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4 authors:

Lia Hapsari
The Indonesian Institute

Siti Nurfadilah
Indonesian Institute of Sciences

Ilham Kurnia Abywijaya
National Research and Innovation Agency (BRIN)

Ridesti Rindyastuti
Purwodadi Botanic Garden-Indonesian Institute of Sciences

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DIVERSITY AND ECOLOGY OF UNDERSTORY PLANT IN SEMPU ISLAND, EAST JAVA, INDONESIA

LIA HAPSARI*, ILHAM KURNIA ABYWIJAYA, SITI NURFADILAH AND RIDESTI RINDYASTUTI

Purwodadi Botanic Garden, Research Center for Plant Conservation and Botanic Gardens, Indonesian Institute of Sciences, Purwodadi, Pasuruan 67163, Indonesia

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ABSTRACT

As indicator for environmental disturbances, the understory is an important structural and functional component of forests ecosystems. Hence, this study was conducted to investigate the diversity and composition of understory plants in the lowland forests adjacent to the trekking paths along Semut Bay (dock entrance) to Segara Anakan Lagoon and some coastal areas in Sempu Island, and to detemine their association with the underlying environmental factors as disturbance indicators by the presence of understory invasive alien species (IAS). Sixty six plots of 2 x 2 m^2 were established to analyze the understory vegetation, the site profiles and the environmental variables. A total of 135 understory plant species belonging to 108 genera and 60 families were recorded within the 66 plots of the study areas. Poaceae was the dominant family, followed by Compositae, Phyllanthaceae, Sterculiaceae, Rubiaceae, Putranjivaceae and Cyperaceae. The understory communities in the lowland forest adjacent to Semut Path were dominated by tree seedlings and had a relatively fewer composition of shrubs. Coastal areas, which have more open canopies, were dominated by grasses and shrubs. Some dominant native understory species include *Cleistanthus oblongifolius, Pterocymbium javanicum, Ischaemum muticum, Guettarda speciosa*, etc. Indicating disturbance, 12 understory IAS were found in the study areas. Four of these are among the world's worst invaders (*Chromolaena odorata*, *Imperata cylindrica*, *Lantana camara* and *Spathodea campanulata*), and three are noxious weeds (*Cyperus rotundus*, *Eleusine indica* and *Imperata cylindrica*). The light intensity and air temperature were strongly positively associated with disturbed sites, while relative humidty, soil pH, and elevation were associated with less disturbed sites. These study results provide the scientific basis for management and recommendations on the current diversity status of the understory plant species at Sempu Island, hoping that these would justify further conservation of indigenous species and their protection from these disturbances.

Keywords: coastal vegetation, disturbance indicator, invasive alien species, lowland forest, Sempu Island, understory plant

INTRODUCTION

Sempu Island is a very small island (UNESCO 1991) with a total area of 8.77 km^2 located in the southern part of Java Island, and is administered by the Malang Regency, East Java Province, Indonesia. The island is un-inhabited and designated as a nature monument by the Governor General of the Dutch East Indies in 1928, then later in 1999, it was decreed as a nature reserve by the Ministry of Forestry (BBKSDA Jawa Timur 2009). It possesses unique and distinctive biotic and abiotic resources. Undoubtedly, small and very-small islands have great potential for development of both biological and non-biological resource-based industries, such as for forestry, plantation, farming, fisheries, mining, marine energy, tourism, etc. However, these small islands having limited land area, small plains, limited fresh water resources containing endemic species with high ecological value and, sometimes situated in isolated location, are highly sensitive and vulnerable to environmental changes brought about by both natural disasters and anthropogenic disturbances (Nurse *et al.* 2001; Morrison 2011).

Activities that are carried out in a nature reserve are limited to the interests of research and development, science, education and other

*Corresponding author, e-mail: hapsari.lia@gmail.com, lia.hapsari@lipi.go.id

activities that support cultivation (Article 17 paragraph (1) of Law RI 5/1990). Sempu Island was decreed as a nature reserve but due to its beautiful landscape and scenery, the island is a popular tourism destination with limitedly permitted visitors (Muttaqin *et al.* 2011; Purnomo *et al.* 2013; Situmorang 2014). Around 37,000 visitors, mostly domestic, went to the island from 2011 to 2015 (BBKSDA Jawa Timur 2015). Tourism activities may create pressures and disturbances on the ecosystems and their services. Anthropogenic risks and impacts due to tourism are even higher on islands than continental areas (Nurse *et al.* 2001). Therefore, an inventory and documentation of Sempu Island's biodiversity is important due to the very fast rate of degradation resulting from various environmental pressures of tourism such as the forest opening, alien species invasion, increasing volume of garbage, among others.

Sempu Island has three types of forest ecosystems; the coastal, mangrove, and lowland forests (BBKSDA Jawa Timur 2009; Abywijaya *et al.* 2014). The understory is an important structural and functional component of any forest ecosystems. It supports the majority of plant species diversity in the forest and affects ecosystem level processes, such as nutrient cycling and energy exchange. Furthermore, the characteristics of the understory have a major impact on the future species composition of the forest canopy (Ares *et al.* 2009). Studies on the understory plant diversity of very small islands, particularly Sempu Island, are thus critically important. Some understory plants were recorded only in two sites on Sempu Island, particularly, Waruwaru and Telonpring (Sadili & Kartawinata 2016). Hence, complementary studies of Sempu Island's lowland forest and coastal areas are still necessary.

Understory plants are mostly opportunistic; they survive and are well adapted to disturbances, have numerous adaptations for dealing with adverse environmental conditions, and have competitive relationships with larger plants of the forest. Understory plants are also effective indicators of disturbances and forest integrity, allowing for the identification of forest patches that warrant further protection (Moffat & McLachlan 2004; Denslow *et al.* 2009). Furthermore, the increasing understory colonization by IAS is alarming. Earlier studies described IAS as occurring primarily in forest gaps and open environments due to disturbances. Their presence contributes to environmental changes by altering the ecosystem composition and functions. Moreover, the existence of invasive plants is positively correlated with disturbance and thus, undisturbed tropical forests harbour fewer alien species (Asner *et al.* 2008; Valladares *et al.* 2016).

The Segara Anakan Lagoon and its surrounding beaches and bays are favorite tourism destinations in Sempu Island, and presumably, have experience high disturbance impact. The objectives of this study were: (i) to investigate the diversity and compositional variation of understory plants in lowland forests, adjacent to the trekking paths along Semut Bay as a dock entrance to Segara Anakan Lagoon and some coastal areas in Sempu Island; (ii) to detemine the underlying environmental factors and (iii) to analyze their association with the presence of understory IAS as disturbance indicators. Results of this study provide scientific information on the current status of understory plant diversity in Sempu Island and hopefully, justify its conservation and further protection.

MATERIALS AND METHODS

Study sites

The study was conducted at Sempu Island Nature Reserve, East Java which is geographically located at 112°40'45" to 112°42'45" E and 8º27'24" to 8°24'54" S. It is about 800 meters from the southern coast of Java Island and separated by the Sempu Strait. Sempu Island is mostly hilly with moderate to steep slopes, elevation ranging from 50-100 m above sea level. The eastern, southern and western parts of the island are bordered by the Indian Ocean, with mostly limestone cliff coastlines (BBKSDA Jawa Timur 2009; Risna 2009). The study sites were on the forests adjacent to the trekking paths from Semut Bay to Segara Anakan Lagoon and on the coastal areas along the western part of Sempu Island (Fig. 1).

Study sites

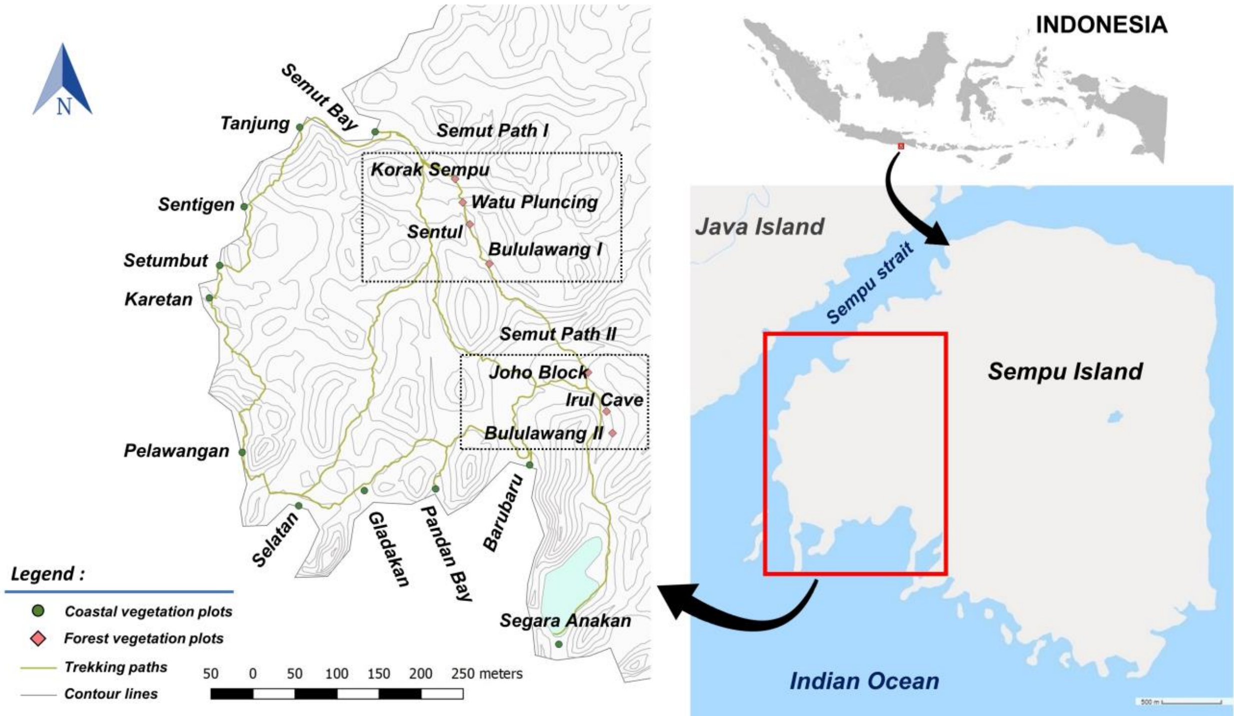

Figure 1 Location map of Sempu Island and sampling sites of the understory vegetation

Sampling Method and Data Collection

Fieldwork was undertaken during the rainy season in May 2016. In total, 66 plots of 2 x 2 m^2 were established to analyze the understory vegetation. For the forests adjacent to the trekking paths, the sampling plots were systematically established along the trekking paths as transect lines. The trekking paths started from Semut Bay, and then headed toward Segara Anakan Lagoon. Two plots were established per site with a left-right line transect orientation at a distance of 20 m between sampling sites. In total, eight plots have been established at Semut Path I (Korak Sempu to Watu Pluncing, Sentul and Bululawang I) and six plots have been established at Semut Path II (Joho Block to Irul Cave and Bululawang II). Meanwhile, for the understory vegetation around Segara Anakan Lagoon and some coastal areas, five sampling plots per site were set up using purposive method, except at Semut Bay which has only two plots because of its limited area.

Ground cover plants and seedlings less than 1.5 m in height were considered as understories. In each plot, the understory plants were identified, counted, categorized according to their plant habit and recorded as tree seedlings, shrubs, grasses, herbs, lianas, ferns and palms. Environmental variables recorded at sampling sites included elevation, air temperature, relative humidity, soil pH and light intensity.

Analysis Methods

The understory taxa in the sampling plots were tabulated and calculated. Their composition was evaluated by analyzing the frequency, density, abundance and Important Value Index (IVI) according to Ludwig and Reynolds (1988). The diversity indices analyzed were the species richness (D_{mg}) using the Margalef index (Margalef 1958), Shannon diversity index (H') of Shannon and Weaver (1949) and species evenness index (E') using the Pielou method (Magurran 1988).

The disturbance effect to the island was indicated by the presence of understory IAS. The determination of invasiveness status of an alien species was assessed using the world IAS online databases including (i) Global Invasive

Species Database (GISD) of the International Union for Conservation of Nature (IUCN) (http://www.iucngisd.org/gisd/), (ii) Invasive Species Compendiun (ISC) (https://www.cabi.org/isc) and (iii) Southeast Asian Regional Centre for Tropical Biology (SEAMEO BIOTROP) database on IAS (http://kmtb.biotrop.org/collections/spias). IAS designations were also cross-checked using other published references i.e., books and journals articles.

Multivariate ordination of principal components analysis (PCA) were conducted using statistical software Paleontological Statistics (PAST) version 3.15. The PCA analysis was performed to identify the association pattern between the abundance of understory IAS with environmental variables using a correlation matrix and scatter biplot (Hammer *et al.* 2001).

RESULTS AND DISCUSSION

Site Characteristics and Environmental Conditions

A typical visitor's journey of about two hours begins at Semut Bay and continues along trekking paths to Segara Anakan Lagoon. The surrounding forest is considered a tropical lowland forest with a relatively wet climate, or type C climate (Schmidt & Ferguson 1951), and an average annual rainfall of 2,132 mm (BBKSDA Jatim 2009; Risna 2009; Kartawinata 2013; Abywijaya *et al.* 2014; Rindyastuti *et al.* 2018). Seven sites were sampled in the lowland forests adjacent to the trekking path to the lagoon. The landscape was divided into two zones. Semut Path I (Korak Sempu to Watu Pluncing, Sentul and Bululawang I) is the first half of the trip to Segara Anakan Lagoon (Fig. 1). Semut Path I is facing-upward slopes (0 - 45°) with an elevation of 38 - 63.5 m above sea level. Semut Path II (Joho Block to Irul Cave and Bululawang II) is the second half of the trip to the lagoon. Semut Path II is facing-downward slopes with an elevation of 44.5 m up to 63.5 m above sea level (Table 1). The forest canopy adjacent to the Semut trekking path is thick; with Semut Path II thicker than Semut Path I. The trekking paths have created openings in the forest canopy and patches of greater light availability. Average light intensity at Semut Path I (1,409.50 lux) was higher than that at Semut Path II (633.50 lux) (Table 1).

Table 1 Environmental profile of the sampling sites in Sempu Island, Indonesia

Site	Sampling plot	Forest/ vegetation type	Site elevation (m)	Average air temperature (℃)	Average relative humidity (%)	Soil pH	Average solar light intensity (lux)
Semut Path I	Korak Sempu	Lowland	38.00 ± 7.07	27.50 ± 0.99	94.00 ± 1.41	6.8 ± 0.00	1,032.50 ± 140.71
	Watu Pluncing	Lowland	56.50 ± 0.71	27.10 ± 0.14	90.50 ± 4.95	6.9 ± 0.14	769.50 ± 194.45
	Sentul	Lowland	47.50 ± 3.54	28.05 ± 0.92	93.50 ± 0.707	7.0 ± 0.00	856.00 ± 371.94
	Bululawang I	Lowland	63.50 ± 7.78	30.15± 0.92	86.50 ± 0.71	7.0 ± 0.00	2,980.00 ± 3,478.97
Semut Path II	Joho Block	Lowland	44.50 ± 2.12	30.05 ± 0.92	90.50 ± 6.36	6.8 ± 0.07	507.50 ± 143.54
	Irul Cave	Lowland	35.00 ± 1.41	29.35 ± 0.21	84.00 ± 4.24	6.8 ± 0.00	832.50 ± 473.05
	Bululawang II	Lowland	36.50 ± 2.12	29.20 ± 0.14	90.00 ± 5.66	6.8 ± 0.00	560.50 ± 464.57
Segara Anakan	Segara Anakan	Coastal cliff	26.80 ± 1.92	31.58 ± 1.77	68.40 ± 4.67	6.8 ± 0.09	93,116.00 ± 62,218.43
Coastal area	Semut Bay	Coastal sand plain	7.75 ± 2.99	29.90 ± 1.12	77.25 ± 2.36	5.7 ± 0.31	75,800.00 ± 4,158.12
	Tanjung	Coastal sand plain	4.33 ± 1.53	29.80 ± 0.87	80.00 ± 1.00	7.1 ± 0.14	4,453.33 ± 1,350.31
	Sentigen	Coastal sand plain	12.50 ± 0.71	26.55 ± 26.55	76.50 ± 0.71	6.9 ± 0.14	1,119.33 ± 650.50
	Setumbut	Coastal sand plain	10.00 ± 1.41	28.15 ± 1.06	83.50 ± 0.71	7.0 ± 0.00	3,936.33 ± 5,205.68
	Karetan	Coastal sand plain	20.00 ± 1.41	33.05 ± 1.34	75.00 ± 2.83	6.8 ± 0.28	71,200.00 ± 35,100
	Pelawangan	Coastal sand plain	9.50 ± 0.71	33.05 ± 1.20	61.50 ± 2.12	7.0 ± 0.00	85,766.67 ± 21,186.40
	Selatan	Coastal sand plain	9.50 ± 0.71	30.90 ± 0.71	65.00 ± 2.83	7.0 ± 0.00	54,800.00 ± 29,089.69
	Gladakan	Coastal sand plain	12.50 ± 0.71	31.30 ± 0.70	69.50 ± 0.71	6.6 ± 0.00	105,733.00 ± 9,308.78
	Pandan Bay	Coastal sand plain	10.50 ± 2.12	33.05 ± 1.20	64.50 ± 2.12	6.9 ± 0.14	82,166.67 ± 38,266.74
	Barubaru	Coastal sand plain	8.00 ± 2.83	35.00 ± 1.41	78.00 ± 11.31	6.9 ± 0.14	93,733.33 ± 12,952.73

Segara Anakan Lagoon is the visitor's most favorite destination in Sempu Island. It has a beautiful landscape with an approximately four hectare lagoon separated from the raging tides of the open ocean by limestone cliffs and the surrounding forests. The unique characteristics of the vegetation around Segara Anakan Lagoon is due to the coastal cliff terrain and thin soil layer. It is considered the harshest environment relative to the other sites. Its elevation ranges from 24 m to 29 m above sea level.

During the fieldwork, the average relative humidity in this site was quite low (68.40% ± 4.67%) and the air temperature was at 31.58 ± 1.77 ºC. The tree canopy in the Segara Anakan forest was quite thin, with high light intensity (Table 1).

The sampling sites on the coastal areas of the western part of the island comprised 10 beaches and two bays (Fig. 1). The beaches and bays also exhibit beautiful landscapes, and despite the challenging trekking paths, these coastal areas still do attract some visitors. The typology of beaches and bays are considered coastal sand plains and their elevations range from 4 m to 27 m above sea level, the relative humidity varies from 73.08% ± 7.45% and the average high light intensity ranges from 1,119 lux to 105,733 lux. The soil pH at the coastal sand plains, coastal cliffs, and lowland forests in Sempu Island were neutral (pH 6.6 - 7) except at Semut Bay where it was slightly acidic (pH 5.7) (Table 1).

Understory Plant Species Community and Compositional Variation

A total of 135 understory plant species belonging to 108 genera and 60 families were recorded inside the 66 plots within the study areas in Sempu Island. The species commonly found were generally understory species from the Euphorbiaceae and Rubiaceae families (11 species each family); followed by the Poaceae (7 species), Annonaceae (6 species) and Compositae (6 species). However, according to the dominance metric and Important Value Index (IVI), the study areas were dominated by Poaceae; followed by Phyllanthaceae, Sterculiaceae, Rubiaceae, Putranjivaceae and Cyperaceae (Table 2). Based on plant habit categorization, the plant composition recorded 68 tree seedling species, 36 shrubs, 12 grasses, eight lianas, six herbaceous species, three ferns and two palm seedlings.

The understory plant community in the lowland forest adjacent to Semut Path was distinctly dominated by tree seedlings with a relatively fewer composition of shrubs and a very small composition of herbaceous plants, grasses, ferns and lianas. The understory plant communities adjacent to Segara Anakan Lagoon and at coastal areas, which had more open forest canopy, were dominated by shrubs and grasses, followed by tree seedlings, and had only a small herbaceous plant community (Table 2). This shows a highly divergent understory plant species composition between the inland lowland forest and the coastal ecosystem in the western part of Sempu Island Nature Reserve.

Tree seedlings from the Euphorbiaceae *sensu lato* (Euphorbiaceae and its segregates families i.e., Phyllanthaceae and Putranjivaceae) had high IVI in the lowland forests adjacent to Semut Path. Species of *Cleistanthus oblongifolius*, *Mallotus ruffidulus* and *Drypetes longifolia* were dominant in Semut Path (Table 2, Fig. 2 D-G-K). The occurrence of Euphorbiaceae, particularly *Mallotus* species, was closely related to intermediate-to-low levels of disturbance in tropical forests. These species prefer open areas with high light intensity (Slik *et al.* 2003). In addition, *D. longifolia* also occurred in the secondary forests usually as a pre-disturbance remnant tree (Cleary & Priadjati 2005). The number of Euphorbiaceae species at Semut Path I was also larger than those at Semut Path II. The composition of species at Semut Path II was more diverse than that at Semut Path I.

Table 2 List of understory plant species with five top important values in lowland forests adjacent to the trekking path to Segara Anakan Lagoon and some coastal areas in Sempu Island

Site	Scientific name	Family	Habit	Status	D (ind./m²)	F	Abundance	IVI
Semut Path I	*Cleistanthus oblongifolius*	Phyllanthaceae	Tree seedling	Native	4.41	0.38	47.00	33.01
	Hypoestes sp.	Acanthaceae	Shrub	Native	1.88	0.38	20.00	16.03
	Globba marantina	Zingiberaceae	Herbaceous	Native	1.50	0.38	16.00	13.51
	Mallotus ruffidulus	Euphorbiaceae	Tree seedling	Native	0.63	0.63	4.00	9.94
	Drypetes longifolia	Putranjivaceae	Tree seedling	Native	0.91	0.25	14.50	8.38
Semut Path II	*Pterocymbium javanicum*	Sterculiaceae	Tree seedling	Native	0.02	0.17	40.00	18.22
	Drypetes longifolia	Putranjivaceae	Tree seedling	Native	0.01	0.50	9.00	16.24
	Mallotus ruffidulus	Euphorbiaceae	Tree seedling	Native	0.01	0.67	5.50	15.87
	Pterospermum javanicum	Sterculiaceae	Tree seedling	Native	0.01	0.33	13.00	14.13
	Globba marantina	Zingiberaceae	Herbaceous	Native	0.05	0.67	2.75	11.33
Segara Anakan	***Synedrella nodiflora***	Compositae	Shrub	**IAS**	33.00	0.60	220.00	83.76
	Ischaemum muticum	Poaceae	Grass	Native	2.80	0.40	28.00	11.96
	Chromolaena odorata	Compositae	Shrub	**IAS**	1.50	0.60	10.00	11.76
	Oplismenus compositus	Poaceae	Grass	Native	0.70	0.60	4.67	9.93
	Croton tiglium	Euphorbiaceae	Tree seedling	Native	0.50	0.60	3.33	9.48
Semut Bay	*Wollastonia biflora*	Compositae	Shrub	Native	1.00	0.50	8.00	39.17
	Justicia gendarussa	Acanthaceae	Shrub	Native	0.88	0.50	7.00	35.83
	Thespesia populnea	Malvaceae	Tree seedling	Native	0.63	0.50	5.00	29.17
	Mallotus resinosus	Euphorbiaceae	Tree seedling	Native	0.25	0.50	2.00	25.83
	Mallotus ruffidulus	Euphorbiaceae	Tree seedling	Native	0.50	0.50	4.00	19.17
Tanjung	*Ischaemum muticum*	Poaceae	Grass	Native	10.10	0.60	67.33	74.64
	Vitex trifolia	Lamiaceae	Liana	Native	1.85	0.40	18.50	18.85
	Peltophorum pterocarpum	Leguminosae	Tree seedling	Native	0.65	0.60	4.33	14.83
	Terminalia catappa	Combretaceae	Tree seedling	Native	0.65	0.40	6.50	11.26
	Gymnema littorale	Apocynaceae	Herbaceous	Native	0.35	0.40	3.50	9.36
Sentigen	*Guettarda speciosa*	Rubiaceae	Shrub	Native	4.90	0.60	32.67	47.53
	Desmodium umbellatum	Leguminosae	Tree seedling	Native	3.00	0.60	20.00	32.33
	Allophylus cobbe	Sapindaceae	Tree seedling	Native	0.75	0.80	3.75	17.11
	Sophora tomentosa	Leguminosae	Tree seedling	Native	0.90	0.60	6.00	15.53
	Drypetes sp.	Putranjivaceae	Tree seedling	Native	0.30	0.40	3.00	7,60
Setumbut	*Drypetes* sp.	Putranjivaceae	Tree seedling	Native	4.05	0.80	20.25	40.93
	Murdannia nudiflora	Commelinaceae	Grass	Native	3.80	0.40	38.00	32.75
	Commelinaceae	Commelinaceae	Grass	Native	2.90	0.20	58.00	23.30
	Diospyros maritima	Ebenaceae	Tree seedling	Native	0.55	0.60	3.67	13.48
	Aglaia lawii	Meliaceae	Tree seedling	Native	0.45	0.60	3.00	12.79
Karetan	*Cyperus* sp.	Cyperaceae	Grass	Native	11.60	1.00	46.40	55.47
	Salvia missela	Lamiaceae	Shrub	Native	4.80	0.80	24.00	28.32
	Pararuellia napifera	Acanthaceae	Shrub	Native	4.55	0.80	22.75	27.42
	Phyllanthus virgatus	Phyllanthaceae	Shrub	Native	1.20	0.60	8.00	12.63
	Aglaia lawii	Meliaceae	Tree seedling	Native	1.45	0.40	14.50	10.75
Barubaru	*Ischaemum muticum*	Poaceae	Grass	Native	32.60	0.60	217.33	97.59
	Cyperus elatus	Cyperaceae	Grass	Native	9.95	0.60	66.33	45.82
	Chromolaena odorata	Compositae	Shrub	**IAS**	0.80	0.60	5.33	24.91
	Ipomoea pes-caprae	Convolvulaceae	Herbaceous	Native	0.15	0.40	1.50	15.73
	Murdannia nudiflora	Commelinaceae	Grass	Native	0.20	0.20	4.00	8.15
Pandan	*Ischaemum muticum*	Poaceae	Grass	Native	57.20	1.00	228.80	128.12
	Derris elliptica	Leguminosae	Liana	Native	1.15	1.00	4.60	33.20
	Acrostichum aureum	Pteridaceae	Fern	Native	0.2	0.40	2.00	12.84
	Pandanus tectorius	Pandanaceae	Herbaceous	Native	0.15	0.40	1.50	12.75
	Scaevola taccada	Goodeniaceae	Shrub	Native	0.20	0.20	4.00	6.59
Gladakan	***Imperata cylindrica***	Poaceae	Grass	**IAS**	31.40	0.80	157.00	74.56
	Ischaemum muticum	Poaceae	Grass	Native	18.65	1.00	74.60	58.86
	Emilia sonchifolia	Compositae	Shrub	Native	7.60	0.20	152.00	18.22
	Passiflora foetida	Passifloraceae	Liana	**IAS**	1.20	0.40	12.00	13.11
	Lantana camara	Verbenaceae	Shrub	**IAS**	0.60	0.40	6.00	12.11
Selatan	***Paspalum conjugatum***	Poaceae	Grass	**IAS**	9.95	0.60	66.33	52.65
	Commelinaceae	Commelinaceae	Grass	Native	6.60	0.40	66.00	34.95
	Aglaia lawii	Meliaceae	Tree seedling	Native	0.95	0.80	4.75	15.34
	Drypetes longifolia	Putranjivaceae	Tree seedling	Native	1.10	0.60	7.33	13.23
	Pandanus tectorius	Pandanaceae	Herbaceous	Native	0.60	0.60	4.00	11.01
Pelawangan	*Ischaemum muticum*	Poaceae	Grass	Native	24.40	1.00	97.60	79.87
	Panicum sp.	Poaceae	Grass	Native	12.25	0.80	61.25	46.87
	Ipomoea pes-caprae	Convolvulaceae	Shrub	Native	1.85	0.80	9.25	22.51
	Cyperus rotundus	Cyperaceae	Grass	Native	2.60	0.20	52.00	10.63
	Emilia sonchifolia	Compositae	Shrub	Native	0.65	0.40	6.50	10.61

Notes: IAS = Invasive Alien Species; D = Individual Density (individual/m²); F = Frequency; IVI = Important Value Index.

The forest floors of both Semut Path I and Semut Path II had high light intensity due to the opening of the trekking path, thus herbaceous plant species of *Globba marantina* dominated the area (Table 2, Fig. 2 H). The species favors open and dry habitats and the bulbils can survive long adverse conditions (Jansen *et al.* 1999). In addition, some clusters of *Alocasia longiloba* were found particularly in areas with relatively more open canopy cover, such as at the Korak Sempu and Bululawang I sites of Semut Path I. *Hypoestes* sp. was the most dominant shrub at Semut Path I (Table 2), while at Semut Path II, shrub species of the genus *Ixora* were observed in moderate IVI (9.18) at Joho Block and Bululawang II closer to the Segara Anakan Lagoon.

The understory plants around Segara Anakan Lagoon (coastal cliffs) was dominated by Compositae, followed by Poaceae and Euphorbiaceae tree seedlings (Table 2). Meanwhile, on the coastal sand plains, the understory plant communities were mostly dominated by grass species from Poaceae family. Furthermore, species from Compositae, Euphorbiaceae, Commelinaceae, Rubiaceae and Cyperaceae were also found with high important values on some coastal sites (Table 2). Unlike the understory vegetation of lowland forests, the vegetation along the coastal sites also varied among sites. This was likely due to different site characteristics and their level of disturbance.

Some typical understory plants of the Indonesian tropical coastal forests were found in the study area (Whitten *et al.* 1996; Monk *et al.* 2000; Goltenboth *et al.* 2006; Kartawinata 2013). Some clusters of *Pandanus tectorius* (Fig. 2 L) and *Scaevola taccada* (Fig. 2 M) were found as understories on the coastal cliff around Segara Anakan Lagoon and on the coastal sandy plains of Pandan Bay and Sentigen. *Terminalia cattapa* seedlings (Fig. 2 O) were found on a wider area throughout the coastal region. *Ipomoea pes-caprae*, the main plant of the *Pes-caprae* formation in coastal forests, was dominant at Barubaru and Pelawangan (Fig. 2 I). Seedlings of *Barringtonia asiatica*, the main plant of the *Barringtonia* formation, were found at Karetan (Fig. 2 C), but were not dominant. Further, *Ischaemum muticum* was found in many patches at Segara Anakan, Tanjung, Barubaru, Pandan, Gladakan and Pelawangan (Fig. 2 J). This *I. muticum* was also found at other places on the Island, i.e., Waru-waru and Telogo Dowo (Abywijaya *et al.* 2014). This grass is resistant to high salinity, wind and high temperatures. In open areas it may grow to a height of 0.4 m (Kartawinata 2013).

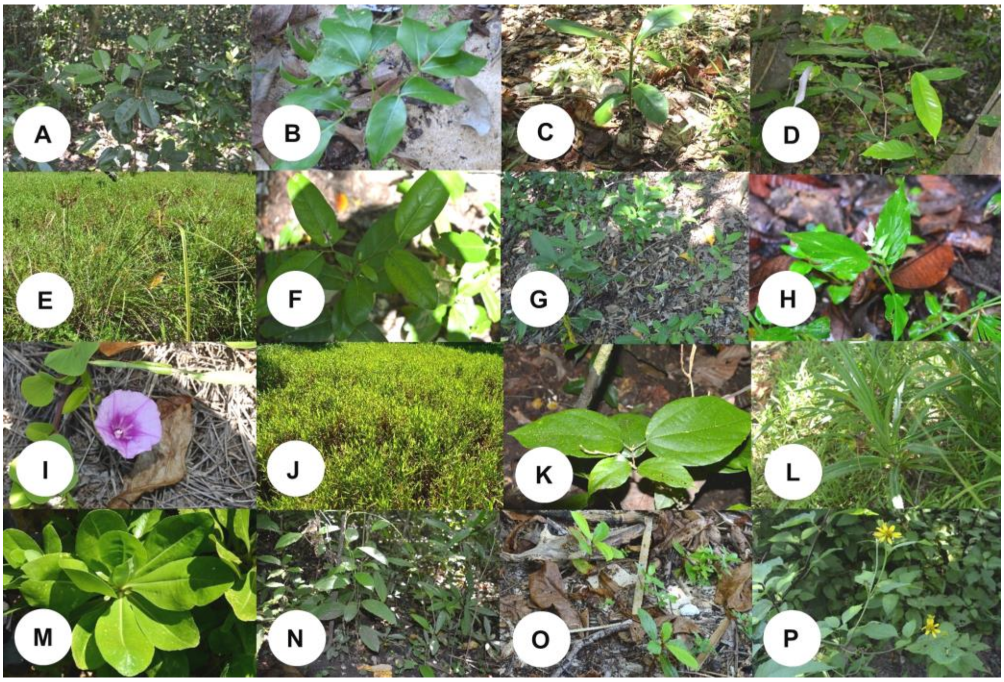

Figure 2 Some understory native species in Sempu Island

Notes: A. *Aglaia lawii*; B. *Alopylus cobbe*; C. *Barringtonia asiatica*; D. *Cleistanthus oblongifolius*; E. *Cyperus elatus*; F. *Diospyros maritima*; G. *Drypetes longifolia*; H. *Globba marantina*; I. *Ipomoea pes-caprae*; J. *Ischaemum muticum*; K. *Mallotus ruffidulus*; L. *Pandanus tectorius*; M. *Scaevola taccada*; N. *Smilax zeylanica;* O. *Terminalia cattapa*; and P. *Wollastonia biflora.*

Diversity Indices of Understory Plant Communities

The understory of the lowland forests adjacent to the Semut Path had higher species richness, species evenness and Shannon diversity than the coastal areas (Fig. 3). In particular, diversity indices at Semut Path II was slightly higher than that at Semut Path I. Both sites had high species richness (7.46; 7.65), and high evenness (0.72; 0.82). Further, Shannon diversity index was high at Semut Path II (3.02) and moderate at Semut Path I (2.78) (Fig. 5). Although, species diversity (Shannon) is a complex measure of how many different types of taxa are present in communities, it takes into account both the species richness as well as species evenness of an ecosystem. It is considered as a tool to measure ecosystem health, resilience and function (Goswami *et al.* 2017). Thus, this study results indicated that Semut Path I experienced higher disturbance than Semut Path II. However, a complementary study with more plot numbers and bigger area coverage of Semut Path are required to enhance this finding.

The coastal forest ecosystems have lower diversity indices than the lowland forest ecosystems as they have limited nutrient and fresh water availability (Goltenboth *et al.* 2006). Their coastal site characteristics and the level of disturbance also affected their diversity indices. Sentigen had the highest species richness (4.17) followed by Setumbut (3.18), Tanjung (2.96) and Segara Anakan (2.96). In addition, understory species evenness of all sampling sites in the coastal areas varied from low, moderate to high (0.10 – 0.89). The Shannon diversity indices of understory communities in coastal areas of Setumbut and Sentigen were moderate (2 < H' < 3), while those of other sites in the coastal areas were low (H' < 2). These diversity indices, indicated that Setumbut and Sentigen experienced lower disturbance than the other sites in the coastal areas. Nonetheless, Pandan Bay had the lowest diversity index probably due to its being highly dominated by the native grass *I. ischaemum* rather than disturbance.

Invasive Understory Plants as Disturbance Indicators

Twelve understory IAS were found in the study area of Sempu Island. Of the twelve, five were shrubs, five were grasses, one was a tree seedling and one liana (Table 3, Fig. 4). Forest integrity in the lowland forests of Sempu Island was considered higher than that in the coastal areas. Most of the understory IAS were found more abundantly in the coastal areas than in the lowland forest. Hence, coastal areas in Sempu Island experienced more disturbances than the lowland forest. Monitoring and management of these understory IAS is recommended, particularly at the sampling sites where they are already present.

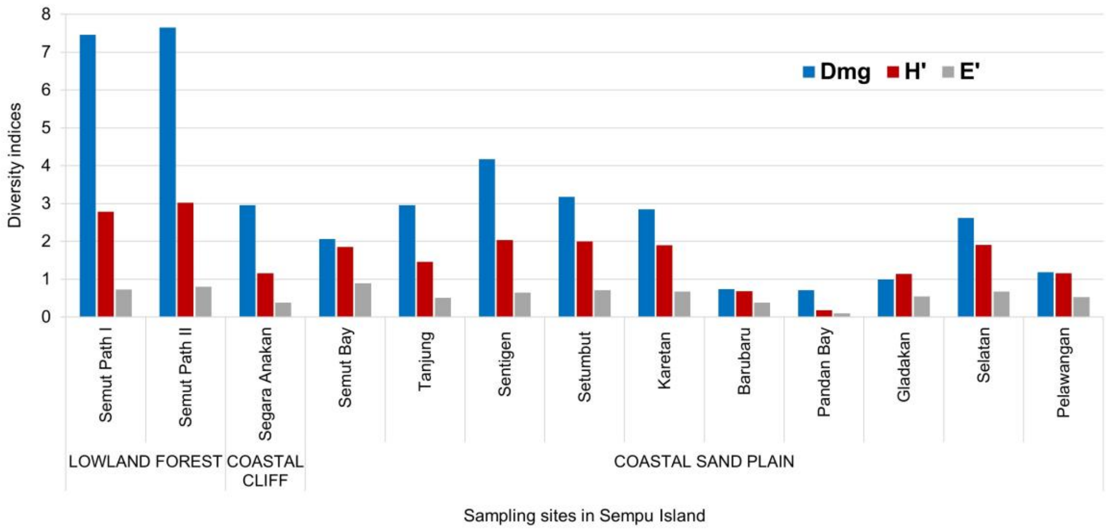

Figure 3 Diversity indices of understory plant species in the lowland forests adjacent to the trekking path to Segara Anakan Lagoon and some coastal areas in Sempu Island, East Java
Notes: Dmg = Margalef species richness index; H' = Shannon diversity index and E' = species eveness index.

The only IAS that occured in the lowland forest adjacent to Semut Path was tree seedlings of *Spathodea campanulata* (Table 3, Fig. 4 F). It was particularly found at Semut Path I. Thus, Semut Path I was considered more disturbed than Semut Path II. This species grew well at the lowland forest of Semut Path and was not found in any of the coastal areas since it favors moist habitats and grows best in sheltered tropical areas (ISSG 2018). Furthermore, an *S. campanulata* mother tree with a diameter at breast height of approximately 60 cm was recorded at Watu Pluncing site of Semut Path I (Hapsari *et al*. 2016). This is alarming since there is no past historical record of this species in Sempu Island. This tree should be removed to stop further seed dispersal, as the seedlings of *S. campanulata* can establish rapidly and grow quickly, thereby making it one of the first trees to colonize open areas and wastelands (ISSG 2018).

With the exception of Semut Bay and Pandan Bay, all the studied coastal areas were invaded by understory IAS (Table 3). Gladakan coastal area had the greatest invasion of understory IAS with 4 species found, followed by Pelawangan (3 species), Karetan (3 species), Tanjung (3 species), Segara Anakan (3 species), Setumbut (2 species), Barubaru (1 species), Selatan (1 species) and Sentigen (1 species). Although Semut Bay acts as a docking entrance, it had little disturbance from IAS. The Pandan Bay area was dominated by the native grasss *I. muticum*, with high IVI and density of 96.87%, and therefore, provided no space for invasion by understory IAS.

Several understory IAS had high IVI in some sampling sites (Table 2) and thus, need urgent remedial intervention. *S. nodiflora* (75.43) and *C. odorata* (3.43) had high IVI on the coastal cliff of Segara Anakan (Table 3) indicating that the vegetation around the lagoon had experienced high disturbance, corresponding to the high visitor activity in this area. Moreover, other IAS with high IVI were *C. odorata* at Barubaru, *I. cylindrica*, *P. foetida* and *L. camara* at Gladakan, *P. conjugatum* at Selatan and *C. rotundus* at Pelawangan (Table 3). Based on IAS occurences, the coastal areas are considered highly disturbed sites compared to the other sites.

Table 3 Understory invasive alien species (IAS) found at the sampling plots in Sempu Island

Species name	Local name	Family	Habitus	Origin	Site found	Key invasiveness characteristics
Axonopus compressus[2, 3]	Rumput paitan (Indon.), Carpet grass (Eng.)	Poaceae	Grass	Tropical America	Karetan	Wide environmental tolerance; spreads by above-ground runners and seeds; persistent grass, can withstand tramplings
Chromolaena odorata[1, 2, 3, 4, 5, 7]	Kirinyuh (Indon.), Siam weed (Eng.)	Compositae	Shrub	Central & South America	Segara Anakan, Tanjung, Sentigen, Pelawangan, Barubaru	Fast growing; forms dense bushes; has allelopathic effects; small seeds and long distance dispersed by wind; long term seed viability
Cyperus rotundus [1, 2, 3, 6]	Rumput teki (Indon.), Nut sedge (Eng.)	Cyperaceae	Grass	India, Afrika	Pelawangan	Rapid growth, propagated by tubers and rhizomes which may survive at adverse conditions, high temperatures and solar radiation; herbicide tolerants
Eleusine indica[2, 3, 6]	Rumput belulang (Indon.), Goose grass (Eng.)	Poaceae	Grass	India	Segara Anakan	Fast-growing grass, tolerant to heavy human disturbance; extensive rhizome system, has allelopathic effect; small seed mass, long term seed viability
Imperata cylindrica[1, 2, 6]	Alang-alang (Indon.), Cogon grass (Eng.)	Poaceae	Grass	Eastern Africa, Tropical Asia, Australia & the Pacific	Gladakan	Very plastic habitat, adapted to poor soils, drought and fire; has extensive rhizome system; tolerant in high light intensity, temperatures and limited moisture
Lantana camara[1, 2, 3, 4, 5, 6, 8]	Tembelekan (Indon.), Wild sage (Eng.)	Verbenaceae	Shrub	Tropical America	Karetan, Gladakan	Wide environmental tolerance; forms dense tickets, has allelopathic effects; seeds widely dispersed by birds; seeds need high light conditions to germinate

Table 3 (Continued)

Paspalum conjugatum[2, 3]	Rumput paitan (Indon.), Sourgrass (Eng.)	Poaceae	Grass	Tropical America	Selatan	Wide environmental tolerance; tolerates shade but can also persist in full sun; spreads by extensive above-ground runners and seeds
Passiflora foetida[1, 2, 3, 6]	Rambusa (Indon.), Stinking passion flower (Eng.)	Passifloraceae	Liana	Tropical America	Gladakan	Wide environmental tolerance; forms dense ground cover which prevents the other species establishment; long term seed viability, dispersed by birds
Spathodea campanulata[1, 2, 7]	Kecrutan (Indon.), African tulip tree (Eng.)	Bignoniaceae	Tree seedling	Tropical Africa	Semut Path I	Best grown in rich soil but tolerate low fertility; fast growing and short juvenile period; seed pod contains many of tissue papery, widely dispersed by winds
Stachytarpheta jamaicensis[2, 3, 4]	Pecut kuda (Indon.), Jamaica vervain (Eng.)	Verbenaceae	Shrub	Tropical America	Tanjung	Tolerate seasonal drought and soil compaction; long term seed viability and unharmed through herbivores's digestive and dry soil
Synedrella nodiflora[2, 3, 6] 3), 7)	Jotang kuda (Indon.), Nodeweed (Eng.)	Compositae	Shrub	Tropical America	Segara Anakan, Setumbut	Very plastic habitat; rapid establishment; forms dense stands; small seed mass dispersed in soil, water and plant debris, clothing, and wind
Chyanthillium cinereum[2, 3, 6, 9]	Buyung (Indon.), Ironweed (Eng.)	Compositae	Shrub	Africa	Tanjung, Setumbut, Karetan, Gladakan, Pelawangan	Prefers sunny or slightly shaded habitats; small seed mass and spreads by wind, seeds secondarily dispersed as a contaminant in crop seeds, pasture seeds, and agricultural machinery

References: 1) ISSG 2018; 2) ISC 2018; 3) BIOTROP 2018; 4) Tjitrosoedirdjo 2005; 5) Sankaran & Suresh 2013; 6) Abywijaya *et al.*. 2014; 7) Mandal & Joshi 2014; 8) Rai & Singh 2015; 9) Nwaogaranya & Mbaekwe 2015.

Among the understory IAS recorded in Sempu Island, three are included in the list of the world's 10 difficult to control noxious weeds (USDA 2012), namely *C. rotundus*, *E. indica* and *I. cylindrica*. Another, four out of 15 understory IAS are included in the list of the world's 100 worst invaders (Lowe *et al.* 2000), namely *C. odorata*, *I. cylindrica*, *L. camara* and *S. campanulata* wherein two particular IAS, *C. odorata* and *L. camara*, require special attention. These two species have successfully invaded many natural protected areas and have caused significant ecosystem changes, such as in the Western Himalayan forest of India (Mandal & Joshi 2014), urban forests of Indo-Burma (Rai & Singh 2015), Alas Purwo National Park (Hakim *et al.* 2005), Ijen Crater Nature Tourism Park (Hapsari *et al.* 2014), and the montane forests of Bawean Island (Trimanto & Hapsari 2016). These IAS may change the structure and species composition of ecosystems by repressing or excluding native species, either directly by out-competing them for resources and/or indirectly by changing the way nutrients are cycled through the system (McNeely *et al.* 2001).

The environmental impact of an IAS as it becomes invasive at its destination depends on its biological characteristics, the ecological role it may play, and other factors, such as its tolerance to environments in the new range (Richardson & Rejmanek 2001; McNeely *et al.* 2001). Biological characteristics refer to the traits or qualities based on characteristics of individual organisms including cellular organization, reproduction, metabolism, homeostasis, heredity, response to stimuli, growth and development, and adaptation through evolution (Rejmanek 2001). Some IAS such as *C. odorata*, *L. camara*, *I. cyllindrica* and *S. campanulata* are considered fast growing plants with short juvenile periods, and therefore, they can rapidly invade new areas. *C. odorata*, *L. camara*, and *E. indica* also have allelopathic effects that prevent the establishment of other plant species, and therefore, become aggressive competitors of native species. In disturbed native forests, these species may become the dominant understories, disrupting succession and decreasing biodiversity (ISSG 2018; ISC 2018). Non-native species and potential invasive species are highly competitive with other species by having high growth rates, high photosynthetic atributes, and expansive leaf areas (Grotkopp & Rejmanek 2007; Rindyastuti & Sancayaningsih 2018).

Grass IAS such as *I. cyllindrica, E. indica, A. compressus, C. rotundus,* and *P. conjugatum* have extensive rhizome systems, and some even have tubers. They are highly adapted to poor soils, pollution, drought, and possess genetic plasticity and fire tolerance (Table 3). They colonize and grow in bare lands, disturbed habitats and fire-stricken sites; provided that moisture is available (ISSG 2018; ISC 2018). In addition, most of the observed IAS produce small seeds, which are dispersed toward long distances by wind, birds, and humans. Some, such as *S. jamaicensis*, *P. foetida*, *C. cinereum*, and *E. indica*, have seeds with long term viability, that can survive passage through an herbivores's digestive tract or dry soil (Table 3). These species most commonly germinate where the soil has been disturbed and is moist and warm (ISSG 2018; ISC 2018).

A large ecological niche breadth is believed to contribute to its invasiveness success (Valladares *et al.* 2016). Due to these invasive characteristics (Table 3), the IAS observed in this study area are serious threats, with their propagules dispersed further by birds and wind as natural dispersal agents (Richardson & Rejmanek 2011). Trekking paths or corridors may facilitate the movement of IAS between connected patches of habitat (Tewksbury *et al.* 2002; Robiansyah & Purnomo 2013; Mukarromah 2015; Purnomo *et al.* 2013) thus, the opening of new trekking paths need to be minimized.

Meanwhile, visitors may also become vectors or carriers of IAS. They carry IAS both in and out to new places that could threaten native ecosystems and primary industries. Vegetative or reproductive materials of IAS may be carried unintentionally by visitors via footwear or clothing, or even intentionally, as ornamental plants. To mitigate these hazards, biosecurity awareness among visitors through education is seen as a cost effective tactic to change visitors behaviour and reduce risk (McNeill *et al.* 2008).

PCA Biplot Pattern between the Abundance of Understory IAS and Environmental Factors

The type of ecosystem and the environmental conditions of individual sites affect the invasion of understory IAS (McNeely *et al.* 2001). PCA biplot analysis in this study produced four clusters, confirming the disturbance level of study sites based on the occurence and abundance of understory IAS and its association with environmental variables. The first three principal component of the PCA have eigenvalues of 3.74, 2.60 and 2.18, rescpectively, and contributed to cumulative 50.13% of the total variance. The highly invaded sites at coastal areas i.e., Segara Anakan, Gladakan, Barubaru, Karetan, Pelawangan, and Selatan were clustered in Group I (Fig. 5, red circle), strongly associated to light intensity and air temperature. While, RH, soil pH and elevation were related to understory IAS abundance at less disturbed sites (Fig. 5; Group II, III, IV).

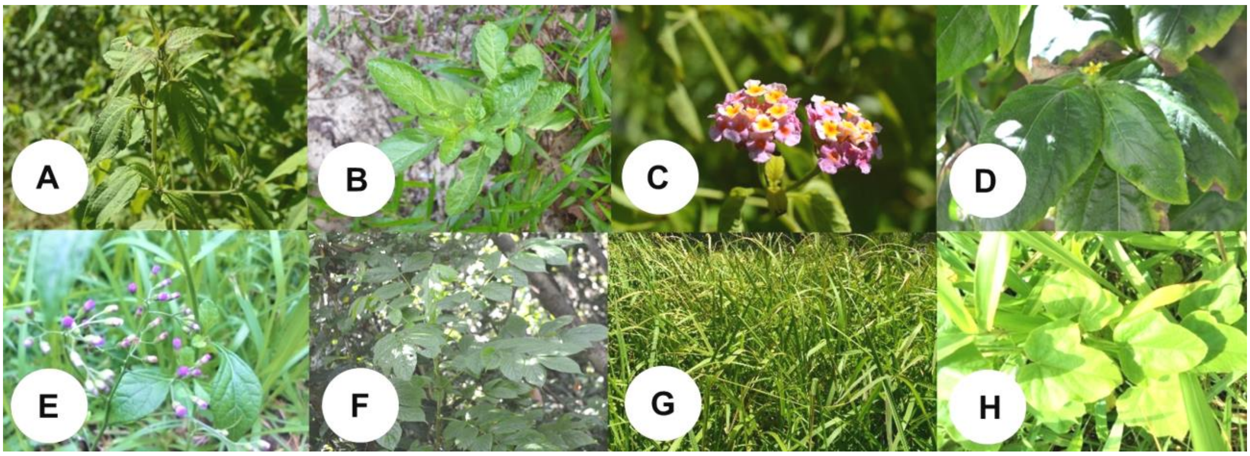

Figure 4 Some understory IAS in Sempu Island

Notes: A. *Chromolaena odorata*; B. *Stachytarpheta jamaicensis*; C. *Lantana camara*; D. *Synedrella nodiflora*; E. *Chyanthillium cinereum*; F. *Spathodea* c*ampanulata*; G. *Imperata cylindrica* and *H. passiflora foetida.*

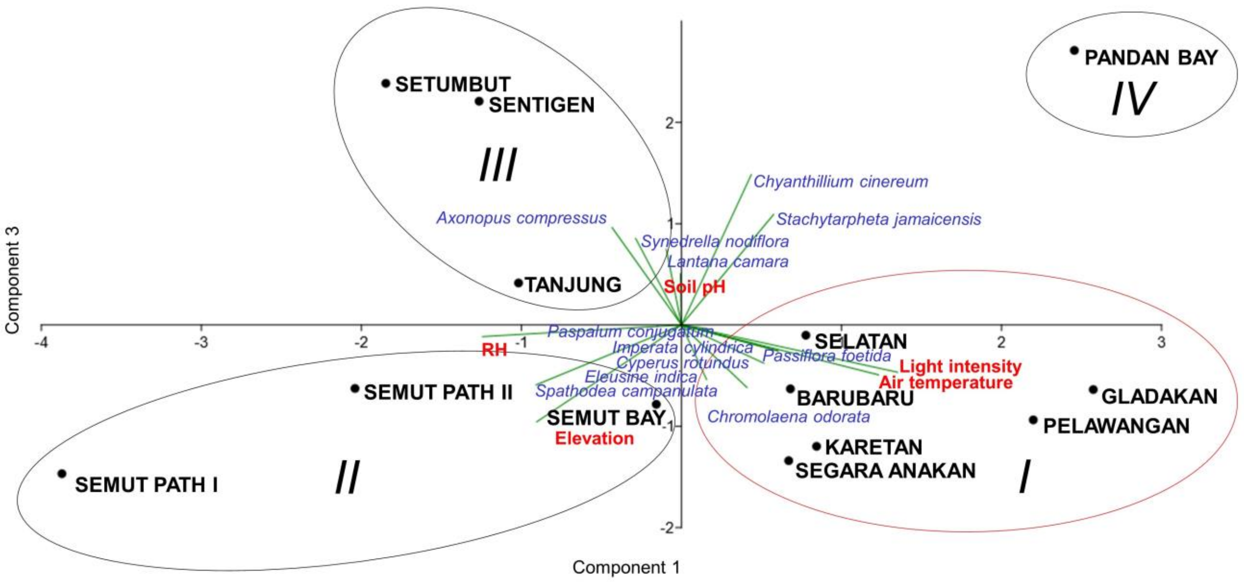

Figure 5 PCA biplot association pattern between the abundance of understory IAS and environmental variables in Sempu Island

PCA result showed that the environmental variables, light intensity and air temperature were most highly associated with the abundance of understory IAS among the study sites in Sempu Island. It was supported by its positive correlation values to the principal components i.e., 0.89 and 0.82, respectively. The patches of empty space and greater light availability enable the establishment of fast growing IAS. The corridors will then facilitate their dispersal between connected patches of habitat (Tewksbury *et al.* 2002; Robiansyah & Purnomo 2013; Mukarromah 2015). Soil pH and RH were in positive correlation to the principal components but in lower values i.e., 0.26 and 0.19, respectively. However, elevation has negative correlation values of -0.59 to -0.13 to the principal components. The study sites elevation on Sempu Island only ranges from 3 m asl to 69 m asl; thus, it possibly will not significantly affect the understory IAS population abundance. Other variables or global change drivers which affect the expansion and abundance of IAS in the understory include elevated atmospheric CO_2 concentration, altered precipitation, and increased soil nutrient availability (Valladares *et al.* 2016).

This current study demonstrates that some understory IAS on Sempu Island are growing in only limited areas, while others are growing more widely (Table 3, Fig. 5). *S. campanulata* was found preferentially growing at sites with high elevation and high humidity, like at Semut Path I. *A. compressus, S. nodiflora, L. camara, C. cinereum, S. jamaicensis* were found preferentially at sites with neutral soil pH, though they have wide environmental tolerance. Meanwhile, *C. odorata* and *C. cinereum*, in particular, were widely distributed IAS on Sempu Island. Species with limited distributions are recommended for physical or chemical elimination or eradication with short (less than 5 years) to mid-term (5 - 10 years) priority (Ryu *et al.* 2017). Whereas, widely distributed species need more than 10 years for eradication.

In addition to physical or chemical elimination, monitoring and spread prevention programs should be carried out in the areas where IAS are widely distributed. Due to time limitations and costly eradication, it is necessary to focus on forest ecosystem integrity. At Jeju Island, for example, the native species were planted to re-establish the habitat (Ryu *et al.* 2017). Since Sempu Island is decreed as a nature reserve, the recommendations preferably, should be of preventions rather than interventions. Recommendations based on the present study are directed at strengthening forest integrity by preventing further spread of the existing IAS, preventing the introduction of new IAS on Sempu Island, and promoting the re-establishment of native species. However, where prevention is not sufficient for some certain locations with serious problems, intervention is also required. For instance, the *S. campanulata* mother plant at Watu Pluncing of Semut Path I should be removed, and eradication of *I. cylindrica* at Gladakan and *C. odorata* at Segara Anakan and Barubaru are necessary for further IAS management.

Native plant species with high conservation values, that are protected and important are recommended to be re-established at Sempu Island. Four are recommended IUCN red-listed tree species i.e., *Myristica teysmannii* (endangered), *Sindora javanica* (vulnerable), *Casearia flavovirens* (vulnerable) and *Ceriops decandra* (near threatened). *Excoecaria agallocha* is also recommended since it is protected by Indonesian Law (SK Mentan No.54/Kpts/Um/ 2/1972). Moreover, some important native species that need re-establishment include *Artocarpus elasticus*, *Pterospermum* spp., *Diospyros* spp., *Garcinia celebica*, etc (Rindyastuti *et al.* 2018). The re-establishment of native species populations would eventually reduce the abundance of IAS. It will restore the plant community and re-conditions the ecosystem habitats that have been invaded, thereby strengthening the forest integrity and the associated habitat attributes from IAS invasions (Lemke *et al.* 2012; Ryu *et al.* 2017).

CONCLUSION

A high species diversity of understory plants was observed at Sempu Island, specifically, on the lowland forests adjacent to the trekking path to Segara Anakan Lagoon and some coastal areas along the western part of the Island. Amongst the diverse native understory species, 12 understory invasive alien species (IAS) were present, indicating an ecosystem disturbance especially at the coastal areas. Four of these IAS are classified as the world's worst invaders and three are noxious weeds. The IAS *Spathodea campanulata* was first recorded at Sempu Island and the present mother plant should be removed. PCA biplot analyses demonstrated a positive association between abundance of IAS and the opening of forest cover caused by visitor's activities.

Based on the current findings, some management interventions are recomended regarding the abundance of understory IAS at Sempu Island Nature Reserve: (1) in controlling and limiting the spread of understory IAS, minimize or prohibit the opening of forest and vegetation for new trekking paths or corridors on Sempu Island; (2) in raising awareness about the threats of IAS and their impact on ecosystems, educate the local guides and recruit them as conservation partners, and provide the visitors with education campaign materials such as banners and information boards; (3) monitor intensively and periodically the IAS status on trekking paths and sites that are oftentimes visited by visitors, including Semut Path, Segara Anakan, and the west coast areas; and (4) strengthen the forest ecosystems integrity by promoting the re-establishment of the protected and important native plant species with high conservation values, in Sempu Island thereby restoring the plant community and reconditioning the habitat.

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