Biodiversity in Central Highland Wetlands, a World Heritage Site in Sri Lanka

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Abstract

Wetland ecosystems are among the most productive ecosystems that support many kinds of life. They are valuable in terms of hydrology, plant and animal survival, and biodiversity. National Wetland Directory of Sri Lanka describes 62 important wetlands, with their status. The central highland complex of Sri Lanka is a unique ecosystem and the most important catchment area of major rivers. Therefore, it is identified as a super biodiversity hotspot and a world heritage site. The major wetland types in the central highland ecosystem are freshwater marshes, streams, waterfalls, human-made lakes, reservoirs, and springs. In Sri Lanka, most of the threatened species, which are associated with aquatic habitats, are found in the central highlands with very restricted distribution. Habitat deterioration and degradation, encroachments, clearing of vegetation, water pollution, and spread of invasive alien species are the most significant threats to the highland wetlands. Therefore, demarcation of wetlands, protection of buffer zones, increased public awareness, and implementation of good agricultural practices would certainly bring beneficial changes to the ecosystems.

Keywords

Biodiversity conservation • Ecosystems • Highland wetlands • Threatened species

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4.1 Introduction

Wetlands, both natural and human-made, currently make up about 15% of the land area of Sri Lanka. The natural wetlands comprise rivers, streams, riverine floodplains, small isolated freshwater bodies, freshwater springs, seasonal ponds, and freshwater marshes. The most important wetlands are associated with Sri Lanka's network of 103 major rivers that originate from the central mountains and radiate across the lowland plains until joining the sea. The irrigation tanks and reservoirs are considered as man-made wetlands in Sri Lanka (Dela 2009). Sri Lanka currently has six sites designated as Wetlands of International Importance Ramsar Sites (*viz.*, Vankalai Sanctuary, Anaiwilundawa Sanctuary, Wilpattu National Park, Bundala National Park, Kumana National Park, and Madu Ganga), with a surface area of 198,172 ha (Young 2013). The Wetland Directory of Sri Lanka lists 62 sites with 24 as moderately threatened and 18 as highly threatened sites (IUCN and CEA 2006).

4.1.1 Classification of Wetlands in Sri Lanka

According to the Ramsar definition, the following categories of wetlands can be identified in Sri Lanka: (1) inland natural freshwater wetlands, (2) marine and saltwater wetlands, and (3) man-made wetlands. Man-made and natural wetlands occur throughout the country and together comprise about 15% of the total land area.

4.1.1.1 Inland Natural Freshwater Wetlands

Rivers, streams, tributaries, riverine floodplains, isolated freshwater bodies, freshwater springs, seasonal ponds, and freshwater marshes comprise inland natural freshwater wetlands (Anon 1999). Swamps and marshes are important for maintaining groundwater table and also for mitigating floods. In addition, they play a vital role in purification of water by removing toxic compounds and also serve as a carbon sink.

4.1.1.2 Marine and Saltwater Wetlands

Sri Lanka as an island is rich in coastal wetlands, which include estuaries, mangroves, salt marshes, lagoons, mudflats and sea grass beds along the coastal belt. Lagoons are salt or brackish water coastal wetlands connected to sea with one or more relatively narrow outlets which may be permanent or seasonal (Anon 2004). About 42 lagoons are found around the coastal belt of Sri Lanka.

Coral reefs and sea grass beds are another group of important marine wetlands found in Sri Lanka. Corals, being a unique set of marine invertebrates, are responsible for the formation of calcareous structures with spectacular beauty. Sea grass beds are composed of rooted, seed-bearing marine plants found in shallow, sheltered marine waters, lagoons, and estuaries. Mangroves, marshes, and sea grass beds are extremely important breeding sites for a wide variety of fish.

4.1.1.3 Man-Made Wetlands

These wetlands were created by humans. Although Sri Lanka does not have large natural lakes, an array of ancient irrigation tanks and reservoirs can be seen countrywide. Over 10,000 human-made wetlands of Sri Lanka are a part of the rich cultural heritage of the country. These tanks are interconnected with long canal systems that measure in kilometers.

The wetlands created for aquaculture and agriculture also fall into this category. Rice fields can be considered as agroecosystems, which provide temporary or seasonal aquatic habitats. At present, approximately 12% of the total land under rice cultivation is distributed over all the agroecological regions (Kotagama and Bambaradeniya 2006). Reservoirs created by dams across major rivers in the central highland contribute to a considerable number of human-made wetlands in Sri Lanka. In addition to the giant reservoirs, a large number of smaller reservoirs have also been constructed to generate hydropower as well as drinking water sources at higher elevations (above 1000 m amsl).

4.2 Classification of Central Highland Wetlands in Sri Lanka

Although Sri Lanka is relatively a small island spread over 65,610 km^2, 103 rivers originate from its central highlands. These rivers play a dominant role in shaping the wetland landscape in the country. The major rivers such as Mahaweli, Walawe, and Kelani originating from the wet highlands are perennials. The streams and tributaries of rivers that flow through the high (above 1000 m) and mid (1000–250 m) elevations create several waterfall habitats. Wetlands, especially marshy lands and freshwater lakes in higher elevations are hydrologically important as catchments of major rivers and reservoirs in Sri Lanka. According to Kotagama and Bambaradeniya (2006), highland wetlands can be classified based on hydrological and ecological features or functions.

4.2.1 Freshwater Marshes/Waterlogged Swamps

These are shallow inland depressions either connected to a river or receive water through surface runoff, river floodwater, and groundwater seepage. In general, highland marshes are seen in the valleys and lower slopes of mountains associated with grasslands. In Sri Lanka, these unique wetland ecosystems are found only in higher elevation (Gunatilleke 2007). The highland grasslands and marshes are best represented in Horton Plains National Park at an altitude of about 2000 m (Fig. 4.1). Rainwater accumulates in marshes during the monsoon and gradually released to tributaries of major rivers throughout the year. Partially decomposed organic material in marshes form peat (IUCN and CEA 2006). Few of the larger marshes are also located in dairy farms established at higher elevations, and many relatively small marshes are found in tea plantations. Most of the threatened highland crabs and amphibian species are associated with the aquatic ecosystems such as marshy lands.

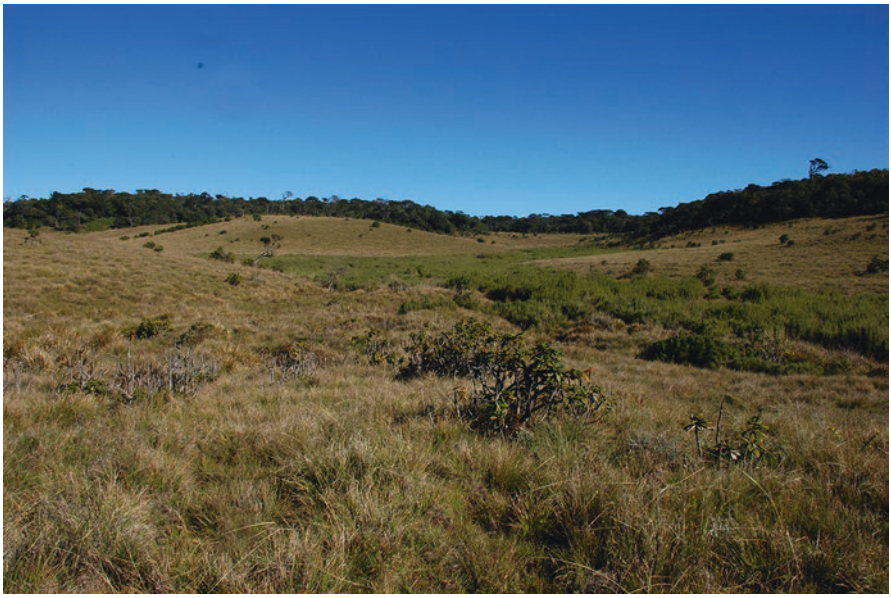

Fig. 4.1 Montane grassland marshes at Horton Plains National Park

4.2.2 Streams

Majority of the rivers originate in the central highlands. Most of the rain falling on the mountain slopes is carried down as surface runoffs leading to fast flowing streams (Amarasiri 2008). These streams contain aquatic plant species that are segregated based on their degrees of tolerance to the rate of water flow (Anon 1999). Grass species such as *Coelachnes impliciuscula* and the sedge *Isolepis fluitans* remain attached to rocks in flowing water. A primitive fern *Osmunda collina* and an endemic dwarf bamboo *Arundinaria densifolia* dominate the banks of streams in Horton Plains National Park. Humid forests in higher altitude exhibit shady condition with thick canopy. In the understory near the streams, various species of *Strobilanthes* dominate. The vegetation structure of streams in tea plantation differs from streams in mountain forests. The invasive Neotropical shrubs *Austroeupatorium inulifolium* and *Tithonia diversifolia* and different species of bamboo dominate in this ecosystem.

Slow flowing streams are very important to aquatic life, especially for invertebrates and amphibians (Fig. 4.2). Crustaceans such as freshwater crabs and shrimps too depend on these streams. Dragonflies dwell in the vicinity of different freshwater habitats. In addition to invertebrates, amphibians except for the direct-developing anurans depend on these water bodies for completion of their life cycle. *Hylarana temporalis*, an endemic but near threatened amphibian species, is regularly observed in the stream and pond habitats within tea plantation ecosystem.

Fig. 4.2 Slow flowing stream in Peak Wilderness Protected Area

4.2.3 Natural and Man-Made Lakes

Although Sri Lanka does not have large natural lakes, the total area covered by human-made water bodies exceeds 170,000 ha (Anon 1999). Majority of larger tanks are located in the dry zone of the country and are used for agriculture purposes. In higher altitude of Sri Lanka (above 1500 m), several tiny natural lakes are scattered in montane ecosystem. Natural lakes in Horton Plains and surrounding forests are important breeding and foraging habitats for threatened fauna especially amphibians and small mammals (Fig. 4.3). In addition to natural lakes, small lakes are constructed in most of the tea plantations for drinking water purpose.

4.2.4 Reservoirs

Reservoirs are large-scale water bodies made for storing surface water. There are several reservoirs built almost exclusively for the purpose of generating hydroelectricity in Sri Lanka and often located in the upper catchments of the major rivers at altitudes above 1000 m (Jayasinghe 2000). Typical example is the Lakshapana complex, which consists of a series of reservoirs. A series of multipurpose reservoirs are available along the Mahaweli, the longest river in the island.

Fig. 4.3 Natural Lake in Horton Plains National Park

4.2.5 Freshwater Springs

A spring is a natural flow of groundwater that intersects the surface of the earth. Many springs are found in the central highland ecosystem and they are active throughout the year. Springs release water stored in the ground that finds way to streams and rivers facilitating continuous flow of water in them throughout the year (Amarasiri 2008). They are valuable sources of water for drinking, bathing, irrigation, etc.

Profuse freshwater springs are found in tea plantations and vegetable cultivation lands in Sri Lanka (Fig. 4.4). With the implementation of Rainforest Alliance Certification in some tea estates, most of the springs and surrounding vegetations have been demarcated for conservation (Kottawa-Arachchi et al. 2015). Many invertebrates and vertebrates depend on these unique habitats to complete their life cycle. Aquatic stage or larval stage of different species of insects and tadpoles live in these springs.

4.2.6 Waterfalls

The country has a large number of waterfalls along the tributaries of major rivers that flow through steep landscape in the central highland. Near the waterfalls and

Fig. 4.4 Freshwater spring in a tea plantation ecosystem

upstream habitats, unique riverine vegetation is seen. Some of the waterfalls are located in montane forests while others are found away from natural forests. The spray zone of waterfalls in the upstream areas harbors herbaceous species such as *Hymenophyllum denticulatum*, *Impatiens* sp., *Sonerila* sp., *Angiopteris fraxinea*, *Asplenium indicum*, *Chirita walkeri*, and *Lindsaea trapeziformis* that grow mostly on rocky substratum.

4.3 Central Highland Complex: A Biodiversity Hotspot

The central highland complex of Sri Lanka is situated in the south central part of the island and comprises of the Peak Wilderness Protected Area (PWPA), the Horton Plains National Park (HPNP), and the Knuckles Conservation Forest (KCF). These montane forests, where the land rises to 2500 m ASL, are home to an extraordinary range of flora and fauna. The region is considered as a super biodiversity hotspot (UNESCO 2010). At present, the central highlands complex consisting of 16 forests is the most important watershed area in Sri Lanka, contributing to less than 5% of the remaining "moist tropical cloud forest" in the world. The Western Ghats in India and Sri Lanka is treated as a Global Biodiversity Hotspot (Myers et al. 2000). More than 50% of Sri Lanka's endemic vertebrates, 50% of the country's endemic flowering plants and more than 34% of its endemic trees, shrubs, and herbs are reported from these diverse montane rain forests and associated grassland areas. Given the number of endemics and threatened species, with their restricted distribution, the Central Highlands Complex including PWPA, HPNP and KCF were declared as

World Heritage Site by UNESCO in 2010. Despite their importance, much of the montane rain forests were cleared in the latter part of the nineteenth century primarily for expansion of plantation or agriculture and allied requirements.

4.3.1 Status of Biodiversity in Central Highland Wetlands

Sustenance of rich biological diversity is the most valuable characteristic of wetlands. A significant number of new species, especially freshwater crabs, have been discovered in and around highland wetlands. The island has 51 species of freshwater crabs, all of which are endemic and approximately 80% are restricted to the island's wet zone, which includes the central highland (Bahir et al. 2005). Recent advances in amphibian taxonomy have revealed that detection of new species of amphibians is higher than previous estimations (Meegaskumbura et al. 2010; Biju et al. 2014). Of the 408 species of vertebrates, 83% of freshwater fishes and 81% of the amphibians in PWPA are endemic. Similarly, 91% of the amphibians and 89% of the reptiles in Horton Plains are endemic (UNESCO 2010). In addition, 64% of the amphibians and 51% of the reptiles in the KCF are endemic (UNESCO 2010). The recent surge in the sphere of Sri Lanka's biodiversity reveals that both species richness and endemism for most groups of animals are much higher than previous estimations (Pethiyagoda 2005). During the last decade, biodiversity research has substantially increased and several new species have been described.

4.3.2 Species Associated with Highland Wetlands

The species composition and the appearance of an aquatic ecosystem vary both temporally and spatially. Sri Lanka harbors over 370 aquatic macrophytes, of which 12% are endemic to the country (Yakandawala 2012). Forty-one percent of the island's aquatic flora is in the threatened category in the National Red List, 2012.

4.3.2.1 Bryophytes and Pteridophytes

There are several species of bryophytes and pteridophytes growing near water bodies. A survey conducted in the central province including highland wetlands reported 44 species of bryophytes, of which 12 were new to science (Ruklani and Rubasinghe 2013). Moss species *Bryum argenteum*, *Pyrrhobryum spiniforme*, and *Hypopterygium* sp. and liverwort species *Plagiochasma nepalense* are common on moist tree branches and embankments near water bodies in Horton Plains. *Cyathea walkerae* and *Cyathea crinite* ferns grow in stream habitats in the central highland.

4.3.2.2 Carnivorous Plants

Where the soil layer is very thin, permanently wet and infertile, carnivorous plants like *Drosera peltata* and *Drosera burmannii* grow among grasslands and wetlands, especially in Nuwara Eliya and Badulla districts (Gunatilleke 2007). In waterlogged depressions and swampy areas in Horton Plains, aquatic plants such as *Juncus*

prismatocarpus, *Garnotia exaristata*, and *Exacum trinervium* are common. Another group of insectivorous plants is the bladderworts, which are associated with wetlands. All the 15 species of bladderworts are found in Sri Lanka. Three species of bladderworts, i.e., *Utricularia caerulea*, *Utricularia graminifolia*, and *Utricularia moniliformis*, have been recorded from Horton Plains (Gunatilleke and Pethiyagoda 2012). Of these, the last one is endemic.

4.3.2.3 Grasses, Sedges, and Herbaceous Plants

The marshes are characterized by tall grasses, sedges, and herbaceous plants, while lake vegetation is characterized by emergent plants toward the periphery and floating aquatics dominating the water surface (Gunatilleke and Pethiyagoda 2012). Grass species, *viz.*, *Garnotia exaristata* and *Juncus effusus*, are common near marshy areas and stream banks. The dwarf bamboos of the genus *Arundinaria* are represented by five endemic species, all of them occurring in the montane zone above 1500 m. *Arundinaria densifolia* and *Arundinaria debilis* grow in bogs and wet valleys among the grasslands in Horton Plains. *A. densifolia* is widespread in Uva Hills, whereas *A. debilis* occurs in forest understory across central highlands including the Knuckles forests. *Arundinaria floribunda* is known from a single population in Namunukula Forest Reserve, while *Arundinaria scandens* is restricted to upper region of Pidurutalagala Hill above 2100 m (Gunatilleke and Pethiyagoda 2012).

Orchid species such as *Ipsea speciosa* (endemic and endangered) and *Satyrium nepalense* (near threatened) occur in wet grasslands in central highlands. Endemic shrubs, *viz.*, *Impatiens leptopoda*, *Impatiens cuspidate* subsp. *bipartita,* and *Impatiens macrophylla*, usually grow in profusion in damp ground closer to stream and swampy areas. Plant communities dominated by *Eriocaulon* sp. are seen at the edge of water and shallow marshes. Critically endangered species, *viz.*, *Aponogeton jacobsenii* and *Isolepis fluitans*, are restricted to the highlands shallow marshes, especially at the Horton Plains.

4.3.2.4 Invertebrate Fauna

In montane habitats in the wet tropics, large-scale tea cultivation is common. The invertebrate taxa known to be sensitive to anthropogenic disturbances and a general assemblage-level analysis showed significant differences in the composition of macroinvertebrate assemblages between forested and tea plantations streams (Biervliet et al. 2009).

Among invertebrate fauna, odonates are indicator of water quality and environmental quality for conservation and biodiversity studies because of their intimate connection to water. Among odonates, critically endangered species *Elattoneura leucostigma* is restricted to well-vegetated streams in the dense montane forests (Poorten and Conniff 2012). Wijeyeratne (2012) recorded 20 species of dragonflies and damselflies including four endemic species (*Indolestes divisus, Indolestes gracilis, Elattoneura leucostigma*, and *Elattoneura tenax*). Another endemic and critically endangered species *Sinhalestes orientalis* was rediscovered from the Peak Wilderness Sanctuary after 154 years (Sumanapala and Bedjanic 2013). Endemic

and vulnerable odonate *Indothemis gracilis* is found in tea plantations at higher elevations (Kottawa-Arachchi et al. 2014a).

Considering crustaceans, two freshwater shrimp species are restricted to the Horton Plains National Park. These include *Lancaris singhalensis* which is confined to streams in and around Horton Plains National Park (alt. 1900–2000 m) and *Lancaris kumariae* which is only found in fast flowing streams (1150 m ASL) away from protected area (Cai and Bahir 2005) of the park. All the 51 species of freshwater crabs recorded from Sri Lanka are endemic. Nearly 90% of the freshwater crabs are globally threatened, and among them, 24 species of freshwater crabs are restricted to montane and submontane habitats (Bahir and Gabadage 2012). Three species of freshwater crabs *Perbrinckia punctata, Perbrinckia glabra*, and *Ceylonthelphusa soror* occur in Horton Plains National Park. Water depth, water-level fluctuations, salinity, and turbidity determine the functions of natural wetlands. These physical parameters influence macrophytes and invertebrates diversity. Macrophytes and invertebrates are the major food source for water birds, which ultimately determines the distribution of water birds communities (Bellio et al. 2009).

4.3.2.5 Vertebrate Fauna

Among the total inland vertebrate species in Sri Lanka, about 30% are ecologically dependent on wetlands (Kotagama and Bambaradeniya 2006). Freshwater fishes, generally considered as important indicator species, are found in all wetland habitats. Several species have become threatened during the past few decades due to habitat loss owing to human intervention and developmental projects. Thus, critically endangered species such as *Dawkinsia srilankensis, Laubuca insularis, Systomus martenstyni, Labeo fisheri*, and *Labeo lankae* are restricted to a single river basin in the Knuckles Forest Reserve (Goonatilake 2012).

Habitat loss, water pollution, and loss of vegetation are the most significant factors for restricted distribution of highland amphibians. Two of the very rare amphibian species were recently rediscovered from the Peak Wilderness, in Central Hills of Sri Lanka (Wickramasinghe et al. 2012, 2013). *Nannophrys marmorata*, an endemic and critically endangered amphibian species, is restricted to the rock strewn streams of the Knuckles Forest Reserve (200–1200 m amsl). Another critically endangered amphibian species, *Adenomus kandianus,* occupies undisturbed primary mountain forests and riparian habitats bordering unpolluted streams (Meegaskumbura et al. 2015). Furthermore, wetland-associated endangered amphibian species, *Taruga eques* and *Pseudophilautus sarasinorum,* are found in freshwater springs and streams in tea plantation ecosystems away from the protected areas in higher elevation (Kottawa-Arachchi et al. 2014b, 2015).

Small mammals, such as *Prionailurus viverrinus* and *Lutra lutra*, living in small lakes and marshes are at risk of their habitat loss, i.e., being converted to human use, endangering these small urban populations. Therefore, different types of wetlands in the central highland can be considered as a place for in-situ conservation of threatened species.

4.3.3 Microclimate of Highland Wetlands

In Sri Lanka, freshwater marshes that are associated with grasslands in higher elevations are subject to wide diurnal temperature fluctuations especially during January to March when rainfall is low and solar radiation is very high. During this period, the night temperature near the ground surface drops below 0 °C and midday temperature goes up to 28 °C (Gunatilleke 2007). Consequently, the plant communities in this ecosystem demonstrate broad adaptability to wide diurnal temperature differences. Within the stream habitats, the ground is sheltered by thick understory and ground vegetation. As a result, the air temperature near the understory goes down to only 10 °C at higher elevations.

Marshlands in tea plantation ecosystems at 1000–1500 m altitude, in close proximity to natural forests, exhibit climatic fluctuations. However, night temperature at ground level may drop to about 5–10 °C during January to March. Besides, the night air temperature in other wetland types such as streams and freshwater springs with good understory may go down only to about 16–19 °C whereas aquatic temperature in man-made lakes is about 17–22 °C (Kottawa-Arachchi et al. 2014b). The wetland habitats especially those of streams associated with thick understory display cool and humid microclimate. The range of relative humidity of wetland habitats in tea plantation ecosystem is about 80–86% (Kottawa-Arachchi et al. 2014b).

4.3.4 Ecosystem Services of Highland Wetlands

Inland wetlands provide an array of services such as provisioning, regulating, and supporting services vital for human well-being. Wetlands are particularly important providers of all water-related ecosystem services (Millennium Ecosystem Assessment 2005). Freshwater marshes and lakes in central highlands play major role as rivers catchments and for regulation and purification of groundwater. Provision of services such as supporting and regulating nutrient cycles and carbon storage are vital ecosystem functions of marshes that deliver many benefits to human and animals. Marshlands are also considered as important breeding habitat for aquatic fauna. Streams and waterfalls in central highlands have high ecotourism values. They are also often inviting places for recreational activities such as hiking, bird watching, and photography.

Groundwater, often discharged through freshwater springs and streams, plays an important role in water supply, providing drinking water to community. Another important water supply for agricultural purpose is represented by the construction of reservoirs that regulate river flow. Besides, hydropower generation is an important role of large reservoirs in higher altitudes. Inland fisheries are of special importance as a primary source of animal protein for rural communities. Therefore, many wetland types including lakes and reservoirs are vital for inland fisheries.

Fig. 4.5 Encroachment of marshland for vegetable cultivation in tea plantation

4.4 Threat to Highland Wetlands

Habitat deterioration and degradation, clearing of vegetation, siltation, water pollution, and spread of invasive alien species are significant threats to highland wetlands (Kotagama and Bambaradeniya 2006). Recent studies revealed that most of the marshy lands and seasonal streams of tea plantations, which support odonates (Kottawa-Arachchi et al. 2014a), amphibians (Kottawa-Arachchi et al. 2014b, 2015), and birds (Kottawa-Arachchi et al. 2015), have been transformed for domestic agriculture by the estate community.

4.4.1 Habitat Deterioration and Degradation

Most of the agricultural lands in the hill country are privately owned, whereas tea plantations are managed by Regional Plantation Companies. Dairy farms are established around Piduruthalagala and Hakgala Mountain forest reserves and Horton Plains National Park. With the increasing demand for agricultural products, wetlands especially marshlands are most vulnerable to encroachment (Fig. 4.5). Encroachment of marshlands and stream habitats happen when the water flow reduces during the dry season. Unfortunately, these encroachments are established permanently leading to significant loss of natural vegetation and biodiversity.

Negligence of soil conservation methods in tea and other agricultural lands lead to soil erosion and land degradation in the hill country (above 1000 m). Consequently,

accumulation of sediments in reservoirs leads to reduction in their capacities. Majority of the endemic and threatened species are confined to the wet zone and especially the montane zone where habitat loss and degradation are taking place at a rapid pace. Furthermore, fragmentation of habitats also has a detrimental effect on small populations, especially those with less mobility.

Construction of dams across major rivers, especially the Mahaweli, has affected the downstream vegetation. Due to further diversion and impoundments in the upstream areas of the river, the water flow has been reduced causing drying up of downstream habitats (Yakandawala 2012). Construction of mini-hydropower plants at a rapid rate during the past few years has added to the deterioration of many habitats of aquatic plants that grow only on stones in rapidly flowing streams and rivers. The best example is the construction of the Upper Kotmale hydropower project and restriction of downstream water flow that have affected downstream plants, *viz.*, *Zeylanidium subulatum* and *Zeylanidium olivaceum* (Yakandawala 2012).

4.4.2 Water Pollution

The main causes of pollution in highland wetlands are poor sanitation and hygiene, soil erosion, and excess usage of agrochemicals including inorganic fertilizers. Pollution of natural ecosystems harms living organisms, disturbs ecological systems, and damages structures and/or services (Amarasiri 2008).

A detail study to monitor water quality of selected aquatic habitats in tributaries of Mahaweli River (Wijayawardhana 2006) (Tables 4.1 and 4.2) showed gradual increase of physical parameters along downstream. These data also indicate that the pH values in select aquatic habitats of Mahaweli River are within the maximum permissible level (MPL) of pH for drinking water. On the contrary, Kottawa-Arachchi et al. (2014b) reported the pH values of different types of wetlands in tea plantations is in the range of 5.47–5.98.

The chemical properties of water depend on total dissolved solid, which mainly consists of cations and anions. High concentration of minerals and salt impurities in the water result in increased total dissolved solid. Consequently, other physical parameters (total alkalinity, electrical conductivity, total hardness, and chemical

Table 4.1 Physical parameters in select aquatic habitats in the tributaries of Mahaweli River

Habitat	pH	TA mg dm^{-3}	EC μS cm^{-1}	TH mg dm^{-3}	TDS mg dm^{-3}	COD mg dm^{-3}
T1	7.08	7.59	14.50	3.39	9.71	15.60
T2	6.78	10.35	34.30	8.89	22.90	14.40
T3	6.94	10.04	44.30	12.50	29.70	17.20
T4	6.90	13.66	53.20	15.49	35.20	15.00

Source: Wijayawardhana (2006)

T1 natural forest, *T2* tea field, *T3* tea with less anthropogenic activity, *T4* tea with high anthropogenic activity, *TA* total alkalinity, *EC* electrical conductivity, *TH* total hardness, *TDS* total dissolved solids, *COD* chemical oxygen demand

Table 4.2 Ionic concentration of select aquatic habitats in the tributaries of Mahaweli river

Habitat	K^+ mg dm^{-3}	Na^+ mg dm^{-3}	Ca^{2+} mg dm^{-3}	Mg^{2+} mg dm^{-3}	SO_4^{2-} mg dm^{-3}	PO_4^{3-} mg dm^{-3}	NO_3^- mg dm^{-3}	Cl^- mg dm^{-3}
T1	0.32	1.26	0.68	0.41	1.44	0.03	0.12	11.10
T2	0.80	2.19	1.86	1.02	1.70	0.04	0.93	12.90
T3	1.17	2.47	2.93	1.25	1.78	0.03	1.59	12.90
T4	2.06	3.17	3.70	1.50	2.47	0.04	1.56	10.00

Source: Wijayawardhana (2006)
T1 natural forest, *T2* tea field, *T3* tea with less anthropogenic activity, *T4* tea with high anthropogenic activity

oxygen demand) also showed an increasing trend with increased anthropogenic activities, which indicate accumulation of inorganic ions from usage of fertilizer in surrounding agricultural lands. Extensive agricultural activities in the hill country, especially vegetable cultivation, require many agrochemicals to control pests and diseases. Therefore, agrochemicals are major pollutants that contaminate upland water bodies. It is reported that water quality depletion of reservoirs near farmlands are due to excessive usage of agrochemicals and fertilizers, mixing of animal dung, and dumping of bio- and nonbiodegradable substances (Weerasekara et al. 2010).

4.4.3 Invasive Alien Species

Several exotic aquatic animal and plant species that have eventually entered wild habitats are posing serious threat to native aquatic biodiversity. Observations made during the past couple of years have documented 10 invasive alien faunal and 12 invasive alien floral species spreading in different wetland ecosystems throughout Sri Lanka (Bambaradeniya 2002).

A very thorny species *Ulex europaeus* that is native of Britain has now become invasive along the streams and marshes in Horton Plains National Park. Invasive Neotropical shrub *Austroeupatorium inulifolium* (Fig. 4.6) has rapidly invaded marshlands and steams in addition to being abundant in tea plantations (Pethiyagoda and Nanayakkara 2011). Other exotic plant species such as *Panicum maximum, Clidemia hirta*, and *Mimosa pigra* are becoming serious threat to marshlands. The spread of alien plants such as *Eichhornia crassipes, Xanthium indicum*, and *Salvinia molesta* is another threat to reservoirs and lakes that compete for resources with native species.

Among the invasive fauna are fish species originally introduced for fishing purposes such as the Rainbow Trout (*Oncorhynchus mykiss*), which was introduced to the streams of Horton Plains National park. Another species *Oreochromis mossambicus* was also introduced to reservoirs and both the species are causing destruction of native species. Therefore, these have been included in the list of the world's 100 worst invasive alien species.

Fig. 4.6 Invasion of *Austroeupatorium inulifolium* along a stream in tea plantation

4.5 Conservation of Wetlands

The Fauna and Flora Protection Ordinance of 1937 can be considered as a major step in wetland conservation. Sri Lanka has signed the Ramsar Convention in 1971 and ratified it in 1990. The Central Environmental Authority (CEA) has identified 84 wetland sites of importance for conservation and management through the Wetland Conservation Project of 1991–1998. All Ramsar wetlands are located in low elevations of Sri Lanka. At present, there are several government and nongovernment organizations involved in wetland conservation and management related activities in Sri Lanka.

4.5.1 Protection of Buffer Zones

Terrestrial habitats surrounding wetlands are critical to the management of natural resources. Although the protection of water resources is assured, it is also apparent that terrestrial areas surrounding wetlands are home for many semiaquatic species that depend on mesic ecotones to complete their life cycle (Semlitsch and Bodie 2003). The amphibians, in particular, frequently use both wetland and surrounding habitats. In the modern agricultural landscape, the natural connections between wetlands and natural vegetations have been greatly altered. Increasing plant diversity with native species in buffer zones, maintaining good canopy and understory, and implementing good agricultural practices would bring necessary beneficial changes to these ecosystems.

A recent study indicates that species richness increases with increased hydrologic connectivity of wetlands (Ishiyama et al. 2014). Therefore, it is understood that hydrologic connectivity of wetlands is important for maintaining biodiversity. Furthermore, buffer zone vegetation may facilitate to restore habitat connectivity that helps to increase the free movement of aquatic fauna. Therefore, both aquatic and terrestrial habitats are essential for maintaining biodiversity, and they must be managed as an integral system to protect wetland biodiversity.

4.5.2 Public Awareness

There is an overall lack of awareness among the public on the importance of wetlands, and these habitats are often considered as wastelands or areas used for waste dumps. To change the mind set of people it is important to conduct awareness among public as well as school children through the print and electronic media. Participatory management of wetlands is another practical approach to minimize environmental impact and resource use conflicts. Active involvement of select community groups to restore the degraded wetlands could bring sustainable management of wetlands.

Lack of awareness programs and unavailability of information in the local languages hinder in implementation of wetland conservation measures. Although, a few organizations have attempted to conduct awareness programs for the estate community, they did not succeed much. Recently, Friends of Horton Plains, an environmental organization located in the central hills, carried out awareness programs regarding importance of wetlands and biodiversity conservation of central hills, targeting students and teachers at various locations. Presentations and printed materials in local languages have been distributed through a project taken in collaboration with Department of Wildlife Conservation to carry out field activities.

4.5.3 Legal Provisions for Protecting Wetlands

Nowadays, the value of wetlands is greatly acknowledged and the scenario for conservation of wetlands is encouraging. Site reports and management plans have been prepared for many wetlands under the Wetland Conservation Project of the Central Environmental Authority (CEA). Furthermore, National Wetland Directory of Sri Lanka has been jointly prepared by the CEA, the IUCN Sri Lanka, and the International Water Management Institute (IWMI) in 2006 that presents an overview of 62 important wetland sites in the country (Kotagama and Bambaradeniya 2006).

Wetland delineation is essential for their management. GIS mapping has high potential to categorize the wetland types according to their present status. It also helps to take administrative decision for future protection. Main institutes such as the Ministry of Environment (ME), Department Wildlife Conservation (DWLC), Forest Department (FD), Central Environmental Authority (CEA), and National

Aquatic Resources Research and Development Agency (NARA) should examine government policies, identify gaps, strengthen existing laws, and review the legal framework relating to the conservation of wetlands.

4.6 Prospective for the Conservation of Highland Wetlands

Highland wetlands being hydrologically very important, their status needs to be improved. These valuable ecosystems face severe anthropogenic activities. Considering various issues and threats discussed above, the future management strategies of central highland wetlands need to be focused to conserve this unique ecosystem in a sustainable manner.

From time to time, various national policies such as the National Conservation Strategy (NCS) 1988, the National Wildlife Policy (NWP) 1990, the National Forest Policy (NFP) 1995, and the National Policy on Wetlands (NPW) 2004 have been formulated. Among these is the establishment of a special Wetland Unit in the Natural Resources Division of the CEA to oversee the interests of wetlands and to implement the National Wetlands Policy of 2006.

4.7 Conclusion

The government of Sri Lanka has implemented national policies for the conservation of wetlands in the past 10 years, but highland wetlands continue to be lost and degraded, and their resources are overexploited. Activities such as clearing vegetation, encroachments and spread of invasive alien species are the most significant threats to highland wetlands. These activities have been identified as major issues that cause loss of highland wetland biodiversity. Various government authorities and nongovernment organizations should come forward for working together to identify gaps, conduct awareness programs, strengthen existing laws, and review the legal framework that relates to the conservation of wetlands. Considering various issues and threats discussed above, the future management strategies of central highland wetlands need to be focused to conserve this unique ecosystem in a sustainable manner.

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References

Amarasiri S (2008) Caring for water. Sri Lanka Nature Forum, Nugegoda

Anon (1999) Biodiversity conservation in Sri Lanka: a framework for action. Ministry of Forestry and Environment, Sri Lanka

Anon (2004) Revised coastal zone management plan, Sri Lanka. Coast Conservation Department and the Ministry of Fisheries and Aquatic Resources Development, Sri Lanka

Bahir MM, Gabadage DE (2012) Taxonomy and conservation status of freshwater crabs (Crustacea: Decapoda) in Sri Lanka. In: Weerakoon DK, Wijesundara S (eds) The national red list 2012 of Sri Lanka; conservation status of the fauna and flora. Ministry of Environment, Colombo, pp 58–64

Bahir MM, Ng PKL, Crandall K, Pethiyagoda R (2005) A conservation assessment of the freshwater crabs of Sri Lanka. Raffles Bull Zool Suppl 12:121–126

Bambaradeniya CNB (2002) The status and implications of invasive alien species in Sri Lanka. Zoo's Print J 17:930–935

Bellio MG, Kingsford RT, Kotagama SW (2009) Natural versus artificial- wetlands and their waterbirds in Sri Lanka. Biol Conserv 142:3076–3085

Biju SD, Garg S, Mahony S, Wijayathilaka N, Senevirathne G, Meegaskumbura M (2014) DNA barcoding, phylogeny and systematics of golden-backed frogs (Hylarana, Ranidae) of the Western Ghats-Sri Lanka biodiversity hotspot, with the description of seven new species. Contrib Zool 83:269–335

Cai Y, Bahir MM (2005) Lancaris, a new genus of freshwater shrimp from Sri Lanka (Crustacea: Decapoda: Atyidae). Raffles Bull Zool Suppl 12:39–46

Dela JDS (2009) Fourth country report from Sri Lanka to the United Nations convention on biological diversity.

Goonatilake SA (2012) The taxonomy and conservation status of the freshwater fishes in Sri Lanka. In: Weerakoon DK, Wijesundara S (eds) The national red list 2012 of Sri Lanka; conservation status of the fauna and flora. Ministry of Environment, Colombo, pp 77–87

Gunatilleke CVS (2007) A nature guide to the world's end trail, Horton plains. Faculty of Science, University of Peradeniya, Sri Lanka

Gunatilleke N, Pethiyagoda R (2012) Grasslands. In: Pethiyagoda R (ed) Horton plains: Sri Lanka's cloud-forest national park. Wildlife Heritage Trust, Sri Lanka, pp 141–168

Ishiyama N, Akasaka T, Nakamura F (2014) Mobility-dependent response of aquatic animal species richness to a wetland network in an agricultural landscape. Aquat Sci 76:437–449

IUCN and CEA (2006) National wetland directory of Sri Lanka. The Central Environmental Authority (CEA), The World Conservation Union (IUCN) and the International Water Management Institute (IWMI), Colombo

Jayasinghe JMPK (2000) Inland aquatic resources. In: Natural resources of Sri Lanka. National Science Foundation, Sri Lanka, pp 195–211

Kotagama SW, Bambaradeniya CNB (2006) An overview of the wetlands of Sri Lanka and their conservation significance. In: National wetland directory of Sri Lanka. IUCN Sri Lanka and Central Environmental Authority, Sri Lanka

Kottawa-Arachchi JD, Gamage RN, Jayathilake GG (2014a) The role of different ecosystems to maintain odonate and butterfly diversity in Mattakelle tea estate, Sri Lanka. In: Proceedings of the International Forestry and Environment Symposium 2014. Department of Forestry and Environmental Science, University of Sri Jayawardenepura, Sri Lanka, p 133

Kottawa-Arachchi JD, Gamage RN, Jayathilake GG, Hiripitiya HSV (2014b) Importance of different habitats for herpetofauna in tea plantation ecosystem in Mattakelle tea estate, Sri Lanka. In: Proceedings of the International Symposium on Agriculture and Environment 2014. University of Ruhuna, Sri Lanka, pp 197–201

Kottawa-Arachchi JD, Gamage RN, Jayathilake GG (2015) Vertebrate diversity and conservation aspects in manmade habitats in Mattakelle Tea Estate, Sri Lanka. WildLanka 3:148–162

Meegaskumbura M, Meegaskumbura S, Bowatte G, Manamendra-Arachchi K, Pethiyagoda R, Hanken J, Schneider CJ (2010) *Taruga* (Anura: Rhacophoridae), a new genus of foam-nesting tree-frogs endemic to Sri Lanka. Ceylon J Sci Biol Sci 39:75–94

Meegaskumbura M, Wijayathilaka N, Abayalath N, Senevirathne G (2015) Realities of rarity: climatically and ecologically restricted, critically endangered Kandian Torrent Toads (*Adenomus kandianus*) breed en masse. Peer J. doi:10.7287/peerj.preprints.1575v2

Millennium Ecosystem Assessment (2005) Ecosystems and human well-being: wetlands and water synthesis. World Resources Institute, Washington, DC

Myers N, Mittermeier RA, Mittermeier CG, Fonseca GAB, Kent J (2000) Biodiversity hotspots for conservation priorities. Nature 403:853–858

Pethiyagoda R (2005) Exploring Sri Lanka's biodiversity. Raffles Bull Zool Suppl 12:1–4

Pethiyagoda RS, Nanayakkara S (2011) Invasion by *Austroeupatorium inulifolium* (Asteraceae) arrests succession following tea cultivation in the highlands of Sri Lanka. Ceylon J Sci Biol Sci 40:175–181

Ruklani NCS, Rubasinghe SCK (2013) A preliminary survey of bryophytes in the central province of Sri Lanka. Ceylon J Sci (Biol Sci) 42:67–72

Semlitsch RD, Bodie JR (2003) Biological criteria for buffer zones around wetlands and riparian habitats for amphibians and reptiles. Conserv Biol 17:1219–1228

Sumanapala AP, Bedjanic M (2013) Rediscovery of a long lost endemic damselfly *Sinhalestes orientalis* (Hagen in Selys, 1862) from peak wilderness sanctuary, Sri Lanka (Zygoptera: Lestidae). Asian J Conserv Biol 2:44–47

UNESCO (2010) Central highlands of Sri Lanka. Report of the decisions adopted by the World Heritage Committee at its 34th session. WHC-10/34.COM/20.

van Biervliet O, Wisniewski K, Daniels J, Vonesh JR (2009) Effects of tea plantations on stream invertebrates in a global biodiversity hotspot in Africa. Biotropica 41:469–475

van der Poorten N, Conniff K (2012) The taxonomy and conservation of the dragonfly fauna (Insecta: Odonata) of Sri Lanka. In: Weerakoon DK, Wijesundara S (eds) The national red list 2012 of Sri Lanka: conservation status of the fauna and flora. Ministry of Environment, Colombo, pp 1–10

Weerasekara KAWS, Amarathunga AAD, Shirantha RRAR, Sureshkumar N, Azmy SAM (2010) Current status of Ambewela reservoir of Sri Lanka with special reference to water pollution. In: Proceedings of the 15th International Forestry and Environment Symposium 2010. University of Sri Jayewardenepura, Sri Lanka, pp 85–92

Wickramasinghe LJM, Vidanapathirana DR, Wickramasinghe N (2012) Back from the dead: the world's rarest toad *Adenomus kandianus* rediscovered in Sri Lanka. Zootaxa 3347:63–68

Wickramasinghe LJM, Vidanapathirana DR, Airyarathne S, Rajeev G, Chanaka A, Pastorini J, Chathuranga G, Wickramasinghe N (2013) Lost and found: one of the world's most elusive amphibians, *Pseudophilautus stellatus* (Kelaart 1853) rediscovered. Zootaxa 3620:112–128

Wijayawardhana RGA (2006) Effect of fertilizer application in up-country tea lands on down-stream pollution. M.Phil. Thesis, University of Peradeniya

Wijeyeratne GS (2012) Dragonfly watching in Horton plains. In: Pethiyagoda R (ed) Horton plains: Sri Lanka's cloud-forest national park. Wildlife Heritage Trust, Sri Lanka, pp 186–188

Yakandawala D (2012) Present status of fresh water aquatic flora in Sri Lanka. In: Weerakoon DK, Wijesundara S (eds) The national red list 2012 of Sri Lanka; conservation status of the fauna and flora. Ministry of Environment, Colombo, pp 186–196

Young L (2013) Wetland conservation in Sri Lanka. The Ramsar Secretariat, Switzerland