranks as the 5th least corrupt country out of 180 countries globally (CPIB 2023).

Singapore is also ranked as the top country in Asia when it comes to the effectiveness of its governance and enforcement of the rule of law (World Justice Project, 2018). The country scores almost 100 in terms of its control of corruption[3], regulatory quality[4], and the rule of law[5], indicating a well-governed and stable country with strong institutions and effective legal frameworks (World Bank, 2021). Besides that, Singapore's effective law enforcement and impartial regulatory frameworks have created a business-friendly environment that attracts foreign direct investment. There are no restrictions on foreign ownership of companies in Singapore, enabling all businesses to operate and compete on a level playing field regardless of their country of origin (U.S. Department of State, 2022). In addition to transparent commercial dispute-resolving systems, Singapore's financial reporting standards are consistent with global reporting standards, such as the International Accounting Standards Board (IASB), which helps promote a level playing field among companies operating in Singapore and facilitates cross-border investments (U.S. Department of State, 2022). As a result, Singapore has consistently been ranked as one of the easiest places to do business in the world, with a transparent and predictable regulatory environment (World Bank, 2019b).

[3] Control of Corruption captures perceptions of the degree to which public authorities use their power for their own personal benefit. This includes both small and large acts of corruption, as well as situations where wealthy and influential groups take control of the government to serve their own interests.
[4] Regulatory quality captures perceptions of the government's effectiveness in creating and enforcing policies and regulations that support and encourage the growth of businesses and industries in the private sector.
[5] Rule of Law refers to how much people trust and follow the rules of society. This includes things like how well contracts are enforced, how property rights are protected, the effectiveness of the police and courts, and the level of crime and violence in a community.

In brief, Singapore's robust national integrity system and regulatory frameworks play a crucial role in maintaining transparency, accountability, and impartiality, which are fundamental to upholding the nation's political stability. These systems ensure the efficient implementation and enforcement of regulations and policies while also establishing laws and policies that support business activities and promote economic competitiveness.

3.4 Infrastructure

Singapore is strongly committed to developing top-quality infrastructure essential for the country's socio-economic activities, including transportation, energy, water and sanitization, and social infrastructure. In fact, Singapore's success can be accredited to its well-designed Master Plan for long-term infrastructure development, which is periodically reviewed every five years to guide the physical development of Singapore to ensure that the physical infrastructures are aligned with the evolving demands of the society (Urban Redevelopment Authority, 2023). Singapore's commitment to this initiative has resulted in an excellent score of 95.4 out of 100 on the Infrastructure Quality Index (World Economic Forum, 2019). This outstanding score is a testament to Singapore's exceptional performance in essential infrastructure such as transportation systems (including air, land, and sea infrastructure), as well as electric and water supply (World Economic Forum, 2019).

As part of the nation's initiatives to combat climate change, as outlined in the Sustainable Singapore Blueprint 2015, the government of Singapore introduced the Land Transport Master Plan (LTMP) 2040, aiming to develop a more inclusive land transport system and reduce the population's reliance on cars (Scheurer, 2020; Singapore Government Agency, 2023). Besides that, Singapore's Building and Construction Authority has also introduced the Singapore Green Building Masterplan (SGBMP) to integrate environmentally friendly design and construction practices (e.g., renewable energy sources, use of sustainable and recycled materials, etc.) into infrastructure projects, including those related to healthcare and education. In turn, this helps expedite Singapore's transition to a net-zero country (Building and Construction Authority, 2022). In terms of energy infrastructure, Singapore is home to one of the world's largest floating solar farms, which spans 111 acres and can produce 60 megawatts of solar photovoltaic capacity. This energy infrastructure is expected to reduce carbon emissions by 32 thousand metric tons (U.S. Energy Information Administration, 2021).

Due to the lack of natural water resources, the Singapore government has developed the Changi Water Reclamation Plant to transform sewage into clean potable water. With the plant's capacity to treat up to 900 million liters of wastewater daily, Singapore is able to improve its water supply and minimize ocean pollution, ultimately promoting a sustainable future (World Economic Forum, 2022). Singapore is also widely recognized for its excellent healthcare infrastructure, boasting a state-of-the-art medical system that sets a benchmark across the ASEAN region. The country prides itself on its superior medical equipment and supplies, ensuring high standards of healthcare delivery (International Trade Administration, 2022a). In addition, top pharmaceutical and biotechnology industry leaders like Pfizer, Novartis, Sanofi, AbbVie, and Amgen have set up manufacturing hubs in Singapore to produce drug products and biomedical products, further adding to the distinction of the country's healthcare infrastructure (Economic Development Board, 2023c).

To sum up, the aforementioned initiatives showcase Singapore's strong dedication to maintaining and upgrading its cutting-edge infrastructure, thereby enhancing its economic growth and competitiveness. This, in turn, has positioned Singapore as a leading hub for business and innovation in the Asia-Pacific region.

3.5 Infostructure

Singapore has long recognized the importance of digital technology and has been investing heavily in developing its digital capabilities as part of its national agenda. This includes initiatives to promote the adoption of advanced digital technologies in various sectors, such as education, healthcare, fintech, smart cities, transportation, and government services, alongside efforts to improve digital infrastructure and cybersecurity (International Trade Administration, 2022b). As a result of these initiatives, Singapore earns a high score of 99.37 out of 100 on the ICT Infrastructure Index, which is a sub-pillar of the Network Readiness Index (Lanvin & Monteiro, 2022). This indicates that Singapore stands out as one of the top achievers across ASEAN in various aspects of the ICT infrastructure, including affordable mobile tariffs and handset prices, widespread Internet access, extensive 4G mobile network coverage, high fixed-broadband subscription rates, abundant international Internet bandwidth, and comprehensive Internet access in schools (Lanvin & Monteiro, 2022). Furthermore, Singapore will be among the first in the world to achieve comprehensive 5G network coverage across the nation by 2025, which is accessible even underground, with better bandwidth and security (International Trade Administration, 2022b). In addition, Singapore has set up the first physical 6G laboratory, the Future Communications Connectivity (FCC) lab, in the ASEAN region (Waring, 2022). Along with this, the government is currently developing a new national digital blueprint that outlines strategies for 6G networks development in the country, signifying Singapore's dedication to stay competitive in the global digital economy (Tham, 2023).

Singapore's efforts in developing its infostructure ecosystem have also been reflected in various national programs and initiatives, such as the Research Innovation Enterprise (RIE) plan, which is aimed at promoting research and innovation in key areas of economic growth, including digitalization and advanced technologies (e.g., 5G, Internet of Things, etc.) (National Research Foundation, 2021). Besides that, the Smart Nation initiative is also a key part of Singapore's efforts to develop its infostructure and leverage technology to improve the lives of its citizens, businesses, and the government. This initiative is based on three primary pillars: Digital Society, Digital Economy, and Digital Government (Smart Nation and Digital Government Office, 2023). As part of the Digital Society pillar, HealthHub is a government-led digital platform encouraging Singaporeans to take charge of their health and well-being through easy access to healthcare information and services, such as health assessments and appointment booking (Telecom Review, 2020). In terms of the Digital Economy pillar, the country's Minister for Communications and Information has recently announced plans to boost broadband speeds up to 10 Gbps from 1 Gbps for both residential and business users, with the purpose of enhancing its digital connectivity and supporting the growth of its digital economy (Dominic, 2022). Under the Digital Government pillar, the Government Commercial Cloud (GCC) initiative was introduced in 2018 to migrate most of the government's IT systems to the commercial cloud, with a proposed completion rate of 70% by the end of 2023. This initiative aims to provide a secure cloud infrastructure to support the digital transformation of the public sector, seeking to enhance the efficiency of public service delivery in Singapore through digital means (Department of Commerce, 2022).

Overall, Singapore is known for its advanced digital infrastructure and early adoption of novel digital technologies. Singapore's strong commitment to developing its infostructure has enabled it to become a Smart Nation and pioneer in the global digital economy (Smart Nation and Digital Government Office, 2023).

3.6 Intellectual Capital

Singapore has been actively promoting the development of its intellectual capital to drive economic growth and maintain its competitiveness in the global market (Quah, 2018). This can be demonstrated through the establishment of the national RIE 2025 strategy, which aims to build a strong knowledge base for transformative innovations and enhance the innovation capabilities of local enterprises in the country (National Research Foundation, 2021). In addition, Singapore possesses a highly educated and skilled workforce attributable to its robust educational systems and workforce training programs (Quah, 2018). In fact, over 72% of its workforce had completed tertiary education (e.g., diplomas, bachelor's degree, master's degree, doctoral degree, etc.) while 37% had completed secondary education (e.g., high schools) (Lanvin & Monteiro, 2022). Moreover, over 60% of Singapore's workforce is employed in high-skilled jobs, showcasing the country's commitment to developing a skilled and knowledgeable workforce (Ministry of Manpower, 2022). As a result, Singapore earned the second spot out of 133 countries on the 2022 Global Talent Competitiveness Index for its outstanding ability to attract, develop, retain, and enable talent (Lanvin & Monteiro, 2022). Furthermore, Singapore scores 92.13 out of 100 on the relevance of the education system to the economy, indicating a strong alignment between its education system and industry demand (Lanvin & Monteiro, 2022).

Singapore is also home to several world-class higher education institutions, including the National University of Singapore (NUS) and Nanyang Technological University (NTU), which have consistently ranked highly in international university rankings (THE, 2021). These universities have introduced initiatives centered around data science and artificial intelligence, collaborating with technology corporations (e.g., Alibaba Group) to cultivate skilled professionals in the field of big data and AI (Alibaba Cloud Community, 2022). Furthermore, to provide a pipeline of industry-ready talent, Singapore's higher education institutions have been working closely with industry partners to develop relevant curricula and provide students with real-world experience through internships and apprenticeships (Ganesan, 2022). For example, the TechSkills Accelerator program provides students with valuable practical experience by assisting them in securing internships with leading IT companies (Woo & Ranamita, 2022). As a result of these initiatives, the percentage of university graduates who secured permanent full-time employment within six months of their final exams increased significantly, rising from 69.8% in 2020 to 84% in 2021 (Ganesan, 2022).

To sum up, Singapore's intellectual capital development efforts have successfully built up the country's human capital and contributed to a robust research and innovation ecosystem, which are essential to the country's economic competitiveness in the global market.

3.7 Incentives

Singapore has a comprehensive set of fiscal and non-fiscal incentives aimed at boosting the country's innovation capacities and encouraging the growth of high-value economic activities. The incentives can be broadly divided into three categories: institutes, industry, and individual incentives, which include cash grants, subsidies, tax exemption, reduced tax rates, etc.

Under the institutes' category, the government offers an additional tax deduction of 250% of qualifying capital expenditure for R&D projects carried out in Singapore between 2019 and 2025, aiming to strengthen R&D activities and foster technology adoption among companies in Singapore (Inland Revenue Authority of Singapore, 2022). To further promote high-value economic activities in Singapore, the government of Singapore has implemented two incentive programs, the Development and Expansion Incentive (DEI) and the Pioneer Certificate Incentive (PC) (Economic Development Board, 2019). By offering a 5% or 10% corporate tax exemption, the DEI and PC seek to incentivize foreign investors to establish their headquarters in Singapore, expand their operational capacities, and engage in knowledge and technology transfer initiatives (Economic Development Board, 2019). Similarly, the Global Trader Program (GTP) is another incentive designed to attract large trading companies to establish their presence in Singapore, strengthening its position as an international trading hub. Specifically, global trading companies are entitled to a 5% or 10% tax exemption on their eligible trading income for a renewable five-year period (ACCA, 2022). Furthermore, to promote sustainable and eco-friendly development in the country, the government has introduced the Green Mark Incentive Schemes (GMIS) to encourage the adoption of green building technologies and sustainable building design by developers, civil engineers, architects, and building owners (Building and Construction Authority, 2023). As part of the GMIS initiative, the GMIS - Existing Buildings 2.0 (GMIS-EB 2.0), worth $63 million, encourages energy-efficient practices in existing buildings by offering monetary grants to building owners whose buildings conform to either Super Low Energy or Zero Energy standards (Building and Construction Authority, 2023).

On the other hand, individual incentives such as the Caregivers Training Grant (CTG) provide eligible caregivers a $200 annual subsidy to encourage their participation in caretaker training programs. These programs equip them with the relevant knowledge and skills to provide care for the elderly and disabled persons (Ministry of Health Singapore, 2023a). Moreover, the government of Singapore also introduced the Home Caregiving Grant (HCG), which provides eligible Singaporeans who suffer from chronic mild to severe disabilities with a monthly cash payment of up to $400 for caregiving costs (Ministry of Health Singapore, 2023a). In addition to caregiving grants, Singapore also offers a wide range of healthcare schemes and subsidies to enhance the health and well-being of its citizens and permanent residents (Ministry of Health Singapore, 2023b). For example, under MediShield Life, a basic health insurance scheme offered by the government, all Singaporeans, regardless of age and health conditions, are entitled to subsidized healthcare treatments in public hospitals. This health subsidy allows citizens and permanent residents to enjoy low-cost and efficient medical treatments and services (Ministry of Health Singapore, 2023b). Other than that, the government introduced the EV Early Adoption Incentive (EEAI) in 2021, aimed at promoting the purchase of electric vehicles. Under this initiative, buyers are entitled to a rebate of 45% off the vehicle's Additional Registration Fee (ARF), up to a maximum of $20,000 (Ministry of Transport Singapore, 2023). This incentive clearly demonstrates Singapore's commitment to achieving net zero greenhouse gas emissions by 2050 (Lee, 2022).

In essence, Singapore's robust incentive systems have expedited the growth of high-value-added economic activities while promoting sustainable living in the nation, contributing to a vibrant and sustainable economy. Besides that, the comprehensive set of individual incentives, such as caregiving and healthcare subsidies, has helped build citizens' confidence in the country's social safety net and economic system.

3.8 Internationalization

To improve its global competitiveness, the Singaporean government is actively seeking regional and international cooperation, as evidenced by its active participation in global value chains. In addition, the government has been actively signing free trade agreements with numerous countries to boost its competitiveness in the global economy. Due to its strategic location in the heart of Southeast Asia, Singapore has become a preeminent gateway for multinational corporations to expand their presence in the ASEAN region. Besides that, Singapore's strategic approach to internationalization strategy has also enabled it to become the largest exporter among the ASEAN countries, with China, the United States, and Malaysia being its top trading partners (Department of Statistics Singapore, 2023).

Singapore's Ministry of Foreign Affairs has signed more than 80 Memoranda of Understanding and agreements with 23 countries, seeking to expand Singapore's capabilities in areas such as public health, smart cities, sustainability, green economy, cybersecurity, and digital economy (Ministry of Foreign Affairs Singapore, 2022). In addition, Singapore is also a member of numerous trade agreements (FTAs) and economic partnerships, including the Regional Comprehensive Economic Partnership (RCEP), which is the world's largest free trade agreement accounting for around 30% of global GDP and contributing to more than 30% of global FDI flows in 2020 (The ASEAN Secretariat and the United Nations Conference on Trade and Development [UNCTAD], 2021). In addition to increasing trade and investment flows between Singapore and its partner countries, the RCEP has also helped attract inward FDI, with a significant increase in its FDI-to-GDP ratio, rising from 16% in the 2000-2004 period to 25.5% in the 2015-2019 period (Matsuura, 2022). As a result, this has moved Singapore up the global value chains (The ASEAN Secretariat and UNCTAD, 2021). Singapore also signed the Digital Economy Agreement with Australia to develop a holistic digital trade ecosystem between the countries (Equinix, 2021). Besides that, the U.S. – Singapore Free Trade Agreement (USSFTA) helps strengthen the protection and enforcement of intellectual property rights, allowing the member countries to vigorously develop their innovation capabilities in knowledge-based sectors (e.g., science and technology) (Ministry of Trade and Industry Singapore, 2020).

Singapore has the strongest level of participation in the global value chains (GVCs), specializing in forward linkages (domestic value added in the form of intermediate products that are exported to third economies to contribute to the nation's gross exports), which contribute to around 42% of Singapore's GDP (ASEAN-Japan Centre, 2018; Singapore Management University, 2018). This is primarily due to Singapore's strong R&D ecosystem and a highly skilled workforce in STI. In turn, this has attracted many multinational corporations to set up their R&D centers in Singapore, further strengthening the country's capabilities in the forward linkages of the GVC. China, Malaysia, and the U.S. are Singapore's largest trading partners, with key products such as electronics, machinery, chemical products, and refined petroleum (Department of Statistics Singapore, 2023).

Clearly, Singapore's robust internationalization strategies have contributed to its economic growth and success, enhancing Singapore's position as a regional and global hub for trade and investment.

4. Conclusion

In conclusion, Singapore is an exemplary country that has established itself as a global leader in various aspects, ranging from institutional leadership to infrastructure and internationalization strategy. This success can be attributed to its robust institutional leadership, where strong "Champions with Clouts" in various sectors have provided the vision and direction necessary to implement sound policies and enhance the country's competitiveness holistically. Additionally, an efficient collaborative ecosystem that involves various stakeholders such as policymakers, industry players, research institutions, and higher education institutions has created a robust knowledge-sharing culture fostering innovation and economic growth. Besides that, a strong national integrity system with a strict rule of law, an impartial judicial system, high regulatory quality, and effective control of corruption has also been crucial in promoting a peaceful society and maintaining investor confidence. In addition to world-class sustainable infrastructure, Singapore also possesses state-of-the-art infostructure, with comprehensive 5G networks and ICT infrastructure. This has led to the rapid growth of the digital economy, enabling organizations to leverage modern technologies to drive business growth and stay agile in the global market. Moreover, Singapore's first-class education system has created a highly skilled workforce that helps drive R&D and innovation capacities, further bolstering the country's position as a global innovation hub. The country's ability to attract high-value economic activities can also be credited to its wide range of effective incentives aimed at promoting R&D initiatives and attracting foreign direct investment. Lastly, Singapore's strategic approaches to internationalization and strong presence in global value chains have also reinforced the country's position as a global hub for trade and investment. In summary, Singapore's comprehensive 8i ecosystem and its remarkable progress in a relatively short period of time serve as an ideal role model for other countries that aspire to achieve similar development goals and socio-economic growth.

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