

Habitat Characteristics of the Critically Endangered Pigmy Hog (*Porcula salvania*) of Manas National Park and Rajiv Gandhi Orang National Park in Assam, Northeast India

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1 Introduction

The pigmy hog (*Porcula salvania*) is one of the endemic animals of northeast India and it is the smallest and the rarest wild Suid in the world. The animal was once distributed in tall, wet grasslands throughout the range of southern foothills of the Himalayas, occurring only in the Indian sub-continent (Oliver 1985). These habitats were known as “terai”, which are essentially flat, thinly-forested and well-drained (Oliver 1980). Pigmy hog is an indicator species of “terai” ecosystem. Currently, however, it is restricted to small populations in a few pockets along Assam’s border with Bhutan. These grasslands are characterized by the presence of tall thatch, or elephant grasses. This habitat is fringed on the south by similar looking lowland savannah, which gets waterlogged during monsoons. Most of this area has been taken over for paddy cultivation.

Pigmy hog was thought to be extinct from India, but in 1971 this species was rediscovered from Manas National Park (NP), Assam (Oliver 1980). In fact, the only viable population of the species exists in the Manas NP and nowhere else in the world (Narayan and Deka 2008). The International Union for Conservation of Nature (IUCN) has accorded the highest priority rating (Status Category 6—Critically Endangered) to the species putting it among the most endangered of all mammals. It is also listed in the Schedule I of the Indian Wildlife (Protection) Act, 1972. Thus the conservation of the species is important on priority basis for ensuring their survival.

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The rural population surrounding pigmy hog habitat exert a tremendous pressure on natural resources to meet their basic needs of fuel wood, bush meat, livestock fodders, and other forest produces. Habitat destruction and alteration for agriculture and silviculture are regarded as some of the key causes of threat to pigmy hog's survival in India. Preservation of the grassland habitat within protected areas of such as Kaziranga National Park involves the process of annual dry-season burning. The burning is carried out to prevent re-forestation, to encourage fresh growth of grasses for ungulate grazers, and to prevent accidental fires. This practice and annual flooding of the parks have drastic negative effects on the pigmy hog. Illegal hunting and trapping is also observed as one of the major direct threat to this species. At present, Manas National Park, claimed to be the 'only or the best habitat for the continued survival of the pigmy hog'.

Research and conservation activities was started by the Pigmy Hog Conservation Programme (PHCP), launched in 1996, to save this species from extinction through conservation breeding, reintroduction in the wild, preservation of its original habitat, modifying the management practices etc. to promote survival of natural population of pigmy hog (Narayan and Deka 2008). However, the quantitative information assessing the link between habitat variables and population size, is not available. This is crucial in not only understanding the ecology of this critically endangered species but also in developing future conservation and management plans. From the conservation and rehabilitation point of view, this paper presents information on the habitat characteristics of pigmy hogs in Manas National Park and proposed rehabilitation/release site Rajiv Gandhi Orang National Park with special reference to community structure (Frequency, Density, Dominance Index, Diversity Index and Importance Value Index) to examine the variables that are important in determining the suitable habitats to release and increase the population density of pigmy hog.

2 Materials and Methods

2.1 Study Animal

Adult pigmy hog measures about 65 cm (25 inches) in length, 25 cm (10 inches) in height and weighs 8–9 kg. Females are a little smaller than males and the newborn babies weigh only 150–200 g. A vestigial tail (2.5 cm) and only three pairs of mammae distinguish it from the wild boar (*Sus scrofa*). It is locally called *Nal Gahori* or *Takuri Borah* in Asamese, *Oma Thakri* in Bodo and *Sano Banel* in Nepali. Pigmy hogs are omnivorous in habit and their diet includes roots and tubers, grass, shoots, insects, fruits, seeds, earthworms, and probably even ground nesting birds, eggs and carrion. They are habitual foragers spending in the region of six to eight hours a day actively searching for food. Their foraging involves rooting with their snout, digging and turning up the litter and topsoil, leaving a characteristic forage mark, distinguishable from signs of other species (Oliver

1980). Searching for food is naturally the primary occupation of pigmy hog activity and in both food preference and feeding behaviour they again seem to be quite comparable to *Sus* sp.

They are non-seasonal nest builders. While nest building during the breeding season is quite widespread amongst suids, non-seasonal nest building behavior exhibited by this species is unusual and unique among suids. The nests, made with thatch and other soft plant material collected from the immediate vicinity, are well-concealed and very efficient at protecting against moisture (Oliver 1980). Nests are generally built by late-term sows as a prelude to furrowing for the protection of neonate infants. Though it was formerly classified under the genus, *Sus*, recent phylogenetic analysis support its classification as a unique genus, *Porcula* (Funk et al. 2007). Pigmy hog belongs to the family Suidae under sub-order Artiodactyla, order ungulata of class mammalia.

2.2 Study Area

Study was conducted in Manas National Park where pigmy hog naturally occurs and Rajiv Gandhi Orang National park where it is to be reintroduced (Fig. 1). Manas NP is the core of a tiger reserve, a biosphere reserve, and an elephant reserve apart from being a world heritage site. It is found at the foothills of the Himalayas, bordering Bhutan. Approximately 60 % of its area is covered by grasslands classified as the Eastern Wet Alluvial Grasslands (Champion and Seth 1968). It spans the Manas River and is bounded on the north by the Royal Manas National Park in Bhutan, on the south by the populous region of North Kamrup and on both east and west by forest reserves (26° 30' N–27° 00'N by 90° 50' E–92° 00'E). Several highly important threatened umbrella species of wildlife such as Royal Bengal Tiger (*Panthera tigris*) Indian elephant (*Elephas maximus*), Indian rhinoceros (*Rhinoceros unicornis*) occurs naturally in the park in addition to giant squirrel (*Ratufa indica*), Particolored flying squirrel (*Hylotropes alboniger*), Indian pangolin (*Manis crassicaudata*), Hispid hare (*Caprolagus hispidus*), Golden langur (*Trachypithecus geei*), Capped langur (*Tracopithecus pileatus*) Hoolock gibbon (*Bunopithecus hoolock*), Ganges dolphin (*Platanista gangeticus*), wild boar (*Sus scrofa*), Pygmy Hog (*Porcula salvania*) Swamp deer or Barasingha (*Cervus duvauceli*), sambar (*C. unicolor*), hog deer (*Axis porcinus*), cheetal (*A. axis*), barking deer (*Muntiacus muntjac*), Gaur (*Bos gaurus*), Asiatic wild water buffalo (*Bubalus bubalis*) etc. The Park lies within one of the world's Endemic Bird Areas where the endangered Bengal florican (*Eupodotis bengalensis*) is found.

The Rajiv Gandhi Orang National Park, located on the north bank of the Brahmaputra River in the Darrang and Sonitpur districts of Assam. It was established as a sanctuary in 1985 and declared a National Park on 13th of April 1999. It is also known as the mini Kaziranga National Park (IUCN site) since the two parks have a similar landscape made up of marshes, streams and grasslands and are inhabited by the Great Indian One-Horned Rhinoceros. The park encompasses an

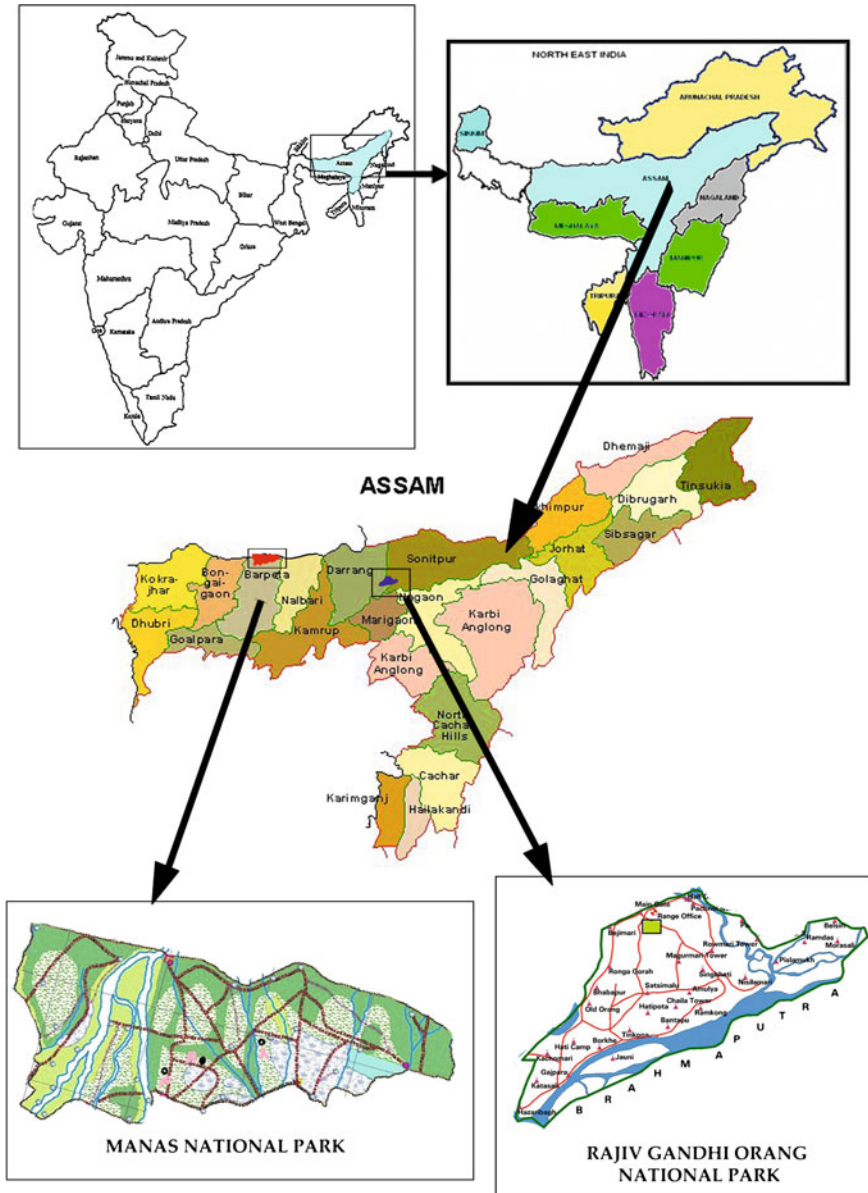


Fig. 1 Location of Manas NP and Orang NP in Assam state, North-East India

area of 78.81 km² (26°28'59"N–26°39'58"N by 92°15'58"E–92°27'00"E/26.483; 92.266). Pachnoi River, Belsiri River and Dhansiri River border the park and join the Brahmaputra River. Except the few species like golden langur, and pigmy hog etc., faunal characteristics of Orang is almost similar to that of Manas.

2.3 Methods

Rapid survey of vegetation was conducted from December 2009 to May 2010. Ten numbers of Belt transects (size: 100 m × 1 m = 100 m²) were laid randomly (Davis and Richards 1933) in activity-sites (natural habitats) of Pigmy hog with identifying marks like foraging marks, footprints, pellets, nests etc. in Manas and 10 belt transects in Orang in selected release sites of the park. All the plant species found within the transect were recorded, and their number counted and identified. If any species, recorded in any of transect, cannot be identified in the field, then herbarium was made for further identification by taxonomic experts. After identification of the species, quantitative analysis of vegetation was done (Mueller-Dombois and Ellenberg 1974 and Sharma 2006). Various community parameters were calculated such as Frequency, Frequency class, Density, Relative frequency, Relative density, IVI, Simpson Dominance Index (C), Shannon-Wiener Diversity Index (H) and Sorensen Similarity index. The comparison between the natural site (Manas NP) and proposed released site (Rajiv Gandhi Orang NP) was made by calculating similarity index of these habitats.

3 Quantitative Analytical Characters Determined

Frequency (%):

$$\text{Frequency (\%)} = \frac{\text{No.of sampling units in which the species occurred} \times 100}{\text{Total no. of sampling units studied}}$$

After determining the frequency (%) of each species, species are distributed among Raunkiaer’s five classes as follows:

Frequency (%)	Frequency class
0–20	A
21–40	B
41–60	C
61–80	D
81–100	E

The value of each of the five frequency classes are found out to prepare the frequency diagram. Raunkiaer on the basis of frequency figures proposed the following law of frequency:- A > B > C <=> D < E The frequency diagram prepared for the study areas is then compared with normal frequency diagram proposed by Raunkiaer.

Density:

$$\text{Density} = \frac{\text{Total no. of individuals of the species in all the sampling units}}{\text{Total no. of sampling units studied}}$$

Relative Frequency:

$$\text{Relative Frequency} = \frac{\text{Frequency of a species}}{\text{Total frequency of all the species}} \times 100$$

Relative density:

$$\text{Relative density} = \frac{\text{Density of the species}}{\text{Total density of all the species}} \times 100$$

Importance Value Index (IVI) = Relative Frequency + Relative Density

Simpson Dominance Index (C): $C = \frac{1}{\sum (n_i/N)^2}$ *

where,

n_i IVI of individual species

N Total IVI of all the species

$$\text{Sorensen Similarity index} := \frac{2C}{(A + B)} \times 100$$

where 'A' is the number of species at area A, 'B' is the number of species at area B and 'C' denotes the number of species common to area "A" and area "B".

4 Results and Discussion

A total of 51 plant species were recorded from the selected both study sites. Of these, 21 plant species were found common to both sites. Photographs of these 51 plants are given in Plates 1, 2, 3, 4, and 5. 36 plant species were recorded and identified from each study site (Table 1). 30 plants were identified up to species level and 21 plants were identified up to only genus level.

4.1 IVI of Pigmy Hog Habitat in MANAS NP and ORANG NP

In Manas NP 36 species of plant were identified under 20 different families, out of which 7 species belong to grass habit and others belong to non-grass habit (Table 1). In Orang NP also, 36 species of plants were identified under 18 families out of which 8 species belong to grass habit and others belong to non-grass habit. Figures 2 and 3 represent bar diagrams of IVI of different species arranged in descending order for Manas and Orang, respectively.

It can be observed that in Manas, species with highest IVI is *Narenga porphyrocoma* (26.61) followed by *Cymbopogon martenii* (20.25), *Saccharum*

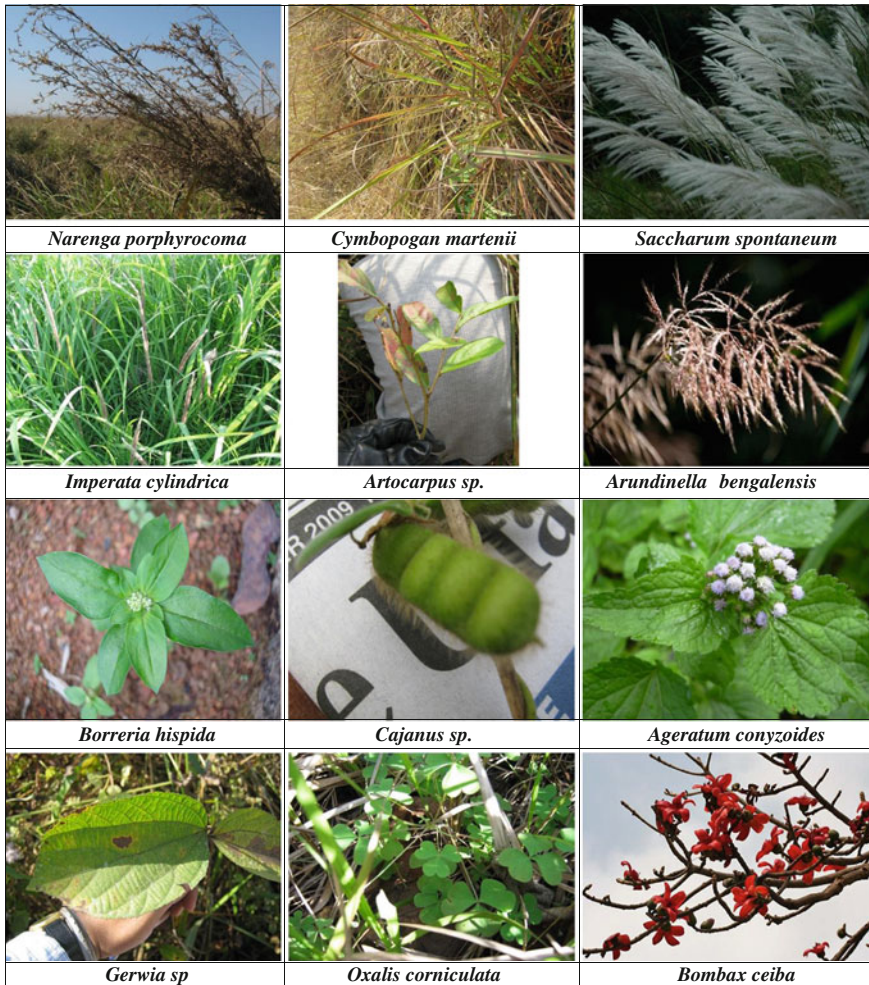


Plate 1 Plant species recorded in Pigmy hog’s habitats of Manas and Orang NP.

spontaneum (19.06), *Imperata cylindrica* (17.98), *Commelina sp.1* (17.63), *Arundinella bengalensis* (17.05), *Commelina bengalensis* (15.54) (Fig. 2). So, these are the dominant species in the surveyed Pigmy Hog natural habitat of Manas. *Narenga porphyrocoma* is mainly used by Pigmy hog for nest building purpose. It also feeds on the root of *Narenga porphyrocoma*, *Cymbopogan martenii*, *Saccharum spontaneum*, *Imperata cylindrica*, and *Arundinella bengalensis*. These dominant species are mainly grass in habit. Kaziranga National Park of Assam is reported to have similar types of dominant tall grass species of *Saccharum procerum*, *Sccharum spontanium* and *Imperata cylindrica* (Mary et al. 1998).

The highest IVI of *Narenga porphyrocoma* (27.43) followed by *Cymbopogan martenii* (20.69442), *Saccharum spontaneum* (16.68), *Arundinella bengalensis*

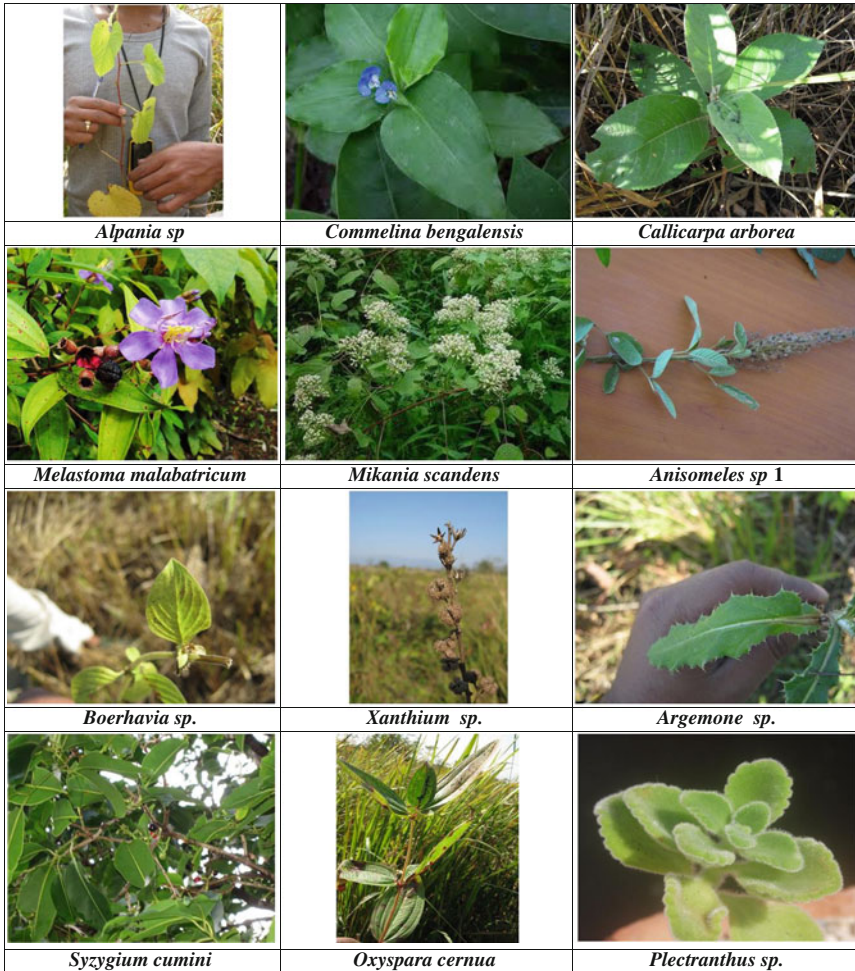


Plate 2 Plant species recorded in Pigmy hog's habitats of Manas and Orang NP.

(15.82), *Commelina* sp.1 (15.76), *Commelina bengalensis* (15.68) etc. were recorded in Orang NP. So, these are the dominant species in the surveyed habitat of Orang NP. *Imperata cylindrica* has important value index of only 5.05 in Orang National Park whereas it has IVI of 17.98 in Manas National Park (Fig. 3).

4.2 Relative Density of Pigmy Hog Habitat in MANAS NP and ORANG NP

Highest relative density of plant species in Pigmy Hog habitat of Manas was *Narenga porphyrocoma* (19.519 %) followed by *Cymbopogon marteni* (13.167 %),

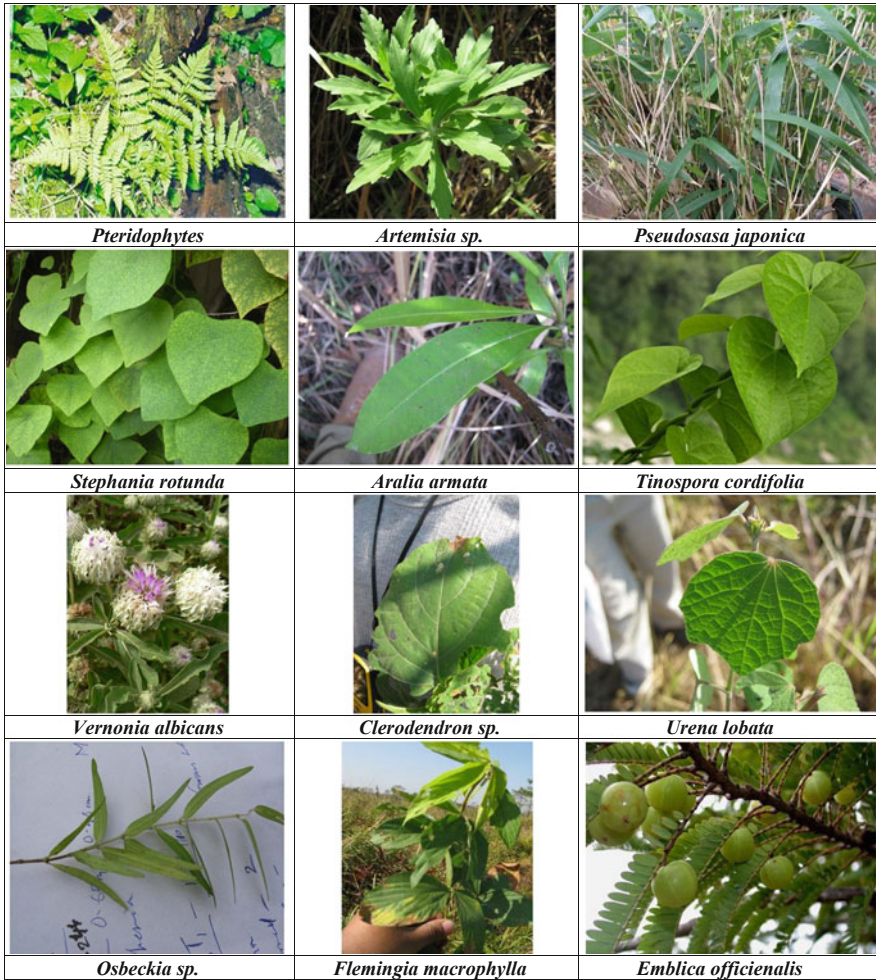


Plate 3 Plant species recorded in Pigmy hog’s habitats of Manas and Orang NP.

Saccharum spontaneum (11.973 %), *Imperata cylindrica* (10.89 %) etc. (Table 1) while plant species with highest relative density in Orang NP were *Narenga porphyrocoma* (21.22 %) followed by *Cymbopogan marteni* (14.48 %) and *Saccharum spontaneum* (10.47 %). *Arundinella bengalensis* has almost same relative density in Orang (9.60 %) and Manas (9.96 %) (Table 1).

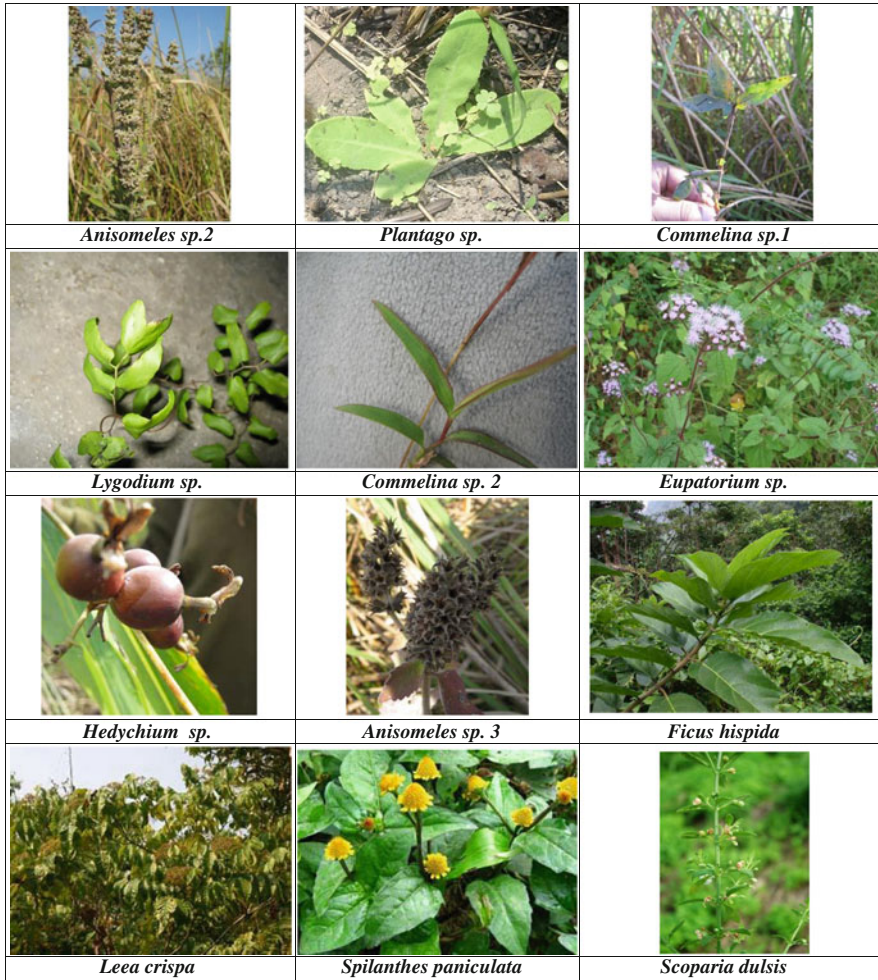


Plate 4 Plant species recorded in Pigmy hog's habitats of Manas and Orang NP.



Plate 5 Plant species recorded in Pigmy hog's habitats of Manas and Orang NP.

Table 1 Different values of vegetation analysis like frequency (*FR*), frequency class (*FRC*), density (*D*), relative frequency (*FR*), relative density (*RD*), importance value index (*IVI*), dominance index (*DI*) and diversity index (*Div. I*) of study sites

Sl. No.	Species	Manas										Orang									
		Family					Manas					Orang					Orang				
		FR	FRC	D	RF	RD	IVI	DI	Div I	FR	FRC	D	RF	RD	IVI	DI	Div I				
1	<i>Narenga porphyrocoma</i>	100	E	12,260	7.09	19.51	26.61	0.11660	0.01773	100	E	12,280	6.21	21.22	27.43	0.018817	0.27				
2	<i>Cymbopogon martinii</i>	100	E	8,270	7.09	13.16	20.25	0.10075	0.01027	100	E	8,380	6.21	14.48	20.69	0.010706	0.23				
3	<i>Saccharum spontaneum</i>	100	E	7,520	7.09	11.97	19.06	0.09734	0.00910	100	E	6,060	6.21	10.47	16.68	0.00696	0.2				
4	<i>Imperata cylindrica</i>	100	E	6,840	7.09	10.88	17.98	0.09410	0.00810	60	C	770	3.72	1.3	5.05	0.000639	0.09				
5	<i>Commelina sp.1</i>	100	E	6,620	7.09	10.53	17.63	0.09303	0.00778	100	E	5,530	6.21	9.55	15.76	0.006216	0.20				
6	<i>Arundinella bengalensis</i>	100	E	6,260	7.09	9.96	17.05	0.09120	0.00728	100	E	5,560	6.21	9.60	15.82	0.006257	0.20				
7	<i>Commelina bengalensis</i>	100	E	5,310	7.09	8.45	15.54	0.08626	0.00605	100	E	5,480	6.21	9.47	15.68	0.006148	0.19				
8	<i>Leea crispa</i>	80	D	2,070	5.67	3.29	8.96	0.06046	0.00201	60	C	1,230	6.21	9.47	15.68	0.006148	0.19				
9	<i>Mikania scandens</i>	50	C	1,560	3.54	2.48	6.02	0.04582	0.00091	90	E	2,390	5.59	4.13	9.72	0.002362	0.14				
10	<i>Grewia sp</i>	70	D	520	4.96	0.82	5.79	0.04456	0.00084	10	A	60	0.62	0.10	0.72	1.31E-05	0.02				
11	<i>Oxalis corniculata</i>	50	C	1,370	3.54	2.18	5.72	0.04417	0.00082												
12	<i>Bombex ceiba</i>	40	B	490	2.83	0.78	3.61	0.03149	0.00033	10	A	200	0.62	0.34	0.97	2.34E-05	0.02				
13	Alpinia	40	B	360	2.83	0.57	3.41	0.03017	0.00029												
14	<i>Pseudosasa japonica</i>	30	B	460	2.12	0.73	2.86	0.02640	0.00020	100	E	670	6.21	1.15	7.36	0.001358	0.12				
15	<i>Callicarpa arborea</i>	30	B	240	2.12	0.38	2.50	0.02380	0.00016												
16	<i>Tinospora cordifolia</i>	30	B	160	2.12	0.25	2.38	0.02292	0.00014												
17	<i>Melastoma malabatricum</i>	20	A	380	1.41	0.60	2.02	0.02017	0.00010	80	D	480	4.96	0.82	5.79	0.000841	0.10				
18	<i>Eupatorium sp.</i>	20	A	300	1.41	0.47	1.89	0.01914	0.00009	30	B	530	1.86	0.91	2.77	0.000193	0.05				
19	<i>Anisomelus sp.1</i>	20	A	270	1.41	0.41	1.84	0.01875	0.00008												
20	<i>Boerhavia sp</i>	20	A	260	1.41	0.41	1.83	0.01867	0.00008												
21	<i>Xanthium sp.</i>	20	A	100	1.41	0.15	1.57	0.01654	0.00006												
22	<i>Argemone sp</i>	20	A	90	1.41	0.14	1.56	0.01645	0.00006												
23	<i>Syzgium cumini</i>	20	A	90	1.41	0.14	1.56	0.01645	0.00006												
24	<i>Oxypara cernua</i>	20	A	50	1.41	0.07	1.49	0.01586	0.00006	10	A	250	0.62	0.43	1.05	2.77E-05	0.02				
25	<i>Platago sp.</i>	20	A	40	1.41	0.06	1.48	0.01578	0.00005	10	A	90	0.62	0.34	0.96	2.34E-05	0.02				
26	<i>Pteridophytes</i>	10	A	300	0.70	0.47	1.18	0.01316	0.00003	60	C	2,550	3.72	4.40	8.13	0.001654	0.13				
27	<i>Artemisia sp</i>	10	A	160	0.70	0.25	0.96	0.01114	0.00002												
28	<i>Clerodendron sp.</i>	10	A	140	0.70	0.22	0.93	0.01085	0.00002	10	A	150	0.62	0.25	0.88	1.94E-05	0.02				

(continued)

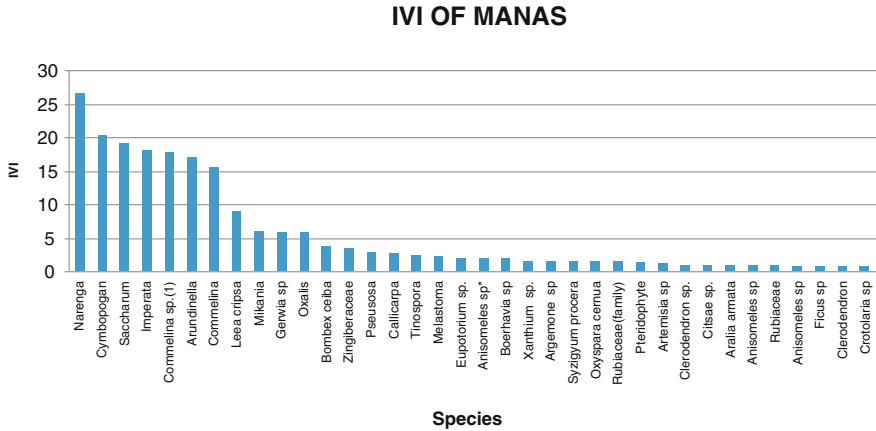


Fig. 2 IVI of plant species recorded in Manas NP

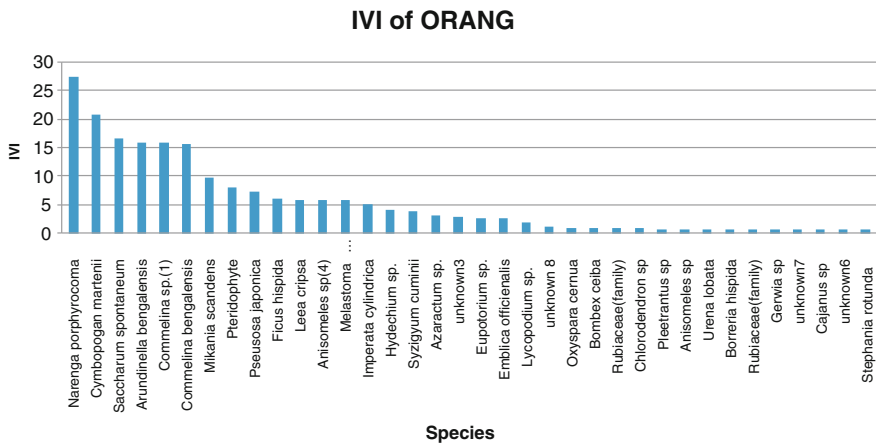


Fig. 3 IVI of plant species recorded in Orang NP

4.3 Frequency Class of Pigmy Hog Habitat in MANAS NP and ORANG NP

The data in Table 1 is used to calculate the frequency no. of frequency classes of Manas NP and Orang NP (Table 2) which is illustrated in Figs. 4 and 5 respectively. Based on which the frequency diagrams obtained for the Pigmy Hog habitat in Manas NP and Orang NP are as follows:- A > B > C = D < E—Manas and A > B > C = D < E—Orang.

The obtained frequency diagrams are similar with that given by Raunkiaer. Hence, it can be concluded that the habitat of Pigmy Hog in Manas NP and the proposed future release area of Orang NP belongs to Normal grassland habitat.

Table 2 Distribution of frequency class in Manas NP and Orang NP

Frequency class	Manas NP			Orang NP		
	Occurrence No	Frequency (%) of frequency class (observed)	Frequency (%) of frequency class (normal)	Occurrence No	Frequency (%) of frequency class (observed)	
A	20	55.56	53	15	41.66	
B	5	13.89	14	7	19.44	
C	2	5.56	9	3	8.33	
D	2	5.56	8	3	8.33	
E	7	19.44	18	8	22.22	

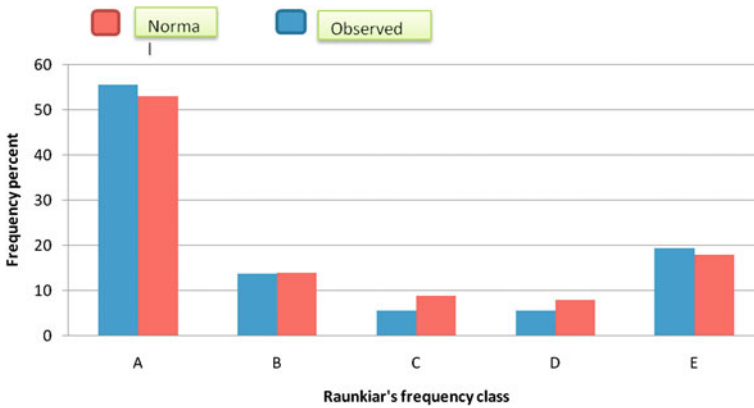


Fig. 4 Frequency distribution of plants species of Pigmy Hog habitat in Manas NP

4.4 Dominance Index and Diversity Index of Pigmy Hog Habitat in MANAS NP and ORANG NP

Using the IVI in Table 1, Simpson dominance index and Shannon-Wiener diversity index of individual species were calculated and their total was calculated as 0.072 and 2.93 respectively for Manas NP. In case of Orang NP the total of dominance indices and total of diversity indices were found to be 0.0666 and 3.01 respectively. These two values are used for comparing the two study areas. So, Diversity of Manas < Diversity Orang. It can be observed that the vegetation in Manas is less diverse than Orang (Table 3 and Fig. 6). Since diversity is less in Manas but higher in Orang, dominance index should be higher in Manas but lower in Orang which can be justified from Table 3 and Fig. 7.

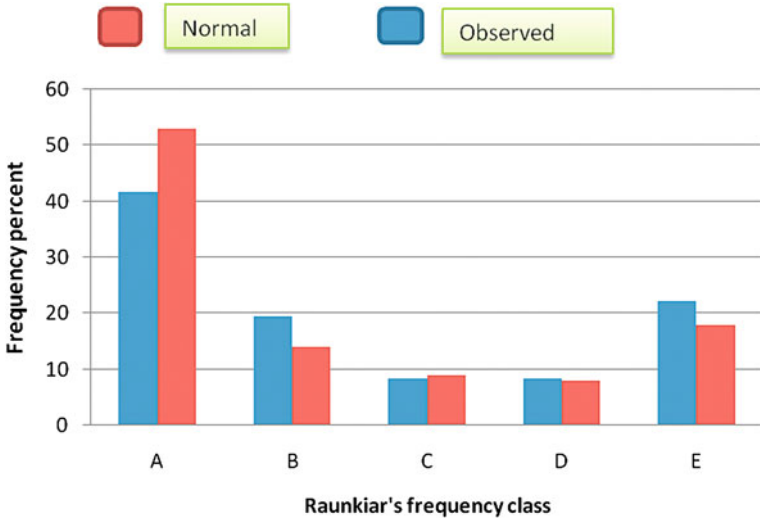


Fig. 5 Frequency distribution of plants species of proposed Pigmy Hog habitat in Orang NP

Table 3 Showing dominance index and diversity index for Manas NP and Orang NP

Sites	Dominance index	Diversity index
Manas	0.072	2.93
Orang	0.0666	3.01

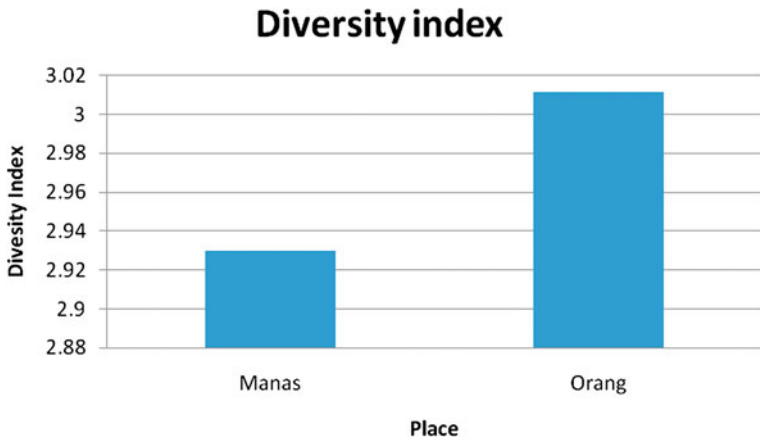


Fig. 6 Diversity index of Manas NP and Orang NP

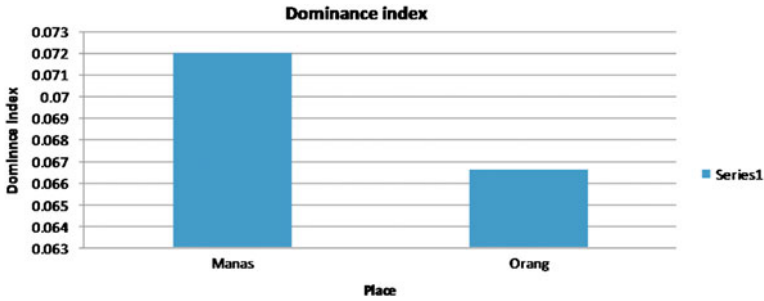


Fig. 7 Dominance index of Manas NP and Orang NP

4.5 Similarity Index of MANAS: ORANG Pigmy Hog Habitats

Sorensen similarity index for Manas-Orang was calculated as 58.33 %. Since it is more than 50 % it can be stated that Pigmy Hog habitat in Manas NP is similar to that of Orang NP.

5 Conclusion

Four species of grasses, *Narenga porphyrocoma*, *Cymbopogon martenii*, *Saccharum spontaneum* and *Arundinella bengalensis*, on which pigmy hog is mostly dependent for food and shelter, were found to be dominant in both habitats (Manas NP and Orang NP). Two species of *Commelina* sp. were also dominant in both parks. It can be concluded that Orang has almost similar vegetation as Manas. Hence, rehabilitation of Pigmy Hog in Orang NP would help in conservation of pigmy hog population. The proposed release site can be more improve by introduction of plant species like *Oxalis corniculata*, *Alpania* sp., *Callicarpa arborea*, *Tinospora cordifolia* etc. which have good IVI values pigmy hog distributed area of Manas NP.

However, only based on vegetation suitability we cannot surely ascertain about the suitable habitat of pigmy hog, because suitability of habitat also depends on various other factors like seasonal vegetation composition, physico-chemical characters of soil, anthropogenic threat, prey-predator relationship, other locality factors etc. Further studies on impacts of the changing climate and global warming on pigmy hog are recommended. It is expected that these vegetation parameters of pigmy hog habitat will help in determining the other factors and will also help in establishing a foundation for suitable habitat of this species.

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References

- Champion HG, Seth SK (1968) A revised survey of forest types of India. The Manager of publications, Dehra Dun
- Davis TAW, Richards PW (1933) The vegetation of Moraballi Creek, British Guiana. An ecological study of a limited area of tropical rain forest. *I J Ecol* 21:350–384
- Funk SM, Verma SK, Larson G, Prasad K, Singh L, Narayan G, Fa JE (2007) The pigmy hog is a unique genus: 19th century taxonomists got it right first time round. *Mol Phylogenet Evol* 45:427–436
- Mary PP, Solanki GS, Limboo D, Upadhaya K (1998) Observations on feeding and territorial behaviour of Indian rhino (*Rhinoceros unicornis*) in Kaziranga National Park, Assam, India. *Tiger Paper* 25(4)4: 25–28
- Mueller-Dombois D, Ellenberg D (1974) Aims and methods of vegetation ecology. Wiley, USA
- Narayan G, Deka PJ (2008) Conservation breeding programme for Pigmy Hogs (*Porcula salvania*). *Zoos' Print* XXIII(11)11:19–21
- Oliver, WLR (1980) The Pigmy Hog: the Biology and conservation of the Pigmy Hog, *Sus salvanius* and the Hispid Hare, *Caprolagus hispidus*. Special scientific report 1980; No. 1, Jersey Wildlife Preservation Trust, Jersey, UK, p 120
- Oliver WLR (1985) The distribution and status of the hispid hare (*Caprolagus hispidus*), with some additional notes on the pigmy hog (*Sus salvania*)—a report on the 1984 field survey. Unpublished. Rrep. to Wildlife Preservation Trust, p 94
- Sharma PD (2006) Ecology and environment, vol 179, 7th edn. Rastogi publications, Meerut, New Delhi, p 191