Vegetation structure of wetlands in Eastern Himalayan Highlands of Gasa, Bhutan

Pema Tendar*a,b,∗, Kitichate Sriditha

a Department of Biology, Faculty of Science, Prince of Songkla University, Songkhla 90110 Thailand
b Department of Science, Chundu Armed Forces Public School, Ministry of Education, Haa 15004 Bhutan

∗Corresponding author, e-mail: pematendar@gmail.com

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ABSTRACT: The study was conducted on the unexplored wetland vegetation of the eastern Himalayan highlands of Gasa District, Northern Bhutan. A random quadrat sampling of 1×1 m² method was used to assess the presence-absence of species, including shrubs, trees, mosses, ferns, and climbers, that were occurring adjacent to plots. Altogether, 201 taxa from 81 families, distributed in 149 genera, were recorded. Among the total species, 6 bryophytes, 20 monilophytes, 2 gymnosperms, and 173 angiosperms species were found. The most abundant life forms represented were herbaceous (62%) and shrub (29%), followed by tree (7%) and climber (2%). The four unique vegetation structure (represented in schematic profile diagrams) of habitats: fresh water meadow, seasonally flooded basin of flat, shallow fresh marsh, and poor fen, were found. The study suggests protecting ecotone (a transition zone between the wetland and surrounding uplands) as part of the measures to protect wetlands and their vegetation in the Himalayas.

KEYWORDS: wetland, vegetation structure, schematic profile diagram, ecotone

INTRODUCTION

Wetlands are biologically diverse ecosystems that provide critical habitat to a wide range of plants and animals in the world. The ability of plants to inhabit wet places and represent a various grouping of species with different ecological tolerances, adaptations, and life history strategies that allows their existence in flooded or saturated soils are termed as wetland plants [1]. Further, wetland plants are defined by their ability to grow on a substrate or in water that is periodically lacking in oxygen due to excessive water content [2].

Wetland plants are interesting as they have unique evolutionary tactics for coping with life in a flooded environment and help us to identify the boundaries of a wetland [1]. These wetland plants occur mostly in heath forests, forest fragments and bottomlands surrounded by upland forests. These small wetland habitats provide unique combination of upland forest species and wetland specialist species with high plant diversity [3]. Further, Kent and Coker [4] claimed that these marginal species from the adjacent areas around the habitat or community type can greatly increase species diversity. Also, Van der Maarel [5], emphasized that transactional or ecotone areas are of great interest ecologically and deserve more attention in research.

The Himalayan Region is known as one of the worldwide significant biodiversity hotspots due to rich repository of native and endemic biodiversity [6]. As part of Eastern Himalaya, Flora of Bhutan documented 5603 species of vascular plants out of which approximately 94 percent are native species [7]. Eastern Himalaya, including Bhutan, is also a remarkable repository for fauna and flora [8,9]. Further, National Biodiversity Centre [10] recorded 144 species as currently endemic to Bhutan Himalaya, which is a remarkable diversity of endemism considering the size of the country. Of the total species recorded (144), about 49% (71) are incredibly recorded in Jigme Dorji National Park (JDNP). Hence, in order to ensure their conservation and management, study of the plants in such environments should be considered of key importance. Moreover, several natural habitats are at risk and the species within them experience potential extinction [11]. There is also massive habitat loss in the buffer zone that results in species destructions [12] and positioning numerous wetland species on threatened and endangered species lists. The lack of International Union for Conservation of Nature (IUCN) assessment further makes it challenging to understand the status of native species of national concern [7]. There was also no comprehensive study on the vegetation structure of
wetlands in Gasa, a part of JDNP, and therefore, objectives of the study were to: (1) provide a checklist of the freshwater wetland plants and (2) describe the structure of habitats in highland wetlands of Gasa, Bhutan.

MATERIALS AND METHODS

Study area

The study was conducted in Gasa, a part of JDNP, along the 28 km road stretch on the left side of Mochu River, that lies between 27°43′05″–28°09′35″ N (latitudes) and 89°45′33″–89°38′44″ E (longitude) (Fig. 1). The elevation ranges from 1597 to 2538 m above sea level. The vegetation type in the region is warm temperate forest [13]. The area experiences short summer and long winter with the mean annual rainfall over a decade (2008–2017) ranged from 498 to 1824 mm and heavy rainfall in the month of July to August. Similarly, air temperature of the region ranges from 5–16 °C [14]. The study areas were mostly occurred in the bottomlands, slopes, and forest fragments surrounded by natural vegetation.

Data collections

Floristic inventory was done almost every month (February to November 2018) to assess the status and flowering seasons for detailed identification of plants. All collected plant materials were prepared according to the guidelines of herbarium handbook [15]. A random quadrat sampling of 1 x 1 m² method was used to assess the presence-absence of species. The number of quadrat samples taken from each site varied due to occurrence of different sizes in wetlands. The vegetation of each quadrat sample was identified in the field and recorded all species in that plot, including the ones (shrubs, trees, mosses, ferns, and climbers) occurring adjacent to the plots, in order to acquire the comprehensive list of plants within the wetlands. The life form group was followed with slight modifications [16]. The classification of wetland habitats according to Smith [17] was followed and later identified habitats [18] were represented in the form of schematic profile diagram to represent the vegetation structure in the region. Vegetation profile of representative sites (X and Y-axes) were drawn accounting the measurement of plant height [19] and length of site (measured using 100 m measuring tape). A graded bamboo stick was used to measure the depth of water in each site. All collected specimens were taken to the National Biodiversity Center, Thimphu, Bhutan for confirmation; and unknown species were identified in consultation with specialized literature and specialists in different taxonomic groups. Floras of Bhutan (including a record of plants from Sikkim [20–23], a record of plants from Sikkim and Darjeeling [24–26], the grasses of Bhutan [27], the orchids of Bhutan [28],
and eFloras of China [29]) were followed for the identification of species and families. The species' names and families were updated in an online data base, the Tropicos. The Angiosperm Phylogeny Group IV classification was followed for the classification of families [30]. All the voucher specimens were deposited at the Herbarium, National Biodiversity Center, Thimphu, Bhutan.

RESULTS

Floristic composition
A total of 201 species of plants, distributed in 149 genera and 81 families, of which 55% (111 species) were within quadrat (1 × 1 m²) sampling plots (226) and 45% (90 species) occurred adjacent to sampling plots (Tables 1 and S1). Among the total species, 6 species of bryophytes, 20 species of monilophytes, 2 species of gymnosperms, and 173 species of angiosperms (125 eudicots, 4 magnoliids, and 44 monocots) are presented in Table 1. The three most dominant families of eudicots were Ericaceae (17 species), Rosaceae (12 species), and Asteraceae (11 species) that comprised 8.5%, 6.0%, and 5.5% of the total flora, respectively. The three most diverse group of monocots were Cyperaceae (12 species), Poaceae (9 species), and Orchidaceae (7 species) that consisted of 6.0%, 4.5%, and 3.5% of the total recorded species, respectively. Dryopteridaceae (4 species, 2.0%), Polypodiaceae (4 species, 2.0%), and Selgeinellaceae (3 species, 1.5%) were the largest families represented in the group in monilophytes. In bryophytes group, single species was represented in each family. In the group of gymnosperms, Pinaceae and Taxaceae represented one species each. The six most dominant families are Ericaceae, Rosaceae, Cyperaceae, Asteraceae, Poaceae, and Orchidaceae (Fig. 2a). Altogether, they comprise about 34% of the total number of species in the studied areas. In this study, every species recorded is provided with taxonomic group, lifeform, flowering season, and voucher number (Table S2).

Lifeform and flowering seasons
The herbaceous and shrub lifeform were the most abundant species, recorded with 62% (125 species) and 29% (59 species), respectively; while the trees and climbers were least represented, at 7% (13 species) and 2% (4 species), respectively (Fig. 2b). The flowering for herbs mostly occurred in April to September, but peaked in July. The shrubs flowered mostly in April to July with the peak month in May. May and April months were the peak flowering seasons for trees and climbers, respectively (Fig. 2c).

The habitat types and vegetation
Based on the topographic features and vegetation of the wetlands, four most characteristic habitat types inhabited by plants were identified (Figs. 3 and 4).

Shallow fresh marsh was usually located near small streams and bottomlands. There is only one aquatic species, Potamogeton crispus L. occurred in such open pools (Fig. 3a). The characteristic species, i.e. Enkianthus deflexus (Griff.) C.K. Schneid., Persicaria nepalensis (Meisn.) H. Gross and Rhododendron dalhousieae var. rhabdotum (Balff. f. & R.E. Cooper) Cullen, were prominently found adjacent to the habitat. The Acorus calamus L. was abundant; and this characteristic species created a mat of vegetation that allowed small streams to run through channeling underneath. These channels
### Table 1 Results showing the floristic composition in wetlands of Gasa.

| Taxonomic group | Families | Genera | Species | Trees | Shrubs | Herbs | Climbers |
|-----------------|----------|--------|---------|-------|--------|-------|----------|
| Angiosperms     | 61       | 126    | 173     | 11    | 59     | 99    | 4        |
| Gymnosperms     | 2        | 2      | 2       | 2     | –      | –     | –        |
| Bryophytes      | 6        | 6      | 6       | –     | –      | 6     | –        |
| Monilophytes    | 12       | 15     | 20      | –     | –      | 20    | –        |
| **Total**       | **81**   | **149**| **201** | **13**| **59** | **125**| **4**    |

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**Fig. 3** Schematic profile diagram at Gasa. (a) Flag marsh vegetation: 1. Acorus calamus, 2. Persicaria nepalensis, 3. firm mat of flag marsh vegetation with water channel underneath, 4. Enkianthus deflexus, 5. open pool with aquatic vegetation, 6. Potamogeton crispus, 7. Rhododendron dalhousieae var. rhadotum, 8. soil (organic matter) with firm mat of sweet flags' spreading rhizomes, 9. soil (loamy sand) with arrow showing the movement of underground water, and 10. channeled stream water and its movement (arrow showing its flow direction). (b) Carex diandra vegetation: 1. Carex diandra, 2. Schoenoplectus mucronatus, 3. Lyonia ovalifolia, 4. Acorus calamus, 5. Cymbidium iridioides, and 6. moderately decomposed sedge peat.

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run on the side of the habitat ensuring minimal entry into the surface of habitat. During rainy seasons, these habitats were partially submerged, but well drained within few weeks.

*Seasonally flooded basin of flat* usually occurred in open bottomlands with floating mats dominated by Carex diandra Schrank. In fact, this habitat usually occurred in narrow zone where there is water underneath. This characteristic species was found only in the wettest part of this filled basin including Schoenoplectus mucronatus (L.) Palla (Fig. 3b). The Acorus calamus L. vegetation inhabited next to this C. diandra Schrank vegetation, followed by Lyonia ovalifolia (Wall.) Drude, Malus baccata (L.) Borkh, and Enkianthus deflexus (Griff.) C.K. Schneid towards edge of forest. The epiphytic orchid, Cymbid-
*Sphagnum palustre* above). Some patches of *Sphagnum palustre* L. vegetation were confined to this habitat and a thick layer of undecomposed peat within this vegetation was also prominent. Another characteristic species inhabited was *Osmunda japonica* Thunb. that occurred in some patches. The ericaceous shrubs were prominent in such habitats, e.g. *Rhododendron arboreum* Sm. and *Malus baccata* (L.) Borkh. (Fig. 4a).

The climber species, *Holboellia latifolia* Wall., was also recorded on the *M. baccata* (L.) Borkh. shrub that occurred in the open habitat. This vegetation was usually influenced by precipitation in the area lacking groundwater and upstream components.

**Fresh water meadow** usually occurred on the slopes, open heath forests and, sometimes, even in fallow lands. This habitat usually has no standing water but remained waterlogged most of the year. The diverse and characteristic species, such as *Lyonia villosa* (Wall. ex C.B. Clarke) Hand.-Mazz., *Spiranthes sinensis* (Pers.) Ames, *Matteuccia struthiopteris* (L.) Tod. and *Alnus nepalensis* D. Don, are inhabited in this habitat. Mostly the characteristic species of herbs in this habitat are stunted (Fig. 4b).

**DISCUSSION**

Most of represented families differed within Himalayan Regions. The topmost dominant family, Ericaceae with 17 species, comprised 21% of total species (81 species) in the country [23]. However, this family was not even appeared in top ten dominant families in the Western and Eastern Himalayas [31] indicating that this family occurred mostly in the wetlands and its surroundings (ecotone). These ericaceous shrubs may be acid loving plants since they are mostly inhabited in the acidic soil/peat of wetlands [32]. Therefore, the diversity of ericaceous shrubs is high and topped the family representation in the wetlands (Fig. 2a). This result is limited to present study and may not represent the actual status of ericaceous plant diversity in the country. Hence further study on quantitative assessment of wetland plants are required to further confirm this result in the country and the region. The second dominant family was Rosaceae (12 species) represented 8.5% of total species (141 species) of the flora of Bhutan. However, in the Eastern and Western Himalayas, the family dominance stood at eighth position and might be changed if similar studies are undertaken there. The third dominant family is Cyperaceae (12 species) which was fourth and fifth in the Eastern and Western Himalayas, respectively. This family has close affinity with the flora of western region and the family may have represented mostly from wetlands (Fig. 2a).

Asteraceae (11 species) represented fourth position in the Eastern Himalayas and, therefore, their suitable habitats could be in wetlands of lower montane areas in the region. In the Western Himalayas, this family represented second position and may indicate diverse habitat preferences. However, this family included one invasive species, *Ageratina adenophora* (Spreng.) R.M. King & H. Rob. which is almost a threat to wetlands; and habitat loss may occur, thereby, threatening many wetland species [7]. Fortunately, this species occurred only in one site due to anthropogenic disturbances since being closed to road and human settlement. Therefore, understanding plants and its habitats may be first step in combating species loses. Orchidaceae presented sixth position, which is topmost dominant family in the country as well as in the Eastern Himalayas (Fig. 2a). These orchids represented 1.5% (7 species) of the total orchids (469 species) in the country [28,33]. The wetland habitats have favored these epiphytic and ground orchids to inhabit in and around the wetlands, thereby diversifying species in the wetlands. Amongst the least represented families, Potamogetonaceae showed unique species in the region. *Potamogeton crispus* L. is only aquatic plant represented in the wetlands and inhabited in small pools and running stream. However, this species was found frequent in Western Himalaya [34]. Altogether, the diversity of species in the wetlands represented 14% of the total flora in Jigme Dorji National Park and 3.6% of flora of Bhutan (Table S2).

The proportion of abundant species in the lifeform group varied within the region. The proportion order of abundant species, i.e. herbs (62%), shrubs (29%), trees (7%), and climbers (2%) were recorded with similar pattern in the region (Fig. 2b). However, proportion of herbs and shrubs species were slightly higher compared to other parts of the country [16,35] and the Western Himalaya [36] that may be an indicator that the species representations are from wetlands including ecotone. Similarly, the proportion of trees and climbers under study are two to three folds lesser, as these wetlands usually are located at edge or open forest fragments, hence less trees and climbers (Fig. 2b).

The flowering seasons of lifeform groups also
varied in the wetlands. The peak flowering seasons for herbs, shrubs and trees, and climbers were in July, May and April months, respectively (Fig. 2c). These data may be useful for the science education programs (e.g. excursions) in schools and colleges to learn about pollination and floral ecology of diverse wetland plants.

The vegetation structure of habitat indicates its uniqueness in supporting the diverse species in each habitat. The species represented in the figures are the ones that are unique and abundant in such habitats. These species differed among habitats may be due to different microhabitats supporting such unique species. Therefore, these natural vegetation profile clearly displayed various structures of the unique vegetation and species composition in each habitat (Figs. 3 and 4).

The only submerged species, Potamogeton crispus L., occurred only in Shallow fresh marsh (Fig. 3a) and, in open pools due to light reaching into the bottom (depth of approximately 1 to 1.5 m) of habitat. The continuous discharge of water from bottom of the pools indicated water table (arrow showing flow of water towards pool) connected by small stream flowing under the firm mat vegetation. This species also occurred in flowing water towards south of the pools indicating undisturbed vegetation. However, there were no ponds nor proper drainage for flowing water to support this species in other three sites of this type of habitat. The abundant and characteristic species, Acorus calamus L., had created a mat (0.1–0.4 m depth of peat and soil) of vegetation and the small stream flowing underneath the mat at few points (about 4 to 6 m distance) (Fig. 3a). This channel may minimize entry of excess water into the surface of habitat. The characteristic species, i.e. Enkianthus deflexus (Griff.) C.K. Schneid., Persicaria nepalensis (Meisn.) H. Gross, and Rhododendron dalhousiae var. rhabdotum (Balf. f. & R.E. Cooper) Cullen may have added local species richness in the wetlands. Therefore, such intact pools, stream running underneath of mat vegetation and adjacent (ecotone) vegetation may have supported diverse species in such habitats (Fig. 3a).

The seasonally flooded basin of flat habitat occurred where there is permanent water underneath that supported the floating mats (Carex diandra Schrank.) vegetation indicating specific habitat (narrow zone) (Fig. 3b). This characteristic species was found only in the wettest part of this filled basin with the depth of about 2 to 2.5 meters of moderately decomposed sedge peat. The Acorus calamus L. and other species inhabited towards edge of forest next to C. diandra Schrank vegetation, which may represent an ecotone for this habitat (Fig. 3b). Therefore, supported unique species may be available due to its differences in availability of water underneath, open space, and flat surface of habitats.

The poor fen habitat occurred slightly at higher elevations with thick layer of partial or undecomposed peat (about 0.4–0.8 m) of Sphagnum palustre L., which indicates the slower biological activity because of cold temperature (Fig. 4a). The ericaceous shrubs, Rhododendron arboreum Sm. and Malus baccata (L.) Borkh., were characteristic species in such habitat; and that may indicate unique composition of species. The Osmunda japonica Thunb. including ericaceous shrubs occurred in some patches that may indicate territorializing the wetland habitats and supporting diverse species.

The fresh water meadow usually occurred on the slopes and open heath forests indicating no standing water during growing seasons. Due to this unique habitat, diverse species of herbs, shrub and trees are supported, including characteristic species such as Spiranthes sinensis (Pers.) Ames, Matteucia struthiopteris (L.) Tod., Lyonia villosa (Wall. ex C.B. Clarke) Hand.-Mazz. and Alnus nepalensis D. Don (Fig. 4b). The characteristic species of herbs in this habitat, such as Equisetum ramosissimum Desf., Neanotis calycina (Wall. ex Hook. F.) W. H. Lewis, Galium aparine L., Iberidium beauverdianum (H. Lév.) Spring., Pedicularis gracilis subsp. stricta (Prain) P. Tsoong, and Spiranthes sinensis (Pers.) Ames, are stunted. This may be due to less nutrients in soil and anthropogenic disturbances since they are located close to human settlements.

CONCLUSION

Wetland study has seen few important implications for conservation and management of biodiversity. Firstly, it shows that wetlands within the heath forests, forest fragments and bottomlands are truly a valuable resource for the conservation of plant diversity due to presence of large number of local species richness and several local rare species. In addition, high conservation priority could be given for wetlands with indicator species in the sites. These small wetland habitats supported both upland forest species and wetland species, which upland landscapes would not support the wetland species. Therefore, such small wetland habitats deserve protection. Secondly, to protect these wetlands, ecotone should also be considered to keep
the wetlands functionally intact. The study suggests protecting ecotone as part of the measures to protect wetlands. Lastly, the lack of IUCN assessment makes it challenging to understand the status of the native species of national/international concern. Therefore, species-based conservation action plans are required to improve their conservation status in the country.

Appendix A. Supplementary data

Supplementary data associated with this article can be found at http://dx.doi.org/10.2306/scienceasia1513-1874.2021.007.

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Appendix A. Supplementary data

Table S1  Total plots sampled and species recorded (in 1 × 1 m² plot and adjacent plot) in each site.

| Site/site code | Gasa1 (S1) | Gasa2 (S2) | Gasa3 (S3) | Damji1 (S4) | Damji2 (S5) | Damji3 (S6) | Tashithang (S7) | Total |
|----------------|------------|------------|------------|-------------|-------------|-------------|-----------------|-------|
| Plots/site     | 44         | 31         | 45         | 48          | 22          | 18          | 18              | 226   |
| Species/site   | 45         | 33         | 37         | 40          | 29          | 29          | 32              | 250   |

Species recorded from 7 sites (plot) 111
Species recorded from adjacent plots (including shrub, liana, fern and tree) 90

Table S2  List of wetland plant species recorded with taxonomic group, lifeform, flowering seasons and voucher number in Gasa, Bhutan. Species in the list are arranged in alphabetical order of families.

| Scientific name | Family          | Group   | Life form | Flowering season | Voucher No. |
|-----------------|-----------------|---------|-----------|------------------|-------------|
| Strobilanthes auriculata Nees | Acanthaceae | Eudicot | Shrub     | Oct–Feb          | PTndar211   |
| Acorus calamus L. | Araceae     | Monocot | Tree      | Apr–Jul          | PTndar003   |
| Viburnum erubescens Wall. | Adoxaceae | Eudicot | Shrub     | Apr–May          | PTndar223   |
| Viburnum mollula Buch.-Ham. ex D. Don | Adoxaceae | Eudicot | Shrub     | Jul–Sep          | PTndar225   |
| Spatharia tengtsumensis H. Li | Gentianaeeae | L. Urb. | Eudicot | May–Aug          | PTndar192   |
| Centella asiatica (L.) Urb. | Apiceae    | Eudicot | Herb     | Mar–Apr          | PTndar037   |
| Oenanthe hookeri C.B. Clarke | Apiceae    | Eudicot | Herb     | Jul–Sep          | PTndar137   |
| Oenanthe javanica (Blume) DC. | Apiceae    | Eudicot | Herb     | Apr–Oct          | PTndar138   |
| Ariaema concinnum Schott | Araceae    | Monocot | Herb     | Apr–Jul          | PTndar013   |
| Ariaema flavum (Forssk.) Schott | Araceae    | Monocot | Herb     | Jun–Jul          | PTndar014   |
| Colocasia esculenta (L.) Schott | Araceae    | Monocot | Herb     | Jul–Sep          | PTndar043   |
| Hedera nepalensis K. Koch | Araceae    | Monocot | Herb     | Oct–Nov          | PTndar094   |
| Hydrocotyle nepalensis Hook. | Araceae    | Monocot | Herb     | May–Jul          | PTndar098   |
| Hydrocotyle sibthorpioides Lam. | Araceae    | Monocot | Herb     | Mar–Apr          | PTndar099   |
| Schefflera rauburghii Gamble | Araceae    | Monocot | Herb     | Apr–Jul          | PTndar195   |
| Ageratina adenophora (Spreng.) R.M. King & H. Rob. | Asteraceae | Eudicot | Shrub     | Jan–Jun          | PTndar005   |
| Anisolea latifolia (D. Don) Sch. Bip. | Asteraceae | Eudicot | Herb     | Mar–Jun          | PTndar008   |
| Anaphalis margaritacea (L.) Benth. & Hook. f. | Asteraceae | Eudicot | Herb     | Jul–Dec          | PTndar010   |
| Artemisia indica Willd. | Asteraceae | Eudicot | Herb     | Jul–Sep          | PTndar015   |
| Artemisia herbaovariana Y. Ling & Y.-R. Ling | Asteraceae | Eudicot | Herb     | Aug–Oct          | PTndar016   |
| Aster neolelegans Grierson | Asteraceae | Eudicot | Herb     | May–Sep          | PTndar018   |
| Cirsium falconeri (Hook. fil.) Petr. | Asteraceae | Eudicot | Herb     | Jul–Oct          | PTndar040   |
| Crassocephalum crepidioides (Benth.) S. Moore | Asteraceae | Eudicot | Herb     | Apr–Dec          | PTndar048   |
| Impatiens racemosa DC. | Asteraceae | Eudicot | Herb     | May–Nov          | PTndar108   |
| Berberis aristata DC. | Berberidaceae | Eudicot | Shrub     | Apr–May          | PTndar020   |
| Mahonia nepalensis DC. | Berberidaceae | Eudicot | Shrub     | Apr              | PTndar131   |
| Alnus nepalensis D. Don | Betulaceae | Eudicot | Tree      | Jul–Oct          | PTndar009   |
| Cyroglossum lanceolatum Forssk. | Boraginaceae | Eudicot | Herb     | Year round       | PTndar051   |
| Cirrhophyllum sp. | Brachytheciaceae | Moss | Herb     | PTndar039   |
| Cardamine flexuosa With. | Brassicaceae | Eudicot | Herb     | Jan–Jun          | PTndar027   |
| Nasturtium officinale W.T. Aiton | Brassicaceae | Eudicot | Herb     | Jun              | PTndar134   |
| Rhodobryum giganteum (Schwägr.) Paris | Brassicaceae | Eudicot | Herb     | PTndar174   |
| Sarcoocca hookeriana Bail. | Buxaceae    | Eudicot | Shrub     | Apr–Jun          | PTndar194   |
| Lobelia erecticula H.Hara | Campanulaceae | Eudicot | Herb     | Jul–Sept         | PTndar125   |
| Cannabis sativus L. | Cannabaceae | Eudicot | Herb     | Jun–Aug          | PTndar026   |
| Dipascas inermis Wall. | Caprifoliaceae | Eudicot | Herb     | Aug–Sep          | PTndar191   |
| Spatharia tengtsumensis H. Li | Caryophyllaceae | Eudicot | Herb     | May–Jun          | PTndar210   |
| Stellaria reticulivena Hayata | Caryophyllaceae | Eudicot | Herb     | Apr–May          | PTndar044   |
| Commelina diffusa Burm. f. | Commelinaceae | Eudicot | Herb     | PTndar044   |
| Commelina paludosa Blume | Commelinaceae | Eudicot | Herb     | May–Nov          | PTndar045   |
| Cygniis vulgaris (Lour.) Roem. & Schult. | Commelinaceae | Eudicot | Herb     | Jun–Oct          | PTndar030   |
| Toricellia tilifolia DC. | Cornaceae    | Eudicot | Shrub     | Apr–May          | PTndar216   |
| Carex condensata Nees | Cyperaceae | Eudicot | Herb     | Apr–Aug          | PTndar028   |
| Carex filicina Nees | Cyperaceae | Eudicot | Herb     | Apr–Aug          | PTndar029   |
| Carex capillacea Boott | Cyperaceae | Eudicot | Herb     | Apr–Jul          | PTndar030   |
| Carex diandra Schrank | Cyperaceae | Eudicot | Herb     | May–Jun          | PTndar031   |
| Carex rara Boott | Cyperaceae | Eudicot | Herb     | Apr–Jul          | PTndar034   |
| Carex rostrata Hoppe ex Schkuhr | Cyperaceae | Eudicot | Herb     | Apr–Aug          | PTndar035   |
| Carex setigera D. Don | Cyperaceae | Eudicot | Herb     | Apr              | PTndar036   |
| Timbrystis ovata (Burm. f.) J. Kern | Cyperaceae | Eudicot | Herb     | Aug–Sep          | PTndar079   |
Table S2 Continued...

| Scientific name | Family | Group | Life form | Flowering season | Voucher No. |
|-----------------|--------|-------|-----------|------------------|-------------|
| Pycreus flavidus (Retz.) T. Koyama | Cyperaceae | Monocot | Herb | Jun–Jul | PTndar169 |
| Pycreus sanguinolentus (Vahl) Nees ex C.B. Clarke | Cyperaceae | Monocot | Herb | Jul–Sep | PTndar170 |
| Schoenoplectus mucronatus (L.) Palla | Cyperaceae | Monocot | Herb | May–Jun | PTndar197 |
| Scirpus wuchurai Kom. | Cyperaceae | Monocot | Herb | Jul–Aug | PTndar198 |
| Acystopteris sp. | Cystopteridaceae | Monilo | Herb | PTndar004 |
| Daphniphyllum himalayense (Miq.) T. C. Huang | Daphniphyllaceae | Eudicot | Tree | May–Sep | PTndar056 |
| Daphniphyllum himalayense | Daphniphyllaceae | Eudicot | Tree | PTndar106 |
| Pieridium revolutum (Blume) Nakai | Daphniphyllaceae | Eudicot | Tree | PTndar167 |
| Dryopteris juxtaposita Christ | Dryopteridaceae | Monilo | Herb | PTndar063 |
| Dryopteris sp. | Dryopteridaceae | Monilo | Herb | PTndar064 |
| Dryopteris uniformis (Makino) Makino | Dryopteridaceae | Monilo | Herb | PTndar066 |
| Polycthon piceopaleaceum Tag. | Dryopteridaceae | Monilo | Herb | PTndar157 |
| Elaphoglossus parvifolia Wall. ex Royde | Elaphoglossaceae | Eudicot | Herb | Apr–Jun | PTndar067 |
| Equisetum ramosissimum Desf. | Equisetaceae | Monilo | Herb | PTndar073 |
| Enkianthus deflexus (Griff.) C.K. Schneider | Ericaceae | Eudicot | Shrub | May–Jun | PTndar070 |
| Gaultheria semi-infera (C.B. Clarke) Airy Shaw | Ericaceae | Eudicot | Shrub | Aug–Sep | PTndar083 |
| Gaultheria nummularioides D. Don | Ericaceae | Eudicot | Shrub | Jun–Aug | PTndar121 |
| Leucothoe griffithiana | Ericaceae | Eudicot | Shrub | PTndar028 |
| Sm. | Ericaceae | Eudicot | Shrub | PTndar150 |
| Lyonia villosa (Wall.) Drude | Lyoniaceae | Eudicot | Shrub | PTndar127 |
| Lyonia ovalifolia | Lyoniaceae | Eudicot | Shrub | Jun–Aug | PTndar128 |
| Rhododendron virgatum | Ericaceae | Eudicot | Shrub | Jun–Sep | PTndar063 |
| Rhododendron retusum | Ericaceae | Eudicot | Shrub | Apr–Jun | PTndar222 |
| Eriocaulon viride Körn. | Eriocaulaceae | Eudicot | Herb | Jul–Oct | PTndar074 |
| Macaranga postulata King ex Hook.f. | Euphorbiaceae | Eudicot | Tree | Nov–Mar | PTndar129 |
| Parochetus communis Buch.-Ham. ex D. Don | Fabaceae | Eudicot | Herb | Mar–Sep | PTndar142 |
| Trifolium repens L. | Fabaceae | Eudicot | Herb | Apr–Jun | PTndar217 |
| Quercus griffithii Hook.f. & Thomson ex Miq. | Fagaceae | Eudicot | Tree | Apr–May | PTndar171 |
| Gentiana cephalodes Edgew. | Gentianaceae | Eudicot | Herb | Aug–Oct | PTndar084 |
| Gentiana capitata Buch.-Ham. ex D. Don | Gentianaceae | Eudicot | Herb | Feb–Jun | PTndar085 |
| Gentiana subalpina (Wall. ex D. Don) Griseb. | Gentianaceae | Eudicot | Herb | Apr–Jun | PTndar086 |
| Gentiana pedatulata (Wall. ex D. Don) Griseb. | Gentianaceae | Eudicot | Herb | May–Sep | PTndar093 |
| Halenia elliptica D. Don | Gentianaceae | Eudicot | Herb | Jul–Oct | PTndar212 |
| Swertia immaculata (Siebold & Zucc.) Hook. f. & Thomson ex C.B. Clarke | Gentianaceae | Eudicot | Herb | Jul–Oct | PTndar080 |
| Geranium lamarkianum Sweet | Geraniaceae | Eudicot | Herb | Jul–Sep | PTndar083 |
| Geranium procurrens (Siebold & Zucc.) Hook. f. & Thomson ex C.B. Clarke | Geraniaceae | Eudicot | Herb | Jul–Sep | PTndar122 |
| Geranium rhabdotum | Geraniaceae | Eudicot | Herb | Jul–Sep | PTndar088 |
| Jasminum humile L. | Oleaceae | Eudicot | Shrub | May–Jul | PTndar113 |
| Juncus bufonius L. | Juncaceae | Monocot | Herb | Apr–Aug | PTndar072 |
| Hypericum hookerianum G. Forst. | Hypericaceae | Eudicot | Herb | Jun–Aug | PTndar063 |
| Hypericum petiolulatum | Hypericaceae | Eudicot | Herb | Jul–Aug | PTndar101 |
| Hypericum perfoliatum Hook. f. & Thomson ex Dyer | Hypericaceae | Eudicot | Herb | Jul–Aug | PTndar103 |
| Hypericum sp. | Hypericaceae | Eudicot | Herb | Jul–Aug | PTndar071 |
| Juglans regia L. | Juglandaceae | Eudicot | Tree | Apr–May | PTndar114 |
| Juncus furcatus L. | Juncaceae | Monocot | Herb | Apr–Aug | PTndar115 |
| Juncus inflexus L. | Juncaceae | Monocot | Herb | Apr–Aug | PTndar116 |
| Luzula effusa Buchenau | Luzulaceae | Monocot | Shrub | Aug–Oct | PTndar069 |
| Elsholtzia fruticosa (D. Don) Rehder | Lamiaceae | Eudicot | Herb | Oct–Nov | PTndar110 |
| Phlomis macrophylla Benth. | Lamiaceae | Eudicot | Herb | Jul–Aug | PTndar149 |
| Picea seed | Pinaceae | Conifer | Conifer | PTndar062 |
| Prunella vulgaris L. | Lamiaceae | Eudicot | Herb | May–Aug | PTndar165 |
| Holboellia latifolia Wall. | Lardizabalaceae | Eudicot | Herb | Apr–Jun | PTndar96 |
| Leucaena leucocephala (Nees) Hook. f. | Leguminosae | Eudicot | Shrub | Apr–Jun | PTndar024 |
| Urticaria bifida L. | Urticaceae | Eudicot | Shrub | Jul–Sep | PTndar219 |
| Scurfuca elata (Edgew.) Danser | Scurfuaceae | Eudicot | Shrub | Apr–Jun | PTndar199 |
| Magnolia campbellii Hook.f. & Thomson | Magnoliaceae | Eudicot | Tree | May–Mar | PTndar130 |
| Leucopilus acanthocephala (Schwagr.) Lindb. | Mimosaceae | Eudicot | Herb | Apr–Jun | PTndar123 |
| Lignum humile L. | Oleaceae | Eudicot | Shrub | Apr–Jun | PTndar139 |
| Lignum undulata (Willd.) Ching | Oleaceae | Eudicot | Herb | Jul–Sep | PTndar071 |
Table S2 Continued . . .

| Scientific name                  | Family       | Group  | Life form | Flowering season | Voucher No. |
|----------------------------------|--------------|--------|-----------|------------------|-------------|
| *Epilobium wallachianum* Hausskn. | Onagraceae   | Eudicot| Herb     | Jul–Sep          | PTndar072   |
| *Matteuccia struthiopteris* (L.) Tod. | Onocleaceae | Monilophytes | Herb | PTndar133         |
| *Buddleja globiflora* (Trin.) H. Gross | Verbenaceae | Eudicot | Shrub | PTndar024         |
| *Cotoneaster franchetii* (L.) Rchb. f. | Rosaceae | Eudicot | Shrub | PTndar019         |
| *Salix adenochlaena* (Wall.) W. H. Lewis | Salicaceae | Eudicot | Shrub | PTndar214         |
| *Taxus baccata* L. | Taxaceae | Gymnosperm | Tree | PTndar213         |
| *Smilax perfoliata* L. | Smilacaceae | Monocot | Liana | PTndar203         |
| *Girardinia diversifolia* (Link) Friis | Urticaceae | Eudicot | Herb | PTndar090         |
| *Siphonochlaena spiralis* var. *rigida* Nottie | Smilacaceae | Monocot | Shrub | PTndar205         |
| *Sphenophyllum stricta* (Mart.) Nilsson | Xyridaceae | Eudicot | Shrub | PTndar081         |

Abbreviation for group: Monilophytes; Gymnosperm; and Magnoliids.