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A classification of subtropical riverine grassland and forest in Chitwan National Park, Nepal

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Abstract

Eight grassland associations with ten phases and two riverine forest associations were identified on the floodplains of Chitwan National Park in lowland Nepal. Two *Themeda arundinacea* associations were primarily stable edaphic associations on mollic soils, often with aquic moisture regimes. *Themeda* associations were floristically similar to adjacent sal forest. Four mixed tall-grass associations primarily of *Narenga porphyrocoma*, *Saccharum bengalense*, and *Saccharum spontaneum* were identified. These and *Themeda arundinacea* types were characterized by a very weak component of woody species. Two grass-shrub associations of *Saccharum bengalense* and *Narenga porphyrocoma* with a strong woody species component typical of riverine forest were described. *Trewia nudiflora-Bombax ceiba* riverine forest and mixed riverine forest types also were identified on the basis of understory composition. Mixed tall-grass and grass-shrub associations appeared to represent early and late phases of grassland succession to riverine forest. Trajectories of succession are controlled primarily by fire and wildlife grazing. The classification refines the general classifications applied to the central Terai of Nepal and India, and should provide insight for classification of other Terai riverine grasslands.

Abbreviations: DS – Dabadghao and Shankarnarayan's 1973 grassland classification for India, IMCY – *Imperata cylindrica*, NAFA – *Narenga fallax*, NAPO – *Narenga porphyrocoma*, PHKA – *Phragmites karka*, SABE – *Saccharum bengalense*, SASP – *Saccharum spontaneum*, THAR – *Themeda arundinacea*

Nomenclature: Grasses: Bor, N. 1960. The grasses of Burma, Ceylon, India and Pakistan. All other species: Hara, H., Chater, A. O. & Williams, L. H. J. 1978–1982. An enumeration of the flowering plants of Nepal, 3 volumes.

Introduction

The Terai riverine grasslands at the base of the Himalayas in Nepal and India are among the most productive in the world (Lehmkuhl 1989), but little work has been done to describe their organization. Grasslands have been classified locally in dry regions of the subcontinent (see Yadava &

Singh 1977 for review), but the broad classification of Dabadghao and Shankarnarayan (1973) (hereafter called DS) remains the commonly cited system for Terai riverine grasslands. The DS *Saccharum-Phragmites-Imperata* grassland type, however, is generalized for all of north India (Yadava & Singh 1977) and is not very useful for research or management of specific locales. The type describes an edaphic climax dominated by *Phragmites karka* that ignores variation in composition with soil conditions and successional change outside of human disturbance regimes. Terai grasslands are more complex than described and beg for a more specific classification.

The riverine grasslands of Chitwan National Park, in the Chitwan dun valley of south-central Nepal, are a prime example of the complexity of Terai grasslands. *Phragmites karka* and *Saccharum spontaneum* form an apparently stable association on marshy sites as described by the DS type, but marshes make up only a small portion of the landscape (Lehmkuhl 1989). Tall-grass associations of *Saccharum*, *Narenga*, and *Themeda* species occupy old and new floodplain terraces with a variety of soil moisture conditions. Some types are apparently edaphic climaxes on poorly drained soils, but the largest area is occupied by tall-grass associations originating on floodplain and succeeding to riverine forest and possibly sal (*Shorea robusta*) forest (Lehmkuhl 1989). *Saccharum spontaneum* forms extensive, tall and dense stands on recent floodplain alluvium. *Saccharum*, *Narenga*, and *Themeda* species from tall (4–7 m) grass swards on hydric sites and grassland-savanna on more well-drained soils with primarily *Bombax ceiba*, but also with the trees *Xeromphis uliginosa* and *Cleistocalyx operculata*. *Imperata cylindrica* forms early-successional monospecific stands on old agricultural sites, and is a subdominant in the tall-grass types. Little is known beyond speculation of the floristic and successional relationships of these grasslands.

I present a classification of riverine grassland and forest for Chitwan National Park in the central Nepal Terai. The classification captures floristic and successional relationship among associations, and provides an ecological basis for grassland management. A more complete account of the landscape- and stand-level organization of these grasslands is found in Lehmkuhl (1989).

Methods

Study area

Grassland was studied in a portion of the Chitwan National Park, Nepal, at longitude 84°, 20 ′E. and latitude 27°, 30 ′N. (Fig. 1). The Park occupies an area of 1040 km^2 in the Chitwan dun valley of the Siwalik physiographic region (Mishra 1982). Elevation ranges from 815 m on the crest of the Churia Hills in the Siwalik Range to 120 m along the Rapti River floodplain terraces (Bolton 1975) where the study area was located.

Park soils are representative of the Chitwan dun-valley types (HMG 1968, Carson *et al.* 1986). Alluvial soils range from sand and coarse loams on new terraces to sandy and silty-clay loam on older terraces. Drainage is variable with the water table ranging seasonally from 0–2 m. Older soils on fans, aprons, ancient river terraces, and Quaternary basin deposits are well-drained sandy loam to loam, with the water table seasonally ranging from 1–15 m.

Sal forest covers about 70% of the Park (Bolton 1975) on well-drained soils, and is considered the 'climatic climax' (Puri 1960; Champion & Seth 1968). Deciduous riverine forest on floodplains constitutes about 7% of the Park (Bolton 1975). Early-successional stands are dominated variously by the trees *Acacia catechu*, *Dalbergia sissoo*, *Bombax ceiba*, and *Trewia nudiflora*. Late-successional stands are characterized by remnant *Bombax* and *Trewia* codiminant with evergreen species such as *Persea* spp., *Syzigium* spp., *Mallotus philippinensis*, *Dysoxylum* sp., and *Ficus racemosa*. Grasslands make up about 23% of the Park (Bolton 1975).

The research study area encompassed 2300 ha along the north-central boundary of the Park near the village of Sauraha (Fig. 1) – the largest area of grassland and riverine forest in the Park. The research area extended 9 km west from the east end of Itcharny Island to the Dumaria area, and

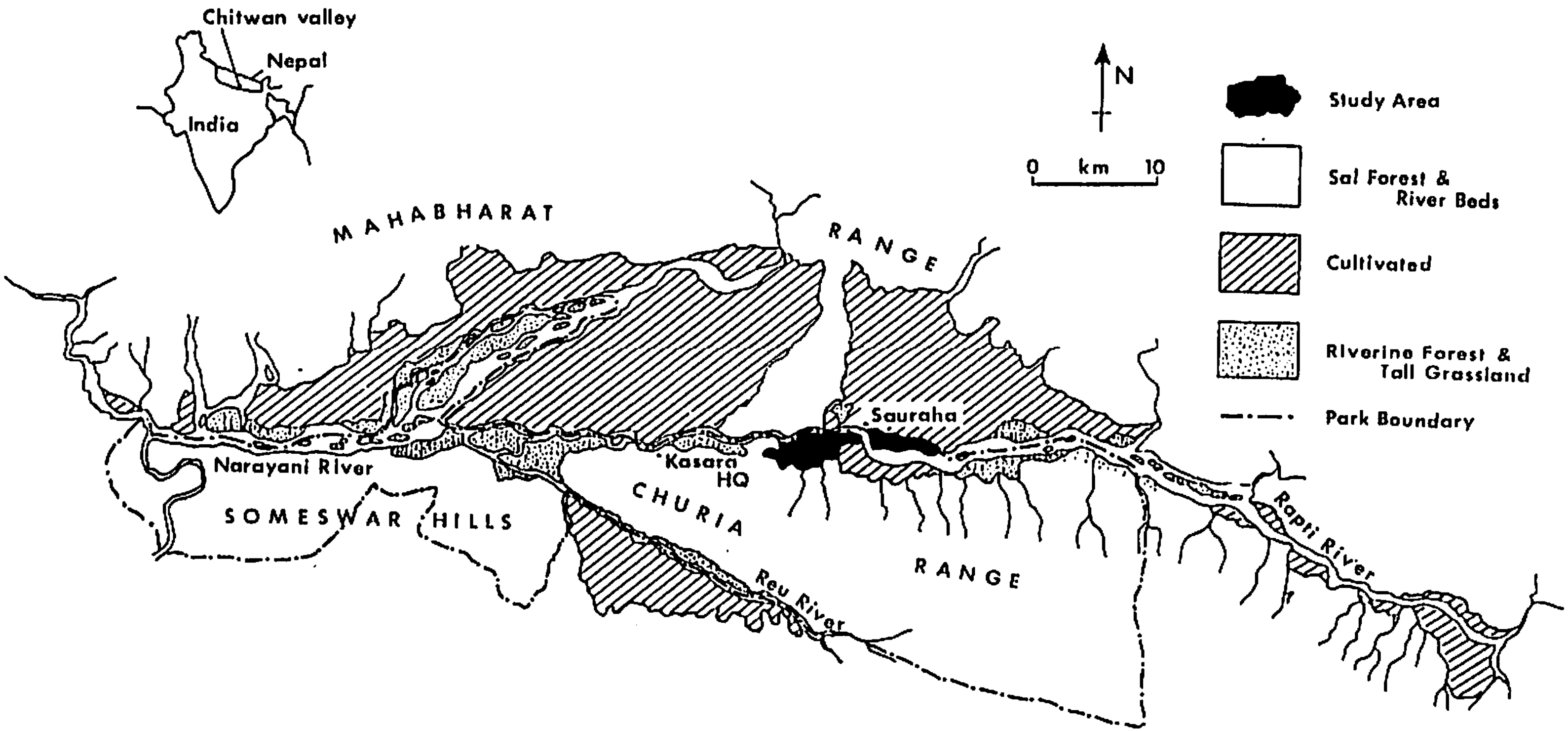

Fig. 1. Map of Chitwan valley, Nepal, showing location of Chitwan National Park, research study area, general plant cover, and land use. (Modified from Laurie 1978).

from the south bank of the Rapti River about 3 km south to the edge of the sal forest. Grassland, savanna, and riverine forest comprised most of the sampled area. Sal forest and small meadows inside the sal forest within 250 m of the sal forest-grassland boundary also were sampled to examine floristic similarities between grassland and sal forest. Classification of sal forest, however, was not an objective of the study.

Sampling procedure

Approximately two-thirds of the study area, extending 6 km west from Sauraha, was sampled with 188 relevé plots. One hundred and sixty-eight of these plots were taken south of the Rapti River, and twenty plots were measured on the north and east side of the river on the floodplain south of Itcharny Island. Plot locations initially were mapped on aerial photographs in a 250 m × 250 m grid pattern, with the starting point randomly chosen. Plots were located in the field with aerial photographs and a hand compass.

Minimum-plot sizes (Mueller-Dombois & Ellenberg 1974) were determined by preliminary sampling of *S. spontaneum* and *Narenga porphyrocoma* swards, and the understory of riverine forest. A plot area on the species-area curves was selected to include at least 90% of the total number of observed species (Fig. 2). Plots of 8.5 m × 8.5 m were used for grassland sample points, and 11 m × 11 m plots were used in riverine forest and sal forest. The riverine forest plot area was considered adequate for sampling sal forest understory because sal forest understory is less diverse than riverine forest, but more diverse than grassland. All herbs, shrubs, and tree regeneration within sample plots were listed and cover/abundance was rated on the Domin-Krajina cover-abundance scale (1–10, or '+' for solitary plants) (Mueller-Dombois & Ellenberg 1974). Unknown species were described, numbered, and collected for later identification at the National Herbarium. Notes were made of overstory tree species inside and outside the plot, and of understory species occurring outside and adjacent to

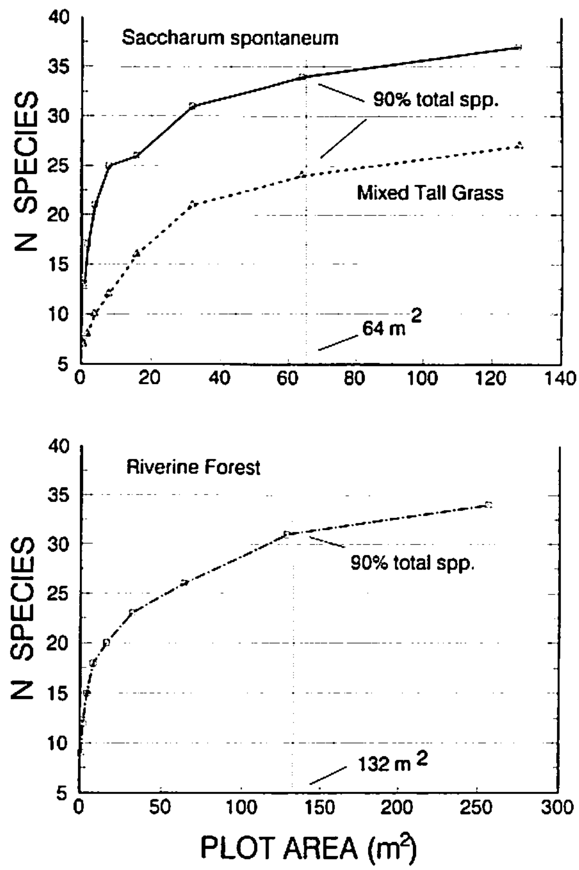

Fig. 2. Species-area curves for (*a*) *Saccharum spontaneum* and mixed tall-grass *Narenga porphyrocoma* and *Saccharum bengalense* grassland types, and (*b*) deciduous riverine forest understory in Chitwan National Park, Nepal.

plots. General soil information was obtained from soil survey maps prepared by HMG Department of Forests (HMG 1968) and Carson *et al.* (1986).

Data analysis

Sample plot classification was performed by polythetic divisive clustering with the TWINSPAN program (Hill 1979). TWINSPAN begins with all samples together in a single group, or cluster, and successively divides each cluster of samples dichotomously into a hierarchy of smaller and smaller clusters until a specified cluster size or number of divisions are attained. I limited classification to a maximum of five division levels, because cluster size became too small for reliable interpretation with more divisions. Clusters derived by the program from a single parent cluster were sometimes later regrouped if the number of sample plots in the cluster was few or the floristic dissimilarity of the clusters were judged insignificant.

Psuedospecies cut-levels were set to group psuedospecies (a single species occurrence divided into separate abundance categories for classification purposes) into five categories of less than 1% cover, 1–5% cover, 6–25% cover, 26–75% cover, and >75% cover. All other program options were at default levels. Cover-abundance values of '+' (solitary, cover insignificant) were grouped with the '1' values (scarce, cover insignificant) to conform to a 1–10 scale for computational simplicity. There was little information lost by grouping these two classes because the difference between the two ratings is minor.

Species with a frequency of five or less plots were eliminated from the analysis, consistent with Gauch's (1982) recommendations, to yield 146 species for inclusion in the cluster analysis. Appendix 2 gives a partial listing of frequency and cover values of species used in the classification. It was not possible to identify some plants to genus and species because collection of plant parts in early phenological stages during the sampling period provided inadequate material for identification, or because the plants of the Park were not well represented in the collection of the National Herbarium. Local names or collection numbers were used to represent unidentified species, which generally did not have great weight in developing the classification.

TWINSPAN selected 'indicator species' that were diagnostic of the particular association. The presence or absence of an indicator species at a particular level in the hierarchy effectively distinguished sample clusters or plant associations. The program also distinguished 'preferential species' that were associated relatively more frequently or were more abundant in one or the other clusters resulting from a cluster division. Only species most strongly identified with an association are reported to avoid lengthy species lists.

Results

General classification

Eight grassland associations with ten phases, and three forest associations were identified by cluster analysis (Table 1). A total of 488 species were identified in the sample plots. The first division of all sample plots by TWINSPAN separated plots with high shrub richness and cover (up to 33%) from plots with few or no shrubs along an apparent successional or woody-species gradient into 'Grassland' and 'Grass-Shrub' groups. Seventy-eight percent of the samples were clustered as Grassland at the first division. The Grassland types were indicated primarily by the absence of the woody riverine-forest plants characteristic of the Grass-Shrub group: the shrubs *Clerodendron viscosum*, *Pogostemon benghalensis*, and *Colebrookia oppostifolia*, and the liana *Acacia rugosa*.

Table 1. Riverine grassland and forest associations identified in the eastern portion of Chitwan National Park in lowland Nepal. The arrangement of the types indicates their floristic similarity and position on an increasing woody-species gradient. Numbers are the numbers of plots sampled.

Sal forest
Shorea robusta (sal) Forest Edges. (9)

Grassland group
Themeda arundinacea-Imperata cylindrica Association. (25)
  Arundinella nepalensis (sal meadow) phase. (9)
  Themeda-Narenga mosaic phase. (16)
Themeda arundinacea-Narenga porphyrocoma Association. (10)
Narenga porphyrocoma-Saccharum bengalense Association. (33)
  Saccharum arundinaceum phase. (17)
  Saccharum spontaneum phase. (16)
Narenga porphyrocoma-Narenga porphyrocoma Association. (14)
Saccharum spontaneum-Saccharum spontaneum Association. (51)
  Imperata cylindrica phase. (18)
  Saccharum spontaneum phase. (33)
Saccharum spontaneum – Phragmites karka Association. (11)

Grass-Shrub group
Saccharum bengalense-Saccharum spontaneum Association. (11)
  Artemisia indica phase. (3)
  Saccharum bengalense phase. (8)
Saccharum bengalense-Narenga porphyrocoma Association. (20)
  Saccharum bengalense phase. (10)
  Narenga fallax phase. (10)

Riverine forest
Trewia-Bombax Riverine Forest. (4)
Mixed Riverine Forest. (5)

Twenty-two percent of the plots were classified as Grass-Shrub by the presence of those woody species.

Grassland and sal forest associations

The Grassland group contained both stable edaphic associations and successional associations. Three sub-groups of associations were identified: (1) Plots dominated by *Themeda arundinacea* with a strong *N. porphyrocoma* component (including sal forest) were edaphic associations on mollic soils usually with a high water table; (2) *N. porphyrocoma* dominated mixed tall-grass associations that formed late-successional associations on old alluvial soils; and, (3) *S. spontaneum* associations on recent floodplain alluvium were early-successional stages. Most sal forest samples were in the Grassland group because of the similarity of the sal forest understory species to adjacent grassland; but, two sal stands were grouped near riverine forest in the grass-shrub cluster.

Sal forest

Sal forest sampled along the grassland-sal forest ecotone was indicated by regeneration of the tree *Dillenia pentagyna*. Sal, *Litsea monopetala* and *Bridelia retusa* regeneration also was common. Shrub species in common with non-forest stands were *Clerodendron viscosum*, *Pogostemon benghalensis*, and *Grewia schlerophylla*. Other common shrubs and herbs were *Helicteres isora*, *Curcuma aromatica*, *Phyllodium pulchellum*, *Cyperus* spp., *Vetiveria zizanioides*, and *Setaria* sp. Understory ground cover was generally very sparse in the area sampled, except in the two samples statistically clustered with riverine forest, which had a high cover of shrubs common to riverine forest.

Themeda arundinacea *associations*

Themeda arundinacea (THAR) associations were indicated by the presence of *T. arundinacea*. *Narenga porphyrocoma*, however, was present in nearly all *T. arundinacea* swards, often as a codominant or dominant species. Composition of THAR associations was most similar to sal forests, with THAR often the dominant grass in the understory of sal forest adjacent to grassland. THAR associations occurred generally on older mollic soils on ancient terraces and basin deposits associated with sal forest, as opposed to the relatively new alluvial soils in the floodplain. Many of the sites had aquic moisture regimes as a result of a perched water table.

Themeda-Imperata *association (THAR-IMCY)*. Dominance of *T. arundinacea* or codominance with *N. porphyrocoma*, and *Imperata cylindrica* with 20–75% cover indicated this association. Strongly associated grass and grass-like species were *Arundinella nepalensis*, *P. karka*, *S. spontaneum*, *Hemarthria compressa* and *Cyperus* spp. Woody species and herbs had very low frequencies and cover. Commonly found species were *Gonostegia pentandra*, *Leea* spp., *Desmodium microphyllum*, and *Persicaria* spp. Regeneration of sal was often present in the *Arundinella nepalensis* phase. Soils were Mollisols on ancient terraces, most with an aquic (saturated for a significant part of the year) moisture regime, and Inceptisols. Two phases were distinguished on the presence of additional species.

An *Arundinella nepalensis* (ARNE) phase was indicated by good regeneration of sal, the presence of the grass *Arundinella nepalensis* and the shrub *Grewia schlerophylla*, and the absence of *Apluda mutica*. *Cyperus* spp. and *Leea crispa* were commonly associated with this phase. These samples occurred at the sal-grassland ecotone, mostly in wet meadows inside the periphery of the sal forest. Sward height varied from 1 to 4 m depending on the abundance of *I. cylindrica*, which is usually < 1 m tall. Soils were Mollisols with an aquic moisture regime caused by a perched water table. Sal seedlings were abundant in plots during the fall sampling period, but this phase appears to be a stable edaphic association because no changes in sward boundaries were detected from 1964 to 1981 on aerial photographs.

A *Themeda-Narenga* mosaic phase was a mixed sward less than 1 m tall that was distinctly characterized by stunted *T. arundinacea* mixed with *I. cylindrica* in mosaic with tall dense NAPO-dominated patches. Abundant *Apluda mutica* indicated this phase. Associated grasses and grass-like species were *Hemarthria compressa*, *S. spontaneum*, *K. karka*, and *Cyperus* sp. Associated woody species and herbs were *Codariocalyx gyroides*, *Phyllanthus amarus*, and *Gonostegia pentandra*. These sites were former paddy fields reclaimed for Park land in 1964. Soils were Mollisols with an aquic moisture regime, primarily caused by a perched water table. An impermeable pan 10–20 cm below the surface may account for the aquic moisture regime and the stunted appearance of the tall grasses. This phase appeared to be a fairly stable edaphic association based on stable boundaries from 1964 to 1981.

Themeda-Narenga *association (THAR-NAPO). N. porphyrocoma* dominated *T. arundinacea* in very tall and dense stands. Shrub and herb species were poorly represented, but *Piper nepalensis*, *Codariocalyx gyroides*, *Vitis auriculata*, *Desmodium gangeticum*, *Zizyphus mauritania*, *Securinega virosa*, *Grewia schlerophylla*, and *Bridelia stipularis* were often present. This association most commonly occurred as open savanna with scattered, large *Bombax ceiba* trees. Seedlings of other trees, *Litsea monopetala*, *Premna obtusifolia*, *Trewia nudiflora*, and *Ehretia laevis*, were present in low numbers. The savanna structure and tree regeneration suggested a successional association largely maintained by fire. Soils were mostly Inceptisols with fair drainage.

Narenga *and* Saccharum *mixed tall-grass associations*

The absence of *T. arundinacea* indicated the mixed tall-grass (MTG) associations within the Grassland group. *N. porphyrocoma* associations occurred primarily on old floodplain terraces, whereas *S. spontaneum* associations occurred on more recent floodplain terraces. MTG associations were most often associated with *Bombax ceiba* in a savanna condition as was the similar THAR-NAPO association. *S. spontaneum* MTG associations were generally tree-less grassland on alluvial Entisol soils with poor to good drainage. Both *Narenga* and *Saccharum* associations appeared to be mostly successional associations initiated on floodplains and developing under the influence of fire, and wildlife grazing and browsing.

Narenga-S. bengalense *association (NAPO-SABE). N. porphyrocoma* codominated with *Saccharum bengalense* in the association. *Imperata cylindrica*, *Zizyphus mauritania*, and *Grewia schlerophylla* were other indicators. *Saccharum arundinaceum*, *Narenga fallax*, and *S. spontaneum* were often associated grass species, as were the woody species *Flemingia macrophylla*, *Desmodium gangeticum*, and *Leea crispa*. Regeneration of *Bauhinia malabarica*, *Ehretia laevis*, *Litsea monopetala*, and *Xeromphis uliginosa* was often associated with this association. Two phases were distinguished based on subdominance of *S. arundinaceum* or *S. spontaneum*.

A *S. arundinaceum* (SAAR) phase was indicated by that species, and the shrubs *Desmodium gangeticum* and *Callicarpa macrophylla*. *N. fallax* and *Hemarthria compressa* were strongly associated grass species. *Codariocalyx motorius*, *Securinega virosa*, *Flemingia macrophylla*, and *Callicarpa macrophylla* were associated shrubs. *Premna obtusifolia* and *Xeromphis uliginosa* tree regeneration was often present.

A *S. spontaneum* (SASP) phase was indicated by a large component of *S. spontaneum* along with the presence of *I. cylindrica* and *Zizyphus mauritania*. Associated species were the grasses *Apluda mutica* and *P. karka*, and the woody species *Uraria lagopus*, and *Leea crispa*. Cover of *N. porphyrocoma* was poorer in this phase than in the SAAR phase.

Narenga-Narenga *association (NAPO-NAPO).* A near complete dominance by *N. porphyrocoma* and the absence of *S. bengalense* indicated this association on wet sites with fairly well developed soils. *S. spontaneum* was sometimes a weak associate along with *Arundo donax*, and the fern

Dryopteris sp. Species richness was usually low, with *Gonostegia pentandra* and *Persicaria* sp. common associates.

Saccharum-Saccharum *association (SASP-SASP).* Floodplain *S. spontaneum* associations were indicated by the near complete dominance of *S. spontaneum*. Strongly associated species occurring at low abundances were *Cynodon dactylon, Adenostemma lavenia, Ageratum conyzoides, Alternanthera sessilis*, and *Lippia nodiflora*. Regeneration of the trees *Bombax ceiba* and *Trewia nudiflora* was commonly associated with this association. Two phases were distinguished.

An *I. cylindrica* (IMCY) phase was indicated by *I. cylindrica* cover from 10–100%. In most cases *I. cylindrica* and *S. spontaneum* were codominants. This phase occurred predominantly as a mosaic in response to apparent micro-relief and micro-soil patterns in recent floodplains, or as heavily cropped grazing lawns or pastures. Prostrate *I. cylindrica, Chrysopogon aciculatus, Eragrostis* spp., and *Cynodon dactylon* were common on heavily grazed sites and pastures. *Saccharum spontaneum* persisted at a low density in heavily grazed locations.

A pure *S. spontaneum* phase comprised the remainder of sites in this association. Nearly complete dominance by *S. spontaneum* indicated this type. Associated shrubs such as *Artemisia indica* and *Triumfetta rhomboides*, and seedlings of *Trewia nudiflora* and *Bombax ceiba* were scarce and with low cover.

Saccharum-Phragmites *(SASP-PHKA) association.* Phragmites karka, *Typha elephantina*, and *N. porphyrocoma*, along with *S. spontaneum* indicated this marsh association. Standing water is present for most of the year at these locations. Associated species were *S. arundinaceum, Cyperus* sp., *Persicaria* spp., and the fern *Dryopteris* sp.

Grass-shrub and riverine forest associations

Grass-shrub associations were characterized by *S. bengalense* and cover up to 33% of the shrubs *Clerodendron viscosum, Pogostemon benghalensis, Colebrookia oppositifolia*, and *Acacia rugosa*. These associations occurred most often in open savanna with large *Bombax ceiba* or smaller *Bauhinia malabarica* trees. Soils were generally well-drained Entisols. Codominance of *S. spontaneum* or *N. porphyrocoma* with *S. bengalense* distinguished several Grass-Shrub associations. *N. fallax* and *S. arundinaceum* were commonly associated grasses, as were the shrubs and herbs *Tinospora cordifolia, Callicarpa macrophylla, Vallaris solanacea*, and *Artemisia indica*. Regeneration of *Litsea monopetala, Premna obtusifolia, Ehretia laevis*, and *Persea* sp. was common. Types with *S. spontaneum* codominant occurred on recent alluvium and dryer soils than types codominated by *N. porphyrocoma*.

Two riverine forest types were included in the Grass-Shrub group because of their similar composition of understory shrubs and a high frequency in grass-shrub plots of riverine-forest tree seedlings and saplings, particularly *Premna obtusifolia, Bauhinia malabarica*, and *Bombax ceiba*. These trees are light-demanding early successional species that are common mid-story species in riverine forests. The similarity of understory suggests the successional nature of the grass-shrub types as stages in succession to riverine forest.

Saccharum bengalense *grass-shrub associations*

S. bengalense-S. spontaneum *association (SABE-SASP). S. spontaneum* was codominant with *S. bengalense* in this association. *Artemisia indica* was a shrub indicator. *S. spontaneum* generally had a cover value of greater than 33%. Other strongly associated species were the grasses *Apluda mutica* and *I. cylindrica*, the shrubs *Zizyphus mauritania, Colebrookea oppositifolia, Callicarpa macrophylla*, and the liana *Acacia rugosa*. The SABE-SASP association was further divided into two weakly different phases based on the presence or absence of the indicator *Artemisia indica*.

The *Artemisia indica* (ARIN) phase was indicated by 10–33% cover of *Artemisia indica*, with a similar cover of *S. bengalense* and *S. spontaneum*. *Cynodon dactylon*, *Hemarthria compressa*, *P. karka*, *Pogostemon benghalensis*, *Callicarpa macrophylla*, *Acacia rugosa*, and *Zizyphus mauritania* were strongly associated with this type. Weedy *Eupatorium odoratum* and *Ageratum conyzoides* were commonly associated species.

A *Saccharum bengalense* phase was characterized by nearly complete *S. bengalense* dominance and scarce *Artemisia indica* and *S. spontaneum*.

S. bengalense-N. porphyrocoma *association (SABE-NAPO)*. A SABE-NAPO association was characterized by a codominant or subdominant presence of *N. porphyrocoma* with *S. bengalense*. *N. porphyrocoma* and *S. arundinaceum* were indicators species. *Arundo donax* and *N. fallax* were strongly associated grass species. *Phragmites karka* and *Hemarthria compressa* were other associated grasses. Associated shrub species were *Desmodium gangeticum*, *Grewia schlerophylla*, and the liana *Vallaris solanaceae*. Soils were generally Entisols that probably were somewhat more developed than SABE-SASP habitats. Two phases were identified.

A *S. bengalense* phase was indicated by *S. bengalense* codominance with *N. porphyrocoma*, and the presence of *Clerodendron viscosum*. *Oplismenus compositus* and *Imperata cylindrica* were associated grasses. *Colebrookea oppostifolia*, *Pogostemon benghalensis*, *Clerodendron viscosum*, *Vallarus solanacea*, and *Ipomoea quamoclit* were strongly associated shrubs and herbs, along with regeneration of *Toona ciliata* and *Litsea monopetala*.

A *N. fallax* phase was indicated by *N. fallax* as a subdominant species. Shrub species were very poorly represented in these plots. This association was similar to the moist NAPO-SABE associations, but with slightly more shrub cover. Regeneration of moist-site trees *Syzigium cumini* and *Bischofia javanica* was associated with this type.

Riverine forest types

Trewia-Bombax *riverine forests*. *Trewia-Bombax* riverine forest was indicated by the presence of *Murraya koenigii*, and strong associations with the grasses *Arundo donax*, *Cynodon dactylon*, *Oplismenus compositus*, the shrubs *Clerodendron viscosum*, *Colebrookea oppositifolia*, *Pogostemon benghalensis*, *Acacia rugosa*, *Vallaris solanaceae*, and the trees *Litsea monopetala*, *Bauhinia malabarica* and *Bridelia retusa*. Common overstory trees were *Bombax ceiba*, *Trewia nudiflora*, *Litsea monopetala*, *Mallotus philippinensis*, *Ehretia laevis*, and *Premna obtusifolia*. Other overstory species that were fairly common are *Albizia* spp., *Cassia fistula*, *Bischofia javanica*, *Acacia catechu*, and *Dalbergia sissoo*. *Coffea benghalensis* is a common understory shrub in some stands that were not sampled.

Mixed riverine forest. Mixed riverine forest indicator species were the shrubs *Murraya paniculata* and *Persea duthiei*, a sparse cover of the grasses *N. porphyrocoma* and *S. bengalense* near the grassland ecotone, and regeneration of the trees *Persea* sp. and *Mallotus philippinensis*. Dominant overstory species found in this forest were *Persea* sp., *Dysoxylum* sp., *Trewia nudiflora*, *Mallotus philippinensis*, *Bombax ceiba*, and *Ficus racemosa*.

Mixed riverine forest occupied the oldest and most well-drained upland sites, and appears to be a later successional development of the *Trewia-Bombax* riverine forests. The relative age of mixed riverine forests is indicated by many old channel cuts on the margins of the stands and by a well-developed evergreen tree overstory, compared to the earlier successional *Trewia-Bombax* riverine forest on obviously newer terraces dominated by shade-intolerant *Trewia* and *Bombax*. Evergreen elements of incipient mixed riverine forest can be found in the *Trewia-Bombax* riverine forest as regeneration and understory plants, and remnants of *Trewia-Bombax* riverine forest species, such as *Bombax ceiba*, can be found in the mixed riverine forest. Evergreen species regenerate under their own canopy in the mixed riverine forest.

Discussion

The presented classification differs markedly from that proposed by Dabadghao and Shankarnarayan (DS) (1973). The generalized DS *Phragmites-Saccharum-Imperata* type fails to account for the variation in riverine grassland associations found in Chitwan, and does not satisfactorily explain primary or secondary succession under a natural disturbance regime. It appears to have very limited value in Chitwan for classifying grassland types and explaining community organization.

The *Phragmites-Saccharum-Imperata* type does seem to correspond rather well, however, to the SASP-PHKA marsh type. Both have similar species composition and are relatively stable edaphic types. Also, the DS scheme appears to explain reasonably well some of the successional changes in response to fire, domestic grazing, and fodder cutting, and the changes with protection from those disturbances described by Lehmkuhl (1989; also see Lehmkuhl, 1992). Frequent human disturbance from combined grazing, cutting, and burning results in dominance of *I. cylindrica* in most grassland types, in which *I. cylindrica* occurred to some extent in nearly all the sample plots. Heavily grazed sites, such as grazing lawns (McNaughton 1984) or pastures, degenerate further into types dominated by prostrate, grazing-resistant, perennial and annual grasses such as *Chrysopogon aciculatus*, *Cynodon dactylon*, *Sporobolus* spp., and *Eragrostis* spp. (Lehmkuhl 1989, 1992). Protection reverses the sequence as suggested by DS. Studies of nearby village pastures protected from grazing found that *S. spontaneum* was a suppressed component of some pastures that responded rapidly to protection by growing to full height in one season (Lehmkuhl 1989, 1992). Abandoned agricultural land was rapidly colonized by *I. cylindrica* (Bolton 1975), and was shown to succeed to THAR and NAPO types (Lehmkuhl 1989).

The relationships between the grassland associations can be understood from the explanation of Chitwan's grassland community organization described by Lehmkuhl (1989). Sal forest, *T. arundinacea* associations, and the *Saccharum spontaneum-Phragmites karka* (marsh) association are relatively stable associations largely determined by edaphic factors on sites where change

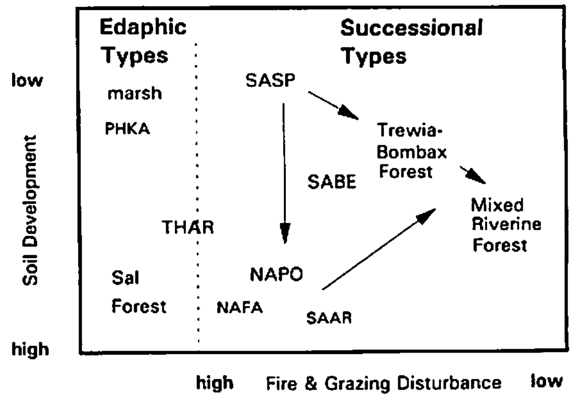

Fig. 3. Generalized riverine grassland and forest types in Chitwan National Park, Nepal, and hypothesized edaphic and disturbance gradients influencing grassland and riverine forest composition. (SASP = *Saccharum spontaneum*; SABE = *Saccharum bengalense*; THAR = *Themeda arundinacea*; NAPO = *Narenga porphyrocoma*; NAFA = *Narenga fallax*; SAAR = *Saccharum arundinacea*; PHKA = *Phragmites karka*).

is slow relative to the dynamic floodplain system on which most other types occur (Fig. 3). Floristic relationships among the other types largely are functions of changes in soil development (nutrient and moisture availability) with time and disturbance primarily from fire and wildlife grazing. *Saccharum spontaneum* associations colonize recent alluvium. Succession takes these sites on a trajectory of change to riverine forest in which *S. bengalense* and riverine-forest shrubs become common. However, fire retards change to riverine forest by destroying woody plants and deflects the successional trajectory along a path of further grassland development in which *S. bengalense* and *N. porphyrocoma*, *S. arundinaceum*, and *N. fallax* become established. Soil development with time, primarily increased nutrient availability with the accumulation of organic matter and allogenic input from flooding and other sources, allows the establishment of other species that require less severe soil nutrient and moisture conditions. The first of these species would be *S. bengalense*, and later *N. porphyrocoma*, *N. fallax*, and *S. arundinaceum*. It also may be the case that these species arrive and become established at the site later as a result of relatively less efficient dispersal mechanisms compared to *Saccharum spontaneum*.

As a result of concurrent soil development and fire, *N. porphyrocoma*, *S. bengalense* and other mixed tall-grass associations become established, then move along a successional trajectory to riverine forest different than the original *S. spontaneum* swards. Fire continues to retard succession, but cannot prevent it entirely because of stochastic variation in fire intensity and occurrence. Livestock, domestic elephant, and wildlife grazing, and fodder cutting for domestic animals add to the disturbance effects of fire. Wild grazers and elephants will eat seedlings of woody species in grassland. Elephant handlers cut and remove *Bombax ceiba* saplings growing within the clumps of tall grass cut for elephant fodder, and also limb small (less than 15 m) *Bombax ceiba* trees for fodder. As woody species become established at the expense of grasses the amount of flashy fuels from grass litter decreases as does the probability and intensity of burning.

The grassland types described in this paper are representative of riverine grassland associations that comprise the majority of the grassland area in Chitwan National Park. However, they do not represent the full variability of grasslands of riverine forests in the Park, especially those grass types associated with sal forest and other sites outside the floodplain. The important *Acacia catechu-Dalbergia sissoo* riverine forest type, which forms the earliest forest successional stage on river floodplains throughout most of north India and Nepal (Champion & Seth 1968), was not present in the study area, and was not included in the classification. Both species are found in the study area as isolated trees; but, they are common in the western portion of the Park in the floodplain of the much larger Narayani River where they form typical forest, especially on floodplain islands. The paucity of these species in the study area is possibly a result of past intensive grazing of domestic livestock on floodplains, current intense grazing of wild herbivores, and annual fires to which they are intolerant (Singh 1982). Perhaps conditions for establishment are poorer on the Rapti floodplain which is more narrow and a higher gradient than the broad Narayani floodplain.

Research in the Park and in other areas of the Indian and Nepalese Terai should build on this classification to develop a more comprehensive classification of riverine grassland and forest communities, and attempt to test the hypotheses of successional change and community organization underlying the classification.

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Appendix 1. A key to the riverine grassland associations of Chitwan National Park, Nepal.

1a. *Clerodendron viscosum*, *Pogostemon benghalensis*, *Colebrookea oppositafolia*, *Saccharum bengalense*, and *Acacia rugosa* present with <33% cover. **Grass-Shrub associations** 6

1b. Above species absent. **Grassland associations** 2

Grassland group

2a. *Themeda arundinacea* present (***Themeda* associations**) 3

3a. *T. arundinacea* dominant or codominant with *Narenga porphyrocoma*; *Imperata cylindric* usually 20–75% cover (***Themeda arundinacea-Imperata cylindrica* Association**).

Appendix 1. Continued.

4a. *Arundinella nepalensis* common. *Apluda mutica* generally absent. Regeneration seedlings of *Shorea robusta* present if site unburned. Usually meadows inside or near sal forest-grassland ecotone, especially near Siwalik foothills. (***Arundinella nepalensis* phase**).

4b. *A. mutica* usually very common to abundant. *Hemarthria compressa* and *S. spontaneum* sometimes present. Usually stunted *T. arundinacea* and *I. cylindrica* patches in mosaic with taller vigorous *N. porphyrocoma*. Sites usually with perched water table near sal forest-grassland ecotone. (***Themeda-Narenga mosaic phase***).

3b. *N. porphyrocoma* dominant; *T. arundinacea* subdominant; *I. cylindrica* absent or scarce. (***Themeda arundinacea-Narenga porphyrocoma* Association**).

2b. *T. arundinacea* not present; *N. porphyrocoma* or *S. spontaneum* dominants 5

5a. *N. porphyrocoma* codominant with *Saccharum bengalense* 9

6a. *I. cylindrica, Zyziphus mauritania, Grewia schlerophylla* present (***Narenga porphyrocoma-Saccharum bengalense Association***) 7

7a. *Saccharum arundinaceum* present; *Desmodium gangeticum, Callicarpa macrophylla* also present. (***Saccharum arundinaceum* phase**).

7b. *S. spontaneum* common; *I. cylindrica, Z. mauritania* present. (***Saccharum spontaneum* phase**).

6b. *N. porphyrocoma* dominance nearly complete; *S. bengalense* scarce. (***Narenga porphyrocoma-Narenga porphyrocoma* Association**).

Appendix 1. Continued.

5b. *S. spontaneum* dominant (***Saccharum spontaneum-Saccharum spontaneum* Association**) 8

8a. *I. cylindrica* 10–100% cover. (***Imperata cylindrica* phase**).

8b. *S. spontaneum* dominance nearly complete. (***Saccharum spontaneum* phase**).

5c. *Phragmites karka* and *Typha elephantina* codominants with *S. spontaneum*; marshy year round. (***Saccharum spontaneum-Phragmites karka* Association**).

Grass-shrub associations

9a. *Artemisia indica* present; *S. spontaneum* cover >33%. (***Saccharum bengalense-Saccharum spontaneum* Association**). 10

10a. *A. indica* 10–33% cover; *S. bengalense* and *S. spontaneum* usually similar cover. (***Artemisia indica* phase**).

10b. *A. indica* scarce; *S. bengalense* dominant; *S. spontaneum* scarce. (***Saccharum bengalense* phase**).

9b. *N. porphyrocoma* and *S. arundinaceum* present; *N. porphyrocoma* subdominant or codominant with *S. bengalense*. (***Saccharum bengalense-Narenga porphyrocoma* Association**) 11

11a. *S. bengalense* codominant with *N. porphyrocoma*; *Clerodendron viscosum* present. (***Saccharum bengalense* phase**).

11b. *Narenga fallax* present as subdominant; shrubs scarce. (***Narenga fallax* phase**).

Appendix 2. Percentage frequency occurrence and mean cover of more common plant species used in classification of riverine grassland associations in Chitwan National Park, Nepal.

Species	Sal[a] forest		THAR-IMCY		THAR-NAPO		NAPO-SABE		NAPO-NAPO		SASP-SASP		SASP-PHKA		SABE-SASP		SABE-NAPO		T-B riv. forest		Mixed riv. forest	
	Freq %	C[b]	Freq %	C	Freq %	C	Freq %	C	Freq %	C	Freq %	C	Freq %	C	Freq %	C	Freq %	C	Freq %	C	Freq %	C
Grasses and grass-likes																						
Apluda mutica	11	1	76	2	70	2	85	2	86	2	24	2	67	1	55	2	40	1	0	0	0	0
Arundinella nepalensis	11	2	28	3	0	0	0	0	7	4	0	0	0	0	0	0	0	0	0	0	0	0
Arundo donax	0	0	0	0	0	0	3	1	21	2	0	0	0	0	9	3	25	2	25	2	0	0
Bothriachloa intermedia	22	3	0	0	0	0	0	0	0	0	0	0	0	0	9	1	5	2	0	0	20	2
Cynodon dactylon	0	0	0	0	10	2	6	2	7	2	39	1	0	0	55	2	45	2	25	1	0	0

Appendix 2. Continued.

Species	Sal[a] forest		THAR-IMCY		THAR-NAPO		NAPO-SABE		NAPO-NAPO		SASP-SASP		SASP-PHKA		SABE-SASP		SABE-NAPO		T-B riv. forest		Mixed riv. forest	
	Freq %	C[b]	Freq %	C	Freq %	C	Freq %	C	Freq %	C	Freq %	C	Freq %	C	Freq %	C	Freq %	C	Freq %	C	Freq %	C
Cyperus sp. 1	0	0	4	2	0	0	0	0	14	2	0	0	50	2	0	0	0	0	0	0	0	0
Cyperus sp. 2	33	1	20	1	0	0	0	0	0	0	2	1	17	3	0	0	0	0	0	0	0	0
Cyperus spp.	11	2	24	2	10	1	3	1	7	1	16	1	50	2	18	2	0	0	50	1	0	0
Digitaria ciliaris	0	0	0	0	0	0	0	0	7	1	8	1	0	0	45	1	10	2	25	1	0	0
Eragrostis spp.	0	0	0	0	0	0	0	0	0	0	16	1	0	0	0	0	0	0	0	0	0	0
Fimbristylis spp.	0	0	0	0	10	2	0	0	7	1	6	1	0	0	9	1	5	1	0	0	20	1
Hemarthria compressa	11	2	60	2	50	1	24	2	14	2	16	1	0	0	45	1	40	2	0	0	0	0
Imperata cylindrica	56	3	80	3	20	1	70	3	29	2	73	3	17	4	82	2	55	2	0	0	0	0
Kyllinga brevifolia	11	1	0	0	10	2	0	0	0	0	8	1	0	0	9	1	0	0	0	0	0	0
Narenga fallax	0	0	0	0	10	2	12	2	7	3	2	2	0	0	0	0	45	3	0	0	0	0
Narenga porphyrocoma	44	3	92	3	100	4	73	4	100	5	10	2	83	3	9	1	80	3	0	0	40	3
Oplismenus compositus	0	0	0	0	0	0	0	0	7	1	0	0	0	0	0	0	10	2	50	1	0	0
Paspalum spp.	0	0	0	0	0	0	0	0	0	0	12	1	0	0	0	0	0	0	0	0	0	0
Phragmites karka	11	1	52	2	20	2	33	2	36	2	22	2	100	4	18	2	20	2	0	0	0	0
Saccharum arundinaceum	0	0	0	0	10	1	21	3	7	3	0	0	17	2	0	0	70	3	0	0	0	0
Saccharum bengalense	11	1	0	0	20	2	73	4	0	0	31	2	0	0	100	3	95	4	25	2	60	2
Saccharum spontaneum	0	0	24	3	0	0	48	3	64	2	100	4	100	3	64	3	5	3	0	0	0	0
Setaria sp.	22	1	0	0	10	1	0	0	0	0	8	1	0	0	18	1	5	1	0	0	0	0
Themeda arundinacea	100	3	96	4	50	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Typha elephantina	0	0	0	0	0	0	0	0	7	1	0	0	83	2	0	0	0	0	0	0	0	0
Herbs																						
Adenostemma lavenia	0	0	0	0	0	0	9	1	0	0	57	1	17	1	27	1	5	1	0	0	0	0
Ageratum conyzoides	44	1	40	1	40	2	15	1	0	0	55	1	33	1	82	2	90	1	75	2	60	2
Alternanthera sessilis	0	0	0	0	0	0	9	1	0	0	27	1	67	1	36	1	5	1	0	0	0	0
Alysicarpus vaginalis	0	0	0	0	0	0	3	1	0	0	8	1	0	0	0	0	0	0	0	0	0	0
Atylosia scarabaeoides	0	0	0	0	0	0	9	1	0	0	10	1	0	0	9	2	0	0	0	0	0	0
Boehmeria spp.	11	1	0	0	20	1	6	1	0	0	4	1	0	0	82	1	20	1	25	1	40	1
Breea arvensis	0	0	0	0	10	1	48	1	29	1	8	1	0	0	0	0	10	1	0	0	0	0
Caryopteris odorata	0	0	0	0	0	0	0	0	0	0	2	1	0	0	18	3	10	1	0	0	0	0
Codariocalyx gyroides	11	1	20	2	40	2	21	2	14	2	4	1	0	0	9	1	5	1	0	0	0	0
Codariocalyx motorius	0	0	0	0	10	1	24	1	21	2	2	2	0	0	0	0	5	1	0	0	0	0
Desmodium gangeticum	0	0	4	1	50	1	36	1	14	2	8	1	0	0	18	1	50	1	0	0	0	0
Desmodium microphyllum	11	1	20	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Desmodium sp.	0	0	0	0	0	0	9	1	7	1	6	1	0	0	9	1	5	2	0	0	0	0
Equisetum debile	0	0	0	0	0	0	0	0	14	1	4	1	17	1	0	0	0	0	0	0	0	0
Eupatorium odoratum	11	1	0	0	60	1	12	1	21	1	10	1	0	0	91	2	70	2	25	2	60	1
Euphorbia hirta	0	0	0	0	0	0	0	0	0	0	10	1	0	0	18	1	0	0	0	0	0	0
Glochidion multiloculare	0	0	48	1	60	1	27	1	7	1	0	0	0	0	0	0	0	0	0	0	0	0
Gonostegia pentandra	11	1	24	1	0	0	3	1	29	1	6	1	67	1	9	1	0	0	0	0	0	0
Heliotropium strigosum	0	0	0	0	0	0	0	0	0	0	12	1	0	0	0	0	0	0	0	0	0	0
Ipomoea quamoclit	0	0	0	0	0	0	0	0	0	0	0	0	0	0	18	1	25	1	25	1	0	0
Justicia spp.	22	1	24	1	0	0	0	0	0	0	8	1	0	0	36	1	30	1	25	1	40	1
Leucas spp.	0	0	0	0	0	0	0	0	0	0	4	1	0	0	18	1	5	1	0	0	0	0
Lippia nodiflora	0	0	0	0	20	1	12	1	7	1	43	1	17	1	18	1	0	0	0	0	0	0
Lycopodium sp.	0	0	16	1	10	1	6	1	0	0	4	1	17	1	18	1	0	0	0	0	0	0
Mimosa pudica	0	0	0	0	0	0	0	0	0	0	8	1	0	0	18	1	0	0	0	0	0	0
Oxalis corniculata	0	0	0	0	20	1	21	1	0	0	6	1	0	0	0	0	15	1	0	0	0	0
Peperomia pellucida	0	0	0	0	0	0	3	1	0	0	8	1	0	0	27	1	35	1	75	1	20	1
Persicaria spp.	0	0	28	1	10	1	6	1	43	2	22	1	83	2	0	0	0	0	0	0	0	0
Phyllanthus amarus	0	0	24	1	20	1	27	1	0	0	25	1	17	1	55	1	20	1	0	0	0	0
Physalis divaricata	0	0	0	0	0	0	0	0	0	0	6	1	0	0	27	1	0	0	0	0	0	0
Piper nepalensis	22	1	0	0	30	1	27	1	29	1	2	1	0	0	36	1	70	1	0	0	20	1
Rabdosia spp.	11	1	4	1	10	1	24	1	0	0	4	1	0	0	18	1	50	1	0	0	20	2
Solanum anguivi	0	0	0	0	0	0	0	0	0	0	14	1	0	0	9	1	10	1	0	0	0	0

Appendix 2. Continued.

Species	Sal[a] forest		THAR-IMCY		THAR-NAPO		NAPO-SABE		NAPO-NAPO		SASP-SASP		SASP-PHKA		SABE-SASP		SABE-NAPO		T-B riv. forest		Mixed riv. forest	
	Freq %	C[b]	Freq %	C	Freq %	C	Freq %	C	Freq %	C	Freq %	C	Freq %	C	Freq %	C	Freq %	C	Freq %	C	Freq %	C
Tinospora cordifolia	11	1	0	0	0	0	6	1	0	0	0	0	0	0	18	1	30	1	50	2	60	1
Trifolium sp.	0	0	12	1	10	1	15	1	0	0	37	1	0	0	27	2	10	1	0	0	0	0
Triumfetta rhomboides	0	0	0	0	0	0	0	0	0	0	20	1	0	0	9	2	5	2	0	0	0	0
Uraria lagopus	22	2	0	0	0	0	15	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Urena lobata	0	0	0	0	0	0	6	1	0	0	8	1	0	0	36	2	0	0	25	1	0	0
Viola sp.	0	0	0	0	20	1	3	1	0	0	4	1	0	0	0	0	0	0	0	0	0	0
Vitis auriculatus	11	1	4	1	30	1	15	1	0	0	12	1	0	0	18	1	30	1	50	1	60	1
Zehneria indica	0	0	16	1	30	1	3	1	7	1	0	0	17	1	9	1	5	1	0	0	0	0
Ban mas[c]	11	1	20	1	0	0	12	1	7	1	0	0	0	0	0	0	10	1	0	0	0	0
Ban mung	0	0	16	1	10	1	3	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Batilpati	22	1	4	1	30	1	0	0	0	0	2	1	0	0	55	1	25	1	50	1	0	0
Beduwa	11	1	8	1	30	1	9	1	0	0	0	0	0	0	0	0	5	1	0	0	0	0
Deem	0	0	4	1	30	1	21	1	0	0	2	1	0	0	0	0	5	1	0	0	0	0
Fern spp.	44	1	24	1	10	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ghol tapre	0	0	8	1	10	1	9	1	7	1	29	1	33	1	36	1	0	0	0	0	0	0
Gita	33	1	4	1	20	1	9	1	0	0	6	1	0	0	18	1	10	1	0	0	0	0
Golabre	0	0	0	0	0	0	3	1	14	1	4	2	0	0	0	0	0	0	0	0	0	0
Heart monocot	0	0	0	0	0	0	24	1	14	1	12	1	0	0	0	0	20	1	0	0	0	0
Kachora	44	2	8	1	0	0	0	0	0	0	0	0	0	0	0	0	5	1	0	0	0	0
Korkolu	0	0	0	0	0	0	0	0	0	0	2	1	67	1	0	0	0	0	0	0	0	0
Kurila	56	1	0	0	10	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Kuturko fern	0	0	4	1	0	0	9	1	29	2	4	2	17	1	0	0	0	0	0	0	0	0
Nuro fern	0	0	44	1	60	1	21	1	57	1	22	1	67	2	9	1	20	1	25	1	40	2
Panilahara	0	0	12	1	0	0	0	0	14	1	0	0	0	0	0	0	0	0	0	0	0	0
Raksi jar	22	1	36	1	30	1	3	1	0	0	0	0	0	0	0	0	5	1	0	0	0	0
Shrubs and lianas																						
Acacia rugosa	22	1	0	0	0	0	12	1	0	0	8	1	0	0	45	2	75	1	50	3	80	1
Artemisia indica	0	0	0	0	0	0	0	0	0	0	18	1	0	0	73	3	5	1	25	2	20	1
Bridelia stipularis	0	0	4	1	20	1	0	0	0	0	0	0	0	0	0	0	10	1	0	0	20	1
Callicarpa macrophylla	11	1	4	1	20	1	39	1	21	2	16	1	0	0	55	2	80	2	50	2	60	1
Clerodendron viscosum	67	3	4	1	10	1	9	2	0	0	0	0	0	0	73	2	75	2	100	3	100	2
Colebrookea oppositifolia	11	1	0	0	0	0	0	0	0	0	2	1	0	0	64	2	50	2	100	4	100	2
Flemingia macrophylla	11	1	4	2	10	2	21	1	7	1	8	1	0	0	18	2	15	1	0	0	0	0
Grewia sclerophyla	67	2	20	1	50	1	55	1	7	2	2	1	0	0	9	1	45	1	0	0	0	0
Helicteres isora	67	2	8	1	0	0	3	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Leea sp.	33	1	20	1	10	1	3	1	0	0	0	0	0	0	0	0	10	1	0	0	40	1
Leea crispus	33	1	20	1	0	0	24	1	7	1	2	1	0	0	0	0	5	1	0	0	0	0
Murraya koenigii	0	0	0	0	0	0	3	1	0	0	0	0	0	0	18	2	5	1	100	2	0	0
Murraya paniculata	0	0	0	0	10	1	0	0	0	0	0	0	0	0	0	0	5	1	0	0	100	3
Persea duthiei	11	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5	1	25	1	80	3
Phyllodium pulchellum	22	2	8	1	10	1	18	1	7	1	8	1	0	0	0	0	5	1	0	0	0	0
Pogostemon benghalensis	44	2	4	1	10	1	3	2	7	1	12	2	0	0	91	2	75	2	100	3	100	2
Securinega virosa	0	0	4	1	30	1	18	1	7	1	6	1	0	0	0	0	0	0	0	0	0	0
Vallaris solanaceae	0	0	0	0	0	0	0	0	0	0	2	1	0	0	9	1	30	1	50	1	0	0
Zizyphus mauritania	0	0	0	0	20	1	52	2	21	1	10	1	0	0	55	2	0	0	0	0	0	0
Trees (regeneration)																						
Bauhinia malabaricum	0	0	0	0	0	0	27	1	7	1	4	1	0	0	27	2	55	1	50	1	0	0
Bischofia javanica	0	0	4	1	10	1	0	0	0	0	0	0	0	0	9	1	10	1	0	0	0	0
Bombax ceiba	11	1	60	1	60	1	82	1	43	1	61	1	0	0	55	1	65	1	25	1	0	0
Bridelia retusa	2	1	8	1	0	0	3	1	0	0	2	1	0	0	0	0	15	1	50	1	0	0
Cleistocalyx operculatus	78	2	44	2	60	1	9	2	0	0	0	0	0	0	0	0	5	1	0	0	0	0
Dillenia pentagyna	89	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Appendix 2. Continued.

Species	Sal[a] forest		THAR-IMCY		THAR-NAPO		NAPO-SABE		NAPO-NAPO		SASP-SASP		SASP-PHKA		SABE-SASP		SABE-NAPO		T-B riv. forest		Mixed riv. forest	
	Freq %	C[b]	Freq %	C	Freq %	C	Freq %	C	Freq %	C	Freq %	C	Freq %	C	Freq %	C	Freq %	C	Freq %	C	Freq %	C
Ehretia laevis	11	1	0	0	30	1	30	1	0	0	8	1	0	0	36	2	80	1	75	1	40	1
Holarrhena pubescens	0	0	0	0	0	0	9	1	0	0	2	1	0	0	9	1	5	2	0	0	0	0
Litsea monopetala	78	2	20	1	70	1	33	1	0	0	2	1	0	0	27	2	65	1	100	2	80	1
Mallotus philippinensis	22	2	4	1	10	1	9	1	0	0	0	0	0	0	0	0	15	1	0	0	60	1
Persea sp.	0	0	0	0	10	1	3	1	7	1	2	1	0	0	0	0	30	1	50	2	100	2
Myrtaceae sp.	44	2	4	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Phyllanthus emblica	22	2	12	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Premna obtusifolia	11	1	0	0	30	1	24	1	0	0	6	1	0	0	45	1	25	1	0	0	0	0
Shorea robusta	89	2	36	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Syzygium cumini	56	1	16	1	0	0	3	1	0	0	2	1	0	0	0	0	15	1	0	0	40	2
Toona ciliata	0	0	0	0	0	0	3	1	0	0	4	1	0	0	0	0	15	1	0	0	0	0
Trewia nudiflora	11	1	0	0	20	1	36	1	29	1	16	1	0	0	27	1	50	1	75	1	80	1
Xeromphis uliginosa	22	1	36	1	50	1	18	1	0	0	2	1	0	0	0	0	5	1	0	0	0	0

[a] Association: Sal = *Shorea robusta*; THAR = *Themeda arundinacea*; IMCY = *Imperata cylindrica*; NAPO = *Narenga porphyrocoma*; SABE = *Saccharum bengalense*; SASP = *Saccharum spontaneum*; PHKA = *Phragmites karka*; *Trewia-Bombax* Riverine Forest; Mixed Riverine Forest.

[b] Species cover coded by cut levels used in TWINSPAN as: 1 = <1% cover; 2 = 1–5%; 3 = 5–25%; 4 = 25–75%; 5 = >75%.

[c] Local names and collection numbers are listed for unidentified plants used in classification.

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