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EVOLUTIONARY DISTINCTIVENESS OF SRI LANKAN AVIFAUNA

D.K. ABEYRAMA and S.S. SENEVIRATNE*

*Avian Evolution Node, Department of Zoology and Environment Sciences, Faculty of Science,
University of Colombo, Colombo 03, Sri Lanka*

*sam@sci.cmb.ac.lk

ABSTRACT - The evolutionary history of a phylogenetically distinct group of organisms (a clade) can be traced by using a phylogenetic tree. Such phylogenetic trees can also be used to measure the amount of evolutionary history captured by each member species (node) in the tree. Evolutionary Distinctness (ED) and Evolutionary Distinct and Globally Endangered Score (EDGE) are two such vital parameters that could elucidate the phylogenetic history captured in member species. Birds evolved from a lineage led by dinosaurs over a period of ~100 million years and today the class Aves is a highly specious lineage with over 10,000 extant species. About 5% of the global avian diversity is represented in Sri Lanka with 34 endemic species. Here we quantify the evolutionary distinctness of Sri Lankan avifauna using a phylogenetic tree constructed for all the 342 bird species that are found in 71 Important Bird Areas (IBAs) of Sri Lanka. We constructed the tree from DNA sequence archives at www.birdtree.org using bioinformatics tools and higher-order phylogenetic backbones. ED and EDGE scores of all 342 birds were calculated in R Package. *Batrachostomus moniliger* (Ceylon Frogmouth) is the most evolutionary distinct (ED) species in Sri Lanka, while *Otus thilohoffmanni* (Serendib Scops-owl) is the most evolutionary distinct endangered lineage (EDGE) of the country. *Harpactes fasciatus* (Malabar Trogon), *Pitta brachyura* (Indian Pitta), *Phoenicopterus roseus* (Greater Flamingo) and *Tachybaptus ruficollis* (Little Grebe) are the rest of the top 5 species with highest ED. *Centropus chlororhynchus* (Green-billed Coucal), *Myophonus blighi* (Ceylon Whistling-thrush), *Leptoptilos javanicus* (Lesser Adjutant) and *Pelecanus philippensis* (Spot-billed Pelican) are the rest of the highest EDGE species in Sri Lanka. Members of order Charadriiformes (shorebirds, terns and gulls) in general have the lowest ED values. The species that have evolved recently and have sister or closely related species have relatively low ED. A species that has a high EDGE score is an isolated node in the phylogenetic tree and a globally threatened species. We believe that these parameters will give a novel evolutionary perspective for both wildlife managers and birders on avifauna of Sri Lanka.

KEY WORDS : avifauna, birds, evolutionary distinctness, evolutionary distinct and globally endangered Score, Phylogeny, Sri Lanka

INTRODUCTION

Birds have evolved from a lineage led by dinosaurs over a period of ~100 million years (Brusatte *et al.*, 2015). The explosive radiation in this lineage however had been taken place in ~50 MYA, which made them highly diverged with about 10,000 extant species (Jetz *et al.*,

2012). Of that about 500 species of birds, 5% of the global avian diversity, is represented in Sri Lanka (Rasmussen & Anderton, 2005). Sri Lanka is a continental island in the Indian Ocean which is periodically connected with the mainland India throughout its geological history (MacArthur & Wilson, 1967). As a result the

avifauna of the island is widely considered as a subset of Indian Avifauna (Ripley *et al.*, 1949; Bossuyt *et al.*, 2004). However Sri Lanka carries a unique avifaunal diversity through accommodating 34 endemic bird species (Fernando *et al.*, 2016, Rasmussen & Anderton, 2005). The endemism birds in Sri Lanka (7.43%) is highest in the region. About 240 resident species, 220 winter migrants and 40 pelagic seabirds comprise the rest of the bird diversity of the Island (National Red List of Sri Lanka, 2012). Does each of these 500 species of birds found in Sri Lanka carry a similar evolutionary significance in representing 100 million years of their evolutionary history?

The evolutionary history of a phylogenetically distinct group of organisms (clade) can be traced using a phylogenetic tree, in which the tips and nodes of the tree stand for descendant taxa and their common ancestors respectively (Vellend *et al.*, 2007). Nee and May, (1997) suggested that the more distal nodes (i.e. species) that a branch carries, the lower the amount of evolutionary history captured by each of its distal nodes in that particular branch (Fig. 01). Based on this principle several phylogenetic parameters are being developed in the recent past to measure how much evolutionary history is captured by a single species (Box 01). Evolutionary Distinctness (ED), and Evolutionary Distinct and Globally Endangered Score (EDGE score) are two of such key parameters that can be used to quantify the amount of phylogenetic history captured by the given entity (Jetz *et al.*, 2014).

In this paper the evolutionary distinctness of Sri Lankan avifauna is quantified using a phylogenetic tree constructed for all the 342 bird species that are found in 71 Important Bird Areas (IBAs; www.birdlife.org/worldwide/programmes/sites-ibas) of Sri Lanka. We constructed the tree from DNA sequence archives in global genetic databases (www.birdtree.org) using bioinformatics tools and higher-order phylogenetic backbones (Hackett *et al.*, 2008).

MATERIALS AND METHODS

Total species list, which contains all recorded species in 71 IBAs was obtained from the IBA database of the Field Ornithology Group of Sri Lanka. The list was fed into the option 'Phylogeny subsets' of 'www.birdtree.org' and a set of 5000 phylogenetic trees was generated. 'Hackett All Species: a set of 10000 trees with 9993 OTUs each', which refers to the database of species in the study by Hackett *et al.* (2008) that contains 10,000 trees each with 9,993 operational units was selected as the source of trees.

To generate the grand tree for all 342 species recorded, we followed four main steps. For the construction of the tree we combined relaxed clock molecular trees of well supported clades with a backbone which contained representatives from each clade (Jetz *et al.*, 2012). As the first step each species was assigned to one of the 158 clades which arise from the 158 tips of the backbone trees. Then relaxed-clock trees were constructed for each

BOX 1: Two parameters used to quantify the amount of evolutionary history captured by a member species (node) in a phylogenetic tree.

Evolutionary Distinctness (ED) is a measure of isolation (of species) in the phylogenetic tree. Higher the Evolutionary Distinctness of a species, lower the number of closely related species it has in the phylogenetic tree (Jetz *et al.*, 2014). ED score for a species is calculated by assigning a value to each branch (which is equal to branch length), dividing it by the number of species diverge from the branch and taking the summation of values for all the branches in its evolutionary path from the root of phylogeny to the present (Fig 01; Isaac *et al.*, 2007).

Evolutionary Distinct and Globally Endangered (EDGE) Score is an index derived from combining ED scores with the IUCN red list categories (Butchart *et al.*, 2010). It is a measure of the evolutionary distinctness of endangered lineages.

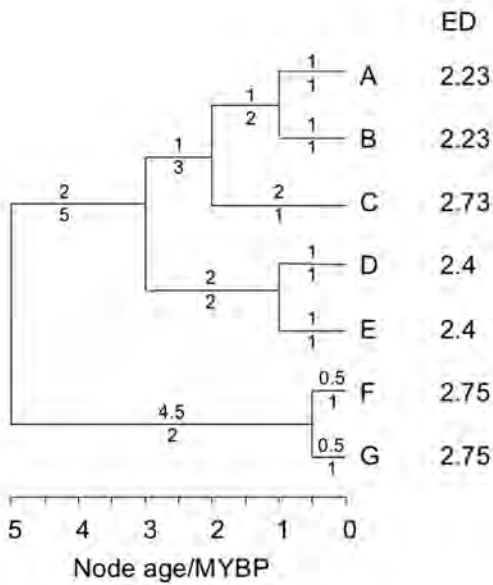


FIGURE 1: Basic procedure for calculating ED for 7 hypothetical species. Numbers above the branches are the branch lengths and numbers below are the number of descendent taxa. MYBP means millions of years before present (Isaac *et al.*, 2007).

clade. The species that do not have genetic information were plugged in to their relevant clades using the information obtained by combining the relaxed clock trees and available taxonomic information (Jetz *et al.*, 2012). The final tree was constructed by merging trees from either of the previous two steps with time calibrated relaxed molecular clock backbone trees (Jetz *et al.*, 2012; www.birdtree.org).

A consensus tree (Fig. 02) was generated from the file of 5000 phylogenetic trees generated by www.birdtree.org using ‘TreeAnnotator v1.8.2’ of the software BEAST (BEAST v1.8.2). First 100 trees were discarded as ‘burnin trees’. ‘User target tree’ was selected as the target tree type while ‘Median heights’ was selected as the node heights. Posterior probability for the tree was 0.75 (Drummond *et al.*, 2007). R platform (R Development Core Team) was used to measure the Evolutionary Distinctiveness (ED) and EDGE scores for each species.

The consensus tree was generated using ‘Treeannotator’ and saved in .tre format. Using the R codes below, the ED of all 342 species were calculated.

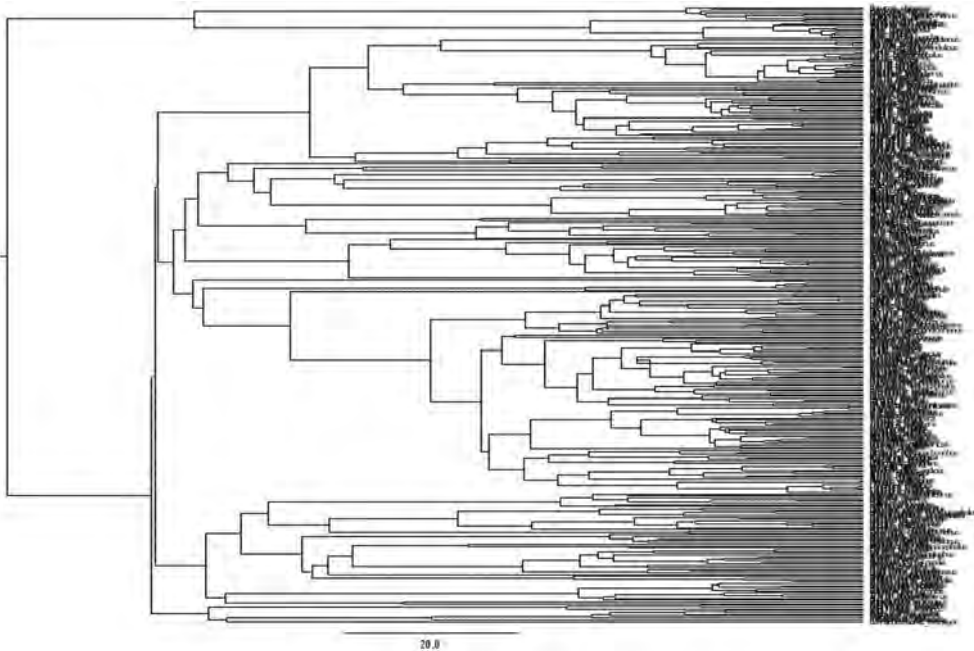


FIGURE 2: Phylogenetic tree of total 342 bird species reported in IBAs of Sri Lanka.

To calculate the Evolutionary Distinctiveness

Originality<-evol.distinct
(tree,type="fair.proportion")

We used $EDGE = \ln(1+ED) + GE * \ln(2)$, to calculate the EDGE scores for each species in the list (Isaac *et al.*,2007).

Where,

ED= Evolutionary Distinctiveness

GE= Red list category weight

(Least Concern=0, Near Threatened and Conservation Dependent=1, Vulnerable=2, Endangered=3, Critically Endangered=4)

We ranked all 342 species based on their ED and EDGE values.

The global ED and EDGE scores of birds were taken from Jetz *et al.* (2014).

RESULTS

According to our calculations the Ceylon Frogmouth (*B. moniliger*), Malabar Trogon (*H. fasciatus*), Indian Pitta (*P. brachyura*), Greater Flamingo (*P. roseus*), Little Grebe (*T. ruficollis*), Spot-billed Pelican (*Pelecanus philippensis*), Eurasian Hoopoe (*Upupa epops*), Osprey (*Pandion haliaetus*), Black-winged Kite (*Elanus caeruleus*) and Oriental Bay-owl (*Phodilus badius*) are the ten most evolutionary distinct (ED) species of birds found in Sri Lanka (Table 01, Fig. 03).



FIGURE 3: Some of the most evolutionary distinct (ED) species of birds in Sri Lanka: A. Ceylon Frogmouth (*B. moniliger*), B. Malabar Trogon (*H. fasciatus*), C. Eurasian Hoopoe (*U. epops*), D. Indian Pitta (*P. brachyura*), E. Little Grebe (*T. ruficollis*), and F. Greater Flamingo (*P. roseus*). Photo credit: Hasitha Perera (images A - F).

TABLE 1: Description of 10 bird species that have the highest evolutionary distinctiveness (ED) in Sri Lanka

ED		Scientific Name	Common English Name	IUCN status	Breeding Status
Local Rank	Global Rank				
01	281	<i>Batrachostomus moniliger</i>	Ceylon Frogmouth	Least Concern	Breeding resident
02	847	<i>Harpactes fasciatus</i>	Malabar Trogon	Least Concern	Breeding resident
03	1426	<i>Pitta brachyura</i>	Indian Pitta	Least Concern	Winter migrant
04	435	<i>Phoenicopterus roseus</i>	Greater Flamingo	Least Concern	Winter migrant and summer loiterer
05	320	<i>Tachybaptus ruficollis</i>	Little Grebe	Least Concern	Breeding resident
06	292	<i>Pelecanus philippensis</i>	Spot-billed Pelican	Near Threatened	Breeding resident
07	49	<i>Upupa epops</i>	Eurasian Hoopoe	Least Concern	Breeding resident
08	08	<i>Pandion haliaetus</i>	Osprey	Least Concern	Rare migrant
09	726	<i>Elanus caeruleus</i>	Black-winged Kite	Least Concern	Breeding resident
10	109	<i>Phodilus badius</i>	Oriental Bay-owl	Least Concern	Rare breeding resident

The ten most evolutionary distinct endangered species (EDGE) of the country are Serendib Scops-owl (*O. thilohoffmanni*), Green-billed Coucal (*C. chlororhynchus*), Ceylon Whistling-thrush (*M. blighi*), Lesser Adjutant (*L. javanicus*), Spot-billed Pelican (*P. philippensis*), Ceylon Blue Magpie (*Urocissa ornata*), Red-faced Malkoha (*Phaenicophaeus pyrrhocephalus*), Malabar Pied Hornbill (*Anthracoceros coronatus*), Ceylon Wood-pigeon (*Columba torringtoniae*) and Black-headed Ibis (*Threskiornis melanocephalus*) (Table 02, Fig 04).

Seabirds belong to Fig 04 the order Charedriiformes such as the Roseate Tern

(*Sterna dougallii*), Common Tern (*Sterna hirundo*), Sandwich Tern (*Sterna sandvicensis*), Lesser Crested Tern (*Sterna bengalensis*) and Great Crested Tern (*Sterna bergii*) have the lowest evolutionary significance and EDGE scores among Sri Lankan birds.

DISCUSSION

Not all species carry the same evolutionary significance because the members from different clades of the tree of life have different levels of phylogenetic isolation (Brusatte *et al.*, 2015). In birds, members of the order Passeriformes have relatively low evolutionary



FIGURE 4: Some of the most evolutionary distinct and endangered (EDGE) species of birds in Sri Lanka: A. Serendib Scops-owl (*O. thilohoffmani*), B. Green-billed Coucal (*C. chlororhynchus*), C. Ceylon Whistling-thrush (*M. blighi*), D. Lesser Adjutant (*L. javanicus*), and E. Ceylon Blue Magpie (*U. ornata*).

Photo credit: Hasitha Perera (images A, D, E) and Gehan Rajeev (images B, C).

distinctiveness than that of some members of non-passerine clades (Jetz *et al.*, 2014). The species with high evolutionary distinctiveness (ED) mostly underwent relatively older speciation events where the ones with low ED

have recent divergent history (Hackett *et al.*, 2008). Furthermore, species with lower ED have diverged recently and are not isolated in the tree of life as they have numerous close relatives near its distal node (Redding *et al.*,

TABLE 2: Description of 10 most evolutionary distinct endangered lineages (EDGE) of birds in Sri Lanka

Local Rank	Global Rank	Scientific Name	Common English Name	IUCN status	Breeding Status
01	406	<i>Otus thilohoffmanni</i>	Serendib Scops-owl	Endangered	Endemic
02	248	<i>Centropus chlororhynchus</i>	Green-billed Coucal	Vulnerable	Endemic
03	504	<i>Myophonus blighi</i>	Ceylon Whistling-thrush	Endangered	Endemic
04	223	<i>Leptoptilos javanicus</i>	Lesser Adjutant	Vulnerable	Breeding Resident
05	557	<i>Pelecanus philippensis</i>	Spot-billed Pelican	Near Threatened	Breeding Resident
06	1079	<i>Urocissa ornata</i>	Ceylon Blue Magpie	Vulnerable	Endemic
07	460	<i>Phaenicophaeus pyrrhocephalus</i>	Red-faced Malkoha	Vulnerable	Endemic
08	1222	<i>Anthracoceros coronatus</i>	Malabar Pied Hornbill	Near Threatened	Breeding Resident
09	1233	<i>Columba torringtoniae</i>	Ceylon Wood-pigeon	Vulnerable	Endemic
10	1022	<i>Threskiornis melanocephalus</i>	Black-headed Ibis	Near Threatened	Breeding Resident

2008). Species that have higher ED are isolated in the phylogenetic tree that is mainly due to extinction of the member species. According to the phylogenetic relationships of birds in Sri Lanka (Fig. 02), it is clear that Ceylon Frogmouth is isolated in the phylogenetic tree and has speciated long ago. As a result Ceylon Frogmouth has the greatest evolutionary significance (75.2995) among Sri Lankan birds. It is noteworthy that no endemic species is listed as the top 10 species with highest ED (Table 01). The reason may be that these endemic species have diverged recently and still they have sister or closely related species in Sri Lanka (Rasmussen & Anderton, 2005; Ripley & Beehler, 1990). For example, *Zosterops ceylonensis* (Highland White-eye) which is an endemic species has *Zosterops palpebrosus* (Oriental White-eye) as its sister species. The ED of these two species are the same and is

relatively low (11.9007). Among the 34 endemic bird species of Sri Lanka (Table 03), *Ocyrceros gingalensis* (Ceylon Grey Hornbill) has the highest ED (49.0085), followed by Green-billed Coucal, *Loriculus beryllinus* (Ceylon Lorikeet), *Glauclidium castanonotum* (Chestnut-backed Owlet) and *Galloperdix bicalcarata* (Ceylon Spurfowl). Among endemics *Sturnus albofrontatus* (White-faced Starling) has the lowest ED (11.7064) followed by *Chrysocolaptes stricklandi* (Layard's Flameback), *Gracula ptilogenys* (Ceylon Hill-myna), *Turdoides rufescens* (Ceylon Rufus Babbler) and Highland White-eye.

The order of ranking is different between the global ranking of ED and the Sri Lankan ranking of ED. For example, Indian Pitta, which ranks 3rd in the local ranking, is 10th when these 10 species are arranged according to their global rankings. Osprey in the other hand ranks

TABLE 3: Evolutionary distinctiveness and EDGE scores of 34 endemic species of birds in Sri Lanka

Rank	Scientific Name	Common English Name	IUCN Status	ED	EDGE
1	<i>Ocyrceros gingalensis</i>	Ceylon Grey Hornbill	LC	49.01	3.91
2	<i>Centropus chlororhynchus</i>	Green-billed Coucal	VU	42.13	5.15
3	<i>Loriculus beryllinus</i>	Ceylon Lorikeet	LC	41.42	3.75
4	<i>Glaucidium castanonotum</i>	Chestnut-backed Owlet	NT	34.25	4.26
5	<i>Galloperdix bicalcarata</i>	Ceylon Spurfowl	LC	28.26	3.38
6	<i>Gallus lafayetii</i>	Ceylon Junglefowl	LC	25.16	3.26
7	<i>Urocissa ornata</i>	Ceylon Blue Magpie	VU	24.38	4.62
8	<i>Phaenicophaeus pyrrhocephalus</i>	Red-faced Malkoha	VU	24.15	4.61
9	<i>Psittacula calthropae</i>	Layard's Parakeet	LC	24.04	3.22
10	<i>Tephrodornis pondicerianu</i>	Common Woodshrike	LC	23.74	3.21
11	<i>Dicaeum vincens</i>	Legge's Flowerpecker	NT	23.33	3.89
12	<i>Otus thilohoffmanni</i>	Serendib Scops-owl	EN	22.99	5.26
13	<i>Columba torringtoniae</i>	Ceylon Wood-pigeon	VU	22.64	4.55
14	<i>Treron pompadora</i>	Sri Lanka Green-pigeon	LC	22.50	3.16
15	<i>Megalaima flavifrons</i>	Yellow-fronted Barbet	LC	21.38	3.11
16	<i>Hirundo daurica</i>	Red-rumped Swallow	LC	20.75	3.088
17	<i>Zoothera imbricata</i>	Sri Lanka Scaly Thrush	NT	20.55	3.76
18	<i>Megalaima rubricapillus</i>	Crimson-fronted Barbet	LC	19.26	3.01
19	<i>Bradypterus palliseri</i>	Ceylon Bush-warbler	NT	18.92	3.68
20	<i>Pycnonotus melanicterus</i>	Black-capped Bulbul	LC	18.55	2.98
21	<i>Pycnonotus penicillatus</i>	Yellow-eared Bulbul	NT	18.41	3.66
22	<i>Myophonus blighi</i>	Ceylon Whistling-thrush	EN	18.38	5.04
23	<i>Pellorneum fuscicapillus</i>	Brown-capped Babbler	LC	18.19	2.95
24	<i>Eumyias sordidus</i>	Dusky-blue Flycatcher	NT	17.82	3.63
25	<i>Dinopium psarodes</i>	Red-backed Flameback	LC	16.72	2.87
26	<i>Pomatorhinus melanurus</i>	Sri Lanka Scimitar-babbler	LC	16.18	2.84
27	<i>Zoothera spiloptera</i>	Spot-winged Thrush	NT	15.87	3.52
28	<i>Garrulax cinereifrons</i>	Ashy-headed Laughingthrush	VU	14.93	4.15
29	<i>Chrysocolaptes stricklandi</i>	Layard's Flameback	LC	14.21	2.72
30	<i>Gracula ptilogenys</i>	Ceylon Hill-Myna	NT	14.02	3.40
31	<i>Turdoides rufescens</i>	Ceylon Rufus Babbler	NT	13.11	3.34
32	<i>Zosterops ceylonensis</i>	Highland White-eye	LC	11.90	2.56
33	<i>Sturnus albofrontatus</i>	White-faced Starling	VU	11.70	3.93
34	<i>Dicrurus lophorhinus</i>	Ceylon Crested Drongo	LC	19.11	3.00

8th in the local list, is 1st when it is taken in the order of global rankings. The reason for this is in the local context, Indian Pitta is a monotypic genus, so its ED goes up when only the birds of Sri Lanka are considered, but when consider the global phylogeny, there are 30 species of pittas (Fig. 02). In the case of Osprey, it is a monotypic genus in both local (Fig. 02) and global contexts. So the ED of Osprey is high locally and globally. As described previously, the EDGE score of a species depends on both the ED and the IUCN red list status of that species (Isaac *et al.*, 2007). Therefore, to have a high EDGE score, the species should be an isolated node in the phylogenetic tree with a globally threatened status. Our results showed that the Serendib Scops-owl has the highest EDGE score (5.26). Serendib Scops-owl however has a relatively low ED (23.00) but it is an endangered endemic. Ceylon Frogmouth topped the list for highest ED, but it is 13th species in the EDGE list. Six species out of the 10 top ranked evolutionary distinct endangered lineages, are endemic to Sri Lanka (Table 03). However the ED of all these endemic species are relatively low.

The order of ranking is again different when considering the National Red List and Global Red List for the calculations of EDGE score. The Serendib Scops-owl which is 1st when using Global Red List is the 23rd when using National Red List, while Slaty-legged Crake (*Rallina eurizonoides*) is 66th when using Global Red List but is 1st when National Red List is used. We stick to Global IUCN rankings because the National Red List tend to overemphasise several small populations of globally widespread species such as Slaty-legged Crake, Yellow-legged Green Pigeon (*Treron phoenicopterus*) and Indian Courser (*Cursorius coromandelicus*), all of them are Critically Endangered in the Local IUCN list due to small population size. On the other hand, some of the range restricted Sri Lankan endemics are lower in the National Red List's vulnerability index even though they are range-restricted endangered species in the IUCN Global list.

The evolutionary past of a clade can be traced through phylogenetic trees. Such phylogenetic trees can also be used to measure the amount of evolutionary history captured by its member species. Evolutionary Distinctness (ED) and Evolutionary Distinct and Globally Endangered Score (EDGE) are two such vital parameters that could elucidate the phylogenetic history captured in member species. Using the total species recorded in IBAs of Sri Lanka we constructed a phylogenetic tree to evaluate the ED and EDGE scores of Sri Lankan Birds. Ceylon Frogmouth is the most evolutionary distinct (ED) species in the island, while Serendib Scops-owl is the most evolutionary distinct endangered lineage (EDGE). Members of order Charadriiformes in general have the lowest ED values.

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