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Ecological niche modeling of invasive alien plant species in a protected landscape

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ABSTRACT

Non-native plants that can cause adverse effects are otherwise known as invasive alien plant species which pose a major threat to plant biodiversity conservation and sustainability. This study is dedicated to determine the plant diversity and to assess the vulnerability of Quezon Protected Landscape, Southern Luzon, the Philippines to invasive alien plant species. Data from 90 10x10 m randomly established plots using the quadrat method showed that there are 318 plant species wherein 208 are native, 100 are non-native, and 10 are invasive. Results from the association of the physicochemical factors and the presence of invasive alien plant species through Spearman rho test revealed that most of the physicochemical factors have significant association except percent slope and hill shade. Soil pH, aspect and number of non-native plants show positive association while soil moisture, leaf litter thickness, elevation, species richness, species evenness, plot species diversity index, and the number of native plants signify negative association. Differences between the plots of with and without invasive alien plant species in physicochemical factors indicate that most of the physicochemical factors have a significant difference between plots of with and without invasive alien plant species except percent slope, hill shade, and aspect. Lastly, the MaxEnt model exemplifies that the most suitable predicted conditions for invasive alien plant species are at the edges of boundary and buffer zones. This study implies that most of the physicochemical factors are linked to the presence of invasive alien plant species and Quezon Protected Landscape has a low vulnerability to invasive alien plant species invasion.

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INTRODUCTION

Non-native species have two fates after establishment: to cause no harm or to cause detrimental effects. Non-native species that can cause adverse effects are known as invasive alien species. Invasive alien species (IAS) is one of the most serious problems that the world is facing due to its threat on biodiversity, economic development, human health, and food security (CBD, 2009; Joshi, 2006; McNeely *et al.,* 2001; Dickey *et al.,* 2018). Biological invasions and climate change have continually initiate change (European Commission, 2013; CBD, 2009; Masters and Norgrove, 2010) that are one of the most difficult to reverse (EEA, 2012). Several studies are conducted about the impacts of invasive alien species worldwide on biodiversity, ecosystem services (Katsanevakis *et al.*, 2014; Kumschick *et al.*, 2014), human health and economic activities (Reaser *et al.*, 2007; Schlaepfer *et al.*, 2010; CBD, 2009; EEA, 2012). However, studies about the impacts of invasive alien species in the Philippines are few and superficial (Joshi, 2006). Philippines is one of the 17 mega diverse countries in the world (Keong, 2015) because of its archipelagic nature that favours geographical isolation and endemism (Persoon and Weerd, 2006; PTFCFI, 2015) but island ecosystems are very vulnerable to invasive alien species that may cause population regressions and extinctions especially to the endemic species (Reaser *et al.*, 2007; CBD, 2009). Philippines is also considered as one of the 10 world's most threatened forest hotspots (ACB, 2010 as cited in Keong, 2015). Quezon Protected Landscape (QPL) is a tropical rainforest (DENR CALABARZON, 2013) situated at within the southern Sierra Madre mountain range in the Philippines (Dagamac *et al.,* 2014). Few accounts are available about the studies conducted at QPL which include plasmodial slime molds (Dagamac *et al.,* 2014), vertebrate mega diversity and endemism (Brown *et al.,* 2012), and analysis in forest and grassland vegetation at the south western side of QPL (Tadiosa *et al.,* 2016). It has been cited that protected areas and landscapes have mounting pressures and one of those is the invasion of invasive alien species (Foxcroft *et al.,* 2018). However, no studies have been conducted about the invasive alien plant species in QPL. This study is committed to assess and to determine the ecology and spatial patterns of invasive alien plant species in QPL through identification and classification of plants that are found in disturbed and undisturbed areas as native, non-native non-invasive, and non-native invasive; Determine significant associations between physicochemical factors and the presence of invasive alien plant species; Determine significant differences physicochemical factors between disturbed and undisturbed areas, and between with and without the presence of invasive alien plant species; Evaluate the vulnerability of QPL in invasive alien plant species invasion through predictive probability distribution analysis using spatial patterns and environmental covariates. This study has been carried out in the Quezon Protected Landscape, Southern Luzon, Philippines in 2018.

MATERIALS AND METHODS

Study area

QPL is a 983.0765-hectare tropical rainforest (DENR CALABARZON, 2013) situated at 121° 46' 30" and 121° 50' 00" East longitude and 13° 58' 30" and 14° 01' 00" North latitude (Proclamation No. 394) within the southern Sierra Madre mountain range (Dagamac *et al.,* 2014). It is located within the three municipalities in Quezon province such as the Atimonan, Pagbilao, and Padre Burgos (DENR CALABARZON, 2013; Tadiosa *et al.,* 2016). Nine transects measuring 500 m each using quadrat method encompassed the disturbed and undisturbed areas in three municipalities of Pagbilao, Padre Burgos, and Atimonan (Table 1). These included forest, agroforest, grassland and residential areas. Transects established were based upon the transects established by the Department of Environment and Natural Resources (DENR) quarterly monitoring and additional transects were made to cover the residential areas. Nested plots are used to account species that were distributed within the sample area. The length of each transect was 500 m with 10x10 m plots and interval of 40 m. Nested plots were done for each transect with a measurement of 10x10 m for trees, 5x5 m for herbs and shrubs, and 1x1 m for weeds and grasses.

Data collection

A total of 90 10x10m plots covering the disturbed and undisturbed areas were established and were mapped using QGIS 2.18.13® software (Fig. 1). At each plot, 14 physicochemical factors were measured. These included soil pH, soil moisture, actual location, elevation, hillshade, percent slope, aspect, leaf litter thickness, species richness, species evenness, species

Table 1: Established transects

Transect No.	Name	Location and Coordinates Covered	Area Classification (Disturbed and Undisturbed)	Type of Area Based on Land Use
1	Buenavista Spot Transect Route	So. Amao, Malicboy, Pagbilao, Quezon S: 13°59.217'N 121°48.752'E E: 13°59.301'N 121°48.913'E	Undisturbed	Forest
2	Magnet Site Transect Route	So. Amao, Malicboy, Pagbilao, Quezon S: 13°59.307'N 121°48.910'E E: 13°59.257'N 121°49.137'E	Disturbed	Agroforest
3	Pinagbanderahan Transect Route (Pinagbanderahan Peak)	Malinao Ilaya, Atimonan, Quezon S: 13°59.822'N 121°48.788'E E: 13°59.941'N 121°48.734'E	Disturbed	Grassland
4	Diversion Road Transect Route	Malicboy, Pagbilao, Quezon S: 13°59.179'N 121°48.202'E E: 13°59.004'N 121°48.132'E	Disturbed	Residential
5	Pinagbanderahan Transect Route (Pinagbanderahan Foot)	Malinao Ilaya, Atimonan, Quezon S: 13°59.610'N 121°49.298'E E: 13°59.710'N 121°49.138'E	Undisturbed	Forest
6	Usli Transect Route	So. Usli, Sipa, Padre Burgos,Quezon S: 13°59.252'N 121°49.144'E E: 13°59.049'N 121°49.064'E	Undisturbed	Forest
7	Santa Catalina Transect Route	Sta. Catalina, Atimonan, Quezon S: 14°0.466'N 121°48.606'E E: 14°0.561'N 121°48.809'E	Disturbed	Residential
8	Malinao Ilaya (Old Zigzag Road) Transect Route	Malinao Ilaya, Atimonan, Quezon S: 13°59.723'N 121°50.017'E E: 13°59.643'N 121°49.898'E	Disturbed	Residential
9	Guitong transect route	So. Guitong, Sipa, Padre Burgos, Quezon S: 13°58.827'N 121°48.989;E E: 13°58.739'N 121°48.893'E	Disturbed	Agroforest

diversity index, number of native plants, non-native plants, and IAPS. The choice of physicochemical factors was based on the factors that may affect the growth of IAS and its effect to the plant community, and the factors that were used in ecological niche modelling. Soil samples were taken within the plot at a depth of 10-15 cm. Actual location and elevation were measured using eTrex 20 Garmin® GPS device. Hillshade, percent slope, and aspect were generated at QGIS 2.18.13 using the digital terrain model obtained from National Mapping and Resource Information Authority (NAMRIA). Leaf litter thickness was measured using meter tape in millimetres. Species richness, number of native plants, non-native plants, and invasive alien plant species were measured by counting the number of species found within the plot (Borja *et al.,* 2015). Species evenness was measured using its formula and species diversity index was measured using Shannon diversity index (Smith and Smith, 2004).

Data analysis

Descriptive statistical measure was used in identification and classification of plants within the plots for every transect. To determine significant associations between physicochemical factors and the presence of IAPS found in different transects, Spearman rho was used. To determine significant differences in physicochemical factors in disturbed and undisturbed areas and with and without the presence of invasive alien plant species, Mann-Whitney test was used. Quantitative analysis of physicochemical factors and environmental parameters was done through the use of Microsoft

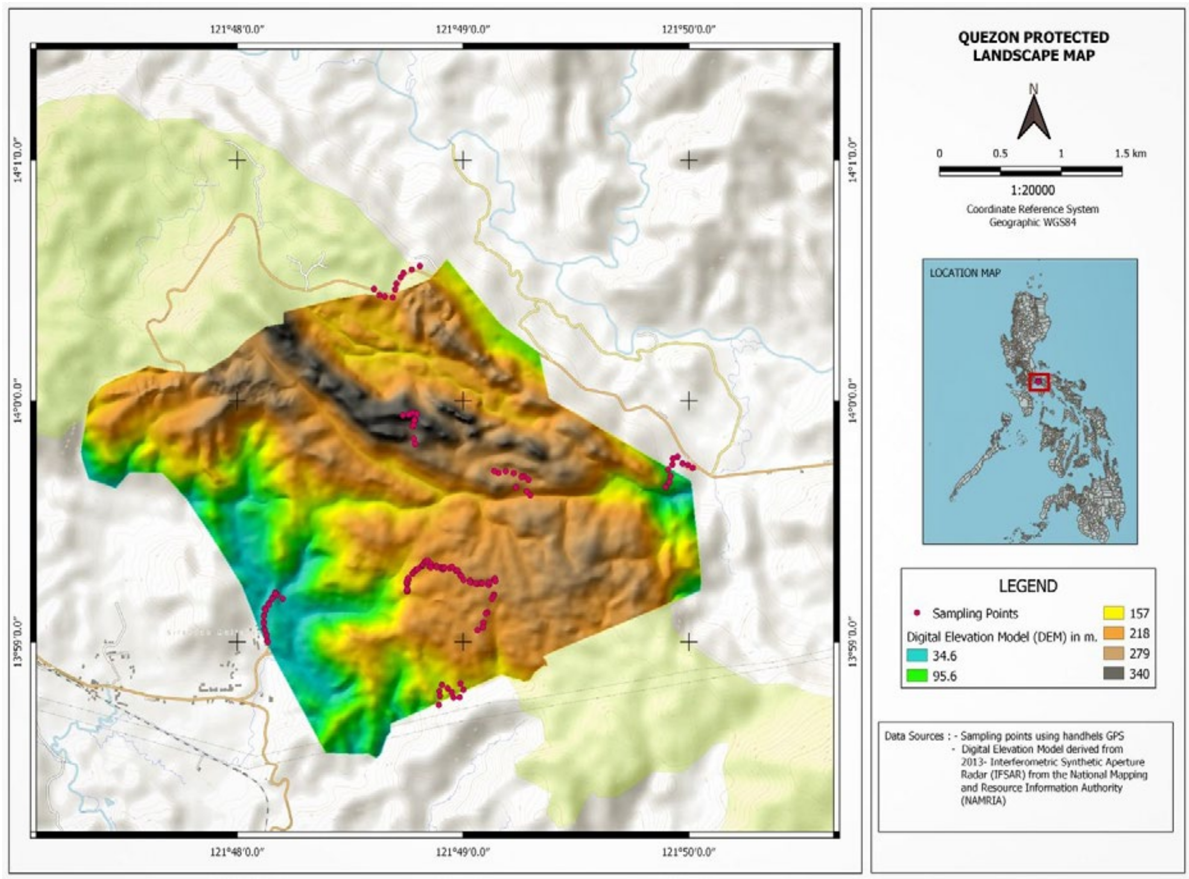

Fig. 1: The geographic location of the study area in Quezon Protected Landscape showing its boundaries and 9 established transects

Excel 2013™ software. Environmental layers such as the elevation, hillshade, aspect, and percent slope were used for the ecological niche modelling done at MaxEnt® software.

RESULTS AND DISCUSSION

Plant assessment

Plant assessment data from 90 10x10m randomly established plots revealed that there are 318 plant species that can be found in Quezon Protected Landscape combining the disturbed and undisturbed areas that were subjected for study. Out of 318 plant species identified within the area, 208 of those are native species, 100 of those are non-native species, and 10 of those are IAPS. *Celtis luzonica* (magabuyo) is the most prominent plant species that was identified having a relative frequency of 65.56%. The 10 IAPS that are present in QPL are *Ageratum conyzoides* L. (bulak-manok), *Calopogonium mucunoides* Desv. (cover crop), *Chromolaena odorata L.* (hagonoy), *Lantana camara L.* (coronitas), *Leucaena leucocephala (Lam.) de Wit* (ipil-ipil), *Melothria pendula L.* (pipinong-gubat), *Mikania cordata (Burm.f.) B.L. Rob.* (uuko), *Mimosa pudica L.* (makahiya), *Stachytarpheta jamaicensis (L.) Vahl.* (kandi-kandilaan), and *Triplaris cumingiana Fisch. & Mey.* (palosanto).

Physicochemical factors and the presence of IAPS

Most of the physicochemical factors have significant association to the presence of IAPS within the plots except to percent slope and hillshade (Table 2). These include soil pH, soil moisture, leaf litter thickness, elevation, aspect, species richness, species evenness, species diversity index, and number of native and non-native plants. The result of the study

Table 2: Association between the Physicochemical Factors to the Presence of IAPS

Physicochemical factors	Mean	IAPS	Correlation
Soil pH	6.09^{X}	5.37^{X}	Positive
Soil moisture	63.39^{X}	5.37^{X}	Negative
Leaf litter thickness	34.56^{X}	5.37^{X}	Negative
Elevation	193.5^{X}	5.37^{X}	Negative
Percent slope	25.78^{X}	5.37^{Y}	Negative
Hill shade	163.33^{X}	5.37^{Y}	Positive
Aspect	183.22^{X}	5.37^{X}	Positive
Species richness	17.53^{X}	5.37^{X}	Negative
Species evenness	0.87^{X}	5.37^{X}	Negative
Species diversity index	2.44^{X}	5.37^{X}	Negative
No. of native plants	12.52^{X}	5.37^{X}	Negative
No. of non-native plants	4.97^{X}	5.37^{X}	Positive

Same letters signify statistically significant association ($p<0.05$) between rows. Letters X and Y indicate no significant association between rows (physicochemical factors and invasive alien plant species)

coincides with the result of Borja *et al.* (2015) in which, the abundance of coffee, a potential invasive alien plant species, decreases as the leaf litter thickness increases. However, the study of Codilla and Medillo (2011) stated that the germination and growth of *C. odorata*, a highly invasive alien plant species, is not greatly influenced by soil pH. Also, increasing soil nutrients, light, and moisture positively affect the success of IAPS (Theorides and Dukes, 2007). Elevation, species richness, species evenness, species diversity index, and number of native plants have significant negative association to IAPS. As the result suggests, IAPS are commonly found at lower elevation than in places with higher elevation. It is stated that majority of IAPS are introduced at lowlands (Dainese *et al.,* 2014) that is why many IAPS are commonly found at lower elevations. Only a subset of lowland IAPS are more likely to spread or to be found at higher elevations or at mountains in line with directional ecological filtering hypothesis (Dainese *et al.,* 2014). In lieu with this, if the area is diverse, IAPS are most likely not to be found. The results corroborate to the statement that high plant richness and high plant diversity minimizes the success of IAPS in establishment and propagation (Theorides and Dukes, 2007; Nijs *et al.,* 2012; European Commission, 2013; Borja *et al.,* 2015; Panetta and Gooden, 2017) due to increased competition in limiting resources which favors established native vegetation rather than the novel species (Borja *et al.,* 2015). On the other hand, number of non-native plants is significantly positive associated with IAPS indicating that IAPS are most likely to be found in places with many non-native plants. Resident species do not always out-compete or suppress the growth and success of IAPS but sometimes, it can contribute to its success due to facilitation (Theorides and Dukes, 2007). Invasive alien plant species have a wide range of competitive ability (Schultheis and MacGuigan, 2018) tolerance in different environmental conditions (CBD, 2009; EEA, 2012; ISSG, 2005; Masters and Norgrove, 2010; McNeely *et al.,* 2001; Theorides and Dukes, 2007) as exemplified with the result of the study that percent slope and hill shade has no clear significance with the presence of invasive alien plant species.

Physicochemical factors in Disturbed and Undisturbed Areas

The results obtained show that most of the physicochemical factors have significant difference in disturbed and undisturbed areas. These include soil pH, soil moisture, leaf litter thickness, elevation, percent slope, species richness, species evenness, species diversity index, number of native plants, number of non-native plants, and number of invasive plants (Table 3). However, hillshade and aspect do

Table 3: Physicochemical factors in disturbed and undisturbed areas

Table 3: Physicochemical factors in disturbed and undisturbed areas

Physicochemical Factors	Disturbed Area	Undisturbed Area
Soil pH	6.4[X]	5.48[Y]
Soil Moisture	51.71[X]	86.76[Y]
Leaf Litter Thickness	28.17[X]	47.32[Y]
Elevation	173.24[X]	234.02[Y]
Percent Slope	28.25[X]	20.84[Y]
Hillshade	159.8[X]	170.4[X]
Aspect	184.55[X]	180.56[X]
Species Richness	15.02[X]	22.57[Y]
Species Evenness	0.84[X]	0.91[Y]
Species Diversity Index	2.25[X]	2.82[Y]
No. of Native Plants	9.68[X]	18.2[Y]
No. Of Non-Native Plants	5.25[X]	4.4[Y]
No. of Invasive Plants	1.17[X]	0.07[Y]

Letters X and Y show the significant difference between rows (physicochemical factors in disturbed and undisturbed areas). Different letters signify statistically significant ($p<0.05$) difference between rows.

not have significant difference between disturbed and undisturbed areas. Species richness, species evenness, and species diversity index show significant difference in disturbed and undisturbed areas. It is worth noting that the species richness, species evenness, and species diversity index are lower in disturbed than in undisturbed areas. These results are supported by the claim that land use change is one of the top four drivers of biodiversity loss (European Commission, 2013; Masters and Norgrove, 2010). Because of the land use change, diversity of plants seem to be lower as exemplified by the study of Nijs *et al*. (2012) stating that species richness is lower in disturbed areas compared to undisturbed areas. Since the diversity of plants lowered, homogenization of plant species may occur favouring the growth of IAPS. Since the spread and presence of IAS are aided by humans (McNeely, 2001; ISSG, 2005; European Commission, 2013), it is not surprising that the results show significant difference in the number of native, non-native, and invasive plants. The spatial arrangement of landscape patterns greatly affects the speed rate of IAPS in propagation (Theorides and Dukes, 2007) and because disturbed areas are mostly habitat patches and fragmented landscapes, it positively influences IAPS. It is also worth mentioning that the number of native plants is lesser in disturbed area than in undisturbed area and the number of non-native plants is greater in disturbed than in undisturbed area. The result of the study coincides with the statement that IAS could cause biodiversity loss because it offers irreversible harm to biodiversity by displacing native species (ISSG, 2005) which can lead to the mixing of species (McNeely *et al*., 2001) and domination of IAS that can lead to homogenization and biodiversity loss globally at species and genetic levels (McNeely *et al*., 2001). Native plants also often require intact habitat with wide undisturbed area while the IAPS are best found in fragmented patches of human-disturbed habitat (Theorides and Dukes, 2007). In lieu with this, the number of non-native plants is greater in disturbed area than in undisturbed area suggesting that non-native plants are mostly the resident species in disturbed areas. Resident species do not always out-compete or suppress the growth and success of IAPS but sometimes, it can contribute to its success due to facilitation (Theorides and Dukes, 2007). Hillshade and aspect do not have significant

Table 4: Physicochemical factors of plots with and without IAS

Physicochemical Factors	Plots without Invasive Alien Plant Species	Plots with Invasive Alien Plant Species
Soil pH	5.87^{X}	6.42^{Y}
Soil Moisture	76.47^{X}	43.78^{Y}
Leaf Litter Thickness	42.29^{X}	22.95^{Y}
Elevation	213.32^{X}	163.78^{Y}
Percent Slope	26.93^{X}	24.07^{X}
Hillshade	162.54^{X}	164.53^{X}
Aspect	170.18^{X}	202.78^{X}
Species Richness	18.98^{X}	15.36^{Y}
Species Evenness	0.88^{X}	0.84^{Y}
Species Diversity Index	2.57^{X}	2.25^{Y}
No. of Native Plants	14.94^{X}	8.89^{Y}
No. Of Non-Native Plants	3.96^{X}	6.47^{Y}

Letters X and Y show the significant difference between rows (physicochemical factors in with and without the presence of invasive alien plant species). Different letters signify statistically significant ($p<0.05$) difference between rows.

difference in disturbed and undisturbed areas but it is still worth taking note that hillshade and aspect mean values are greater in undisturbed than in disturbed area. Topography and elevation is said to influence the vegetation in terms of assemblages and species composition (Bunyan *et al.*, 2013).

Physicochemical factors of plots with and without IAPS

Most of the physicochemical factors have significant difference in relation to the presence and absence of invasive alien plant species. However, percent slope, hillshade, and aspect have no significant difference in relation to the presence and absence of invasive alien plant species (Table 4). Soil pH, soil moisture, leaf litter thickness, and elevation have significant difference in plots with and without IAPS. Soil pH is higher in plots with IAS than in plots without IAPS. On the other hand, soil moisture, leaf litter thickness, and elevation are higher in plots without IAPS than in plots with IAPS (Fig. 2). Invasions tend to affect the concentration of nutrients and richness of the soil biota in an increasing pattern rather than in decreasing pattern (Pysek *et al.*, 2012) which contributes to the success of invasion (Wamelink *et al.*, 2018). Plant community characteristics such as the species richness, species evenness, species diversity index, number of native plants, and number of non-native plants demonstrate significant difference in plots with and without the IAPS. It shows that species richness, species evenness, species diversity index, and number of native plants are higher in plots without IAPS compared to plots with IAPS while the number of non-native plants is higher in plots with IAPS than in plots without IAPS. These results corroborate to the reports of Borja *et al.* (2015) stating that the plots with coffee have lesser endemic and threatened species and the number of exotic species is higher in plots with coffee. High plant richness and high plant diversity minimizes the success of IAPS in establishment and propagation (Theorides and Dukes, 2007; Nijs *et al.*, 2012; European Commission, 2013; Borja *et al.*, 2015) due to increased competition in limiting resources which favours established native vegetation rather than the novel species (Borja *et al.*, 2015). Niche complementarity having phenologically, morphologically, and physiologically similar can suppress the growth of IAPS because this can contribute to community's biotic resistance (Theorides and Dukes, 2007). Hillshade, percent slope, and aspect do not have clear significant difference in plots with and without IAPS. This coincides with the statement of Steinbauer *et al.* (2017) wherein spatial and elevation gradients have

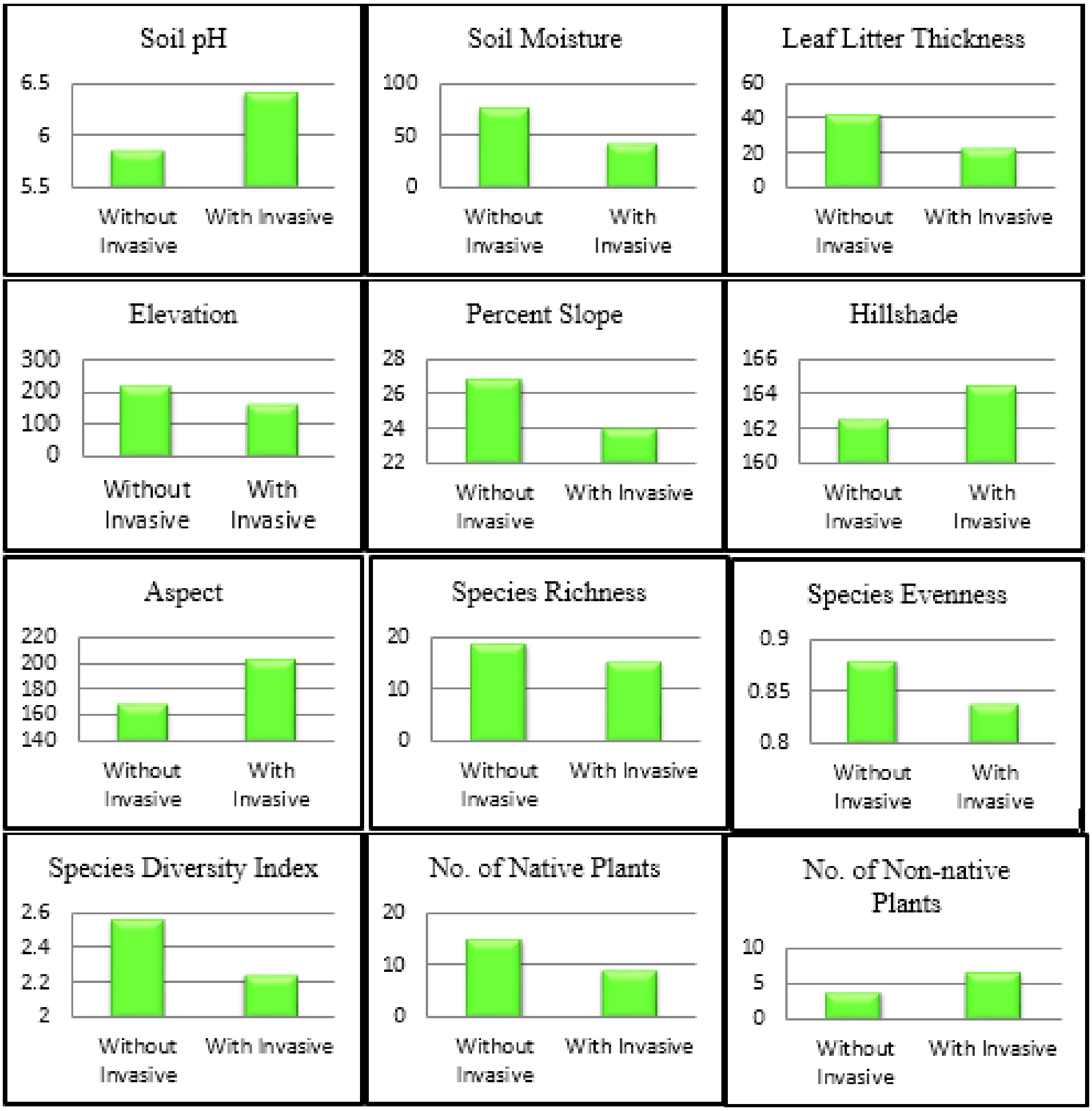

Fig. 2: Physicochemical factors of plots with and without invasive alien plant species

directional ecological filtering thus controlling the dispersal and establishment of native and non-native species. Since invasive alien plant species have a wide range of tolerance in different environmental conditions (McNeely *et al.,* 2001; ISSG, 2005; Theorides and Dukes, 2007; CBD, 2009; Masters and Norgrove, 2010; EEA, 2012), it can be argued that IAPS has no preference when it comes to the physical profile of the area. The steepness of the area, the orientation of the light source, and the direction of the slope have no bearing for the IAPS to grow and propagate. Because of this, if the problem of IAPS will not be properly addressed, its eradication will be hard because of its eurytopic characteristic. IAPS have no preference when it comes to the physical profile of the area as exemplified by the studies of

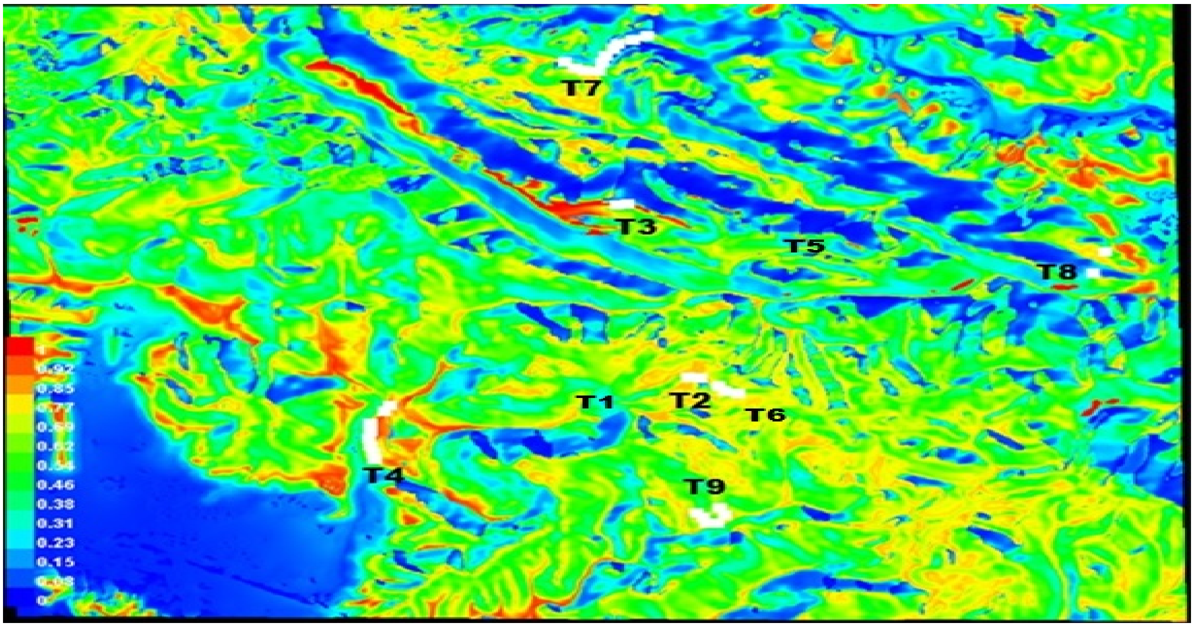

Fig. 3: Predicted conditions to IAPS. White dots show the PO data. Warmer colours indicate the most suitable predicted conditions (MaxEnt3.4.1 Software)

CBD (2009), EEA (2012), McNeely *et al.,* (2001), ISSG (2005), Masters and Norgrove (2010) and Theorides and Dukes (2007).

Vulnerability of Quezon Protected Landscape to invasive alien plant species

It has been stated by several studies (McNeely *et al.,* 2001; Reaser, 2007; CBD, 2009; EEA, 2012) that island ecosystems are very vulnerable to invasive alien species. In the Philippines, impacts of invasive alien species are poorly understood and mostly superficial (Joshi, 2006). Not only mitigation of the impacts where invasive alien species are present is needed, also, where they are expected to be found and where they are likely to have an undesirable impact in the future should also be mitigated (Kumschick *et al.,* 2014; Foxcroft *et al.,* 2018). Alien distribution and abundance data is one way to promote effective monitoring programs (Cheney *et al.,* 2018) especially to protected areas and landscapes. To predict the future distribution of invasive alien plant species, Maxent model is used. The most suitable predicted conditions for IAPS are mostly found at the edges of the boundary and buffer zones of QPL as exemplified by the Maxent model wherein warmer colours are mostly found at the said locations (Fig. 3). Penetration of IAPS to undisturbed areas will be hard due to several reasons: In accordance to the directional ecological filtering hypothesis, only a subset of invasive alien plant species that are found at the lowlands can spread up to the mountains (Dainese *et al.,* 2014). Species richness, species evenness, and species diversity index of undisturbed areas in QPL are high. High plant richness and high plant diversity minimizes the success of IAPS in establishment and propagation (Theorides and Dukes, 2007; Nijs *et al.,* 2012; European Commission, 2013; Borja *et al.,* 2015) due to increased competition in limiting resources which favours established native vegetation rather than the novel species (Borja *et al.,* 2015). Because the numbers of non-native plants are lower in undisturbed areas, facilitation of IAPS will be limited so the success rate may be diminished.

CONCLUSION

This study has focused on the assessment of plant diversity and evaluation of the vulnerability of Quezon Protected Landscape (QPL) in invasive alien plant species through ecological niche modelling. The results of the study imply important points: First, IAPS had the least number of plants as revealed by the plant assessment wherein 208 are native, 100 are non-native, and 10 are invasive; Second, most of the physicochemical factors exemplified significant association to the presence of IAPS; Third, most of the physicochemical factors showed significant difference in disturbed and undisturbed areas, and plots with and without invasive alien plant species. Fourth, the most suitable predicted conditions for IAPS are mostly found at the edges of the boundary and buffer zones. Above all, Quezon Protected Landscape has a low vulnerability to invasive alien plant species with respect to the association of physicochemical factors to IAPS, differences of physicochemical factors to disturbed and undisturbed areas, differences of physicochemical factors to the plots with and without IAPS, and to the MaxEnt model showcasing the suitable predicted conditions for IAPS. With these results, continuous regular monitoring and management should be given priority for biodiversity conservation and sustainability. Also, other invasive alien species aside from plants should also be studied because it may also affect other forms of organisms. Species distribution modelling (SDM) using other climatic factors is also commended for the management of IAPS as it continues to pose threat to biodiversity and sustainability.

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CONFLICT OF INTEREST

The author declares that there is no conflict of interests regarding the publication of this manuscript. In addition, the ethical issues, including plagiarism, informed consent, misconduct, data fabrication and/ or falsification, double publication and/or submission, and redundancy have been completely observed by the authors.

ABBREVIATIONS

%	Percentage
CBD	Convention on Biological Diversity
cm	Centimetre
E	East
EEA	European Environment Agency
Fig.	Figure
GPS	Global positioning system
IAPS	Invasive alien plant species
IAS	Invasive alien species
ISSG	Invasive Species Specialist Group
m	Meter
MaxEnt	Maximum Entropy
N	Native Plant
N	North
NP	Non-native Plant
pH	Potential of hydrogen
PO	Presence only
QGIS	Quantum Geographic Information System
QPL	Quezon Protected Landscape
S	South
SDM	Species Distribution Modelling
So.	Sitio
W	West

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