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Environmental problems and biodiversity conservation through silviculture in Sri Lanka: Current state, struggles and cooperation with Czech foresters – A review

Channa Suraweera, Josef Gallo, Stanislav Vacek, Martin Baláš*

Department of Silviculture, Faculty of Forestry and Wood Sciences, Czech University of Life Sciences Prague, Prague, Czech Republic

**Corresponding author: gallo@fld.czu.cz*

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Abstract: Sri Lanka, as a developing tropical country, faces serious environmental challenges. Forests, as important ecosystems of Sri Lanka, are under pressure from intensive human activities and climate change. Invasive species represent a great hazard to autochthonous plant species and ecosystems, which are, at the same time, hosts to extraordinarily high biodiversity, of which a high percentage is endemic. In this paper, we reviewed the most challenging environmental problems of Sri Lanka and suggested the improvement of a number of them through silvicultural measures and cooperation with international experts, namely Czech foresters. We also reviewed the main forest biomes and addressed the specific problems and management of different forest types.

Keywords: Ceylon; climate change; forestry; protection; tropical ecosystems

Sri Lanka is an island country situated on the Isnad of Ceylon in the Indian Ocean and separated from peninsular India by the Palk Strait (Peiris, Arasaratnam 2024). It has maritime borders with India to the northwest and with the Maldives in the southwest (Kawshalya 2020). Its geographical location has made it of great strategic importance for trade, from the time of the ancient Silk Road through to the Second World War and beyond (Kawshalya 2020).

It is a developing country with an increasing population. Its population was 22.156 million inhabitants (estimate 2021; DCS 2024). The area of Sri Lanka is 65 610 km^2, resulting in a population density of 353 persons per km^2.

Such a growing population and its pressure have potential negative effects on forests and their biodiversity (Ellis et al. 2013; Grainger 2013). The information on Sri Lanka's current forest cover varies slightly depending on the source and the definition used, but it generally falls in the 29–32% range. According to the Forest Resources Assessment (FRA 2020), Sri Lanka's forest cover is 29.8%, which is roughly 1 933 000 ha. Samaranayake (2023) points out that the rainforests of southwestern and central areas of the island are, as hubs of global biodiversity, most threatened by biodiversity loss as a result of intensive urbanisation. As in other tropical parts of the world, the terrestrial biosphere has transitioned from pre-

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dominately wild to mostly anthropogenic during the past 300 years (Newbold et al. 2014; WWF 2016). It is interesting to compare the state of forests in this tropical island country to the Central European Czech Republic, a country of similar size. In comparison to the Czech Republic:

– Czech Republic: 34.1% (FMI 2022)
– Sri Lanka: 29.8% (FRA 2020)
– total forest area of the Czech Republic: 2 680 372 ha (MoA 2023)
– total forest area of Sri Lanka: 1 955 178 ha (FRA 2020)

In respect to forest cover, the Czech Republic has a slightly higher forest cover than Sri Lanka (by 4.3 percentage points or 718 214 ha in difference). While the Czech Republic and Sri Lanka share similarities in terms of forest cover percentage, they differ totally in their tree species composition. The Czech Republic is dominated by coniferous species like Norway spruce and Scots pine, while Sri Lanka has a higher proportion of broadleaved trees with a higher percentage of primary forests. Sri Lanka's tropical climate and diverse ecosystems present a vastly different context for forest management compared to the temperate forests of Central Europe. The Czech Republic demonstrates distinctive silvicultural practices adapted to its climate and tree species (e.g. Gallo et al. 2018; Brichta et al. 2023; Černý 2023; Vacek et al. 2020, 2023). Understanding the forest cover dynamics in Sri Lanka offers valuable insights into tropical forest ecosystems worldwide. By comparing these trends with those found in Central Europe, such as in the Czech Republic, we can develop a more holistic understanding of global forest management strategies. The recent forest management issues in Sri Lanka highlight a challenge faced by tropical nations worldwide. Interestingly, the Czech Republic has historically experienced similar pressures (human population growth and subsequent urbanisation, forest cover decrease, agriculture and industry development, etc.), showcasing potential avenues for knowledge exchange and collaboration between these geographically distinct regions. For these reasons, there is a lot of pressure on biodiversity in Sri Lanka and cooperation between local and Czech foresters is being developed with the aim of contributing to the solution of these problems.

The cooperation of Czech foresters with those from South-East Asia has a long tradition. For example, Prof. E. Václav worked on several projects in forestry under the FAO in Bangladesh, Laos and Vietnam. Other Czech experts include Ing. J. Slavický (worked in Bangladesh, Thailand, Bhutan, and Pakistan) and Prof. J. Jeník, who worked in Afghanistan (Václav 2007). Recent activities of Czech foresters include the efforts to initiate the establishing of forestry courses at three universities in Laos and thereby improve forestry education there under the 'FORHEAL' project (Marušák 2019).

The aim of this study is to introduce Sri Lankan forest ecosystems, review the most challenging environmental problems of Sri Lanka, as well as present the examples of cooperation with Czech foresters in the introduction of silvicultural measures for nature and biodiversity conservation.

COMPOSITION OF FORESTS AND THEIR CHARACTERISTICS

Sri Lanka, a biodiversity hotspot, boasts a diverse range of forest ecosystems brought about by variations in air temperatures, rainfall, altitude and soil variations in topography (FRA 2020). Here is a brief overview of the various forest types found in Sri Lanka and their characteristics according to Ashton (1991), Volk et al. (2012), and FRA (2020):

Tropical montane forests (Figure 1). Found in the central highlands of Sri Lanka, typically above 1 000 m a.s.l. (1 500 m a.s.l.) and are characterised by cooler temperatures. The average annual temperature is around 15 °C and annual rainfall amounts to more than 1 800 mm. They are distinguished by dominant tree species *Syzygium cumini* (jambu), *Cinnamomum zeylanicum* (True cinnamon), and *Elaeocarpus serratus* (Ceylon olive; veralu). At higher elevations, these forests experience frequent mist and fog, with epiphytes and mosses thriving on the abundant moisture. They are mostly located in the districts of Nuwara Eliya, Kandy, Badulla, Matale, and Ratnapura. Their total extent is around 3 000 ha (~ 0.15%).

Sub-montane forests (Figure 2). Biomes located below the montane forests, at altitudes ranging from 500 m a.s.l. to 1 000 m a.s.l. They exhibit a mix of montane and lowland characteristics, with diverse vegetation and wildlife. The average annual temperature is around 15–20 °C and annual rainfall amounts to 1 800 mm or more. They are also rich in species composition and endemism is about 50%. The dominant trees are dun, keena (*Calophyllum* spp.), *Syzygium* spp., *Shorea gardneri, S. trapezifolia*, *Palaquium* spp., *Homalium ceylanicum, Cullenia* spp., *Cryptocarya wightiana,* and *Neolitsea involucrata* (NCHM 2024). Examples of such for-

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Figure 1. Tropical montane forest

Source: Photo by Channa Suraweera

ests are Knuckles range, Peak wilderness, Hatton, Kotagala, upper slopes of Sinharaja and Deniyaya, Sooriyakanda forests. They are located in the districts of Nuwara Eliya, Ratnapura, Kandy, Matale, Badulla, Kegalle, Matara, Anuradhapura, and Monaragala. Their total extent is around 66 000 ha (~ 3%).

Figure 2. The landscape with a tropical sub-montane forest in the Knuckles range

Source: Photo by Sri Lanka Biodiversity, National Clearing House Mechanism (NCHM)

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Lowland rainforests (Figure 3). These forests thrive in the lowland regions of Sri Lanka, particularly in the wet zone. Abundant rainfall supports lush vegetation and a high biodiversity, including many endemic species. Therefore, these evergreen forests dominate the southwestern lowlands, characterised by high humidity, annual rainfall of more than 2 500 mm with no deficit period, and temperatures constantly more than 20 °C. Their key features include three distinct layers, each with typical species: (*i*) emergent layer (the overstory) – composed of tall trees exceeding 40 meters, like *Dipterocarpus zeylanicus* (hora), *Shorea robusta* (sal) and *Canarium zeylanicum* (kekuna); (*ii*) canopy layer – dense with diverse canopy trees reaching 20–30 meters, including *Mesua ferrea* (Ceylon ironwood), *Calophyllum calaba*, *Palaquium ellipticum*; and (*iii*) understory – characterised by shade-tolerant shrubs, climbers, and small trees. The districts containing this biome are Ratnapura, Kalutara, Galle, Matara, Kandy, Matale, Kegalle, Nuwara Eliya, Colombo, Badulla, Monaragala, and Gampaha. Their total extent is around 124 000 ha (~ 6%).

Tropical moist monsoon forests (Figure 4). Found in areas influenced by the southwestern and northeastern monsoons, typically located in the intermediate zones between the wet and dry zones of the island. They exhibit characteristics of both lowland rainforests and dry forests, with moderate rainfall and diverse vegetation. The average annual temperature is around 15–20 °C and annual rainfall amounts to 1 800–2 500 mm with a dry period of 3 months. They are found in the districts of Monaragala, Polonnaruwa, Ampara, Matale, Badulla, Batticaloa, Ratnapura, Kandy, Nuwara Eliya, Matara, Kurunegala, Hambantota, Gampaha, and Trincomalee. Their total extent is around 221 000 ha (~ 11%).

Dry monsoon forests (Figure 5). Predominantly found in the dry zone of Sri Lanka, which includes the northern and southeastern parts of the island. Characterised by a distinct dry season and lower rainfall compared to wet zone forests. The vegetation is adapted to drought conditions, including mostly semi-deciduous trees accompanied by deciduous trees and scrublands. It has a distinct seasonal rainfall peak from mid-October to January (coinciding with monsoon rains) and a dry period for 3–6 months, occurring at elevations of less than 600 m a.s.l. and often on slopes. Mean annual rainfall amounts to 1 000–1 800 mm, mean temperature is above 20 °C. Dry monsoon forests spread in the districts of Anuradhapura, Mullaitivu, Monaragala, Mannar, Trincomalee, Vavuniya, Puttalam, Ampara, Polon-

Figure 3. The internal structure of lowland rainforest in Sri Lanka

Source: Photo by Channa Suraweera

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Figure 4. Moist monsoon forests

Source: Photo by Channa Suraweera

Figure 5. Dry monsoon forest

Source: Photo by Sri Lanka Biodiversity, National Clearing House Mechanism (NCHM)

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naruwa, Kilinochchi, Batticaloa, Hambantota, Matale, Kurunegala, Ratnapura, Badulla, Jaffna, and Matara. Their total extent is around 1 090 000 ha (~ 56%).

Riverine dry forests (Figure 6). Found along riverbanks and seasonal watercourses in the dry zone as they are subject to periodic flooding and drought conditions, shaping the vegetation composition. They occur in elevations up to 600 m a.s.l., annual rainfall amounts to 1 000–1 800 mm. They are also called 'dry zone forests' according to FRA (2020). They are mostly covering the northern and eastern regions, with dominant tree species being *Manilkara hexandra* (ironwood), *Azadirachta indica* (neem), *Santalum album* (sandalwood). Many species exhibit features like deep root systems, deciduous leaves, and drought-resistant bark. Districts in which they spread are Ampara, Monaragala, Hambantota, Trincomalee, Puttalam, Mannar, and Polonnaruwa. Their total extent is around 22 000 ha (~ 1%).

Mangrove forests (Figure 7). Located in coastal areas, particularly in estuaries, lagoons, and brackish water environments, they adapted to thrive in saline conditions. Mangroves provide vital ecosystem services such as coastal protection and nursery grounds for marine life. Rich in biodiversity, supporting a variety of specialised flora and fauna. Found along the coastline, these saline-tolerant forests play a crucial role in coastal protection against erosion and provide habitat for diverse marine life. Common species include *Rhizophora mucronata* (red mangrove), *Bruguiera gymnorrhiza* (oriental mangrove), *Ceriops tagal* (Indian mangrove), rarer species are, for example, from the genus *Lumnitzera* spp. The artificial regeneration of mangrove forests is often difficult, due to the seeds of some mangrove tree species having a low germination rate (Perera et al. 2019). Mean temperature and rainfalls are variable as they are present along intertidal sheltered coastlines, usually associated with river mouths and lagoons. Districts of occurrence are Puttalam, Trincomalee, Batticaloa, Mannar, Hambantota, Mullaitivu, Killinochchi, Ampara, Jaffna, Galle, Gampaha, Kalutara, and Matara. Their total extent is around 8 700 ha (~ 0.4%).

As noted, dry monsoon forests cover the largest area in Sri Lanka, followed by moist monsoon forests and lowland rainforests. Each forest type plays a cru-

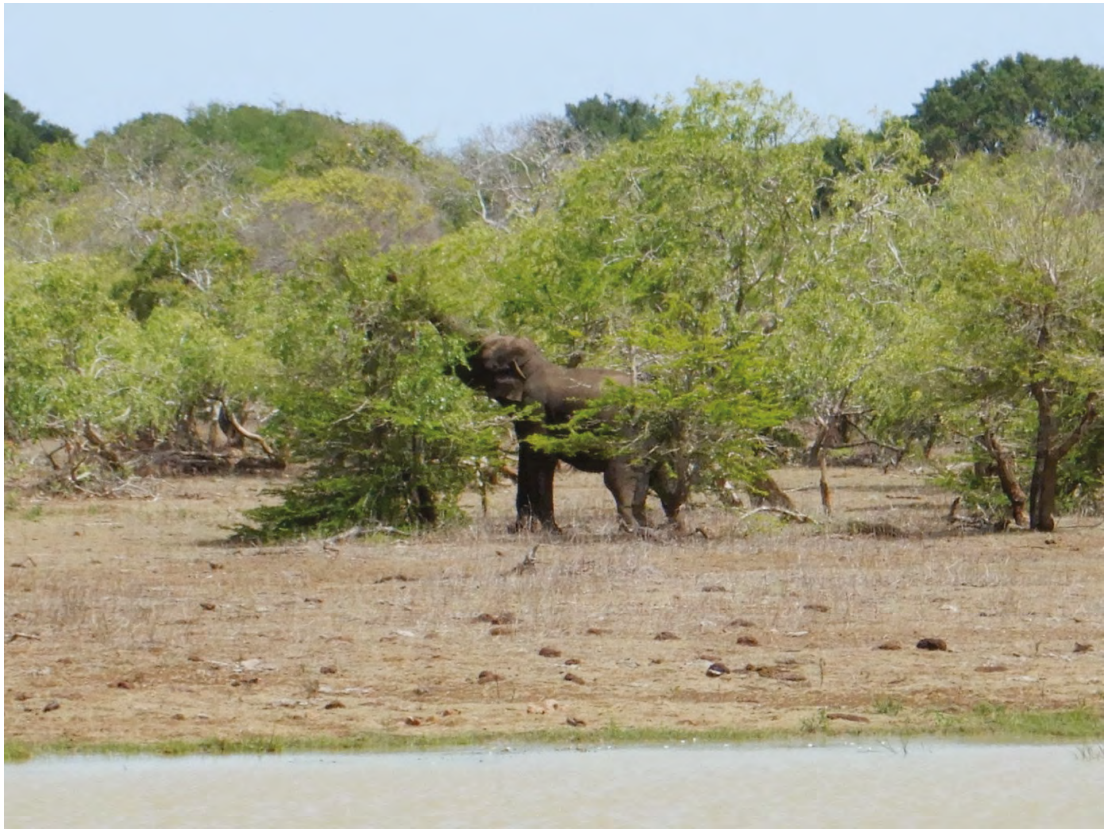

Figure 6. Riverine dry forest

Source: Photo by Channa Suraweera

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Figure 7. Mangrove forest

Source: Photo by Channa Suraweera

cial role in supporting the island's ecosystems and sustaining its unique biodiversity (Volk et al. 2012).

CURRENT STATE OF BIODIVERSITY PROTECTION

General threats. Sri Lanka is a biodiversity hotspot, with a rich variety of ecosystems and species (Bandaratillake 2001). However, the country's biodiversity is under threat from many factors, including deforestation, habitat loss, pollution, and climate change (Gunatilleke et al. 2008; Geekiyanage et al. 2015; Kottawa-Arachchi, Wijeratne 2017).

The government of Sri Lanka has taken many steps to protect the country's biodiversity (Ekanayake, Murindahabi 2017). In 1980, the government established the National Conservation Strategy, which set out a framework for the conservation and sustainable use of Sri Lanka's natural resources. The government has also established a number of protected areas, including national parks, wildlife sanctuaries, and marine reserves (Marasinghe 2014; Suraweera et al. 2024).

Despite the government's efforts, there are several challenges to protecting Sri Lanka's biodiversity according to Surasinghe et al. (2019): deforestation, habitat loss, pollution and climate change. Illegal deforestation is a major threat to Sri Lanka's biodiversity. Forests are a habitat for a wide variety of plants and animals, and deforestation can lead to the loss of these species. Habitat loss is another major threat to Sri Lanka's biodiversity. It can occur due to a number of factors, including illegal deforestation, industry development, population increase, agriculture intensification, and air and water pollution. Air pollution comes from various sources, including factories and transportation. Water pollution is caused mostly by industrial and agricultural production. Finally, climate change is a major threat to Sri Lanka's biodiversity too. Climate change can lead to changes in air temperatures, rainfall, and sea levels. These changes can damage both maritime and terrestrial ecosystems and make it difficult for species to survive (Surasinghe et al. 2019).

Main goals for improving biodiversity conservation in Sri Lanka. The government of Sri Lanka can

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take a number of steps to improve biodiversity conservation (DWC 2007; Gunatilleke et al. 2008). These steps include:

(*i*) Increasing investment in conservation: The government needs to increase its investment in conservation. This investment (subsidies) can be used to support a variety of activities, such as establishing new protected areas, restoring degraded ecosystems, controlling invasive species and practising sustainable forest management. However, the administrative system (including subsidies) should not be overcomplicated, which is counterproductive (Baláš et al. 2024).

(*ii*) Addressing the underlying causes of biodiversity loss: The government needs to do more to address the underlying causes of biodiversity loss, such as poverty and inequality. This can be done by investing in education, healthcare, and economic development.

(*iii*) Strengthening environmental law enforcement: The government needs to strengthen environmental law enforcement. This will help to deter illegal activities that damage the environment, such as deforestation.

(*iv*) Promoting sustainable development: The government needs to promote sustainable development. This means developing the economy in a way that does not damage the environment.

SELECTED BIODIVERSITY PROTECTION CHALLENGES

Loss of habitats due to deforestation, shifting cultivation. Sri Lanka is characterised by a remarkable diversity of forest types, a result of spatial variations that can be broadly classified as tropical rainforests. Forests play a crucial role in mitigating climate change, contributing to the removal of 17–25% of annual greenhouse gas emissions globally (Brack 2019; Gamage et al. 2021). However, the progress of deforestation in Sri Lanka is a contentious issue, with debates surrounding both its scope and quantity. Consequently, gaining an understanding of the drivers of deforestation is essential for the development of policies and measures aimed at addressing and amending the current status of deforestation activities. This understanding can pave the way for more favourable and environmentally friendly outcomes (NBSAP 2016; Gamage et al. 2021).

The historical relationship between the people of Sri Lanka and their forests reflects a recognition of the environmental and cultural significance of these ecosystems, serving as a vital source for basic needs. However, during colonial times, there was a notable shift as forests were cleared for activities such as shifting cultivation, paddy cultivation, plantation crops, and human settlements. Even in areas where forests remained, they were subject to selective and intensive timber exploitation (Wijesinghe 2003; UN-REDD 2017).

The alarming levels of deforestation and forest degradation underscore the apparent negligence of several policies during the implementation stage by responsible institutions and officials. Estimates of Sri Lanka's original forest cover varies slightly, but most reliable sources agree it was around 40–50% of the total land area, while today it has dropped to around 28% (FRA 2020). According to UN-REDD (2017), the forest cover had decreased from 40.0% to 29.7% between 1940 and 2017. Disturbingly, new indicators suggest a rapid reduction in forest cover to 16.5% after 2019, attributed to the actions of the newly elected Executive President and the government (Sellapperumage 2020).

The findings of Gamage et al. (2021) indicate a decrease in forest area from 1990 to 2010, with subsequent stabilisation, suggesting the success of nationwide reforestation and afforestation programs. Notably, various factors such as income, agricultural gross domestic product, crop production, crop production area, poverty, population, literacy rate, agricultural labour force, and agricultural land area have demonstrated significant impacts on changes in forest cover. However, none of these factors indicate any significant impact on burnt tropical forest cover (Gamage et al. 2021).

Generally, by the year 2000, the forest cover had diminished to 22.3% of the land area, marking a stark decline from 84% in 1881. Recognising the importance of curbing deforestation and rehabilitating degraded land, the Forest Department initiated forestation projects in both dry and wet zones. These projects aimed to alleviate pressure on natural forests for timber and contribute to the restoration of degraded landscapes. The historical context underscores the ongoing challenges in balancing human needs with sustainable forest management practices (Bandaratillake 2001; Wijesinghe 2003; Grainger 2013).

The government introduced a general ban on logging in natural forests and wet zones in 1990 (UN-REDD 2015; FRA 2020) and encouraged sustainable management practices in forest reserves and

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plantations outside the wet zones (NHCM 2024). Reforestation efforts have been implemented to restore degraded forest areas and increase forest cover, as well as programs to involve local communities in forest management and conservation efforts have been launched (FRA 2020).

Conflicts in policies, institutions, and responsibilities contribute to the exacerbation of deforestation in Sri Lanka. Furthermore, the desire of politicians from the governing party and their supporters to seize lands has led to the deactivation of forest policies for personal gain. Currently, the government's policy priorities do not align with forest-friendly initiatives; instead, they seem to encourage actions that facilitate the confiscation of forest lands (UN-REDD 2017; Akurugoda, Karunaratne 2022).

Such a substantial decrease underscores the urgent need for effective conservation measures and sustainable forest management practices to mitigate the impacts on biodiversity and ecosystem health. A significant problem for forest restoration and other conservation projects could lie in the growing and complicated legislation related to intended land use changes, as shown for the Czech Republic (Baláš et al. 2024).

Habitat invasion by exotics and harsh colonisation by invasive alien species. The impacts of invasive species on native biodiversity and ecosystem services are significant, ranking second only to habitat fragmentation and degradation in terms of environmental threats. Invasive species can outcompete native flora and fauna, disrupt the ecological balance, and negatively affect various ecosystem services (NCHM 2024).

Opuntia dillenii (Ker-Gawler) Haworth, commonly known as prickly pear, belongs to the family *Cactaceae* and is originally native to the Caribbean Islands, North and South America. Introduced to Sri Lanka as an ornamental plant in the 19th century, *Opuntia dillenii* has since become an invasive species, particularly along the coastal area stretching from Hambantota to Yala National Park, including Bundala National Park (Bambaradeniya 2001, 2002). This succulent perennial shrub has the characteristic of forming low clumps or tall branched bushes, sometimes featuring distinct trunks. In the specific context of Bundala National Park (BNP), *Opuntia dillenii* has invaded several hectares of sand dune areas, adjacent scrub forests, and pasture lands. The invasion is particularly problematic, with dense coverage in certain areas forming large prickly patches that are entirely inaccessible to both humans and animals (Suraweera et al. 2017).

The spread of *Opuntia dillenii* seeds is facilitated by macaque monkeys and some bird species. According to Bambaradeniya et al. (2002), the invasion of this cactus disrupted the regeneration of coastal vegetation, including species like *Pandanus odoratissimus, Scaevola takkada*, and *Spinifex littoreus,* which have already been significantly affected by the tsunami waves in 2004. Manual removal of *Opuntia dillenii* is deemed impractical due to the vast extent it has covered in the affected areas (Suraweera et al. 2024). As of 2017, *Opuntia dillenii* had become the most highly invasive species in BNP, covering an estimated 9% of the total area, which is approximately 567 hectares (Suraweera et al. 2017). This invasive plant's extensive coverage highlights the ecological challenges posed by *Opuntia dillenii* in BNP, affecting the natural vegetation and ecosystem dynamics in the area. Efforts to manage and control the spread of *Opuntia dillenii* in BNP would be essential to mitigate its impact on the native flora and fauna (Suraweera, Dahanayaka 2017; Suraweera et al. 2024). The main native tree species that gives its character to BNP, *Manilkara hexandra* (Roxb.) Dubard (Perera 2007), is also threatened by introduced and invasive *Prosopis juliflora*, originating in Central and South America (Gunarathne, Perera 2014). It was introduced to Sri Lanka for reforestation purposes and presently, an extensive area of BNP has been invaded by it, which results in heavy damage to the native ecosystems of BNP, which serve as a refuge for diverse flora and fauna (Weerawardane, Dissanayake 2005; Suraweera et al. 2024).

The ongoing changes in air temperatures, precipitation patterns, sea levels, and other climatic factors have far-reaching consequences on ecosystems and biodiversity (Habibullah et al. 2022). Climate change exacerbates existing environmental challenges and introduces new stressors to ecosystems, affecting species distribution, migration patterns, and overall ecosystem functioning (Aukema et al. 2017). Both invasive species and climate change contribute significantly to the complex web of ecological challenges faced by the planet. Integrated and adaptive management strategies are essential to address these issues and mitigate their impact on native biodiversity and ecosystem services (IPCC 2014).

Climate change. The Intergovernmental Panel on Climate Change (IPCC) has highlighted that a significant number of plant species face heightened risks of extinction in the future. The spatial distribution of many species is expected to shift due to climate change, impacting their habitats and ecological

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niches. These shifts can significantly influence the dynamics of invasive alien plant species which could replace some native species in their current habitats. The interactions between climate change and invasive species dynamics can have profound consequences for ecosystems, biodiversity, and the services they provide (Moodley et al. 2020; Brichta et al. 2024; Suraweera et al. 2024). Addressing the challenges posed by both climate change and invasive species requires integrated and adaptive management strategies that consider the complex interactions between these environmental stressors. Conservation efforts focused on preserving native biodiversity, restoring ecosystems, and managing invasive species are crucial components of effective climate adaptation and mitigation strategies (Taylor 2013; Kumar et al. 2014; Fandohan et al. 2015).

The considerable increase in the Earth's temperature over the past century is a key indicator of climate change with a potential to accelerate the rate of species extinction. This emphasises the severity of the impact that climate change may have on global biodiversity, including the South Asia region (Woodruff 2010).

The analysis conducted on long-term climate data from 19 meteorological stations in Sri Lanka, as reported by Jayawardena et al. (2017), indicates that mean annual daytime maximum and mean annual night-time minimum air temperatures increased. Additionally, multi-model ensemble projections suggest that both maximum and minimum temperatures in Sri Lanka are expected to increase in the future, as outlined under both moderate emission (RCP 4.5) and high emission (RCP 8.5) scenarios (Meinshausen et al. 2011; Jayawardena et al. 2017).

The adaptive strategies to mitigate the potential consequences of climate change on biodiversity and ecosystem services will be crucial to maintain the high level of biodiversity (IPCC 2014). Understanding these projections is vital for informed decision-making in areas such as agriculture, water resource management, and infrastructure planning, as the impacts of climate change can have wide-ranging consequences on various sectors of society and the environment.

Overexploitation for human consumption. Sri Lanka, positioned as a tropical island and a biodiversity hotspot in a strategically significant geopolitical centre in the Indian Ocean, is facing increasing pressure on its land due to large-scale investment and development projects (MMDE 2016). As one of the world's 35 biodiversity hotspots, Sri Lanka demonstrates a high level of endemicity across various taxonomic groups, showcasing a significant number of species found nowhere else in the world. Additionally, the country is home to a considerable number of species that are classified as threatened, highlighting the need for conservation efforts to preserve its unique and diverse ecosystems (MSDWRD 2018).

However, the country has become a political, economic, and military battleground for global powers like the United States of America, China, and India. The rising population growth on the island has intensified the demand for land, primarily for agriculture and housing, resulting in detrimental impacts on Sri Lanka's forest cover (Akurugoda, Karunaratne 2022). The specific impacts are unsustainable harvesting practices, deforestation, and forest degradation (Kottawa-Arachchi, Wijeratne 2017), the conversion of forest land into farms, further reducing forest cover (Dissanayake et al. 2017) and overgrazing in forest areas, damaging vegetation and hindering regeneration (Aluthwatta et al. 2015).

Coastal ecosystems damage. The escalation in population poses a threat to the coastal zone (Katupotha 2014; Gopalakrishnan, Kumar 2020). Sri Lanka has grappled with the challenge of coastal erosion, leading to severe socioeconomic and environmental repercussions (Prasetya 2007). This phenomenon entails the depletion of natural beaches and recreational spaces, impacting both the local communities' livelihood activities, such as fisheries and tourism (CRMD 2006; Clark 2018). With population expansion outpacing available resources, there is a justification for overutilisation, overexploitation, and over-extraction as measures for survival (Vitharana, Abeysinghe 2020).

The consequence of this strain on resources is evident in the severe issue of coastal erosion. This problem leads to the damaging or destruction of beach biodiversity and coastal structures, loss of human habitats, and disruption of ecological balance (Prasada et al. 2015; Yincan 2017). The tsunami in 2004 further exacerbated the problems of the coasts of Sri Lanka, causing severe and widespread impacts (Nayanananda 2008). Continuing improper disposal of garbage (lack of waste management) into the sea and coastal areas poses a significant and perilous problem, posing threats to the natural environment and marine life (MEPA 2021; Ranatunga et al. 2023). The 'Global Coastal Index' for Sri Lanka placed the island fifth out of 20 countries known for dumping polythene and plastic into the ocean (Fernando et al. 2020). The Sri Lanka Coast Guard (SLCG), in collaboration

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with the Maritime Environment Protection Authority, is actively involved in marine cleaning operations (Jayathilaka et al. 2023).

Coral and sand mining along the coasts contribute to the issue of coastal erosion, posing a threat to the sustainability of coastal habitats, including mangroves (Dissanayake, Rupasinghe 1996). The coastal locations of Lansigama and Uswetakeiyawa have been subjected to the most severe erosions (Lakmali et al. 2016). Approximately one-third of Sri Lanka's population resides in its coastal regions, relying on diverse economic pursuits like tourism, fishing, manufacturing, and contemporary urban services for their livelihoods (World Bank 2017). As a result, the nation is vulnerable to the repercussions of any adverse effects on its tourism sector (Warnakulasooriya 2020).

The Coastal Zone Management Plan (CZMP) issued in 1990 pinpointed coastal erosion as a significant issue, particularly along the South-Western (SW) coast of Sri Lanka (CCD 1997). Subsequent to that, the Coastal Zone Management Plan (CZMP) incorporated traditional coastal protection measures, including a series of groins, revetments, jetties, and offshore breakwaters (CCD 1997; CRMD 2006). Since 2000, Sri Lanka has implemented soft engineering methods as part of the Coastal Zone Management Plan (CZMP) to mitigate erosion. These methods include sand nourishments, the maintenance of setback lines, dune reestablishments, and a combination of these approaches (CRMD 2006; Jayathilaka 2015).

Human-animal conflict, human injuries and fatalities. Human-wildlife conflict in Sri Lanka is a significant issue that arises from the interaction between expanding human populations and the natural habitats of wildlife. Several factors contribute to this conflict. Direct confrontations between humans and wildlife, especially large mammals like elephants and leopards, can result in injuries or fatalities on both sides. Elephants, in particular, may become aggressive when their natural migratory routes are obstructed (Fernando et al. 2005; Fernando 2015).

Habitat encroachment. As human populations grow, there is increased encroachment into natural habitats for agriculture, settlements, and infrastructure development. This encroachment reduces the available space for wildlife, leading to conflicts as animals venture into human-occupied areas (Kottawa-Arachchi, Wijeratne 2017; Perera et al. 2017, 2021; Anuradha et al. 2019; Dissanayake 2021).

Crop raiding. Wildlife, such as elephants and monkeys, may raid agricultural fields in search of food, causing economic losses for farmers. Elephants, in particular, are known for damaging crops and property, leading to conflicts with local communities (Nijman, Nekaris 2010; Ekanayaka et al. 2011; Hatturusinghe, Weerakoon 2012).

Conservation success. Conservation efforts have been successful in protecting certain wildlife species, leading to population increases. While this is positive for biodiversity, it also brings about challenges as the animals compete for space with human communities (Fernando et al. 2005; Thilakarathna et al. 2021). Conservation principles for southwestern rainforests, such as allowing natural disturbances and the simultaneous initiation of a new forest stand, site-specific enrichment planting and planting of late-seral rainforest tree species, were proposed by Ashton et al. (2001).

Lack of mitigation measures. In some cases, the lack of effective mitigation measures exacerbates conflicts. Insufficient or poorly maintained electric fences, for example, may fail to prevent elephants from entering agricultural areas (Pathiraja et al. 2014). Efforts to address human-wildlife conflict in Sri Lanka involve a combination of strategies such as the development of effective mitigation measures, habitat protection, public awareness campaigns, and community-based conservation initiatives. Balancing the needs of both humans and wildlife is crucial for sustainable coexistence (Buultjens et al. 2017). Also, following examples of Central Europe, the government could suggest measures aimed at helping affected farmers secure their fields in a better way, as well as introducing paid reimbursement for damages by wildlife and administrative simplification (Lososová et al. 2019).

Intensive tourism. Coastal zones, in particular, are threatened by ever-growing mass tourism and the urbanisation that comes with it. Threats of tourism to Sri Lankan forests include habitat fragmentation and degradation as tourism infrastructure development (e.g. hotels, roads, trails) fragments forests, disrupting ecosystems and isolating animal populations. Additionally, activities like off-road driving, trekking, and camping can damage vegetation and soil structure (Rathnayake 2015). Tourists observing or interacting with wildlife can disrupt their behaviour and increase stress levels. Additionally, illegal wildlife trade and poaching can be exacerbated by tourism activities (Buultjens et al. 2017; Karunarathna et al. 2017; Sumanapala, Wolf 2020; Dushani et al. 2021).

Tourism activities often generate significant amounts of waste, like plastic packaging and food scraps, leading to pollution and harming forest eco-

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systems. Additionally, wastewater from tourist facilities can contaminate water sources (Vidanaarachchi et al. 2006; Fernando 2019). It is important to note that tourism can also have positive impacts on Sri Lankan forests, such as raising awareness about conservation efforts and generating revenue for local communities. However, it is crucial to manage tourism responsibly and sustainably to minimise its negative effects on these valuable ecosystems (Zoysa 2022).

STRUGGLES OF BIODIVERSITY PROTECTION

Deforestation

Forest cover in Sri Lanka has considerably decreased in recent years. It was 32.2% in 1995, 28.8% in 2010, 29.7% in 2017, and around 28–29% in 2023 (FRA 2020). According to Dr. Ravindra Kariyawasam (News 1st 2019), in 1882, the country's forest density was around 82%. Between 1990 and 2000, Sri Lanka lost an average of 26 800 ha of forest per year, which amounts to an average annual deforestation rate of 1.14%. In total, between 1990 and 2005 alone, Sri Lanka lost 17.7% of its forest cover (Mongabay 2011; FRA 2020). Only 9.0% of Sri Lanka's forests are classified as primary forests, which are the most biodiverse form of forest and, together with soils (Lal 2003; Ostle et al. 2009), one of the biggest carbon sinks on Earth (Mongabay 2011). For this reason, it is necessary to protect autochthonous stands with effective conservation procedures and further expand these trees to suitable habitats where they previously occurred. Only effective conservation and forestry measures can protect autochthonous stands and their biodiversity against the introduced plants under conditions of advancing climate change. Between 1990 and 2010, Sri Lanka lost an average of 1.0% (or 24 500 ha) per year. In total, between 1990 and 2010, Sri Lanka lost 20.9% of its forest cover, i.e. around 490 000 ha (Mongabay 2011).

Most harvested timber species and their impact on Sri Lankan forests

Two economically important timber species are introduced trees: Mahogany (*Swietenia macrophylla*) and teak (*Tectona grandis*). *Swietenia macrophylla* was introduced from Central America, and mahogany became a highly sought-after timber due to its aesthetic qualities and durability. However, its popularity led to over-exploitation, contributing to deforestation and raising concerns about its sustainability (Danquah et al. 2019). *Tectona grandis* is valued for its strength, stability, and resistance to rot. Similar to mahogany, its popularity has driven over-exploitation and raised concerns about its sustainable management (Subasinghe, Jayerathne 2012). Research showed that its production characteristics are dependent on the provenances used (Černý et al. 2023).

Native species targeted for valuable wood include tree species such as mee, kumbuk, and jak trees. Mee (*Azadirachta indica*) also known as 'neem', is valued for its timber used in construction and furniture making. Additionally, its leaves and other parts hold various medicinal properties, increasing its economic significance. Kumbuk (*Terminalia arjuna*) is a native tree species valued for its strong, durable timber used for construction, furniture, and agricultural implements. Its bark also holds medicinal properties, adding to its economic importance. Jak (*Artocarpus heterophyllus*) is a versatile native tree species which provides timber used in construction, furniture, and boat building. It also produces edible fruits and seeds, contributing to its economic value (FRA 2020).

The over-exploitation of these commercially valuable timber species has resulted in several negative impacts on Sri Lankan forests:

- Deforestation: Unsustainable harvesting practices have led to the loss of forest cover, impacting biodiversity and ecosystem services.
- Forest degradation: Selective logging can damage remaining trees and disrupt forest structure, hindering regeneration and ecosystem functions.
- Loss of biodiversity: Over-exploitation can lead to the decline of specific tree populations, impacting dependent animal and plant species.
- Soil erosion: Deforestation and degradation can increase soil erosion, reducing soil fertility and productivity.

Restoration efforts recognise the negative consequences of unsustainable logging practices as Sri Lanka has implemented various restoration initiatives:

- Plantation programs: Establishing plantations of native and commercially valuable species aims to meet timber demands and reduce pressure on natural forests.
- Community forestry: Engaging local communities in forest management and promoting sustainable harvesting practices.
- Conservation reserves: Establishing protected areas to conserve natural forests and their biodiversity.

These efforts are crucial for restoring Sri Lankan forests and ensuring their long-term sus-

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tainability. However, addressing the demand for timber, promoting responsible forestry practices, and enforcing regulations remain ongoing challenges (UN-REDD 2015; FRA 2020).

Invasive alien plants (IAS)

The challenge is to mitigate the negative impacts of IAS on natural ecosystems and to stop the spreading of particular invasive tree species. Nevertheless, unwanted invasion and further non-native tree species spreading can threaten particularly the centres of biodiversity, such as tropical forests (Fine 2002; Rojas-Sandoval et al. 2022). Below, we present three examples of invasive species management projects from three national parks (NP) carried out in cooperation with Czech foresters: Bundala NP, Horagolla NP, and Horton Plains NP.

Bundala NP. According to the last baseline survey done by the Department of Wildlife Conservation (DWC 2005), *Prosopis juliflora* and *Opuntia dillenii* covered approximately 486 ha (8%) and 567 ha (9%) in the total area of the park, respectively (Suraweera et al. 2017). Silvicultural measures proved to be effective in regulating these invasive species (Suraweera et al. 2024). In long-term ecosystem protection, not only the number of species and individuals, but also the total biomass of the organisms is an important parameter (Zumr et al. 2024).

Horagolla NP. Horagolla is a small forested national park in the vicinity of a large, urbanised area. Beside the direct human pressure, it also faces the challenge of IAS. Sri Lanka's Horagolla National Park faces a number of challenges that threaten its biodiversity and ecological integrity. The main problems include:

– Invasive species. Invasive plants such as *Lantana camara* and *Chromolaena odorata* became rampant in the park, crowding out native species. This has a negative impact on the biodiversity of the park and its food chain.
– Poaching. Poaching is a serious problem in the park, threatening the population of elephants, deer and other animals. Poachers hunt animals for meat, hides and horns, threatening their survival.
– Pollution. Pollution from surrounding areas, including agriculture and human settlements, pollutes the park's water resources and affects the quality of animal and plant life.
– Inadequate management. Horagolla National Park suffers from a lack of funding and personnel, which limits the park's ability to effectively protect biodiversity and combat the above-mentioned problems.

Examples of proposed adequate silvicultural measures:

There are sites with individual distribution of native species such as *Dipterocarpus zeylanicus* (common name: hora) and also groups of this invasive species such as *Artocarpus elasticus* (common name: budal). First it is needed to properly differentiate between *Dipterocarpus* and *Artocarpus*. Second, it is desirable to properly mark individual trees for particular treatment.

On the plots with individual distribution of *Artocarpus*, cut *Artocarpus* individual mature trees, ring *Artocarpus* individual mature trees with a different intensity of ringing (left 20% × 10% × 0% of cambium/phloem circumference), control with no silvicultural measure.

On the plots with groups of *Artocarpus*, ring *Artocarpus* individual mature trees with a different intensity of ringing (left 20% × 10% × 5% of cambium/phloem), control with no silvicultural measure. Then, it is necessary to decide about a pure group of *Artocarpus*, whether to prioritise the design of the research, or to keep the main layer at the cost of not having a complete experiment.

Horton Plain NP. Horton Plain National Park (HPNP) are grasslands with edged pigmy forest patches in the upper montane region of Sri Lanka. They are threatened due to the harsh colonisation of gorse [*Ulex europaeus* (Gunatilleke, Gunatilleke 1986; DWC 2007)]. The area is a habitat of a number of ungulate species, including the threatened *Rusa unicolor* and the mountain mouse deer (*Moschiola* sp. nov.), endemic to the region. Gorse threatens the entire ecosystems by increasing fire hazards as well as invading hospitable lands for the endemic plant species *Rhododendron zeylanicum.* Thus, HPNP urges to adopt a strategy to control and manage gorse. Initially, *U. europaeus* were manually uprooted in three selected plots and burnt on-site in a closed steel chamber. Then, silvicultural measures were implemented. The preliminary results demonstrated that manual removal of *U. europaeus* facilitates the recolonisation of endemic plant species.

CONCLUSION

In this study, we reviewed the crucial environmental problems for nature conservation and biodiversity improvement in Sri Lanka. As a developing country, it faces many specific engineering challenges that need to be addressed sensitively considering the island's

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high biodiversity. The government has taken a number of steps to protect the country's biodiversity, but more effort is required. By increasing investment in conservation, addressing the underlying causes of biodiversity loss, strengthening environmental law enforcement, and promoting sustainable development, the government and the people of Sri Lanka can protect the country's unique natural heritage for future generations.

In this regard, protection and suitable management in forestry is of utmost importance because forests play a major role in terrestrial biodiversity conservation and enhancement. Based on experiences from the Czech Republic, silvicultural measures, including species composition change, thinning, tending and uprooting to support biodiversity are useful tools for nature protection under the current conditions of intensive human impact on forest ecosystems and ongoing climate change. It starts with strict protection of the core of primary forests and continues with applying a suitable silvicultural system in surrounding secondary forests (plantations). Since international help and cooperation showed many times its effectiveness and sense, we have presented the results of cooperation between Sri Lanka's authorities and Czech foresters. This is evidenced, for example, in the publication of Suraweera et al. (2024), where the state of forest vegetation and its biodiversity was evaluated on model plots in the Bundala National Park, and ways to stabilise these stands were proposed.

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REFERENCES

Akurugoda I., Karunaratne M. (2022): Addressing the challenge of deforestation in Sri Lanka. In: XV World Forestry Congress – Building a Green, Healthy and Resilient Future with Forests, Seoul, May 2–6, 2022.

Aluthwatta R.G.S.T., Ranawana K.B., Dangolla A., Chandrajith R. (2015): Socio-ecological consequences of illegal cattle rearing and its eradication in Bundala National Park, Sri Lanka. In: Pallewatte N. (ed.): Wetlands Sri Lanka: Volume 2. Colombo, University of Colombo: 37–42.

Anuradha J.M.P.N., Fujimura M., Inaoka T., Sakai N. (2019): The role of agricultural land use pattern dynamics on elephant habitat depletion and human-elephant conflict in Sri Lanka. Sustainability, 11: 2818.

Ashton P.S. (1991): Toward a regional classification of the humid tropics of Asia. Tropics, 1: 1–12.

Ashton M.S., Gunatilleke C.V.S., Singhakumara B.M.P., Gunatilleke I.A.U.N. (2001): Restoration pathways for rain forest in southwest Sri Lanka: A review of concepts and models. Forest Ecology and Management, 154: 409–430.

Aukema J.E., Pricope N.G., Husak G.J., Lopez-Carr D. (2017): Biodiversity areas under threat: Overlap of climate change and population pressures on the world's biodiversity priorities. PLoS ONE, 12: e0170615.

Baláš M., Gallo J., Czacharowski M., Pástor M., Jankovič J., Štefančík I., Kuneš I., Hasenauer H. (2024): Administrative system of afforestation in the Czech Republic: A long journey to a new forest. Journal of Forest Science, 70: 41–63.

Bambaradeniya C.N.B. (2001): Guide to Bundala: A Guide to the Biodiversity of Bundala National Park, a Ramsar Wetland in Sri Lanka. Colombo, IUCN Sri Lanka: 54. Available at: https://policycommons.net/artifacts/1371762/guide-to-bundala/1985936/ (accessed Feb 15, 2023).

Bambaradeniya C.N.B. (2002): The status and implications of alien invasive species in Sri Lanka. Zoos' Print Journal, 17: 930–935.

Bambaradeniya C.N.B., Ekanayake S.P., Fernando R.H.S.S., Perera W.P.N., Somaweera R. (2002): A Biodiversity Status Profile of Bundala National Park: A Ramsar National Wetland of Sri Lanka. Colombo, IUCN Sri Lanka: 37.

Bandaratillake H.M. (2001): Impacts and effectiveness of logging bans in natural forests: Sri Lanka. In: Durst P.B., Waggener T.R., Enters T., Cheng T.L. (eds): Forests Out of Bounds: Impacts and Effectiveness of Logging Bans in Natural Forests in Asia-Pacific. Bangkok, FAO: 137.

Brack D. (2019): Forests and Climate Change: Background Study Prepared for the Fourteenth Session of the United Nations Forum on Forests, March 2019. United Nations: 56. Available at: https://static.un.org/esa/forests/wp-content/uploads/2019/03/UNFF14-BkgdStudy-SDG13-March2019.pdf

Brichta J., Vacek S., Vacek Z., Cukor J., Mikeska M., Bílek L., Šimůnek V., Gallo J., Brabec P. (2023): Importance and potential of Scots pine (L.) in 21st century. Central European Forestry Journal, 69: 3–20.

Brichta J., Šimůnek V., Bílek L., Vacek Z., Gallo J., Drozdowski S., Bravo-Fernández J.A., Mason B., Roig Gomez S., Hájek V., Vacek S., Štícha V., Brabec P., Fuchs Z. (2024): Effect of climate change on Scots pine (*Pinus sylvestris* L.) growth across Europe: Decrease of tree-ring fluctuation and amplification of climate stress. Forests, 15: 91.

Buultjens J., Ratnayake I., Gnanapala A.C. (2017): Managing wildlife tourism in Sri Lanka: Opportunities and challenges. In: Fatima J.K. (ed.): Wilderness of Wildlife Tourism. New York, Apple Academic Press: 161–186.

https://doi.org/10.17221/19/2024-JFS

CCD (1997): Coastal Zone Management Plan (CZMP). Revised. Colombo, Coast Conservation Department: 137.

Černý J. (2023): Výchovný zásah v mladých smrkových porostech jako nástroj mitigace globální klimatické změny? Zprávy lesnického výzkumu, 68: 149–158. (in Czech)

Černý J., Haninec P., Novosadová K., Patočka Z., Haninec P., Maděra P. (2023): Provenance affects the growth and mortality of teak (*Tectona grandis* L.f.) plantations cultivated in central Nicaragua. Journal of Forest Science, 69: 1–10.

Clark J.R. (2018): Coastal Zone Management Handbook. Boca Raton, CRC Press: 720.

CRMD (2006): Coastal Zone Management Plan (CZMP). Part I Sec (I) Gazette Extraordinary of the Democratic Socialist Republic of Sri Lanka 2006. Colombo, Coast Conservation and Coastal Resources Management Department: 141.

Danquah J.A., Appiah M., Osman A., Pappinen A. (2019): Geographic distribution of global economic important mahogany complex: A review. Annual Research & Review in Biology, 34: 1–22.

DCS (2024): Sri Lanka at a Glance. Department of Census and Statistics – Sri Lanka. Available at: http://www.statistics.gov.lk/DashBoard/srilanka_glance/ (accessed Mar 7, 2024).

Dissanayake L. (2021): Stream corridor encroachment and its consequences: The case of Pinga Oya tributary in the upper Mahaweli River in Sri Lanka. Modeling Earth Systems and Environment, 7: 1907–1916.

Dissanayake C.B., Rupasinghe M.S. (1996): Environmental impact of mining, erosion and sedimentation in Sri Lanka. International Journal of Environmental Studies, 51: 35–50.

Dissanayake D.M.M.R., Seneviratne H.T.J., Sumanasekara V.D.W. (2017): Influence of the land use on dynamic soil quality; a review. In: NBRO Symposium 2015 – Innovations for Resilient Environment. Colombo, National Building Research Organisation, Sri Lanka. Available at: https://www.nbro.gov.lk/images/content_image/pdf/symposia/28.pdf

Dushani S.N., Aanesen M., Vondolia G.K. (2021): Balancing conservation goals and ecotourism development in coastal wetland management in Sri Lanka: A choice experiment. Ocean & Coastal Management, 210: 105659.

DWC (2005): Management Plan: Bundala National Park. Sri Lanka Protected Areas Management and Wildlife Conservation Project. Colombo, Department of Wildlife Conservation, Ministry of Environment and Natural Resources: 60.

DWC (2007): Biodiversity Baseline Survey: Horton Plains National Park. Sri Lanka Protected Areas Management and Wildlife Conservation Project. Colombo, Department of Wildlife Conservation, Ministry of Environment and Natural Resources: 40.

Ekanayaka S.K.K., Campos-Arceiz A., Rupasinghe M., Pastorini J., Fernando P. (2011): Patterns of crop raiding by Asian elephants in a human-dominated landscape in southeastern Sri Lanka. Gajah, 34: 20–25.

Ekanayake E.M.B.P., Murindahabi T. (2017): Forest policy for sustainability of Sri Lanka's forest. International Journal of Sciences, 6: 28–33.

Ellis E.C., Kaplan J.O., Fuller D.Q., Verburg P.H. (2013): Used planet: A global history. Proceedings of the National Academy of Sciences, 110: 7978–7985.

Fandohan A.B., Oduor A.M.O., Sodé A.I., Wu L., Cuni-Sanchez A., Assédé E., Gouwakinnou G.N. (2015): Modeling vulnerability of protected areas to invasion by *Chromolaena odorata* under current and future climates. Ecosystem Health and Sustainability, 1: 1–12.

Fernando P. (2015): Managing elephants in Sri Lanka: Where we are and where we need to be. Ceylon Journal of Science (Biological Sciences), 44: 1–11.

Fernando P., Wikramanayake E., Weerakoon D., Jayasinghe L.K.A., Gunawardene M., Janaka H.K. (2005): Perceptions and patterns of human–elephant conflict in old and new settlements in Sri Lanka: Insights for mitigation and management. Biodiversity & Conservation, 14: 2465–2481.

Fernando R.L.S. (2019): Solid waste management of local governments in the Western Province of Sri Lanka: An implementation analysis. Waste Management, 84: 194–203.

Fernando R.L.S., Herath H.M.I.U.P., Rathnayake R.B.P.M. (2020): Coastal conservation in Sri Lanka: Problems and prospects. In: Singh A., Fernando R.L.S., Haran N.P. (eds): Development in Coastal Zones and Disaster Management. Disaster Research and Management Series on the Global South. Singapore, Palgrave Macmillan: 339.

Fine P.V. (2002): The invasibility of tropical forests by exotic plants. Journal of Tropical Ecology, 18: 687–705.

FMI (2022): Forest cover of the Czech Republic is 34.1%. Brandýs nad Labem, Forest Management Institute. Available at: https://www.uhul.cz/lesnatost-cr-je-341/?lang=en (accessed Feb 28, 2024).

FRA (2020): Global Forest Resources Assessment 2020. Rome, FAO. Available at: https://www.fao.org/forest-resources-assessment/past-assessments/fra-2020/en/ (accessed Feb 28, 2024).

Gallo J., Kuneš I., Baláš M. (2018): Contribution of reforestation using saplings to conservation of forest ecosystems. Wildlanka, 6: 100–107.

Gamage M., Guruge S., Udugama M., Iffam M., Anjalee I. (2021): What drives deforestation? A case of deforestation drivers in Sri Lanka. Applied Bio-Systems Technology, 1: 33–41.

Geekiyanage N., Vithanage M., Wijesekara H., Pushpakumara G. (2015): State of the Environment, Environmental Challenges and Governance in Sri Lanka. Abingdon, Routledge: 17.

https://doi.org/10.17221/19/2024-JFS

Gopalakrishnan T., Kumar L. (2020): Potential impacts of sea-level rise upon the Jaffna Peninsula, Sri Lanka: How climate change can adversely affect the coastal zone. Journal of Coastal Research, 36: 951–960.

Grainger A. (2013): Controlling Tropical Deforestation. London, Routledge: 314.

Gunarathne R.M.U.K.; Perera G.A.D. (2014): Die-out of *Manilkara hexandra* from Bundala National Park, Sri Lanka: Causes and some possible underlying mechanisms. Journal of Tropical Forestry and Environment, 4: 14–27.

Gunatilleke C.V.S., Gunatilleke I.A.U.N. (1986): Horton Plains: Some aspects of its vegetation and ecology. Sri Lanka Wildlife, 3: 9–11.

Gunatilleke N., Pethiyagoda R., Gunatilleke S. (2008): Biodiversity of Sri Lanka. Journal of the National Science Foundation of Sri Lanka, 36: 25–62.

Habibullah M.S., Din B.H., Tan S.H., Zahid H. (2022): Impact of climate change on biodiversity loss: Global evidence. Environmental Science and Pollution Research, 29: 1073–1086.

Haturusinghe H.S., Weerakoon D.K. (2012): Crop raiding behaviour of elephants in the northwestern region of Sri Lanka. Gajah, 36: 26–31.

IPCC (2014): Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Geneva, Intergovernmental Panel on Climate Change: 151.

Jayathilaka R.M.R.M. (2015): Large scale sediment budgets in data poor environments via numerical modelling: A case study of Sri Lanka's south-west coast. [Ph.D. Thesis] Delft, UNESCO-IHE Institute.

Jayathilaka R.M.R.M., Ratnayake N.P., Wijayaratna T.M.N., Silva K.B.A., Arulananthan K. (2023): A review of coastal erosion mitigation measures on Sri Lanka's western coast, an island nation in the Indian Ocean: Current gaps and future directions, Ocean & Coastal Management, 242: 106653.

Jayawardena S., Dharshika T., Herath R. (2017): Observed climate trends, future climate change projections and possible impacts for Sri Lanka. Neela Haritha – The Climate Change Magazine of Sri Lanka, 2: 144–151.

Karunarathna S., Ranwala S., Surasinghe T., Madawala M. (2017): Impact of vehicular traffic on vertebrate fauna in Horton Plains and Yala national parks of Sri Lanka: Some implications for conservation and management. Journal of Threatened Taxa, 9: 9928–9939.

Katupotha K.N.J. (2014): Anthropogenic impacts on urban coastal lagoons in the Western and North-western coastal zones of Sri Lanka. ESOFT Metro Campus International Journal, 2: 39–56.

Kawshalya H.K. (2020): Sri Lanka's strategic location and Indian Ocean hegemony: Special reference to the new maritime Silk Road. Journal of International Studies, 7: 157–176.

Kottawa-Arachchi J.D., Wijeratne M.A. (2017): Climate change impacts on biodiversity and ecosystems in Sri Lanka: A review. Nature Conservation Research, 2: 2–22.

Kumar D., Kodra E., Ganguly A.R. (2014): Regional and seasonal intercomparison of CMIP3 and CMIP5 climate model ensembles for temperature and precipitation. Climate Dynamics, 43: 2491–2518.

Lakmali E., Deshapriya W., Jayawardene K., Raviranga R., Ratnayake N., Premasiri H., Senanayake I. (2016): Long term coastal erosion and shoreline positions of Sri Lanka. In: Hemalal P.V.A. (ed.): Proceedings of the ERE 2016 Annual Conference on Earth Resources Management. Colombo, July 8, 2026: 69–73.

Lal R. (2003): Global potential of soil carbon sequestration to mitigate the greenhouse effect. Critical Reviews in Plant Sciences, 22: 151–184.

Lososová J., Kouřilová J., Dohnalová A. (2019): Increasing conflict between predator protection and pastoral farming in the Czech Republic. Trames, 23: 381–409.

Marasinghe M.S.L.R.P. (2014): Strategic conservation: A review of protected area management. Journal of Environmental Professionals Sri Lanka, 2: 66–76.

Marušák R. (2019): FLD přispívá k lesnickému vzdělávání v Laosu. Živá univerzita – Zpravodaj České zemědělské univerzity v Praze, 1/2019: 31. (in Czech)

Meinshausen M., Smith S.J., Calvin K., Daniel J.S., Kainuma M.L., Lamarque J.F., Matsumoto K., Montzka S.A., Raper S.C.B., Riahi K., Thomson A., Velders G.J.M., van Vuuren D.P.P. (2011): The RCP greenhouse gas concentrations and their extensions from 1765 to 2300. Climatic Change, 109: 213–241.

MEPA (2021): Marine Environment Protection Authority: Home. Available at: http://www.eservices.mepa.gov.lk/advancenotification/home.action (accessed Feb 29, 2024).

MMDE (2016): National Biodiversity Strategic Action Plan (NBSAP) 2016–2022. Colombo, Biodiversity Secretariat, Ministry of Mahaweli Development and Environment: 284.

MoA (2023): Zpráva o stavu lesa a lesního hospodářství České republiky v roce 2022. Prague, Ministry of Agriculture of the Czech Republic: 138. (in Czech)

Mongabay (2011): Sri Lanka Forest Information and Data. Available at: https://worldrainforests.com/deforestation/2000/Sri_Lanka.htm (accessed Feb 15, 2024).

Moodley D., Foxcroft L.C., Novoa A., Pyšková K., Pergl J., Pyšek P. (2020): Invasive alien species add to the uncertain future of protected areas. NeoBiota, 57: 1–5.

MSDWRD (2018): Sri Lanka Voluntary National Review on the Status of Implementing Sustainable Development

https://doi.org/10.17221/19/2024-JFS

Goals. Rajagiriya, Ministry of Sustainable Development, Wildlife and Regional Development – Government of the Democratic Socialist Republic of Sri Lanka: 115. Available at: https://sustainabledevelopment.un.org/content/documents/19677FINAL_SriLankaVNR_Report_30Jun2018.pdf (accessed Jan 19, 2024).

Nayanananda O.K. (2008): The Study of Economic Significance of Coastal Region of Sri Lanka in the Context of Environmental Changes of Pre and Post Tsunami. Colombo, Coast Conservation Department and the Ministry of Environment and Natural Resources: 120.

NCHM (2024): Sri Lanka Biodiversity: Forest and Related Ecosystems. National Clearing House Mechanism, Secretariat of the Convention on Biological Diversity. Available at: https://lk.chm-cbd.net/ecosystems/forest-and-related-ecosystems (accessed Mar 6, 2024).

Newbold T., Hudson L.N., Phillips H.R.P., Hill S.L.L., Contu S., Lysenko I., Blandon A., Butchart S.H.M., Booth H.L., Day J., De Palma A., Harrison M.L.K., Kirkpatrick L., Pynegar E., Robinson A., Simpson J., Mace G.M., Scharlemann J.P.W., Purvis A. (2014): A global model of the response of tropical and sub-tropical forest biodiversity to anthropogenic pressures. Proceedings of the Royal Society B: Biological Sciences, 281: 20141371.

News 1st (2019): Red Alert by Mother Nature: 'SL forest density reduced from 85% to 16.5%'. Colombo, News 1st. Available at: https://www.newsfirst.lk/2019/04/14/red-alert-by-mother-nature-sl-forest-density-reduced-from-85-to-16-5

Nijman V., Nekaris K.A.I. (2010): Testing a model for predicting primate crop-raiding using crop-and farm-specific risk values. Applied Animal Behaviour Science, 127: 125–129.

Ostle N.J., Levy P.E., Evans C.D., Smith P. (2009): UK land use and soil carbon sequestration. Land Use Policy, 26: S274–S283.

Pathiraja K., Balaraman M., de Silva S. (2014): Study of Climate Change Adaptation Measures Lacking Funding in Sri Lanka. Colombo, International Centre for Ethnic Studies: 77.

Peiris G.H., Arasaratnam S. (2024): Sri Lanka. Encyclopedia Britannica. Available at: https://www.britannica.com/place/Sri-Lanka (accessed Mar 12, 2024).

Perera N. (2007): An overview of Bundala National Park: An exceptional wetland facing multitude of problems. Siyoth, 2: 4–8.

Perera P., Wijesinghe S., Dayawansa N., Marasinghe S., Wickramarachchi C. (2017): Response of tropical birds to habitat modifications in fragmented forest patches: A case from a tropical lowland rainforest in south-west Sri Lanka. Community Ecology, 18: 175–183.

Perera P.L.M.M., Jayasuriya K.M.G.G., Gunaratne A.M.T.A., Karunaratne W.A.I.P., Damunupola J.W., Prassanna M.G.M. (2019): Conservation attempt of critically endangered mangrove *Lumnitzera littorea* (Jack) Voigt in Madu Ganga Ramsar site of Sri Lanka; stand composition and seed germination. Ceylon Journal of Science, 48: 225–234.

Perera W.P.T.A., Prematilaka P.H.K.L.A., Haseena M.H.A., Athapaththu A.H.L.C.M., Wijesinghe M.R. (2021): Changes in habitat coverage from 2005 to 2019 in the Udawalawe National Park, Sri Lanka. Ceylon Journal of Science, 50: 467–474.

Prasada S., Fernando R.L., Arachchige B., Konasinghe K. (2015): Complexities in individual capacity in interagency collaboration: The case of law enforcement in marine environment protection in Sri Lanka. In: 12th International Conference on Business Management, Colombo, Dec 7–8, 2015: 28. Available at: https://papers.ssrn.com/sol3/papers.cfm?abstract_id=2706349

Prasetya G. (2007): Thematic paper: The role of coastal forests and trees in protecting against coastal erosion. In: Braatz S., Fortuna S., Broadhead J., Leslie R. (eds): Coastal Protection in the Aftermath of the Indian Ocean Tsunami: What role for forests and trees? Proceedings of the Regional Technical Workshop, Khao Lak, Aug 28–31, 2006: 103–130.

Ranatunga R.R.M.K.P., Wijetunge D., Ranaweera W.V.P.H., Hung C.C., Liu S.Y.V., Schuyler Q., Lawson T.J., Hardesty B.D. (2023): Ranking Sri Lanka among the world's top mismanaged waste polluters: Does model data change the story? Sustainability, 15: 2687.

Rathnayake R.M.W. (2015): How does 'crowding' affect visitor satisfaction at the Horton Plains National Park in Sri Lanka? Tourism Management Perspectives, 16: 129–138.

Rojas-Sandoval J., Ackerman J.D., Marcano-Vega H., Willig M.R. (2022): Alien species affect the abundance and richness of native species in tropical forests: The role of adaptive strategies. Ecosphere, 13: e4291.

Samaranayake N. (2023): Deforestation and biodiversity loss in SL's rainforests. Colombo, The Morning. Available at: https://www.themorning.lk/articles/xFlDNqBin7Ci-JfZghiWj (accessed Feb 28, 2024).

Sellapperumage S. (2020): Fighting Deforestation in Sri Lanka: Can Sri Lanka Live up to President Gotabaya Rajapaksa's Environmental Commitments? Arlington, The Diplomat. Available at: https://thediplomat.com/2020/10/fighting-deforestation-in-sri-lanka/ (accessed Jan 20, 2024).

Subasinghe S.M.C.U.P., Jayerathne K.M.T.S. (2012): Evaluation of growth and management of teak (*Tectona grandis* L.F.) established in farmer woodlots in dry and intermediate zones of Sri Lanka. The Sri Lanka Forester, 34: 37–50.

Sumanapala D., Wolf I.D. (2020): Think globally, act locally: Current understanding and future directions for nature-based tourism research in Sri Lanka. Journal of Hospitality and Tourism Management, 45: 295–308.

Surasinghe T., Kariyawasam R., Sudasinghe H., Karunarathna S. (2019): Challenges in biodiversity conservation in a highly modified tropical river basin in Sri Lanka. Water, 12: 26.

https://doi.org/10.17221/19/2024-JFS

Suraweera P.A.C.N.B., Dahanayaka D.D.G.L. (2017): Assessment, Monitoring and Management of Invasive Alien Species at Bundala National Park (A Ramsar Wetland) in Sri Lanka. Colombo, Wetlands Sri Lanka, Central Environmental Authority, Sri Lanka: 80–85.

Suraweera C., Kumari B., Dahanayaka D.D.G.L. (2017): Assessment of invasive alien species at Bundala Ramsar wetland, Sri Lanka, for their control and management. In: Proceedings of the National Symposium on Invasive Alien Species. Colombo, Biodiversity Secretariat, Ministry of Mahaweli Development and Environment: 14.

Suraweera C., Gallo J., Vacek Z., Cukor J., Vacek S., Baláš M. (2024): Silvicultural Practices for Diversity Conservation and Invasive Species Suppression in Forest Ecosystems of the Bundala National Park, Sri Lanka. Plants, 13: 121.

Taylor M. (2013): Climate change, relational vulnerability and human security: Rethinking sustainable adaptation in agrarian environments. Climate and Development, 5: 318–327.

Thilakarathna A., Godage W.M.C.P. (2021): From conflict to coexistence: A critical look at issues related to human-wildlife interactions in Sri Lanka. Asian Journal of Law and Governance, 3: 47–59.

UN-REDD (2015): Report on Drivers of Deforestation and Forest Degradation in Sri Lanka: Assessment of Key Policies and Measures. Battaramulla, Sri Lanka UN-REDD Programme: 120.

UN-REDD (2017): Ninth Consolidated Annual Progress Report of the UN-REDD Programme Fund. Battaramulla, Sri Lanka UN-REDD Programme: 96.

Vacek Z., Prokůpková A., Vacek S., Cukor J., Bílek L., Gallo J., Bulušek D. (2020): Silviculture as a tool to support stability and diversity of forests under climate change: Study from Krkonoše Mountains. Central European Forestry Journal, 66: 116–129.

Vacek Z., Zeidler A., Cukor J., Vacek S., Borůvka V., Šimůnek V., Gallo J. (2023): Sustainable biomass production of introduced spruce species plantations under climate change. Trees, 37: 1781–1799.

Václav E. (2007): Přínos českých lesníků v poznání a rozvoji světového tropického a subtropického lesnictví. Prague, Czech University of Life Sciences Prague: 98. (in Czech)

Vidanaarachchi C.K., Yuen S.T., Pilapitiya S. (2006): Municipal solid waste management in the Southern Province of Sri Lanka: Problems, issues and challenges. Waste Management, 26: 920–930.

Vitharana S., Abeysinghe C. (2020): Understanding the polity and political dynamics in contemporary Sri Lanka: Historical overview. KALAM – International Research Journal, 13: 139–156.

Volk R., Bandaratilake H.M., Vidanage S. (2012): Sri Lanka FAA 118/119 Tropical Forest & Biodiversity Analysis. Burlington, ARD: 63.

Warnakulasooriya W.M.S. (2020): Resilience and persistence of sustainable travel and tourism industry during the impact of COVID-19 pandemic. In: International Conference on Business Innovation (ICOBI), Colombo, Dec 11, 2020: 130–138.

Weerawardane N.D., Dissanayake J. (2005): Status of forest invasive species in Sri Lanka. In: Proceedings of the Asia-Pacific Forest Invasive Species Conference 'The Unwelcome Guests', Kunming, Aug 17–23, 2003: 114–120.

Wijesinghe L.C.A. (2003): Forestry in Sri Lanka a voyage through time. Tropical Agricultural Research and Extension, 6: 14–21.

Woodruff D.S. (2010): Biogeography and conservation in Southeast Asia: How 2.7 million years of repeated environmental fluctuations affect today's patterns and the future of the remaining refugial-phase biodiversity. Biodiversity and Conservation, 19: 919–941.

World Bank (2017): Sri Lanka: Managing Coastal Natural Wealth. Washington, D.C., The World Bank Group: 68. Available at: https://documents.worldbank.org/en/publication/documents-reports/documentdetail/935641540997593260/sri-lanka-managing-coastal-natural-wealth

WWF (2016): Living Planet Report 2016: Risk and Resilience in a New Era. Gland, World Wildlife Fund International: 144.

Yincan Y. (2017): Coastal erosion. In: Yincan Y. (ed.): Marine Geo-Hazards in China. Amsterdam, Elsevier: 269–296.

Zoysa M.D. (2022): Forest-based ecotourism in Sri Lanka: A review on state of governance, livelihoods, and forest conservation outcomes. Journal of Sustainable Forestry, 41: 413–439.

Zumr V., Nakládal O., Gallo J., Remeš J. (2024): Deadwood position matters: Diversity and biomass of saproxylic beetles in a temperate beech forest. Forest Ecosystems, 11: 100174.

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