Results

3.1 Tree species diversity and distribution across three PAs

During the field study carried out at the three PAs, a total of 125 tree species belonging to 85 genera and 38 families were documented (Table 3.1). Among these, it was found that 31 species were common across all the three PAs. The recorded diversity of tree species was relatively consistent at SWS and VNP, with 73 and 70 species, respectively, while MTR exhibited a higher diversity with 80 species. The number of families represented by these tree species showed little variation across the PAs, ranging from 29 to 31. Interestingly, members of the Fabaceae family were more prevalent among the recorded species in the three PAs. Their prevalence was higher in drier PAs compared to the wetter one (Table 3.2). The number of singleton species (species represented by only one individual) was higher at MTR in comparison to SWS and VNP (Table 3.2).

The canopy phenology of tree species exhibited diverse phases during the AVIRIS-NG flight pass over the three PAs. Drier PAs exhibited a greater proportion of deciduous species, accounting for 84% of the observed tree species, with the remaining 16% being evergreen. Conversely, wetter PA had a relatively higher proportion of evergreen species, comprising 59% of the total, while deciduous species constituted 41%. Variations were observed even within the deciduous species category. Deciduous species at MTR displayed greener canopies compared to those in the other two PAs.

The proportion of PA-specific species among the recorded species consistently increased, reaching nearly 53% of the total species at MTR (Figure 3.1a). The number of abundant species (87%–93% spread across the forest cover of each PA) was 23 (SWS), 22 (VNP), and 21 (MTR) along with one additional class ‘others’ at each PA. A list of the abundant species at each PA is given in Table 3.3. Amongst the marked abundant species of three PAs, 22 species were common at two PAs at the least and 15 were PA-specific (Table 3.2). The number of PA-specific species increased in MTR and correspondingly common species numbers decreased (Figure 3.1b).

The field-recorded biophysical parameters of trees, such as canopy spread and height and, exhibited higher values at MTR in comparison to the other two PAs, as summarized in Table 2.4. Tree DBH ranged between 0.04–1.43 m for all the PAs. The mean and median DBH values for each PA are given in Table 3.4. The development of a canopy spectral library for abundant species was made possible with the GPS locations of trees marked with bigger dimensions and/or clusters of a species with > 4 m spread during the field study. These spectra were used to develop abundant species maps using the RF and SVM classifiers.

Table 3.1| List of all the recorded species at three PAs during the field study.

Sr. No.	Botanical Name	Family	Phenology
1	*Acacia catechu* (L.f.) Willd.	Fabaceae	Deciduous
2	*Acacia ferruginea* DC.	Fabaceae	Deciduous
3	*Acacia nilotica* (L.) Willd. ex Delile	Fabaceae	Evergreen
4	*Acacia polyacantha* Willd.	Fabaceae	Deciduous
5	*Aegle marmelos* (L.) Corrêa	Rutaceae	Deciduous
6	*Alangium salviifolium* (L.f.) Wangerin	Cornaceae	Deciduous
7	*Albizia chinensis* (Osbeck) Merr.	Fabaceae	Deciduous
8	*Albizia lebbeck* (L.) Benth.	Fabaceae	Deciduous
9	*Albizia odoratissima* (L.f.) Benth.	Fabaceae	Deciduous
10	*Albizia procera* (Roxb.) Benth.	Fabaceae	Deciduous
11	*Albizia saman* (Jacq.) Merr.	Fabaceae	Deciduous
12	*Alstonia scholaris* (L.) R.Br.	Apocynaceae	Evergreen
13	*Anogeissus latifolia* (Roxb. ex DC.) Wall. ex Guillem. & Perr.	Combretaceae	Deciduous
14	*Aphanamixis polystachya* (Wall.) R.Parker.	Meliaceae	Evergreen
15	*Artocarpus heterophyllus* Lam.	Moraceae	Evergreen
16	*Bauhinia malabarica* Roxb.	Fabaceae	Deciduous
17	*Bauhinia racemosa* Lam.	Fabaceae	Deciduous
18	*Bauhinia variegata* L.	Fabaceae	Deciduous
19	*Bischofia javanica* Blume	Phyllanthaceae	Deciduous
20	*Bombax ceiba* L.	Malvaceae	Deciduous
21	*Bridelia retusa* (L.) A.Juss.	Phyllanthaceae	Deciduous
22	*Buchanania cochinchinensis* (Lour.) M.R.Almeida	Anacardiaceae	Deciduous
23	*Butea monosperma* (Lam.) Kuntze	Fabaceae	Deciduous
24	*Careya arborea* Roxb.	Lecythidaceae	Deciduous
25	*Casearia championii* Thwaites	salicaceae	Deciduous
26	*Casearia esculenta* Roxb.	Salicaceae	Evergreen
27	*Casearia graveolens* Dalzell	Salicaceae	Deciduous
28	*Casearia tomentosa* Roxb.	Salicaceae	Deciduous
29	*Cassia fistula* L.	Fabaceae	Deciduous
30	*Cassine albens* (Retz.) Kosterm.	Celastraceae	Evergreen
31	*Cassine glauca* Kuntze	Celastraceae	Evergreen
32	*Casuarina equisetifolia* L.	Casuarinaceae	Evergreen

33	*Celtis tetrandra* Roxb.	Cannabaceae	Deciduous
34	*Cinnamomum malabatrum* (Burm.f.) J.Presl	Lauraceae	Evergreen
35	*Cinnamomum verum* J.Presl	Lauraceae	Evergreen
36	*Cordia dichotoma* G.Forst.	Boraginaceae	Deciduous
37	*Cordia obliqua* Willd.	Boraginaceae	Deciduous
38	*Dalbergia lanceolaria* L.f.	Fabaceae	Deciduous
39	*Dalbergia paniculata* Roxb.	Fabaceae	Deciduous
40	*Dalbergia latifolia* Roxb.	Fabaceae	Deciduous
41	*Delonix regia* (Bojer ex Hook.) Raf.	Fabaceae	Evergreen
42	*Dendrocalamus strictus* Nees	Poaceae	Deciduous
43	*Desmodium oojeinense* (Roxb.) H.Ohashi	Fabaceae	Deciduous
44	*Dillenia pentagyna* Roxb.	Dilleniaceae	Deciduous
45	*Diospyros melanoxylon* Roxb.	Ebenaceae	Deciduous
46	*Diospyros montana* Roxb.	Ebenaceae	Deciduous
47	*Dolichandrone atrovirens* K.Schum.	Bignoniaceae	Deciduous
48	*Dolichandrone falcata* (Wall. ex DC.) Seem.	Bignoniaceae	Deciduous
49	*Elaeocarpus tuberculatus* Roxb.	Elaeocarpaceae	Evergreen
50	*Erythrina variegata* L.	Fabaceae	Deciduous
51	*Eucalyptus cinerea* F.Muell. ex Benth.	Myrtaceae	Evergreen
52	*Eucalyptus globulus* Labill.	Myrtaceae	Evergreen
53	*Eucalyptus grandis* W.Hill	Myrtaceae	Evergreen
54	*Ficus amplissima* Sm.	Moraceae	Evergreen
55	*Ficus drupacea* Thunb.	Moraceae	Deciduous
56	*Ficus lacor* Buch.-Ham.	Moraceae	Evergreen
57	*Ficus microcarpa* L.f.	Moraceae	Evergreen
58	*Ficus racemosa* L.	Moraceae	Deciduous
59	*Ficus religiosa* L.	Moraceae	Evergreen
60	*Ficus tsjahela* Burm.f.	Moraceae	Evergreen
61	*Ficus virens* Aiton	Moraceae	Deciduous
62	*Firmiana colorata* (Roxb.) R.Br.	Malvaceae	Deciduous
63	*Firmiana simplex* (L.) W.Wight	Malvaceae	Deciduous
64	*Flacourtia indica* (Burm.f.) Merr.	Salicaceae	Deciduous
65	*Garuga pinnata* Roxb.	Burseraceae	Deciduous
66	*Glochidion heyneanum* (Wight & Arn.) Wight	Phyllanthaceae	Evergreen
67	*Gmelina arborea* Roxb.	Lamiaceae	Deciduous
68	*Grevillea robusta* A.Cunn. ex R.Br.	Proteaceae	Deciduous
69	*Grewia tiliifolia* Vahl	Malvaceae	Deciduous
70	*Haldina cordifolia* (Roxb.) Ridsdale	Rubiaceae	Deciduous
71	*Heterophragma quadriloculare* K.Schum.	Bignoniaceae	Deciduous
72	*Holarrhena pubescens* Wall. & G.Don	Apocynaceae	Deciduous
73	*Holoptelea integrifolia* (Roxb.) Planch.	Ulmaceae	Deciduous
74	*Hymenodictyon orixense* (Roxb.) Mabb.	Rubiaceae	Deciduous
75	*Kydia calycina* Roxb.	Malvaceae	Evergreen
76	*Lagerstroemia lanceolata* Wall.	Lythraceae	Deciduous
77	*Lagerstroemia parviflora* Roxb.	Lythraceae	Deciduous
78	*Lannea coromandelica* (Houtt.) Merr.	Anacardiaceae	Deciduous
79	*Macaranga peltata* Müll.Arg.	Euphorbiaceae	Deciduous
80	*Madhuca longifolia* (L.) J.F.Macbr.	Sapotaceae	Deciduous
81	*Mallotus philippensis* (Lam.) Müll.Arg.	Euphorbiaceae	Evergreen
82	*Mallotus tetracoccus* Kurz	Euphorbiaceae	Deciduous
83	*Mangifera indica* L.	Anacardiaceae	Evergreen
84	*Melia azedarach* L.	Meliaceae	Deciduous
85	*Meliosma pinnata* (Roxb.) Maxim.	Sabiaceae	Evergreen
86	*Meliosma simplicifolia* (Roxb.) Walp.	Sabiaceae	Evergreen
87	*Meyna laxiflora* Robyns	Rubiaceae	Deciduous
88	*Miliusa tomentosa* (Roxb.) Finet & Gagnep.	Annonaceae	Deciduous
89	*Mitragyna parvifolia* Korth.	Rubiaceae	Deciduous
90	*Morinda citrifolia* L.	Rubiaceae	Evergreen
91	*Neolitsea javanica* (Blume) Backer	Lauraceae	Evergreen

92	*Olea dioica* Roxb.	Oleaceae	Evergreen
93	*Oroxylum indicum* (L.) Benth. ex Kurz	Bignoniaceae	Evergreen
94	*Persea macrantha* (Nees) Kosterm.	Lauraceae	Evergreen
95	*Phyllanthus acidus* (L.) Skeels	Phyllanthaceae	Deciduous
96	*Phyllanthus emblica* L.	Phyllanthaceae	Deciduous
97	*Pinus patula* Schltdl. & Cham.	Pinaceae	Evergreen
98	*Pithecellobium dulce* (Roxb.) Benth.	Fabaceae	Evergreen
99	*Pongamia pinnata* (L.) Pierre	Fabaceae	Evergreen
100	*Pterocarpus marsupium* Roxb.	Fabaceae	Deciduous
101	*Radermachera xylocarpa* K.Schum.	Bignoniaceae	Deciduous
102	*Salix tetrasperma* Roxb.	Salicaceae	Deciduous
103	*Schleichera oleosa* Merr.	Sapindaceae	Deciduous
104	*Schrebera swietenioides* Roxb.	Oleaceae	Deciduous
105	*Semecarpus anacardium* L.f.	Anacardiaceae	Evergreen
106	*Soymida febrifuga* (Roxb.) A.Juss.	Meliaceae	Deciduous
107	*Sterculia gutata* Roxb.	Malvaceae	Deciduous
108	*Stereospermum chelonoides* DC.	Bignoniaceae	Deciduous
109	*Stereospermum tetragonum* DC.	Bignoniaceae	Deciduous
110	*Syzygium cumini* (L.) Skeels	Myrtaceae	Evergreen
111	*Syzygium densiflorum* Wall. ex Wight & Arn.	Myrtaceae	Evergreen
112	*Tamarindus indica* L.	Fabaceae	Deciduous
113	*Tectona grandis* L.f.	Lamiaceae	Deciduous
114	*Terminalia bellirica* (Gaertn.) Roxb.	Combretaceae	Deciduous
115	*Terminalia catappa* L.	Combretaceae	Deciduous
116	*Terminalia chebula* Retz.	Combretaceae	Deciduous
117	*Terminalia tomentosa* Wight & Arn.	Combretaceae	Deciduous
118	*Toona ciliata* M.Roem.	Meliaceae	Deciduous
119	*Trema orientalis* (L.) Blume	Cannabaceae	Evergreen
120	*Viburnum punctatum* Buch.-Ham. ex D.Don	Adoxaceae	Evergreen
121	*Vitex altissima* L.f.	Lamiaceae	Evergreen
122	*Wrightia arborea* (Dennst.) Mabb.	Apocynaceae	Deciduous
123	*Wrightia tinctoria* R.Br.	Apocynaceae	Deciduous
124	*Ziziphus jujuba* Mill.	Rhamnaceae	Deciduous
125	*Ziziphus xylopyrus* (Retz.) Willd.	Rhamnaceae	Deciduous

Table 3.2| Grouping of recorded tree species across three PAs.

All species found in field survey				
	SWS	**VNP**	**MTR**	**Total of three PAs**
Total Species	73	70	80	125
Number of Families	31	29	30	38
Number of species in Fabaceae	20	19	14	24
Number of PA-specific species	9	11	27	47
Number of singleton species	11	17	21	–
Abundant species				
Total abundant species	23	22	21	37
Deciduous species	19	20	16	30
Evergreen species	4	2	5	7
Common species	21	18	15	22
PA-specific species	2	4	9	15
% occupancy abundant species	85.27	84.59	80.21	–
% occupancy abundant species along with others	92.11	93.02	86.85	–

Table 3.3| Abundant tree species recorded at each PA and their abbreviation.

Sr. No.	SWS	VNP	MTR
1	*Albizia procera* (Albipro)	*Albizia procera*	*Anogissus latifolia* (Anoglat)
2	Bamboo species (Bambsps)	Bamboo species	*Artocarpus heterophyllus* (Artohet)
3	*Bridelia retusa* (Bridret)	*Butea monosperma*	Bamboo species
4	*Butea monosperma* (Butemon)	*Dalbergia lanceolaria*	*Celtis tetrandra* (Celttet)
5	*Dalbergia latifolia* (Dalblat)	*Dalbergia latifolia*	*Dalbergia latifolia*
6	*Ficus racemosa* (Ficurac)	*Diospyros melanoxylon* (Diosmel)	*Eucalyptus globulus* (Eucaglo)
7	*Ficus religiosa* (Ficurel)	*Ficus racemosa*	*Ficus racemosa*
8	*Ficus virens* (Ficuvir)	*Ficus religiosa*	*Ficus tsjahela* (Ficutsj)
9	*Garuga pinnata* (Garupin)	*Garuga pinnata*	*Ficus virens*
10	*Haldina cordifolia* (Haldcor)	*Haldina cordifolia*	*Grevillea robusta* (Grevrob)
11	*Lagerstroemia lanceolata* (Lagelan)	*Lagerstroemia parviflora*	*Grewia tilifolia* (Grewtil)
12	*Lagerstroemia parviflora* (Lagepar)	*Lannea coromandelica* (Lanncor)	*Lagerstroemia lanceolata*
13	*Madhuca longifolia* (Madhlon)	*Madhuca longifolia*	*Mangifera indica*
14	*Mangifera indica* (Mangind)	*Mangifera indica*	*Pterocarpus marsupium*
15	*Miliusa tomentosa* (Militom)	*Miliusa tomentosa*	*Radermachera xylocarpa* (Radexyl)
16	*Mitragyna parvifolia* (Mitrpar)	*Mitragyna parvifolia*	*Schleichera oleosa*
17	*Pongamia pinnata* (Pongpin)	*Pterocarpus marsupium* (Ptermar)	*Sterospermum tetragonum* (Stertet)
18	*Schleichera oleosa* (Schlole)	*Tamarindus indica* (Tamaind)	*Syzygium cumini*
19	*Syzygium cumini* (Syzycum)	*Tectona grandis*	*Tectona grandis*
20	*Tectona grandis* (Tectgra)	*Terminalia bellirica*	*Terminalia bellirica*
21	*Terminalia bellirica* (Termbel)	*Terminalia tomentosa*	*Terminalia tomentosa*
22	*Terminalia tomentosa* (Termtom)	*Wrightia tinctoria*	***Diospyros montana***
23	*Wrightia tinctoria* (Wrigtin)	***Acacia catechu***	***Erythrina variegata***
24	***Anogeissus latifolia***	***Bombax ceiba***	***Melia azedarach***
25	***Albizia lebbeck***	***Bridelia retusa***	***Olea dioica***
26	***Bombax ceiba***	***Dalbergia paniculata***	
27	***Diospyros melanoxylon***	***Desmodium oojeinense***	
28	***Grewia tiliifolia***	***Grewia tiliifolia***	

*Bold ones are species in ‘others’ class at each PA, spread over 8%─10% of forest cover.

Table 3.4| Mean and median values of trunk DBH for abundant species at three PAs.

PAs	Mean (m)	Median (m)
SWS	0.39	0.34
VNP	0.36	0.34
MTR	0.61	0.60

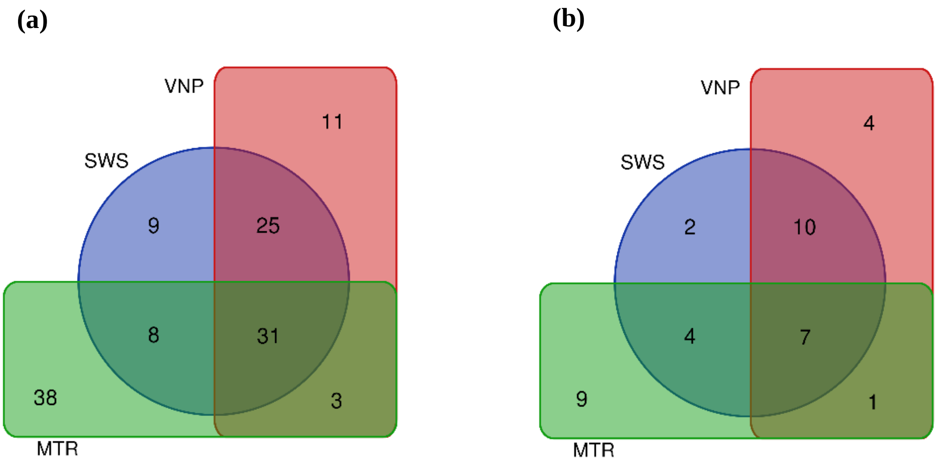

Figure 3.1| Venn diagram showing the distribution of all recorded species (a) and abundant species (b) as common (at two/three PAs) and PA-specific species. Blue represents SWS, red represents VNP, and green represents MTR.

3.1.1 Estimation of species and rank abundance curves

Among the various methods utilized to estimate species richness within each PA, the Bootstrap method showed estimates that were relatively closer to the observed values and was having minimum error (Table 3.5). These estimates revealed a greater species richness at MTR compared to the other two PAs. The large differences in species number estimates from nonparametric estimators arise from their differing assumptions, sensitivity to sample size, handling of rare species, and the distribution patterns of species in the dataset.

The log-based rank abundance curves, constructed for both the abundant species and all recorded species within each PA, as depicted in Figure 3.2, displayed varying widths and similar slopes. This suggests a high degree of variability in the occurrence of these species and an uneven distribution across the PAs. The sharp descending and shorter curves implied a less widely distributed species were situated in the lower portion of the abundance curve, with many of them sharing the same rank, indicating their relatively lower abundance compared to more widely distributed species. The presence of flat tails in all curves suggested the existence of singletons. It was also observed that *Tectona grandis* remained the most abundant species across all PAs.

Table 3.5| Estimated values of species number present at each PA derived from various methods assessed for measuring species richness along with their standard errors (s.e.).

PAs	n	N	Jackknife1 (s.e.)	Jackknife2 (s.e.)	Chao (s.e.)	Bootstrap (s.e.)
SWS	20	73	103 (8.95)	124	122 (24.10)	86 (4.47)
VNP	19	70	95 (7.70)	110	106 (19.26)	81 (3.74)
MTR	21	80	118 (12.80)	138	120 (16.90)	97 (6.49)

n = number of sample plot, **N** = number of observed species

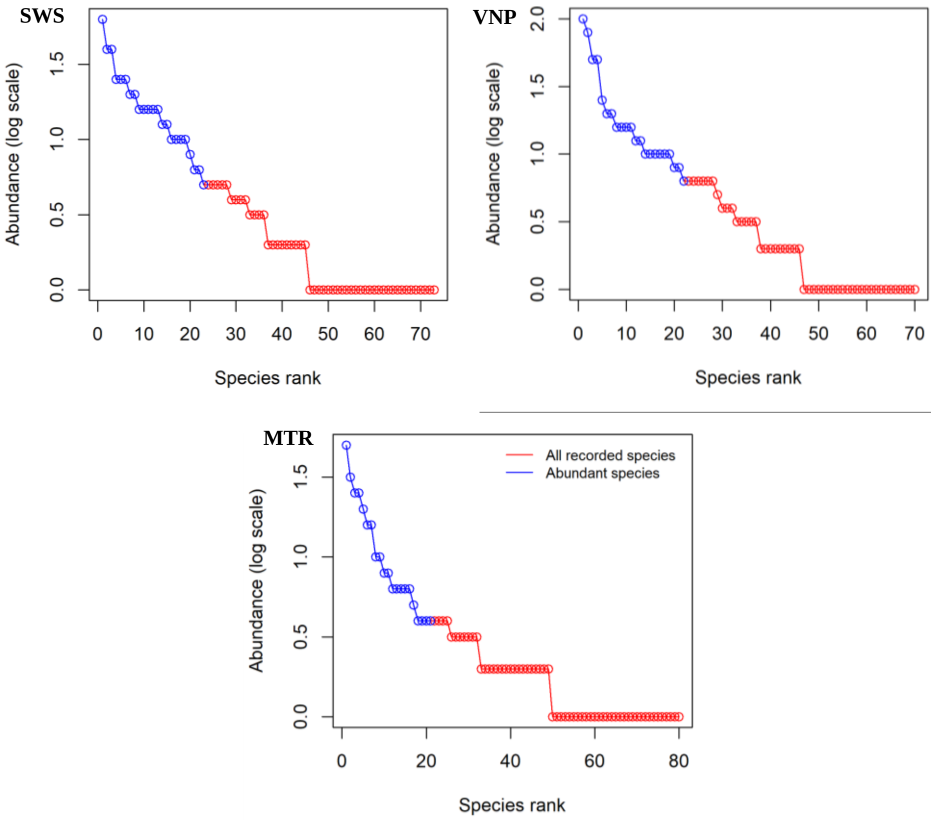

Figure 3.2| Rank abundance curves of all recorded and abundant tree species at each PA.

3.2 Spectral characterization of abundant species

A comparison was conducted between the mean spectral profiles of the abundant species within each PA, as illustrated in figure 3.3. To clearly distinguish the spectra of each abundant species for classification at each PA, spectral regions where spectra of all abundant species overlaps were removed. The spectral regions that emerged as significant were those where all the abundant species exhibited distinct spectral behaviors. Upon a thorough visual assessment, it became evident that these crucial spectra were predominantly located in the four distinct spectral regions, the visible (VIS) region, spanning from 550 to 650 nm, the near-infrared (NIR) region ranging from 750 to 1250 nm, and two regions within the short-wave infrared (SWIR) region (1500 to 1750 nm and 2000 to 2250 nm). These selected spectral regions constituting 226 spectral bands were then subjected to further analysis.

The NIR region of spectra coming from VNP and MTR demonstrated the most pronounced differences among species. In the case of SWS, it was observed that segments of the SWIR regions possessed the capability to distinguish the spectra of Tectgra, Lagepar, Albipro, and Mangind (Figure 3.3). At VNP, the highest spectral variability was observed for Albipro within the NIR region (Figure 3.3). Interestingly, in MTR, Tectgra and Eucaglo displayed the most discriminating wavebands within the SWIR regions of the spectrum (Figure 3.3). This in-depth analysis of the spectral data offers valuable insights into the spectral characteristics of these abundant tree species within their respective protected areas.

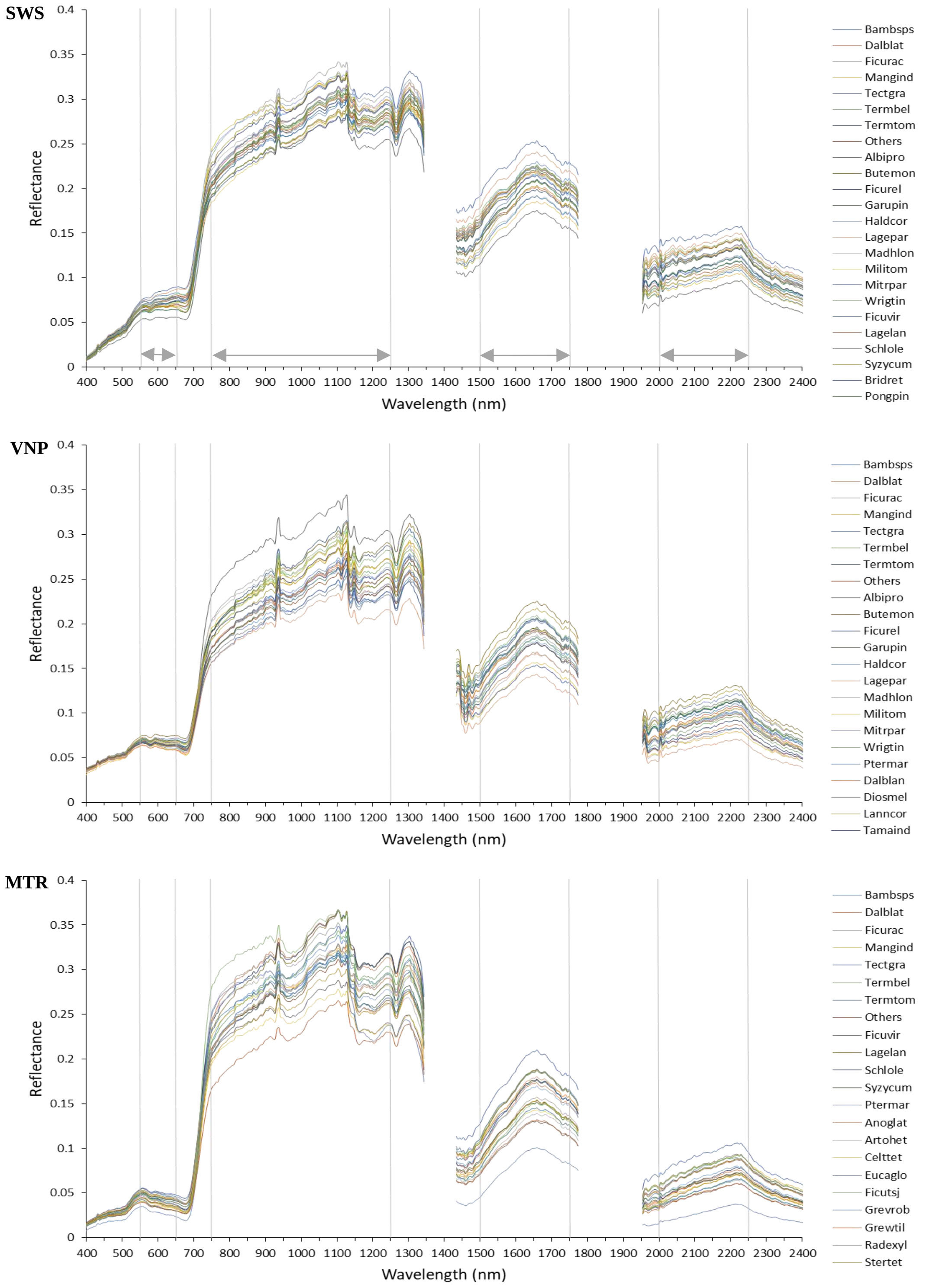

Figure 3.3| Mean spectra of abundant tree species in each PA, with a selection of spectral regions marked by vertical gray lines.

3.3 Abundant species maps and accuracy evaluation

The distribution of abundant species generated from the field survey is shown in Table 3.6 for each PA. A total of 3,106 pixels were extracted from the AVIRIS-NG image, with pixel counts ranging from 887 to 1158 for each PA. These pixels, derived from a total of 1084 tree crowns across all PAs, exhibited an average crown size of 68.7 m^2. The performance of two classifiers, Random Forest (RF) and Support Vector Machine (SVM), was individually assessed at pixel level. The classification maps of abundant species resulting from each classifier applied to subsets of AVIRIS-NG image data of each PA are displayed in Figures 3.4 and 3.5. For the RF classifier, classification maps of each PA exhibited fair overall accuracy, ranging from 76.92% to 81.04%, with kappa coefficients ranging from 0.76 to 0.80 (Table 3.7). Additional accuracy assessment parameters, such as the producer's accuracy and the user's accuracy, were consistent (Table 3.7). The SVM classifier, when tested for the classification of abundant species within each PA, performed well, achieving accuracy levels ranging from 76.92% to 80.57% and kappa coefficients between 0.75 and 0.80 (refer to Table 3.8 for detailed accuracy levels and other relevant information regarding the SVM classifier).

Comparing the performance of both classifiers, it was observed that the RF exhibited slightly higher (~4%) overall accuracy than the SVM at MTR, while at SWS and VNP, their performance was nearly the same (Figure 3.6). An analysis of producer's and user's accuracies revealed that certain classes were consistently classified with high accuracies, while others varied depending on the classifier used. Producer's and user's accuracy were compared for seven common abundant species within each PA for both classifiers. The RF classifier yielded producer's accuracy ranging from 66.67–100% at SWS, 60–100% at VNP, and 61.54–100% at MTR (Tables 3.9-3.11). In contrast, the SVM classifier had producer's accuracy values of 64.29–94.74% at SWS, 60–100% at VNP, and 53.85–91.30% at MTR (Tables 3.12-3.14). These results demonstrated that the RF classifier performed better than the SVM classifier in terms of the producer's accuracy for the common species across different PAs.

Regarding user’s accuracy, results from the RF classifier ranged from 64.29–100% at SWS, 40–100% at VNP, and 50–100% at MTR (Tables 3.9-3.11). The SVM classifier produced user's accuracy values of 71.43–100% at SWS, 50–100% at VNP, and 45.45–

100% at MTR (Tables 3.12-3.14). The user's accuracy for common abundant species was higher in the SVM classifier at SWS and VNP. However, at MTR, the user’s accuracy of the RF classifier was superior. Visually abundant species maps coming from the RF classifier were sharper as compared to SVM classifier ones, so for subsequent analysis, RF classification maps were used.

The accuracy of the RF classifier was additionally validated using receiver operating characteristic (ROC) curves for each species, and the corresponding area under the curve (AUC) was calculated (Figure 3.7). The mean AUC values across all three PAs ranged from 0.95 to 0.98, indicating the precision and specificity of the developed species maps.

In agreement with field data, the proportion of spread of PA-specific species (Figure 3.8), and of evergreen species (Figure 3.9) was more at wetter PA. The common abundant species across all three PAs included Dalblat, Ficurac, Mangind, Tectgra, Termbel and Termtom. Additionally, Bamboo species (represented by *Dendrocalamus strictus* at SWS and VNP and *Bambusa bambos* at MTR) ranked as the seventh common abundant species across the PAs. However, it's important to note that the relative distribution and hierarchy of these common abundant species, as revealed in the abundant species maps, exhibited variations among the three PAs (Figure 3.10). For instance, the distribution of Dalblat and Termtom increased at wetter PA having higher rainfall, while bamboo species displayed the opposite trend. Termbel exhibited a more limited distribution at VNP, whereas Tectgra showed a broader spread. Mangind exhibited a lesser spread, while Ficurac showed a greater distribution at MTR. These differences in species distribution highlight the importance of understanding local environmental factor’s impact on these tree species distribution dynamics.

Table 3.6| Total number of crowns for each species at each PA along with their corresponding total pixel count for abundant species

Sr. No.	Species	Number of crowns			Number of pixels		
		SWS	VNP	MTR	SWS	VNP	MTR
1	*Albizia procera*	11	14	–	26	55	–
2	*Anogeissus latifolia*	–	–	21	–	–	56
3	*Artocarpus heterophyllus*	–	–	10	–	–	28
4	Bamboo sps	30	14	29	65	46	80
5	*Bridelia retusa*	20	–	–	42	–	–
6	*Butea monosperma*	20	10	–	33	27	–
7	*Celtis tetrandra*	–	–	9	–	–	25
8	*Dalbergia lanceolaria*	–	12	–	–	36	–
9	*Dalbergia latifolia*	11	8	27	24	20	84
10	*Diospyros melanoxylon*	–	8	–	–	20	–
11	*Eucalyptus globulus*	–	–	24	–	–	85
12	*Ficus racemosa*	16	10	18	42	38	68
13	*Ficus religiosa*	10	13	–	34	55	–
14	*Ficus tsjahela*	–	–	7	–	–	30
15	*Ficus virens*	12	–	19	41	–	82
16	*Garuga pinnata*	15	10	–	32	30	–
17	*Grevillea robusta*	–	–	25	–	–	60
18	*Grewia tiliifolia*	–	–	7	–	–	20
19	*Haldina cordifolia*	24	13	–	68	38	–
20	*Lagerstroemia lanceolata*	16	–	27	46	–	80
21	*Lagerstroemia parviflora*	11	8	–	22	18	–
22	*Lannea coromandelica*	–	8	–	–	25	–
23	*Madhuca longifolia*	20	20	–	80	70	–
24	*Mangifera indica*	16	19	9	72	53	30
25	*Miliusa tomentosa*	20	9	–	40	28	–
26	*Mitragyna parvifolia*	22	15	–	45	49	–
27	*Pongamia pinnata*	17	–	–	43	–	–
28	*Pterocarpus marsupium*	–	8	6	–	23	20
29	*Radarmachera xylocarpa*	–	–	5	–	–	20
30	*Schleichera oleosa*	10	–	13	23	–	46
31	*Stereospermum tetragonum*	–	–	7	–	–	22
32	*Syzygium cumini*	10	–	18	35	–	50
33	*Tamarindus indica*	–	10	–	–	33	–
34	*Tectona grandis*	19	23	32	46	60	85
35	*Terminalia bellirica*	22	8	25	66	31	70
36	*Terminalia tomentosa*	23	18	18	50	55	60
37	*Wrightia tinctoria*	14	10	–	24	20	–
38	Others	25	19	27	62	57	57
	Total	414	287	383	1061	887	1158

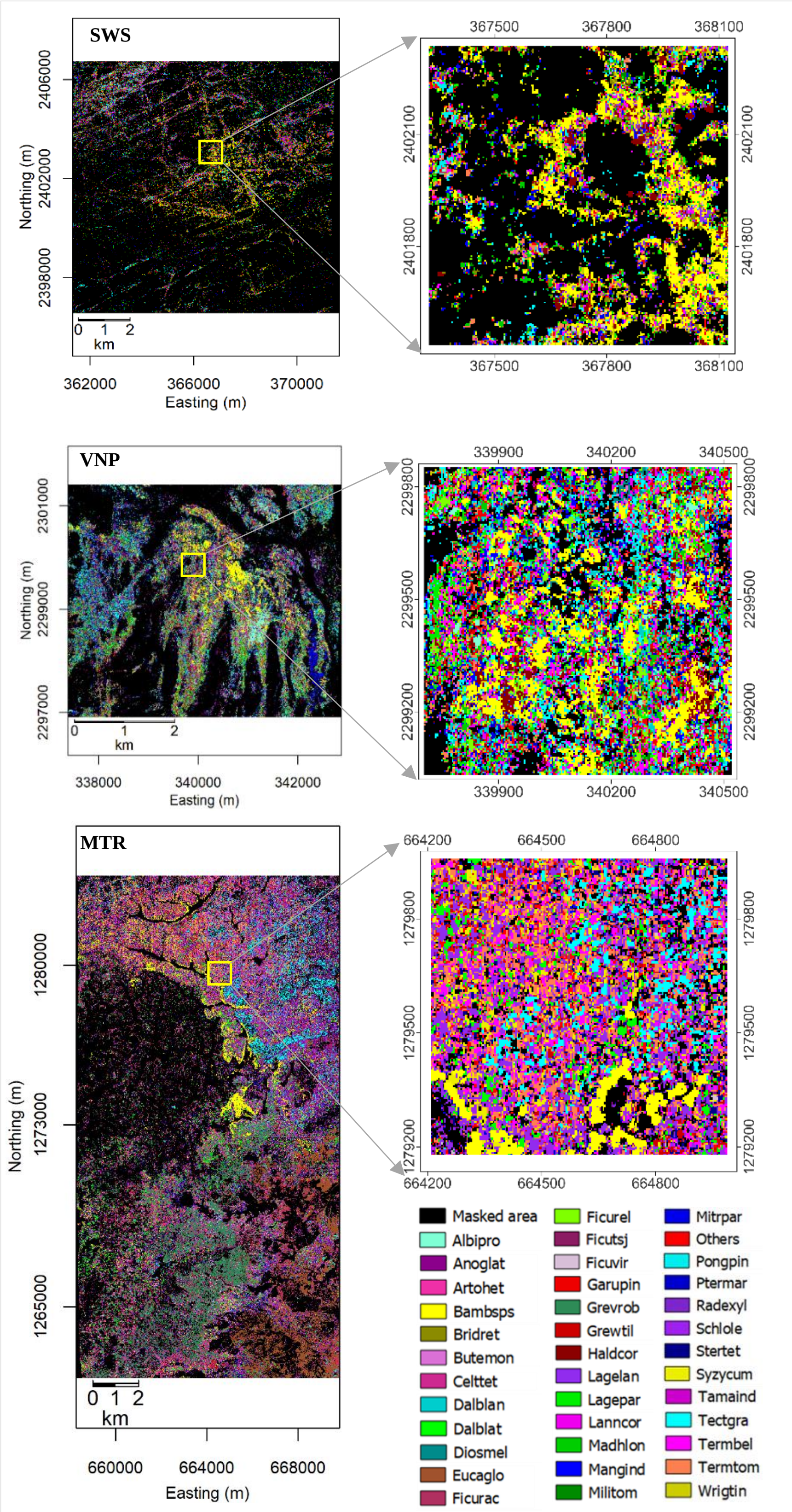

Figure 3.4| Abundant species classification maps of three PAs generated using the Random Forest classifier, applied to processed subsets of AVIRIS-NG images (Complete names of species are given in Table 3.3) and its zoomed view. Black color indicates masked areas such as non-forest vegetation and urban areas.

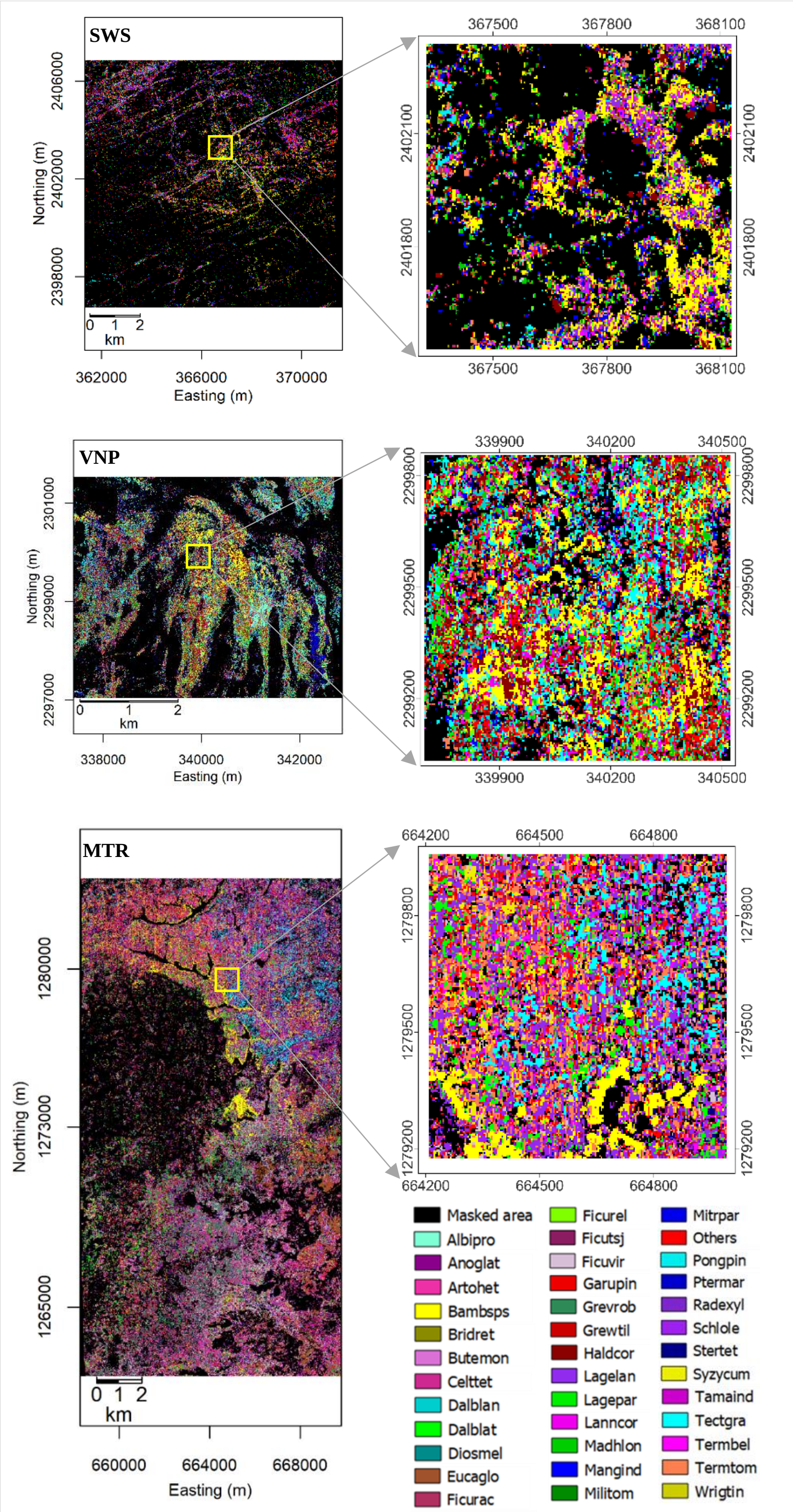

Figure 3.5| Abundant species classification maps of three PAs generated using the Support Vector Machine classifier, applied to processed subsets of AVIRIS-NG images (Complete names of species are given in Table 3.3) and its zoomed view. Black color indicates masked areas such as non-forest vegetation and urban areas.

Table 3.7| Accuracy values and classification parameters of the RF classifier applied over three PAs.

Parameters	SWS	VNP	MTR
Overall accuracy (%)	76.92	81.04	80.00
Kappa coefficient	0.76	0.80	0.79
Producer's accuracy (%)	76.78	79.24	75.75
User's accuracy (%)	76.97	80.18	78.70
OOB error (%)	11.13	9.27	11.23
MNF bands	20	15	20
mtry	2	2	2
ntree	300	500	700

Table 3.8| Accuracy values and classification parameters of the SVM classifier applied over three PAs.

Parameters	SWS	VNP	MTR
Overall accuracy (%)	76.92	80.57	76.43
Kappa coefficient	0.76	0.80	0.75
Producer's accuracy (%)	76.78	79.8	73.22
User's accuracy (%)	79.21	80.44	75.12
MNF bands	20	15	20
Gamma kernel (sigma)	0.07	0.05	0.05
Penalty parameter	5	5	5

Table 3.9| Confusion matrix for RF classification of SWS. The top row represents the reference trees, while the left column represents the classified trees.

Prediction	Albipro	Bambsps	Bridret	Butemon	Dalblat	Ficurac	Ficurel	Ficuvir	Garupin	Haldcor	Lagelan	Lagepar	Madhlon	Mangind	Militom	Mitrpar	Others	Pongpin	Schlole	Syzycum	Tectgra	Termbel	Termtom	Wrigtin	Total	User's accuracy (%)
Albipro	**7**	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	8	87.50
Bambsps	0	**12**	0	0	0	0	0	0	0	0	1	0	0	0	1	0	0	0	0	0	0	0	0	1	15	80.00
Bridret	0	2	**7**	1	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	1	0	0	2	15	46.67
Butemon	0	1	0	**7**	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	1	0	0	10	70.00
Dalblat	0	0	0	0	**4**	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	6	66.67
Ficurac	0	0	0	0	0	**10**	0	1	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	12	83.33
Ficurel	0	0	0	0	0	0	**6**	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6	100.00
Ficuvir	0	0	0	0	0	0	0	**8**	1	0	0	0	0	1	0	1	1	0	0	0	0	0	0	0	12	66.67
Garupin	0	0	0	0	0	0	0	0	**2**	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	3	66.67
Haldcor	0	0	0	0	0	0	0	0	1	**9**	0	0	1	0	0	0	0	0	0	0	0	0	0	0	11	81.82
Lagelan	0	0	0	0	0	0	2	1	0	0	**5**	1	0	0	0	0	0	0	0	0	0	0	0	0	9	55.56
Lagepar	0	0	0	0	0	0	0	0	0	0	0	**4**	0	0	0	0	0	0	0	0	0	0	0	0	4	100.00
Madhlon	0	0	0	0	0	0	0	0	1	0	0	0	**19**	1	0	0	1	0	0	0	0	0	0	1	23	82.61
Mangind	0	0	0	0	0	0	0	0	0	0	0	0	0	**17**	0	0	0	0	0	0	0	0	0	0	17	100.00
Militom	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**5**	0	0	0	0	0	0	1	0	1	7	71.43
Mitrpar	0	0	0	1	0	0	0	1	0	0	0	0	0	0	0	**5**	1	0	0	0	0	0	2	0	10	50.00
Others	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	**6**	0	0	0	0	1	0	0	8	75.00
Pongpin	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**10**	0	0	0	0	0	0	10	100.00
Schlole	0	0	0	0	0	1	2	0	0	0	0	1	1	0	0	0	0	0	**6**	0	0	0	0	0	11	54.55
Syzycum	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**5**	0	0	0	0	5	100.00
Tectgra	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**12**	0	0	0	13	92.31
Termbel	0	2	0	0	0	1	0	0	0	0	0	0	0	0	1	0	1	0	0	0	0	**9**	0	0	14	64.29
Termtom	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**12**	0	13	92.31
Wrigtin	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1	0	0	0	0	0	0	0	**3**	5	60.00
Total	8	18	7	9	4	12	10	11	5	9	6	7	21	19	11	7	12	13	6	5	13	12	14	8	247	
Producer's accuracy (%)	87.50	66.67	100.00	77.78	100.00	83.33	60.00	72.73	40.00	100.00	83.33	57.14	90.48	89.47	45.45	71.43	50.00	76.92	100	100	92.31	75.00	85.71	37.50		

Table 3.10| Confusion matrix for RF classification of VNP. The top row represents the reference trees, while the left column represents the classified trees.

Prediction	Albipro	Bambsps	Butemon	Dalblan	Dalblat	Diosmel	Ficurac	Ficurel	Garupin	Haldcor	Lagepar	Lanncor	Madhlon	Mangind	Militom	Mitrpar	Others	Ptermar	Tamaind	Tectgra	Termbel	Termtom	Wrigtin	Total	User's accuracy (%)
Albipro	**13**	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	15	86.67
Bambsps	0	**12**	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	13	92.31
Butemon	0	0	**8**	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	10	80.00
Dalblan	0	0	0	**8**	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	8	100.00
Dalblat	0	0	0	0	**4**	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	5	80.00
Diosmel	0	0	1	0	0	**3**	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	5	60.00
Ficurac	0	0	0	0	0	1	**7**	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	8	87.50
Ficurel	0	0	0	0	0	0	0	**11**	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	12	91.67
Garupin	0	0	0	0	0	0	0	0	**4**	1	0	0	0	0	0	1	0	0	0	0	0	0	0	6	66.67
Haldcor	0	0	0	0	0	0	0	0	0	**4**	0	1	0	0	0	0	1	0	0	0	0	0	0	6	66.67
Lagepar	0	0	0	0	0	0	0	0	0	0	**6**	0	0	0	0	0	1	0	0	0	0	0	0	7	85.71
Lanncor	0	0	0	0	0	0	0	0	0	0	0	**3**	0	0	0	0	0	0	0	0	0	0	0	3	100.00
Madhlon	0	0	0	0	0	1	0	0	0	0	0	0	**17**	0	0	0	1	0	0	0	0	2	0	21	80.95
Mangind	0	0	0	0	0	0	1	0	0	0	0	0	0	**12**	0	0	0	0	0	0	0	0	0	13	92.31
Militom	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**5**	0	0	0	0	0	0	0	0	5	100.00
Mitrpar	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**10**	0	0	0	0	0	0	0	10	100.00
Others	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**5**	1	0	0	0	0	0	6	83.33
Ptermar	0	0	0	0	1	0	0	0	2	0	0	1	0	0	0	0	1	**3**	0	2	0	0	0	10	30.00
Tamaind	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	**7**	0	0	0	0	9	77.78
Tectgra	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**6**	0	0	0	6	100.00
Termbel	0	0	0	1	0	0	0	1	0	0	0	0	0	0	0	0	1	0	0	0	**2**	0	0	5	40.00
Termtom	0	0	1	0	0	0	0	0	1	1	0	0	0	0	0	0	1	0	0	0	0	**16**	0	20	80.00
Wrigtin	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	1	1	**5**	8	62.50
Total	13	12	10	9	6	5	10	13	7	8	6	6	17	12	5	11	13	4	7	10	3	19	5	211	
Producer's accuracy (%)	100.00	100.00	80.00	88.89	66.67	60.00	70.00	84.62	57.14	50.00	100.00	50.00	100.00	100.00	100.00	90.91	38.46	75.00	100.00	60.00	66.67	84.21	100		

Table 3.11| Confusion matrix for RF classification of MTR. The top row represents the reference trees, while the left column represents the classified trees.

Prediction	Anoglat	Artohet	Bambsps	Celttet	Dalblat	Eucaglo	Ficurac	Ficutsj	Ficuvir	Grevrob	Grewtil	Lagelan	Mangind	Others	Ptermar	Radexyl	Schlole	Stertet	Syzycum	Tectgra	Termbel	Termtom	Total	User's accuracy (%)
Anoglat	**10**	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	2	0	13	76.92
Artohet	0	**4**	0	0	0	0	0	0	0	1	0	1	0	1	0	0	0	0	0	0	1	0	8	50.00
Bambsps	0	0	**23**	0	1	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	25	92.00
Celttet	0	0	0	**3**	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	100.00
Dalblat	0	0	0	0	**19**	0	1	0	0	0	0	0	0	0	2	0	1	0	1	0	1	0	25	76.00
Eucaglo	0	0	0	0	0	**24**	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	25	96.00
Ficurac	0	0	0	0	0	0	**12**	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	13	92.31
Ficutsj	0	0	0	0	0	0	0	**4**	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	100.00
Ficuvir	0	1	0	0	0	0	0	0	**14**	0	1	0	0	0	0	0	0	0	0	0	0	0	16	87.50
Grevrob	0	0	0	1	0	0	0	0	1	**14**	0	0	0	0	0	0	0	0	0	0	0	0	16	87.50
Grewtil	0	0	0	0	1	0	0	0	0	0	**2**	0	0	0	0	0	0	0	0	0	0	0	3	66.67
Lagelan	1	0	0	0	0	0	0	0	0	0	0	**20**	0	1	0	0	0	1	0	0	0	0	23	86.96
Mangind	0	0	0	0	0	0	0	0	0	0	0	0	**7**	0	0	0	0	0	0	0	0	0	7	100.00
Others	0	0	0	0	1	0	0	0	1	0	1	0	0	**3**	0	0	0	0	0	0	0	0	6	50.00
Ptermar	1	0	0	1	1	0	0	0	0	0	0	0	0	0	**3**	0	0	0	0	0	0	0	6	50.00
Radexyl	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**3**	0	0	0	0	0	0	3	100.00
Schlole	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**12**	0	1	0	0	0	13	92.31
Stertet	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	**3**	0	0	1	0	5	60.00
Syzycum	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	**9**	0	0	0	10	90.00
Tectgra	3	0	0	0	0	0	0	0	0	0	0	0	0	3	0	1	1	1	0	**21**	0	0	30	70.00
Termbel	1	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	1	0	0	0	**8**	2	14	57.14
Termtom	1	0	0	0	1	0	0	0	0	0	0	1	0	0	0	0	0	0	0	3	0	**6**	12	50.00
Total	17	5	23	5	24	24	13	4	16	15	4	23	8	12	6	4	16	5	11	24	13	8	280	
Producer's accuracy (%)	58.82	80.00	100.00	60.00	79.17	100.00	92.31	100.00	87.50	93.33	50.00	86.96	87.50	25.00	50.00	75.00	75.00	60.00	81.82	87.50	61.54	75.00		

Table 3.12| | Confusion matrix for SVM classification of SWS. The top row represents the reference trees, while the left column represents the classified trees.

Prediction	Albipro	Bambsps	Bridret	Butemon	Dalblat	Ficurac	Ficurel	Ficuvir	Garupin	Haldcor	Lagelan	Lagepar	Madhlon	Mangind	Militom	Mitrpar	Others	Pongpin	Schlole	Syzycum	Tectgra	Termbel	Termtom	Wrigtin	Total	User's accuracy (%)
Albipro	**7**	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	8	87.50
Bambsps	0	**13**	0	1	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	15	86.67
Bridret	0	1	**6**	1	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1	0	0	2	12	50.00
Butemon	0	2	0	**6**	0	0	0	0	0	0	1	0	0	0	1	0	1	0	0	0	0	0	0	1	12	50.00
Dalblat	0	0	0	0	**3**	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	100.00
Ficurac	0	0	0	0	0	**10**	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1	0	12	83.33
Ficurel	0	0	0	0	0	0	**6**	1	0	0	0	0	0	0	0	0	1	0	0	0	1	0	1	0	10	60.00
Ficuvir	0	0	0	0	0	0	0	**9**	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	10	90.00
Garupin	0	0	0	0	0	0	0	0	**3**	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	100.00
Haldcor	0	0	0	0	1	1	0	0	1	**9**	0	0	0	1	0	0	0	0	0	0	0	0	0	0	13	69.23
Lagelan	0	0	0	0	0	0	0	0	1	0	**5**	0	0	0	0	0	2	0	0	0	0	0	0	0	8	62.50
Lagepar	0	0	0	0	0	0	0	0	0	0	0	**4**	0	0	0	0	0	0	0	0	0	0	0	0	4	100.00
Madhlon	0	0	0	0	0	0	0	0	0	0	0	0	**19**	0	0	0	1	0	0	0	0	0	0	1	21	90.48
Mangind	0	0	0	0	0	0	0	0	0	0	0	0	0	**18**	0	0	0	0	0	0	0	0	0	0	18	100.00
Militom	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**6**	0	0	0	0	0	0	1	0	0	7	85.71
Mitrpar	0	1	0	0	0	0	0	0	0	0	0	1	2	0	0	**6**	0	0	0	0	0	0	2	0	12	50.00
Others	0	1	0	0	0	0	2	1	0	0	0	0	0	0	0	1	**7**	0	0	0	0	1	0	0	13	53.85
Pongpin	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**8**	0	0	0	0	0	0	8	100.00
Schlole	0	0	0	0	0	0	2	0	0	0	0	1	0	0	0	0	0	0	**6**	0	0	0	0	0	9	66.67
Syzycum	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	**5**	0	0	0	0	6	83.33
Tectgra	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	**11**	0	0	0	14	78.57
Termbel	0	0	0	1	0	1	0	0	0	0	0	1	0	0	1	0	0	0	0	0	0	**10**	0	0	14	71.43
Termtom	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	**9**	0	11	81.82
Wrigtin	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**4**	4	100.00
Total	8	18	7	9	4	12	10	11	5	9	6	7	21	19	11	7	12	13	6	5	13	12	14	8	247	
Producer's accuracy (%)	87.50	72.22	85.71	66.67	75.00	83.33	60.00	81.82	60.00	100.00	83.33	57.14	90.48	94.74	54.55	85.71	58.33	61.54	100.00	100.00	84.62	83.33	64.29	50.00		

Table 3.13| Confusion matrix for SVM classification of VNP. The top row represents the reference trees, while the left column represents the classified trees.

Prediction	Albipro	Bambsps	Butemon	Dalblan	Dalblat	Diosmel	Ficurac	Ficurel	Garupin	Haldcor	Lagepar	Lanncor	Madhlon	Mangind	Militom	Mitrpar	Others	Ptermar	Tamaind	Tectgra	Termbel	Termtom	Wrigtin	Total	User's accuracy (%)
Albipro	**13**	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	14	92.86
Bambsps	0	**11**	0	0	0	0	0	0	0	1	0	1	0	0	0	0	1	0	0	0	0	0	0	14	78.57
Butemon	0	0	**8**	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	10	80.00
Dalblan	0	0	0	**9**	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	10	90.00
Dalblat	0	0	0	0	**5**	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5	100.00
Diosmel	0	0	0	0	0	**3**	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	100.00
Ficurac	0	0	0	0	0	1	**8**	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	11	72.73
Ficurel	0	0	0	0	0	0	0	**11**	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	11	100.00
Garupin	0	0	0	0	1	0	0	0	**4**	0	0	0	0	0	0	1	1	0	0	0	0	0	0	7	57.14
Haldcor	0	1	0	0	0	0	0	0	0	**4**	0	1	0	0	0	0	2	0	0	0	0	3	0	11	36.36
Lagepar	0	0	0	0	0	0	0	0	0	0	**6**	0	0	0	0	0	0	0	0	0	0	0	0	6	100.00
Lanncor	0	0	0	0	0	0	0	0	0	0	0	**4**	0	0	0	0	0	0	0	0	0	0	0	4	100.00
Madhlon	0	0	0	0	0	0	0	0	0	0	0	0	**17**	0	0	0	2	0	0	0	0	0	1	20	85.00
Mangind	0	0	0	0	0	0	0	0	0	0	0	0	0	**12**	0	0	0	0	0	0	0	0	0	12	100.00
Militom	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**5**	0	1	0	0	0	0	0	0	6	83.33
Mitrpar	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	**10**	0	0	0	2	0	0	0	14	71.43
Others	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	**4**	0	0	0	0	0	0	5	80.00
Ptermar	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	**4**	0	1	0	0	0	7	57.14
Tamaind	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	**7**	0	0	0	0	8	87.50
Tectgra	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**6**	0	0	0	7	85.71
Termbel	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	**2**	0	0	4	50.00
Termtom	0	0	1	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	**14**	1	17	82.35
Wrigtin	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	**3**	5	60.00
Total	13	12	10	9	6	5	10	13	7	8	6	6	17	12	5	11	13	4	7	10	3	19	5	211	
Producer's accuracy (%)	100.00	91.67	80.00	100.00	83.33	60.00	80.00	84.62	57.14	50.00	100.00	66.67	100.00	100.00	100.00	90.91	30.77	100.00	100	60.00	66.67	73.68	60.00		

Table 3.14| Confusion matrix for SVM classification of MTR. The top row represents the reference trees, while the left column represents the classified trees.

Prediction	Anoglat	Artohet	Bambsps	Celttet	Dalblat	Eucaglo	Ficurac	Ficutsj	Ficuvir	Grevrob	Grewtil	Lagelan	Mangind	Others	Ptermar	Radexyl	Schlole	Stertet	Syzycum	Tectgra	Termbel	Termtom	Total	User's accuracy (%)
Anoglat	**15**	0	0	0	1	0	0	0	0	0	0	1	0	0	1	0	0	0	0	4	2	0	24	62.50
Artohet	0	**2**	0	0	0	0	0	0	0	1	0	0	0	1	0	0	0	0	0	0	0	0	4	50.00
Bambsps	0	0	**21**	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	22	95.45
Celttet	0	0	0	**3**	0	0	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	5	60.00
Dalblat	0	0	0	0	**17**	0	1	0	0	0	0	0	0	1	0	0	2	0	0	0	1	0	22	77.27
Eucaglo	0	0	0	0	0	**24**	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	25	96.00
Ficurac	0	0	0	0	0	0	**10**	0	0	2	0	0	0	1	0	0	0	0	0	0	0	0	13	76.92
Ficutsj	0	0	0	0	0	0	0	**4**	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	100.00
Ficuvir	0	2	0	0	0	0	0	0	**15**	0	1	0	0	0	0	0	0	0	0	0	0	0	18	83.33
Grevrob	0	1	0	2	0	0	1	0	0	**12**	0	0	0	0	0	0	0	0	0	0	0	0	16	75.00
Grewtil	0	0	0	0	1	0	0	0	0	0	**2**	0	0	0	0	0	0	0	0	0	0	0	3	66.67
Lagelan	0	0	0	0	0	0	0	0	0	0	0	**20**	0	0	0	0	1	1	0	0	1	0	23	86.96
Mangind	0	0	0	0	0	0	0	0	0	0	0	0	**7**	0	0	0	0	0	0	0	0	0	7	100.00
Others	1	0	0	0	1	0	0	0	1	0	0	0	0	**3**	1	0	0	1	1	0	0	0	9	33.33
Ptermar	0	0	1	0	3	0	0	0	0	0	0	0	0	0	**4**	0	0	0	0	1	0	0	9	44.44
Radexyl	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**4**	0	0	0	0	0	0	4	100.00
Schlole	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**11**	0	0	0	0	0	11	100.00
Stertet	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**3**	0	0	0	0	3	100.00
Syzycum	0	0	0	0	1	0	0	0	0	0	0	0	1	0	0	0	0	0	**9**	0	2	0	13	69.23
Tectgra	0	0	0	0	0	0	0	0	0	0	0	1	0	3	0	0	0	0	0	**16**	0	1	21	76.19
Termbel	1	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	1	0	0	0	**7**	2	13	53.85
Termtom	0	0	1	0	0	0	0	0	0	0	0	1	0	0	0	0	1	0	0	3	0	**5**	11	45.45
Total	17	5	23	5	24	24	13	4	16	15	4	23	8	12	6	4	16	5	11	24	13	8	280	
Producer's accuracy (%)	88.24	40.00	91.30	60.00	70.83	100.00	76.92	100.00	93.75	80.00	50.00	86.96	87.50	25.00	66.67	100.00	68.75	60.00	81.82	66.67	53.85	62.50		

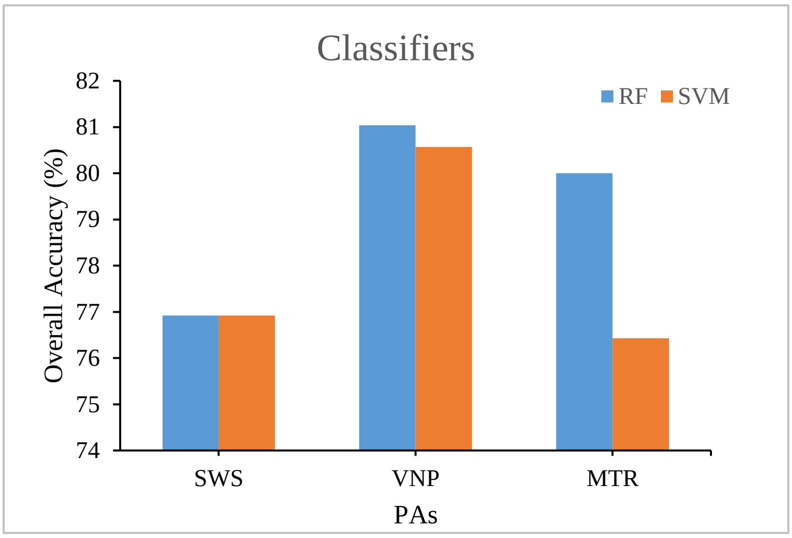

Figure 3.6| Classifier performance for each PA highlights changes in overall accuracy. The RF classifier exhibited a substantial enhancement across the three PAs.

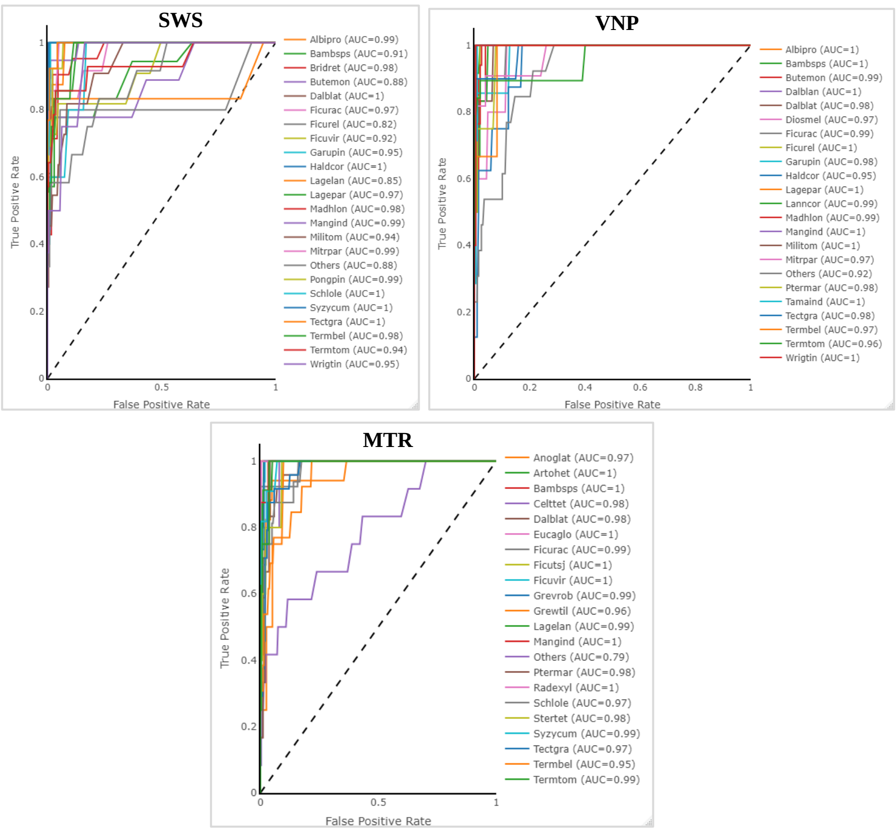

Figure 3.7| Receiver operating characteristic (ROC) curve for each species considered in RF classification, along with the corresponding area under the curve (AUC) of three PAs. The mean AUC value for each PA was 0.95 (SWS), 0.98 (VNP), and 0.98 (MTR).

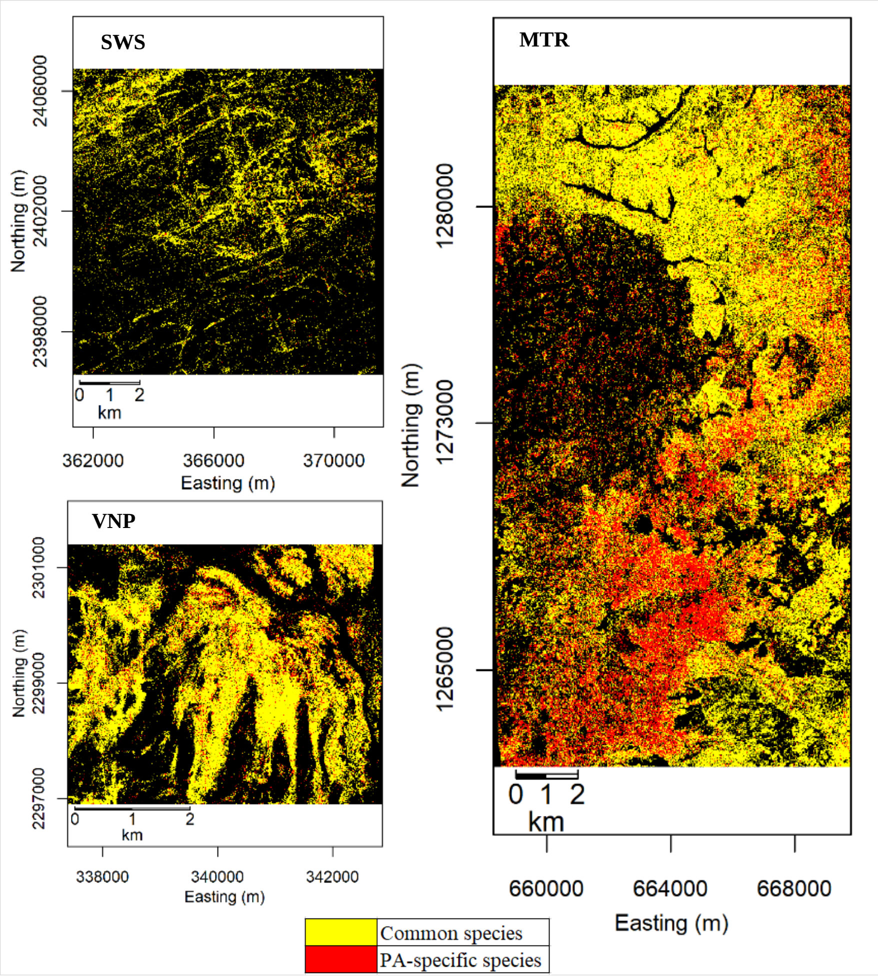

Figure 3.8| Progressive spread of PA-specific species across the three PAs obtained from RF abundant species maps.

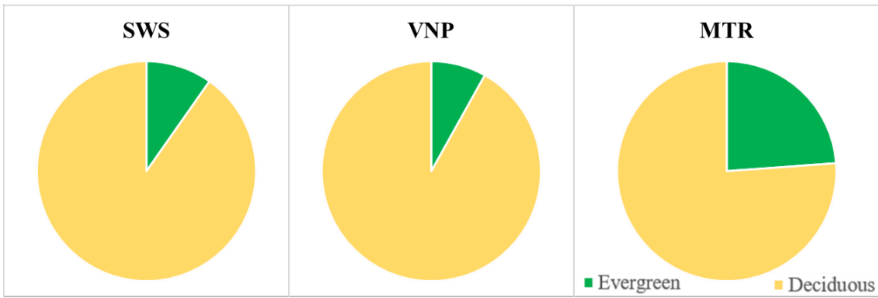

Figure 3.9| Distribution percentage of evergreen and deciduous species in three PAs obtained from the developed RF abundant species maps.

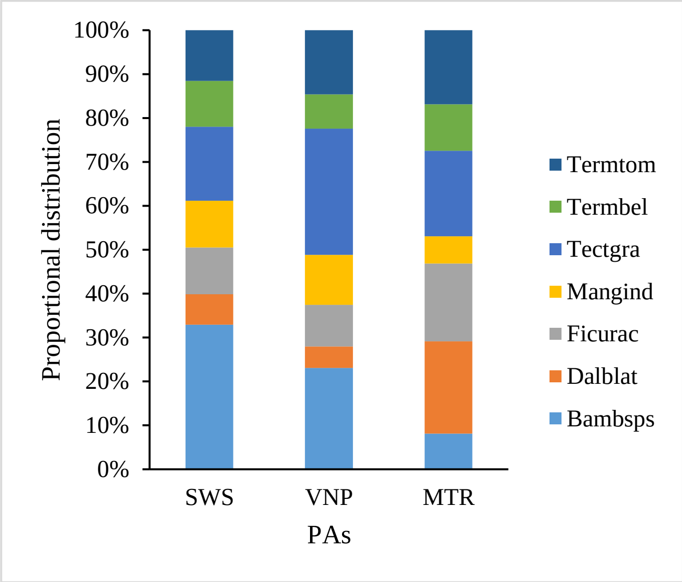

Figure 3.10| Proportional distribution of seven common abundant species across the three PAs based on the RF abundant species maps.

3.4 Correlation of species and spectral diversity

3.4.1 CHVs of plots and species from classification maps

The abundant species maps were used to investigate how spectral diversity metrics, derived from remote sensing data, can provide insights into species diversity and distribution. The CHV values, obtained from spectral data of 0.5-hectare plots selected from abundant species maps of each PA, showed a positive correlation with the observed number of species observed in each plot across all three PAs (Figure 3.11a & b). This correlation emphasizes that as the diversity of species within a given area increases, so does the spectral diversity, with CHV serving as a quantifiable measure. The spectral diversity, computed as CHV (from the first three PCs), increased with species number. This relationship between species diversity and spectral diversity was statistically robust, as indicated by the high R^2 values (Figure 3.11c), suggesting that spectral diversity metrics have the potential to serve as a reliable proxy for understanding species diversity, especially in areas with limited accessibility and insufficient exploration of forest cover.

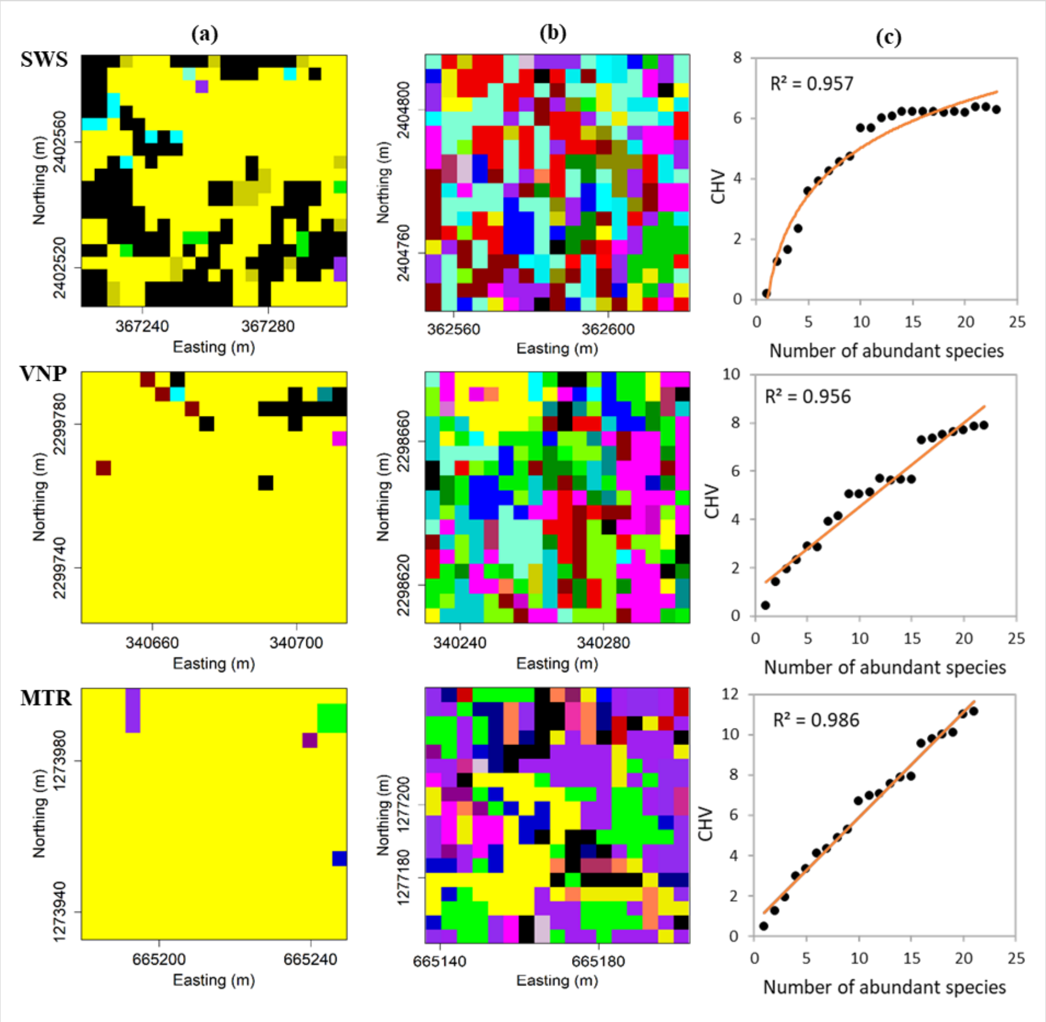

Figure 3.11| CHVs of 0.5 ha plots (n = 2) selected in abundant species maps of three PAs with varying numbers of abundant species. Panels (a) and (b) represent low and high diversity plots, respectively, while panel (c) displays the regression line depicting the cumulative CHVs and the number of abundant species. CHV values are as follows: a = 1.13 (n = 5), and b = 4.85 (n = 21) for SWS, a = 3.43 (n = 5), and b = 5.42 (n = 21) for VNP, and a = 2.68 (n = 5), b = 6.35 (n = 18) for MTR.

3.4.2 Species and spectral diversity-area curves

The sum of variance in the first three PCs and convex hull volume (CHV) for the first three PCs calculated following the code given in Dahlin, (2016) to compare the spectral diversity within and across the three PAs, revealed the potential of remote sensing data in assessing biodiversity-related variables for unapproachable areas. The findings of this method provide insight into the spectral diversity of the tree cover present in the forests of each PA. The spectral diversity-area curves derived from the summed variance of 175 plots displayed an increasing trend in variance across three PAs, with the lowest variance observed in SWS and the highest in MTR (Figure 3.12a).

Furthermore, the CHVs of 175 plots in MTR were nearly twice as high as those in SWS (Table 3.15), indicating significantly greater spectral diversity in the wetter PA. The species diversity-area curves of each PA showed higher diversity at MTR compared to SWS (Figure 3.12b). The spectral diversity-area curves generated for field plots also exhibited an increase in spectral diversity at MTR. Interestingly, this analysis revealed that the abundant species in each PA showed higher spectral diversity compared to all recorded tree species (Figure 3.12c).

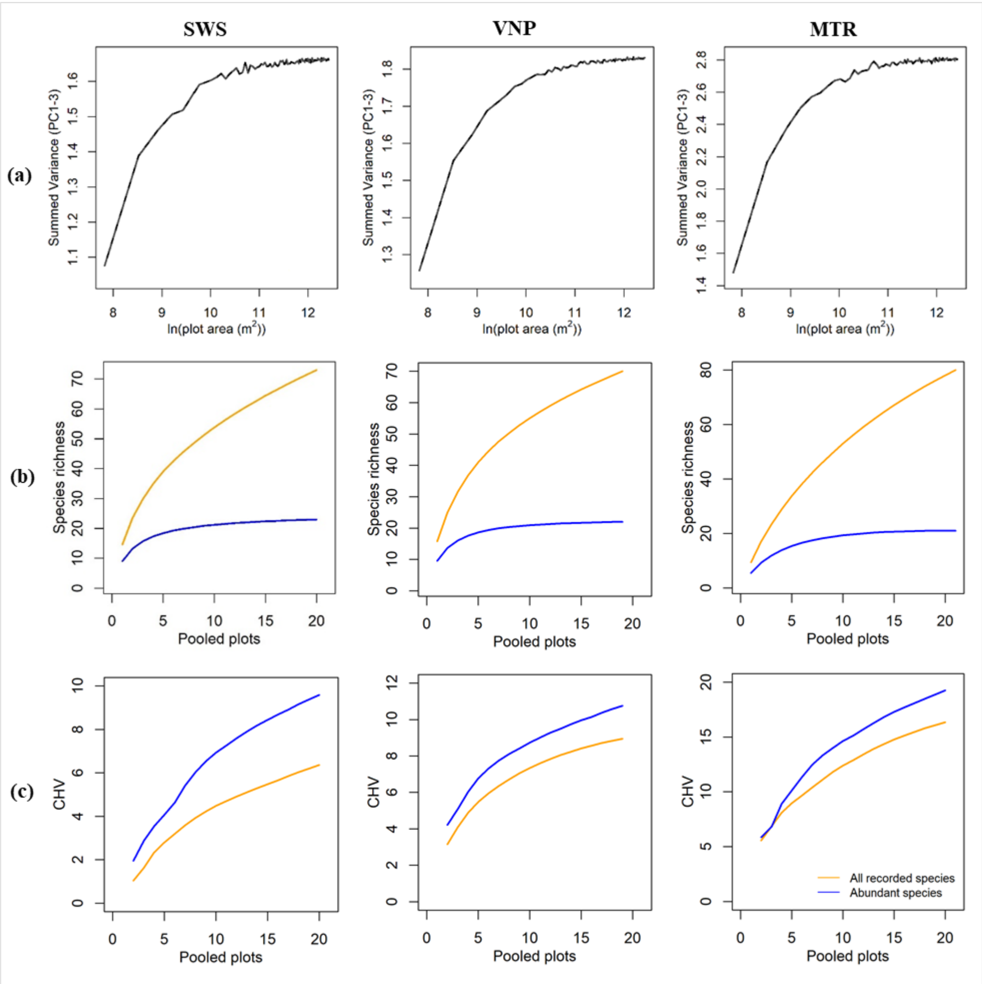

Figure 3.12| Diversity-area curves for three PAs. (a) Spectral diversity-area curves for summed variance of 175 plots, (b) Species diversity-area curves, and (c) Cumulative CHVs and area curves.

Table 3.15| Range, Variance, Kurtosis and CHV values for the first three principal components across 175 random plots in (a) SWS, (b) VNP, and (c) MTR.

Principal Components	Range	Variance	Kurtosis	Convex Hull Volume
(a) PC 1	8.08	1.47	0.15	—
PC 2	3.89	0.16	0.66	—
PC 3	1.60	0.03	0.21	—
Three PCs combined	13.57	1.66	—	20.17
(b) PC 1	8.07	1.60	-0.33	—
PC 2	2.99	0.18	0.05	—
PC 3	1.67	0.05	0.03	—
Three PCs combined	12.73	1.83	—	17.07
(c) PC 1	9.56	2.34	-0.03	—
PC 2	4.25	0.37	0.04	—
PC 3	2.83	0.10	0.63	—
Three PCs combined	16.64	2.81	—	40.82

3.4.3 Bray-Curtis dissimilarity

Heat maps depicting Bray-Curtis dissimilarity graphs computed for pairwise plot combinations for all the recorded species and abundant species, revealed variations in the values of species and spectral diversity (as CHVs) metrics (Figures 3.13 and 3.14). The heat maps revealed distinct patterns among the three PAs. For all recorded species (Figure 3.13), the Bray-Curtis dissimilarity had the highest mean values obtained from spectral diversity metrics (0.72-0.81) compared to the values derived from field-based metrics (0.63-0.70) at SWS and VNP. Conversely, in MTR, values obtained from spectral diversity metrics (0.83) were slightly lower compared to the values derived from field-based metrics (0.85).

For abundant species (Figure 3.14), the Bray-Curtis dissimilarity displayed the highest mean values when computed from spectral diversity metrics (0.73-0.83), outperforming values derived from field-based metrics (0.56-0.81) across all three PAs. This observation suggests that spectral data metrics capture a broader range of diversity within these regions, primarily because remote sensing displays enhanced sensitivity in detecting variations in spectral signatures and, thus, species composition. Among all three PAs, for both all recoded and abundant species, mean values of Bray-Curtis dissimilarity were highest at MTR (>0.81), indicating strong dissimilarity in tree species composition and a high amount of unique species.

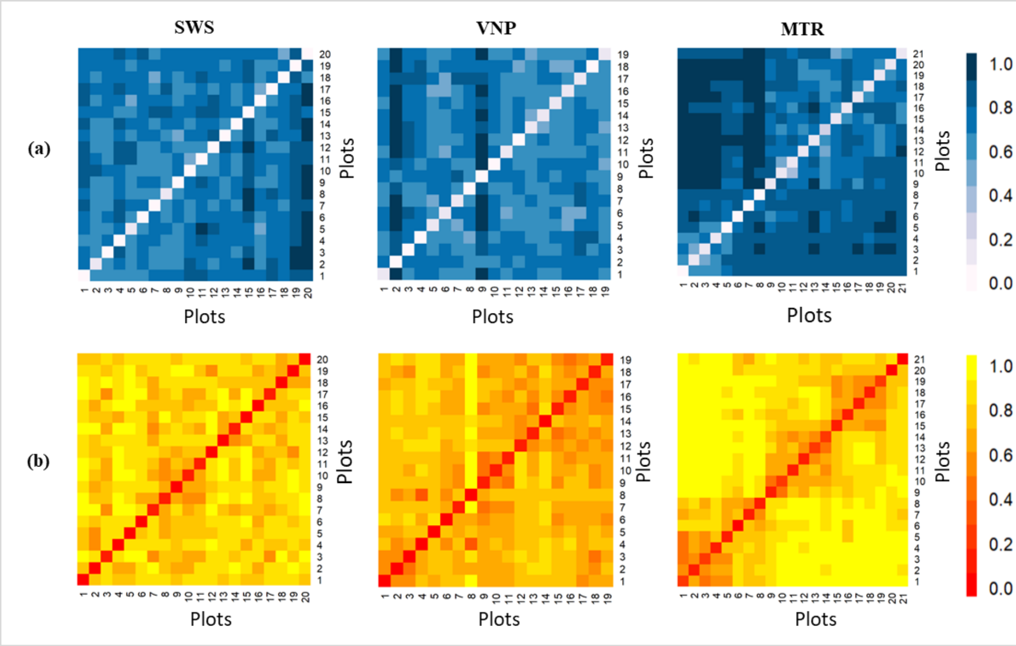

Figure 3.13| Heatmap depicting Bray-Curtis dissimilarity graphs for all recorded species. The mean dissimilarity values for species abundance data (a) and spectral diversity represented as CHVs (b) are as follows: 0.70 and 0.81 for SWS, 0.63 and 0.72 for VNP, and 0.85 and 0.83 for MTR, respectively. Bray–Curtis dissimilarity ranges from 0 to 1, reflecting 100% similarity (0) to complete dissimilarity (1) between species in a pair of plots.

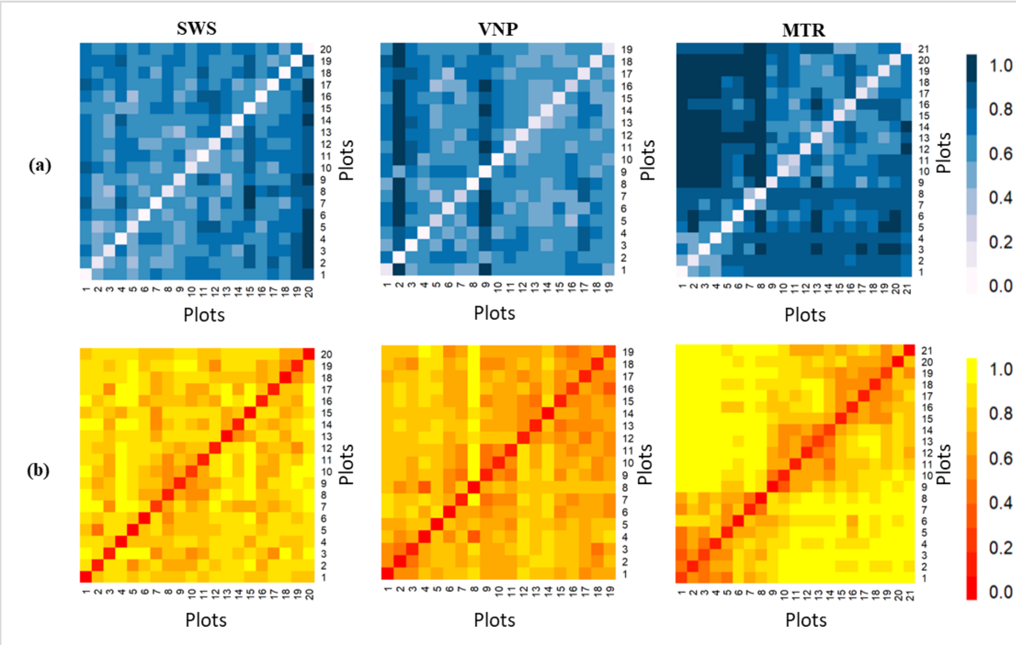

Figure 3.14| Heatmap depicting Bray-Curtis dissimilarity graphs for abundant species. The mean dissimilarity values for species abundance data (a) and spectral diversity represented as CHVs (b) are as follows: 0.65 and 0.82 for SWS, 0.56 and 0.72 for VNP, and 0.81 and 0.83 for MTR, respectively. Bray–Curtis dissimilarity ranges from 0 to 1, reflecting 100% similarity (0) to complete dissimilarity (1) between species in a pair of plots.

3.5 Intra- and Inter-species spectral diversity

The abundant species maps, which were generated using AVIRIS-NG datasets, proved to be useful for assessing both intra- and inter-species spectral variability in the distribution of species spread over ~85% of the cover at all three PAs. This method allowed for a comprehensive exploration of the spectral characteristics of the abundant species, shedding light on their diversity. An observation was made by examining the CHV values obtained from sets of 500 spectra for each common abundant species. These CHV values served as an indicator of the spectral variability within and between species. The CHV values were not uniform for all species; they exhibited variability within species, indicating that individuals of the same species can adapt and display diverse spectral traits in response to changing climatic conditions.

It was observed that the CHV variability was relatively narrow for Tectgra (Figure 3.15). This indicates that Tectgra had limited spectral diversity, meaning that individuals within this species had relatively similar spectral characteristics at three PAs. On the other hand, Ficurac and Mangind exhibited substantially higher CHV variability, suggesting a broader range of spectral characteristics within these species. In addition to intra-species variability, the study also examined inter-species variability, which refers to the differences in spectral characteristics between different species. It was observed that the CHV value was relatively higher at MTR for all common abundant species, as depicted in Figure 3.15. This finding implies that there were more pronounced differences in spectral signatures between different species in the MTR compared to the other PAs, reflecting a greater diversity of species and their unique spectral traits in that specific environment.

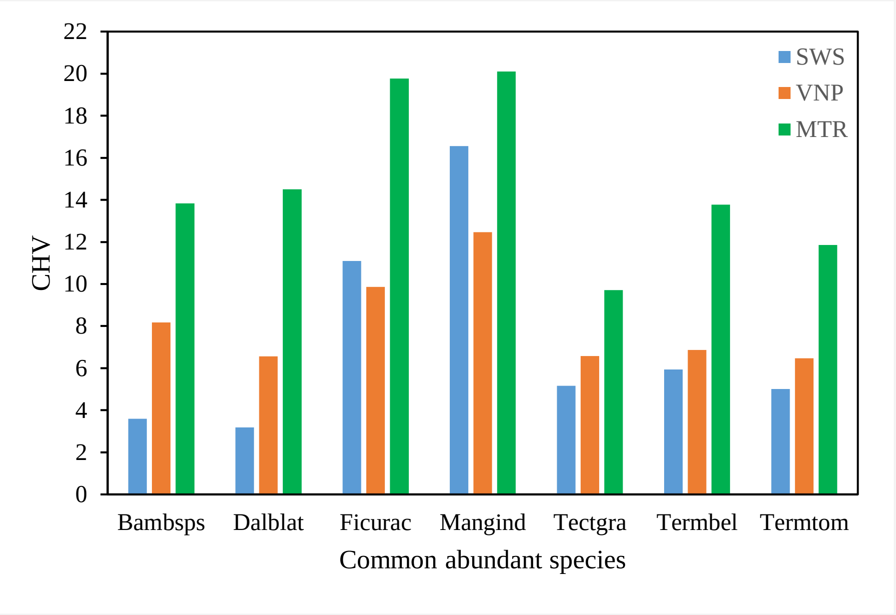

Figure 3.15| Intra- and inter-species spectral variability represented by CHVs at three PAs.