TAPROBANICA, ISSN 1800-427X. October, 2012. Vol. 04, No. 02: pp. 92-102.

Historical land-use patterns in relation to conservation strategies for the Riverstone area, the Knuckles massif, Sri Lanka: insights gained from the recovery of anuran communities.

Sectional Editor: Lee E. Harding *Submitted*: 15 December 2011, *Accepted*: 24 September 2012

Senarathge R. Weerawardhena [1,2] and Anthony P. Russell[1]

[1] Department of Biological Sciences, University of Calgary 2500, University Drive NW, Calgary, T2N 1N4, Alberta, Canada; Email: arussell@ucalgary.ca
[2] Department of Zoology, University of Kelaniya, Kelaniya 11600, Sri Lanka; Email: zoosrw@kln.ac.lk

Historical land-use patterns in Sri Lanka

Agriculture on the Indian sub-continent dates back to the fourth and third millennia BC (Lawton & Wilkes, 1979), but only in more recent times did its intensity escalate in a major way. During the colonial era, the British established that the hilly areas of Sri Lanka were suitable for the rearing of coffee (*Coffea arabica*), for which much of the arable land of the island was extensively cultivated. Later, however, resulting from the severe impact of “Coffee Rust,” caused by the fungus *Hemileia vastatrix*, the coffee industry of Sri Lanka declined dramatically (Forrest, 1967). Former coffee plantations were abandoned, but are still distinguishable as damaged areas (Marby, 1972). The truncation of coffee growing on the island created vacant room for another cash-crop.

After the 1960s, tea (*Camellia sinensis*), with a long history of commercial cultivation (Carter, 2008; Mair & Hoh, 2009; Moxham, 2003), quickly became the major commercial agricultural commidity in Sri Lanka. Tea was introduced to Sri Lanka directly from China by the British before 1824 as an exhibitive specimen in the Royal Botanical Gardens at Peradeniya. Prior to 1867, it was not cultivated on a large commercial scale (Marby, 1972). In 1867**,** seven hectares were planted with tea and by 1967, 24,038 ha in wet mountainous areas (700–1,300 m a.s.l.) were devoted to tea plantations (Forrest, 1967; Jayaraman, 1975). These were established by extensively clearing the virgin forest (Manamendra-Arachchi, 1999). By the middle of the 20^{th} century, “Ceylon tea” (Ball, 1980) had become very popular worldwide (Mair & Hoh, 2009).

The Knuckles Mountain Forest Range

The Knuckles Mountain Forest Range (hereafter KMFR) is situated at 7° 21’ N, 81° 45’ E in the Intermediate Zone of the Central Province of Sri Lanka. It covers approximately 2.1×10^4 ha. The traditional Sinhalese name for this is “*Dumbara Kanduvetiya*”: “mist-laden mountain range” (Cooray, 1984) because the landscape is rugged with at least 35 peaks rising above 900 m (Ekanayake & Bambaradeniya, 2001).

The KMFR experiences a wide range of rainfall (de Rosyro, 1958). It is oriented perpendicular to the two principal wind currents that bring rains (the Southwest and Northeast monsoon) to Sri Lanka and acts as a climatic barrier. The highland and western areas of the KMFR are extremely wet throughout the year, with an annual rainfall of about 5,000 mm, whereas the lower eastern slopes are considerably drier, experiencing less than 2,500 mm annual rainfall (Bambaradeniya & Ekanayake, 2003). The KMFR also exhibits major temperature differentials with the mean monthly temperature ranging from 15 °–25 °C.

The KMFR is an important watershed, housing more than 500 streams (de Silva *et al*., 2005) that are the source of many rivers and streams that drain East into the lower Mahaweli River system (Heen Ganga, Hasalaka Oya, and Maha Oya), Southwest into the upper Mahaweli River system (Hulu Ganga), and Northeast into the Amban Ganga River system (Kalu Ganga, and Teligam Oya). The KMFR catchments area contributes about 30 % of water to the three reservoirs (Victoria, Randenigala and Rantambe) of the Mahaweli River system (Bambaradeniya & Ekanayake, 2003).

Traditional human settlements occur along the narrow river valleys of the KMFR. Five ancient villages were situated in the KMFR. Currently, 80 villages are immediately outside of, and encircle, the KMFR (Nanayakkara *et al*., 2009). The main food of Sri Lankans, rice (*Oryza sativa*), has been cultivated in the KMFR, mainly in valleys and terraced hill slopes, for several centuries. In addition to paddy-field cultivation, farmers use the traditional practice of slash and burn cultivation which provides a livelihood and subsistence source of food supply (Bambaradeniya *et al.*, 2004; Wickramasinghe *et al*., 2008). This provides more than 20 % of household income of the local villages (Gunatilake *et al*., 1993).

Several forested habitats of the KMFR, such as the lowland forest, the sub-montane forest, and the montane forest, were greatly degraded as a result of commercial farming during the British colonial era (Bambaradeniya & Ekanayake, 2003). The vast majority of forest clearing in the KMFR was for agricultural purposes, in particular to create land for cash-crops. During this period, major estates were located in the KMFR: Kalebokka, Nichola Oya, and Rangalle (Marby, 1972). For example, 2,796 ha in the Kalebokka area of the KMFR were planted with tea between 1874 and 1875 (Forrest, 1967).

Cardamom (*Elettaria cardamomum*) was also cultivated in this region (Marby, 1972), under the canopy of the sub-montane and the montane forest (900 m a.s.l.). Although cardamom cultivation was initially introduced to the KMFR over a hundred years ago, it was not developed on a large commercial scale until the 1960's. Due to the high income generated by this cash-crop, the local government encouraged its cultivation in the 1960s on lands of the KMFR leased to individuals and groups for export-oriented cardamom cultivation (Wickramasinghe *et al.*, 2008).

Some commercial plantations of tea and cardamom (legal as well as illegal) still remain in the KMFR (Bandaratillake, 2005; Forrest, 1967). Wickramasinghe *et al*. (2008) documented the impact of cardamom cultivation on the sensitive areas of the KMFR, resulting from the partial removal of the over-storey and the complete removal of undergrowth. A recent survey conducted by the Forest Department indicates that about 500 plots for cardamom cultivation, ranging from 2–200 ha, are located within the KMFR. This impact is increased by the location of about 90 % of the cardamom processing and drying barns in the KMFR. They all use wood gathered from the forest as fuel, leading to further degradation of the forest.

As a result of these uncontrolled anthropogenic agricultural practices, in particular the clearing of land for the cultivation of cash-crops, the sub-montane forest of the KMFR has become highly fragmented and the virgin forest has been drastically reduced in area, with 21 % of it being heavily degraded, and only 12 % persisting as open canopy forest (Wickramasinghe *et al*., 2008).

Importance of the KMFR: Floral diversity

The range of landscape and climatic features present in the KMFR supports a variety of natural vegetation types: montane forests; sub-montane forests; lowland semi-evergreen forests; riverine forests; rock-outcrop forests; savannah; patâna grasslands; and scrublands (de Rosyro, 1958). In the KMFR, virgin sub-montane forest represents a transitional biological belt between lowlands and highlands. Typical patches of the sub-montane forests are found at Cobert's Gap; Kelabokka; and the Riverstone area. These lie between 600 and 1,300 m a.s.l. Trees in the sub-montane forest are stunted, much branched and aerodynamically shaped by strong winds. Three strata are present in the sub-montane forest: the herb/shrub layer (2 m): the sub-canopy (5 m): and the canopy (15 m), each consisting of its own unique plant species (Bambaradeniya & Ekanayake, 2003).

The occurrence of particular vegetation types in the KMFR is most affected by patterns of rainfall (de Rosyro, 1958), which determines the location (Touflan & Tallow, 2009) and type of vegetation. The different vegetation types constitute a complex mosaic structure and collectively support a rich flora. For example, the KMFR contains approximately 1,033 vascular plant species, including 170 endemic woody trees (3 % of which are nationally threatened) (Bambaradeniya & Ekanayake, 2003) and several endemic flowering herbs and shrubs (Gunathillake & Gunathillake, 1995). Furthermore, the KMFR harbours 33 % of all the flowering plant species of the island, and it has a high level of floral endemism (Ashton & Gunathillake, 1987).

Importance of the KMFR: Faunal diversity

The diverse and stratified vegetation types found in the KMFR, harbour a rich fauna, with large numbers of endemics and some of which are threatened species. Within the KMFR, around 262 species of vertebrates have been recorded of which around 69 are endemic and around 60 are nationally endangered.

Importance of the KMFR: Anuran diversity

Based on reliable literature (Manamendra-Arachchi & Pethiyagoda, 2005, 2006) we prepared a list of anuran species that we expected to encounter in the Riverstone area. It is evident that few researchers (e.g. Nizam *et al*., 2005) erroneously included species of doubtful occurrence and extinct species in their listing. Our list (Table 1) was based upon confirmed occurrence and likelihood of encounter in the habitats being investigated. The preparation of this list of anurans likely to be encountered helped us to focus our sampling strategies.

We investigated patterns of recolonization of abandoned tea plantations by terrestrial and arboreal anurans. Overall our five sampling periods (Weerawardhena & Russell, 2012) over a time span of 16 months yielded a total of 237 post-metamorphic anurans, representing 21 species arrayed among the families Bufonidae, Microhylidae, Nyctibatrachidae, Ranidae and Rhacophoridae. The KMFR is, therefore an important locality in Sri Lanka in terms of its biological diversity and endemism.

Why is conservation of the KMFR necessary?

The KMFR is an important natural forest in Sri Lanka in many respects – it harbours rich floral and faunal diversity; it exhibits high endemism; it is occupied by several endangered species; it consists of diverse habitat types; and it is an important watershed and catchment area for several rivers and streams. However, the KMFR faces severe and imminent threats. Among these are extensive agricultural practices, in particular illegal cardamom plantations. Much of the virgin forest of the KMFR has been cleared to make way for the cultivation of cash-crops, and to supply timber as well as fuelwood for villages. Illegal felling of timber and fuel wood species and illegal hunting of animals continue to be prevalent in the KMFR. Over-collection of common and rare medicinal plants for local use, as well as plant and animal specimens for scientific study, pose serious threats, especially to the populations of endemic and threatened species in the KMFR. Furthermore, unregulated research work, and the construction of resorts and other buildings including houses, uncontrolled tourism access, and human-set forest fires constitute further threats to the KMFR.

Global Amphibian Decline

In late 1980's herpetologists first became aware of the large scale of amphibian declines globally, but at that time had no clear picture of the causative agents. Today we recognize that the same basic causal agents that have led to the decline of other vertebrate taxa have also been responsible for the declines in many amphibian species. These include deforestation, environmental pollution, habitat destruction and degradation, introduction of invasive species, global climate change, and infectious diseases (Stuart *et al*., 2004). Prominent among the diseases is chytridiomycosis, caused by a fungus, that has been implicated in amphibian declines globally (Berger *et al*., 2000) and is spread by bullfrogs, often transported live as a delicacy (Schloegel, 2012), among other vectors. Among other causal agents, habitat destruction and degradation represents the greatest threat to amphibians (Wells, 2007). The transformation of natural habitats into agricultural lands plays an important role in habitat degradation. It is estimated that 9 x10^8 ha of the earth's surface had been converted into crop-lands by 2005 (Spellerberg, 2005).

Table 1: Anuran species of the Riverstone area of the KMFR ◄ The list of the possible anuran species of the KMFR; ▼ The list of anurans species encountered in our study (Weerawardhena & Russell, 2012); [E] endemic to Sri Lanka.

Anuran species	◄	▼
Adenomus kelaartii [E]	√	-
Duttaphrynus melanostictus	√	√
Fejervarya limnocharis	√	-
Nannophrys marmorata [E]	√	-
Kaloula taprobanica	-	√
Ramanella obscura [E]	√	√
Lankanectes cf. *corrugatus* [E]	√	√
Hylarana temporalis [E]	√	√
Pseudophilautus cavirostris [E]	√	√
Pseudophilautus fergusonianus [E]	√	√
Pseudophilautus fulvus [E]	√	√
Pseudophilautus hankani [E]	√	-
Pseudophilautus hoffmanni [E]	√	√
Pseudophilautus macropus [E]	√	√
Pseudophilautus mooreorum [E]	√	√
Pseudophilautus cf. *ocularis* [E]	-	√
Pseudophilautus sarasinorum [E]	√	√
Pseudophilautus cf. *silus* [E]	-	√
Pseudophilautus steineri [E]	√	√
Pseudophilautus stuarti	√	√
Pseudophilautus (red head) sp.	-	√
Pseudophilautus (white eye) sp.	-	√
Pseudophilautus (yellow dorsum) sp.	-	√
Polypedatus cruciger [E]	-	√
Taruga cf. *eques* [E]	√	√
Total	18	21

Abandonment of agricultural lands in the KMFR

Both slash and burn cultivation and also some cash-crop cultivation (coffee, tobacco, and tea) have led to abandonment of land due to the loss of soil fertility. Nitrogen-phosphorus-potassium fertilizers were used on tea plantations in large quantities and this ultimately led to lower soil fertility over a period of several decades (Mohammed, 1996). Other factors contributing to the abandonment of tea plantations are higher levels of soil acidity (Weerawardhena, 1993), leaf and root diseases, and pest (in particular insects) infestations (Marby, 1972). For example, in the Duckwari Group of the KMFR, most of its 655 ha was planted in tea prior to 1898, but by 1967 only 481 ha of the total were planted in tea, 48 ha were under cardamom plantation, one hactare was cultivated with rice paddy, and 125 ha had been abandoned (Marby, 1972). Typically these abandoned lands have either been replanted—for example, 20.5 ha were replanted in Guatemala grass (*Tripsacum laxum*) (Marby, 1972)—or allowed to secondary succession.

Secondary succession in abandoned agricultural lands

Following abandonment, secondary succession takes place and these plots become increasingly occupied by native plant taxa. Within a few years of abandonment, dominance shifts to fast growing tree species with intermediate and high shade tolerance. These plants tend to grow taller than the general mass of vegetation, resulting in stratification of the forest canopy similar to that of the primary forests.

Factors that delay secondary succession

Secondary succession may be delayed by several factors or processes. One of the most important of these is the availability of seeds of wild plant species. Many studies have shown that seeds of these plant species are generally absent from the soil seed bank (Leck *et al*., 1989; Uhl *et al*., 1981). The seeds and vegetative propagules, such as roots and stags of wild plant species, are destroyed by agricultural practices (Skinner, 2004), and thus seeds of such species must disperse into the abandoned agricultural plots for successful secondary succession. Wickramaratne *et al.* (2009a) showed that the availability of seeds acts as a limiting factor for secondary succession in degraded grasslands in the KMFR. Some regeneration studies have demonstrated that the seed-rain declines rapidly within few meters of the edge of forest (Holl, 1998). According to Hooper and co-workers (2005) seed dispersal limitation is a major barrier to natural regeneration or secondary succession.

Another contributing factor to the slow rate of recovery of abandoned agricultural plots relates to the high percentage of such seeds that are dispersed by the wild birds and small mammals. These animals mainly inhabit the forest or exploit habitat near the edge of the forest rather than occupying the disturbed habitats. The seeds that do arrive in the abandoned agricultural plots are often distributed patchily, again that delaying the process of secondary succession.

Additionally, the combination of a hard seed-coat and a hilum whose opening is controlled by environmental conditions are also responsible for an induced dormancy of seeds of wild plant species (Degreef *et al*., 2002). This dormancy also delays the process of secondary succession. Furthermore, seed that do arrive in the abandoned agricultural plots are subjected to high rates of seed predation and herbivory (Holl, 1998; Skinner, 2004) because common seed predators, such as ants, birds and small mammals, constitute the main faunal components of abandoned agricultural plots. The rates of seed predation differ between species of seed predators, which also affects the pattern of secondary succession.

Wickramaratne *et al.* (2009b) pointed out that competition for above- and below-ground resources exerted by grasses on newly established plant-seedlings can also impact the potential for successful establishment of plant species in abandoned agricultural plots in the KMFR. The limited colonization success of forest plant species in abandoned agricultural plots is also contributed to by aggressive grasses that often form a monoculture in tropical environments throughout Southeast Asia (Holl, 1998; Iwata *et al*., 2003; Ohtsuka, 1999; Padoch *et al*., 1998; Vasey, 1979). Such grasses may limit recolonization in many ways (Nepstad *et al*., 1990), such as by competing for soil moisture (Holl, 1998), increasing the possibility of fire that kills plant seedlings (Skinner, 2004), being unattractive to seed dispersers, and providing shelter for seed and seedling predators (Hooper *et al*., 2005).

The microclimatic conditions of the KMFR may also have an effect on recovery of disturbed habitats (Skinner, 2004). Holl (1998) and Skinner (2004) noted that air and soil temperatures, as well as light levels, are elevated and soil moisture and humidity levels are reduced in abandoned agricultural lands compared to those of virgin forest habitats. We found that air and soil temperature levels in abandoned agricultural lands were higher than those in the sub-montane forest, and conversely we found that relative humidity and soil moisture were low in abandoned lands relative to those in the virgin sub-montane forest. Such different and stressful microclimatic conditions may facilitate and promote the growth and survival of grasses (Aide and Cavalier, 1994) while inhibiting seed germination, plant-seedling growth and the survival of colonizing woody plants (Holl, 1998). Ultimately these factors also limit the process of secondary succession. Additionally, the availability of propagules (Skinner, 2004), lack of nutrients (Hooper *et al*., 2005; Vitousek and Sanford, 1986), lack of mycorrhizae, (Janos, 1980) and highly compacted soil (Buschbacher *et al*., 1988) in abandoned agricultural lands may also retard the process of secondary succession. The relative importance of these factors depends on the original ecosystem, the history of disturbances, and the landscape pattern.

Lessons learned from the recovery of anuran communities following abandonment and secondary succession

Our main research investigated the patterns of recolonization by tropical anurans associated with forest habitat alteration after the abandonment of tea plantations in the KMFR of the Central Region of Sri Lanka.

Our results revealed that conditions in abandoned agricultural lands in former forest became increasingly favourable for anurans in successive stages of secondary succession. For example, relative humidity and soil moisture content increased, whereas air and soil temperature decreased. In terms of vegetational characteristics, litter cover and depth, crown cover, density of woody trees, girth at breast height and height of vegetation increased, whereas the density of tea plants decreased.

With increasingly favourable environmental conditions in the abandoned farm plots, anuran species richness, complexity of species composition, and diversity increased. Furthermore, our results indicate that the similarity between successional stages decreases as the time since abandonment increases, indicating that species turnover rate is high. Our findings show that the various species of anuran species encountered occupy sites with particular physico-chemical, vegetational and structural characteristics.

Based on our field observations and from information gathered from the local community such as forest officers, farmers and neighbouring villagers, it became evident that the natural virgin forest in several areas had already become degraded, through various human actions, before the establishment of tea plantations. In the Riverstone area, for example, hundreds of hectares of virgin forest had been entirely cut down to make way for coffee plantations. Furthermore, human-induced fires had also contributed to vegetational change.

Our field observations revealed that vegetational recovery through natural regeneration and secondary succession proceeds at a much slower pace in open areas than in closed ones. Open habitat had been degraded or drastically altered, making it less responsive to secondary colonization. Changes to the substrate were both physical (erection of stone walls; digging of trenches to combat soil erosion in the tea plantations) and chemical (higher acidity level of the soil; formation of brick layers). The poor capacity of the open areas for recovery was also contributed to by the loss of parent trees, without which there was no possibility of regeneration. Compared to the open areas, the regeneration of closed areas has been much more rapid. Wind and animals (in particular birds and bats) acted as seed dispersal agents. The seeds were derived from a wide variety of species growing in the neighbouring virgin forest.

Our study allows us to make comments pertinent to matters relevant to enhancing the regenerative potential of the secondary forest. We trust that our suggestions and recommendations can be implemented in efforts to enhance regeneration efforts in the KMFR as a whole.

The impact of enforcement of conservation legislation

Illegal felling of timber and fuelwood species, the illegal hunting of wild animals, the over collection of plants and animals have been reduced considerably, mainly as a result of enforcement of conservation legislation by the State. Because of its unsustainable agricultural practices such as slash and burn cultivation are now recognized as activities that damage the environment and are prohibited in many parts of the KMFR (e.g., Laggala and Pallegama).

The virgin forests of Sri Lanka have been owned and managed by the Forest Department of Sri Lanka since the end of the colonial period. At present, nearly all natural forest habitats are State-owned and fall under the purview of three institutions: the Divisional Secretaries; the Department of Wildlife Conservation; and the Forest Department. The main policy-making body for protected areas in Sri Lanka is the Department of Wildlife Conservation. All legislation has been prepared according to the FFPO. Current legislation relating to protected areas (buffer zones; jungle corridors; national parks; nature reserves; refuges; sanctuaries; and marine reserves) is mainly covered by the Fauna and Flora Protection Ordinance (FFPO)-1937 (Sri Barathi, 1979). This, is an amended form, was approved by the Cabinet of Ministers on March 12th, 2008. Some of the policies relating to protected areas are covered by the Management and Wildlife Conservation National Policy. Fines and penalties are imposed for illegal activities conducted in protected areas mentioned in the ordinance.

Suggestions for improved conservation measures in the KMFR

The results of our studies provide insights that could prove useful for conservation measures relating to wildlife, including anuran species, in the KMFR. We suggest that agricultural practices such as tea, tobacco, and cardamom plantations should not be permitted in the remaining virgin forest habitats, or in formerly forested areas of the KMFR, especially in areas located at 1,000 m a.s.l. or above. In 2000, the Forest Department declared a Conservation Zone for the KMFR, in regions above

1,000 m a.s.l. to protect the forest in order to eliminate cardamom plantation, and to stop slash and burn cultivation, over-grazing, illegal timber felling, and firewood cutting (Nanayakkara *et al*., 2009). This zone should be rigorously enforced.

Priority monitoring

With the ever-increasing loss of habitat and their associated species, ecological monitoring and research are required to identify the implications of these practices. However, it is neither possible nor practical to monitor all species, communities or ecosystems, or to conduct field research that covers all of these areas. Therefore, some kind of prioritization is needed, and such could be given to regions or areas that have been subjected to the greatest anthropogenic impacts. In this way the effects of land-use can be managed in a sustainable manner (Spellerberg, 2005). The Convention on Biological Diversity (CBD) in 1993 (Heywood, 1995) identified priorities for inventorying and monitoring habitats and ecosystems with high biological diversity and large numbers of endemic or threatened species (Spellerberg, 2005). Preserving ecosystems involves establishing individual protected areas and creating networks of protected areas. According to the IUCN definition, a protected area is "*a clearly defined geographical space, recognized, dedicated and managed, through legal or other effective means, to achieve the long-term conservation of nature with associated ecosystem services and cultural values* (www.iucn.org)". Protecting areas that contain healthy, intact ecosystems is the most effective way of preserving overall biodiversity (Primark, 2010).

Another approach to monitoring and much less expense is by analysis of satellite images. Methods of monitoring deforestation are well developed, can be adapted from global to site scales, and the images readily available at modest cost (e.g., Eva *et al.*, 2010). A central agency could undertake such an analysis of KMFR, at, for example, annual intervals and this would not only provide for trend analysis, but could identify where enforcement is needed.

Since 1975, Dotalugala, a prominent peak in the KMFR, has been recognized as a "Man and the Biosphere Reserve". Under this remit the Forest Department is authorized to protect its biological diversity (Sri Barathi, 1979). In May 2000, this biosphere reserve was included in the 17,500 ha of the KMFR by Gazette Notification, and according to this, area above 1,067 m a.s.l. became protected. This declaration stipulates the cessation of anthropogenic activities, including cardamom cultivation, within the protected area. To protect the biological diversity of the KMFR, several government departments, non-government organizations and the environmental associations have recognized the KMFR as a "World Heritage Site".

Conservation strategies for anuran amphibians in the Riverstone Region – Bellweathers of habitat recovery

Secondary forest will likely play a major role in the conservation of biological diversity in tropical areas (Ficetola *et al*., 2008). There are however, few studies on their potential for supporting forest species and for the recovery of faunal communities. During our studies of secondary succession in the KMFR we discovered there is a high potential of recolonization by anurans of abandoned agricultural plots that undergo extended periods of secondary succession. Furthermore, the positive relationship between anuran species richness and the vegetational successional stages investigated reveals that this mountain range should be managed carefully to permit the continuance and enhancement of these recovery processes. Our studies revealed that a relatively long time period is required before anuran fauna begin to substantially resemble those of the virgin forest – perhaps 100 years or more. Distance from a potential source area is also important in affecting the rate at which recolonization takes place.

The conservation of the KMFR should protect the wild fauna and flora. On the other hand, it should also generate economic benefits for the peripheral human communities. So that conservation efforts do not negatively affect the lives of humans through restriction of their livelihoods (Wickramasinghe *et al*., 2008).

Future of amphibians in the KMFR

Rapid habitat deterioration of many virgin forests has limited the number of studies that have been able to employ sufficiently robust sample sizes and replicates. Therefore, the effects of habitat alteration on species and, in particular, anurans have been poorly documented and should receive considerably more attention in the future.

We do not know whether current trends will continue as they are, will improve, or will get worse. But we do know that, in general, amphibians are declining as their habitats are being degraded. This implies, generally, that if their habitats survive, this may enhance the survival or recovery of amphibians. Our studies indicate that the anurans of the KMFR are resilient and exhibit strong tendencies to recolonize areas that revert back to a forested state through the process of secondary succession. Thus, if land-use patterns in the KMFR are regulated and monitored effectively there is a reasonable chance that the forest amphibian communities can recover and remain sustainable. As indicators of the health of environments in general, anurans can then be used, through monitoring programs, to assist in monitoring the health of the forests in general.

The practical alternative to deforestation is the introduction of economic alternatives that permit an increase in the protection of virgin forest habitats and promote the restoration of secondary forests in areas of high amphibian diversity while sustaining the livelihood of the local human population.

In the light of evidence about the recolonization patterns by anurans of abandoned tea plantations, the recovery patterns of vegetation, the discovery of several species that have not previously been recorded from the KMFR, and the discovery of unidentified species (many more likely await discovery) in the KMFR, we hope that our current study will prompt further research based on the wildlife of this area. In the meantime, if proper conservation practices are continued, these will assist in protecting the known and unknown species of wildlife in the KMFR.

We propose that anurans can be used as agents to convey a message to the general public about the need to conserve these diminishing and invaluable habitats. If we make correct decisions, act quickly and work accordingly such ends are achievable.

Literature Cited

Aide, T. M. and J. Cavelier, 1994. Barriers to lowland tropical forest restoration in the Sierra Nevada de Santa Marta, Colombia. *Restoration Ecology*, 2: 219 – 229.

Ashton, P. S. and C. V. S. Gunathillake, 1987. New light on the plant geography of Ceylon 1. Historical plant geography. *Journal of Biogeography*, 14: 249 – 285.

Ball, S., 1980. *An account of the cultivation and manufacture of tea in China*. Garland Publishing, New Yolk, USA: xix+382.

Bambaradeniya, C. N. B. and S. P. Ekanayake, 2003. *A guide to the Biodiversity of Knuckles Forest Region*. IUCN, Country office, Colombo, Sri Lanka: vi+68.

Bambaradeniya, C. N. B., J. P. Edirisinghe, D. N. De Silva, C. V. S. Gunatilleke, K. B. Ranawana and S. Wijekoon, 2004. Biodiversity associated with an irrigated rice agro-ecosystem in Sri Lanka. *Biodiversity & Conservation*, 13 (9): 1715-1753.

Bandaratillake, H. M., 2005. The Knuckles Range: Protecting livelihoods, protecting forests. *In*: Durst, P. B., C. Brown, H. D. Tacio and M. Ishikawa, (eds.). *In search of excellence: Exemplary forest management in Asia and the Pacific*. FAO, RECOFTC: 22.

Berger, L., R. Speare and A. Hyatt, 2000. Chytrid fungi and amphibian declines: Overview, implications and future directions. *In*: A. Campbell (ed.), *Declines and disapparances of Australian frogs* Canberra, Australia: Environmental Australia: 21-31.

Buschbacher, R., C. Uhl and E. A. S. Serrao, 1988. Abandoned pastures in eastern Amazonia: 1. Patterns of plant succession. *Journal of Ecology*, 76: 663–681.

Carter, R. E., 2008. *The Japanese arts and self-cultivation*. State University of New Yolk Press, Albany, USA: 185.

Cooray, P. G., 1984. *An introduction to the geology of Sri Lanka*. Department of Geology, Government Printing Press, Colombo, Sri Lanka: xix+340.

Degreef, J., O. J. Rocha, T. Vanderborght and J. P. Baudoin, 2002. Soil seed bank and seed dormancy in wild populations of lima bean (Fabaceae): Consideration for in-situ and ex-situ conservation. *American Journal of Botany*, 89 (10): 1644-1650.

de Rosyro, R. A., 1958. The climate and vegetation of the Knuckles Region of Ceylon. *The Ceylon Forester*, 3 (3&4): 207-260.

de Silva, A., A. M. Bauer, C. C. Austin, S. Gunawardene, J. Drake, P. de Silva, M. G. T. H. Abeyrathna, T. Dassanayaka, G. S. Samarawickrama, R. D. C. S. K. Dasanayaka, A. M. R. K. Amarakoon and M. M. Goonasekara, 2005. The diversity of the Knuckles ecosystem: with special reference to its herpetofauna, The diversity of the Dumbara Mountains (The Knuckles Massif, Sri Lanka): With special reference to its herpetofauna. *Lyriocephalus* (Special issue), 6 (1&2): 13-33.

Ekanayake, S. P. and C. N. B. Bambaradeniya, 2001. *Trekking in the Knuckles Forest: A trekking guide to Alugallena, Dekinda and Nite cave nature trails*. IUCN, Country office, Colombo, Sri Lanka: i+27.

Eva, H., S. Carboni, F. D. R. Achard, N. Stach, L. Durieux, J. -F. O. Faure and D. Mollicone, 2010. Monitoring forest areas from continental to territorial levels using a sample of medium spatial resolution satellite imagery. *Journal of Photogrammetry & Remote Sensing*, 65 (2): 191-197.

Ficetola, G. F., D. Furlani, G. Colombo and F. de. Bernardi, 2008. Assessing the value of secondary forest for amphibian, *Eleutherodactylus* frogs in a gradient of forest alteration. *Biodiversity & Conservation*, 17 (2): 2185-2195.

Forrest, D. M., 1967. *A hundred years of Ceylon tea: 1867-1967*. Chatto and Windus, London, United Kingdom: 320.

Garwood, J., 1989. Tropical soil seed banks: a review. *In*: Leck, M. A., M. A. V. T. Parker and R. L. Simpson, (eds.). *Ecology of soil seed banks*. Academic Press, San Diego, California: 149-209.

Gunatillaka, N. and C. V. S. Gunatillake, 1995. *Knuckles: Sri Lanka in WWF and IUCN (1994-1995) Centers of plant diversity: A guide and strategy for their conservation*, 2: 123-126.

Gunatilake, H. M., D. M. A. H. Senaratne, P. Abeygunawardena, 1993. Role of non-timber products in the economy of peripheral communities of the Knuckles National Wilderness Area of Sri Lanka: Farming systems approach. *Economic Botany*, 47 (3): 271 – 281.

Holl, K. D., 1998. Tropical moist forest restoration on agricultural land in Latin America, *In*: Rana, B. C. (ed.). *Damaged ecosystems and Restoration*. World Scientific Corporation Limited, Farrer Road, Singapore: 25-42.

Heywood, V. H., 1995. *The Global Biodiversity Assessment*. United Nations Environmental Programme, Cambridge University Press, Cambridge, United Kingdom: xi+1140.

Hooper, E., P. Legendre and R. Condit, 2005. Barriers to forest regeneration of deforested and abandoned land in Panama. *Journal of Applied Ecology*, 42: 1165-1174.

IUCN, 2007. *The red list of threatened fauna and flora of Sri Lanka*. Ministry of Environment and Natural Resources of Sri Lanka: xiii+148.

IUCN & Forest Department, 1994. *Management plan for the conservation of the Knuckles Forest (Phase 2).* Forest Department, Battaramulla, Sri Lanka: 22.

Iwata, T., S. Nakano and M. Inoue, 2003. Impacts of past riparian deforestation on stream communities in a tropical rain forest in Borneo. *Ecological Applications*, 13 (2): 461-473.

Janos, D. H., 1980. Mycorrhizae influence tropical succession. *Biotropica*, 12 (Supplement), 56 –64.

Jayaraman, R., 1975. *Caste continuities in Ceylon: A study of the social structure of three tea plantations*. Popular Prakashan, Bombay, India: ix+240.

Lawton, H. W. and P. J. Wilke, 1979. Ancient agricultural systems in dry regions. *In*: Hall, A. E., G. H. Cannell and. H. W. Lawton (eds.). *Agriculture in semi-arid environments.* Springer-Verlag Berlin Heidelberg, Germany: 1-44.

Leck, M. A., M. A. V. T. Parker and R. L. Simpson, 1989. *Ecology of soil seed banks*. Academic Press, San Diego, California: xxii+462.

Mair, V. and E. Hoh, 2009. *The true history of tea*. Thames and Hudson Ltd, London, United Kingdom: 280.

Manamendra-Arachchi, K. and R. Pethiyagoda, 1999. Sri Lanka: the global amphibian hotspot. *Sri Lanka Nature*, 51-54.

Manamendra-Arachchi, K. and R. Pethiyagoda, 2005. The Sri Lankan Shrub-frogs of the Genus *Philautus* Gistel, 1848 (Ranidae: Rhacophorinae), with description of 27 new species. *The Raffles Bulletin of Zoology* (Supplement), 12: 163-303.

Manamendra-Arachchi, K. and R. Pethiyagoda, 2006. *"Sri Lankave Ubayajiween"* (Amphibians of Sri Lanka – Sinhala text). Wildlife Heritage Trust, Colombo, Sri Lanka: 440+88pls.

Marby, H., 1972. *Tea in Ceylon: An attempt at a regional and temporal differentiation of the tea growing areas in Ceylon*. Franz Steiner Verlar GMBH - Wiesbaden, Germany: xxii+238.

Meegaskumbura, M., F. Bossuyt, R. Pethiyagoda, K. Manamendra-Arachchi, M. M. Bahir, M. C. Milinkovitch and C. J. Schneider, 2002. Sri Lanka: An Amphibian hot spot. *Science*, 298: 379.

Meegaskumbura, M., K. Manamendra-Arachchi and R. Pethiyagoda, 2009. Two new species of shrub frogs (Rhacophoridae: *Philautus*) from the lowlands of Sri Lanka. *Zootaxa*, 2122: 51 - 68.

Mohammed, F. 1996. Tea and environmental pollution. *Journal of Tea and Coffee Trade*, 2.

Moxham, R. 2003. *Tea: Addiction, exploitation and empire*. Carroll and Graf Publishers, New Yolk, 10038-2607, USA: 224.

Nanayakkara, A., H. M. D. R. Herath and K. Wickremasinghe, 2009. *Forest Governance Project, Strengthening voices for better choices: Sri Lanka Country Report*. IUCN, Country Office, Colombo, Sri Lanka: 63.

Nepstad, D. C., C. Uhl and E. A. Serrão, 1990. Surmounting barriers to forest regeneration in abandoned, highly degraded pastures: a case study from Paragominas, Pará, Brazil, *In*: Anderson, A. B. (ed.). *Alternatives to deforestation: Steps towards sustainable use of the Amazon Rain Forest*. Colombia University Press, New York, USA: 215-229.

Nizam, B. Z., U. K. G. K. Padmalal and S. W. Kotagama, 2005. Amphibian species diversity alone the northern flank of the Knuckles Range in Sri Lanka, The diversity of the Dumbara Mountains (The Knuckles Massif, Sri Lanka): With special reference to its herpetofauna. *Lyriocephalus* (Special issue), 6 (1 & 2): 267 – 273.

Ohtsuka, T., 1999. Early stages of secondary succession on abandoned cropland in north-east Borneo Island. *Ecological Research*, 14 (3): 281-290.

Padoch, C., E. Harwell and A. Susanto, 1998. Swidden, sawah, and in-between: agricultural transformation in Borneo. *Human Ecology*, 26 (1): 3-20.

Pethiyagoda, P., K. Manamendra-Arachchi, M. M. Bahir and M. Meegaskumbura, 2006. Sri Lankan amphibians: diversity, uniqueness and conservation, *In*: Bambaradeniya, C. N. B. (ed.). *The fauna of Sri Lanka*. IUCN – The World Conservation Union, Sri Lanka: 125-133.

Schloegel, L. M., L. F. Toledo, J. E. Longcore, S. E. Greenspan, C. A. Vieira, M. Lee, S. Zhao, 2012. Novel, panzootic and hybrid genotypes of amphibian chytridiomycosis associated with the bullfrog trade. *Molecular Ecology*, published online 31 July 2012.

Skinner, K. E., 2004. Tree seedling regeneration in *Camelia sinensis* estates: assessing the potential for forest restoration across the forest-grassland boundary in Knuckles Forest reserve, central Sri Lanka. MSc thesis: 87.

Spellerberg, I. F., 2005, M*onitoring ecological change*. Second Edition, The Edinburgh Building, Cambridge, CB2 2RU, United Kingdom: 350.

Sri Barathi, K. P., 1979. Man and Biosphere reserves in Sri Lanka. *Sri Lanka Forester*, 14 (1&2): 37-40.

Stuart, S., J. S. Chanson, N. Cox, B. Young and R. W. Waller, 2004. Status and trends of amphibian declines and extinctions worldwide. *Science*, 306: 1783-1786.

Stuart, S., M. Hoffmann, J. Chanson, N. Cox, R. Berridge, P. Ramani and B. Young, 2008. *Threatened amphibians of the world*. Lynx Edison, Barcelona, Spain, IUCN, Gland, Switzerland and Conservation International, Arlington, Virginia, USA: 758.

Touflan, P. and B. Tallow, 2009. Spatial reliability of soil charcoal analysis: the case of subalpine forest soils. *Ecoscience*, 16 (1): 23-27.

Uhl, C. K., H. Clark, K. Clark and P. Murphy, 1981. Early plant succession after forest cutting and burning in the Upper Rio Negro region of the Amazon Basin. *Journal of Ecology*, 69: 631-648.

Vasey, D. E., 1979. Population and agricultural intensity in the humid tropics. *Human Ecology*, **7** (3): 269-283.

Vitousek, P. M. and J. Sanford, 1986. Nutrient cycling in moist tropical forest. *Annual Review of Ecology and Systematics*, 17: 137 – 167.

Weerawardhena, S. R., 1993. Some aspects of the population ecology of earthworms in the Central Region of Sri Lanka. *Proceedings in Sri Lankan Association for Advancement of Science*, 49: 153 – 154.

Weerawardhena, S. R. and A. P. Russell, 2012. Cover-dependency of anurans in the Riverstone, Knuckles mountain forest range, Sri Lanka. *Taprobanica*, 4 (1): 12-19.

Wells, K. D., 2007. *The ecology and behaviour of amphibians*. The University of Chicago Press, Chicago, USA: xi+1148.

Wickramaratne, S. D. D. W., S. M. Weerasinghe, C. V. S. Gunathilake, D. F. R. P. Burslem and A. M. T. A. Gunarathna, 2009a. Seed availability as a limiting factor for the succession in degraded grasslands in the Knuckles Forest Reserve, Sri Lanka. *Proceedings of the National Forestry Research Symposium*: 23.

Wickramaratne, S. D. D. W., S. M. Weerasinghe, I. A. U. N. Gunathilake, C. V. S. Gunathilake and D. F. R. P. Burslem, 2009b. The effect of some biotic and abiotic factors for the establishment of *Macaranga indica* in grasslands at the Knuckles Conservation area, *Proceedings of the National Forestry Research Symposium*: 24 – 25.

Wickramasinghe, K., P. Steele and A. Senaratne, 2008. Socio-economic impacts of forest conservation on peripheral communities: Case of Knuckles National Wilderness Heritage of Sri Lanka. *12th Biennial Conference of the International Association for the Study of Commons, Cheltenham England*, available online <http://dlc.dlib.indiana.edu/>: 1-15.