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Predicting Invasion Probability from Botanic Gardens using Exotic Species Traits

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Abstract

Preventative management, such as framework-based assessment, considered as the best option for invasive species management. Alternatively, risk assessment can be conducted based on traits of occurred invasive species to build prediction system for invasive risk assessment. This study aimed to test whether trait-based assessment system can differentiate the escaped from non-escaped exotic collections of botanic gardens and to compare the reliability of trait-based versus framework-based risk assessment on differentiating these escaped from non-escaped exotics. In this study, Bayesian logistic regression analysis was conducted to assess the reliability of framework-based and trait-based risk assessment systems. For trait-based system, clear effect of leaf trait, height, and dispersal method to escape probability was detected. For framework-based system, clear effect of Tropical Weed Risk Assessment Protocol on escape probability was detected. Leaf trait, dispersal method and height are reliable predictors for escaped probability of botanic gardens exotic collection. The fact that the reliability of trait-based assessment systems is better than the commonly used framework-based system is the main novel finding in this study. This finding implies that trait-based is better than framework-based for invasive species risk assessment approach in Indonesian botanic gardens. Trait-based assessment also a relevant tool to support management with limited resources to conduct adequate early risk assessment.

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INTRODUCTION

Apart from its important role in ex-situ plant conservation (Hidayat *et al.*, 2017), botanic gardens are important sources of invasive plant species (Heywood, 2011). There is an urgent need to predict the risk of spread of exotic and invasive species from botanic gardens (Corlett, 2010). The ability to assess weed risks will allow botanic gardens to set priorities for the management of their exotic collections (Corlett, 2010; Heywood, 2011). Several studies provide some preliminary ideas about assessing invasive risk from tropical botanic gardens exotic collections (Daehler, 2009; Dawson *et al.*, 2009a; Dawson *et al.*, 2011). Framework-based invasive species risk assessments for botanic gardens were also developed and implemented for sub-tropical areas of Australia (Virtue *et al.*, 2008) using Botanical Garden Weed Risk Assessment Protocol (BG-WRAP) and tropical Africa (Dawson *et al.*, 2009b) using Weed Risk Assessment (WRA) system.

Preventative management is the ideal approach for invasive species management and already implemented in multiple geographical contexts, such as regional-level (Foxcroft *et al.*, 2008; Pritekel *et al.*, 2006), country-level (Williams & West, 2000) and continent-level (Brunel *et al.*, 2010). Technically, preventative management may consist of early detection, screening, and implementation of designated risk assessment framework for exotic species that are potentially invasive (Leung *et al.*, 2012).

There are many risk assessment frameworks (e.g. WRA) that were suggested as reliable systems for global application (Chong *et al.*, 2011). However, most of these assessment frameworks were need specific data, either traits data or other supporting information.

Consequently, the application of framework-based assessment may become unrealistic for users with limited data availability. This is because we need lots of specific data in the application of these frameworks. An assessment system should be simple and easy to apply, a user-friendly system. These framework-based systems could be irrelevant if the data are limited (Sheil & Padmanaba, 2011). Thus, the application of framework-based system will be difficult if the data needed are not available.

At some situations, we can only rely on limited trait information to conduct a risk assessment and early rapid risk assessments are mostly relevant for preventative management contexts, which is considered as the best option for invasive species management (Leung *et al.*, 2012). Risk assessment may also be constructed based on the occurred invasion data to incorporate possible ecological explanation to build prediction system for invasive species risk assessment. We can utilize potential traits as a proxy to explain naturalization and invasion probability instead of using risk assessment system.

This study aimed to test whether a set of traits that suggested as important for tropical invasions can differentiate the escaped from non-escaped exotic collections of tropical botanic gardens in to adjacent tropical rainforests. This study also aimed to compare the reliability of trait-based versus framework-based risk assessment (WRA, BG-WRAP, and Tropical Weed Risk Assessment Protocol (T-WRAP)) on differentiating the escaped from non-escaped exotics. If trait-based risk assessment is as reliable as framework-based assessment, then this trait-based risk assessment may become simpler, cheaper and faster approach than framework-based system. This is because trait-based approach will need relatively fewer data. Furthermore, this simpler, cheaper and faster approach will support a better invasive species management for decision-makers or stakeholders with resource limitation problem.

METHODS

The study was conducted in four tropical forests in Indonesia that contain escaped exotic species from adjacent botanic gardens. These study sites were Mount Gede-Pangrango, Mount Ciremai, Mount Slamet, and Bukit Tapak, which were located next to Cibodas Botanic Gardens (CBG), Kuningan Botanic Gardens (KBG), Baturraden Botanic Gardens (BRBG), and Eka Karya Bali Botanic Gardens (EKBG) respectively. Line transect distance sampling (Buckland *et al.*, 2007) analysis was conducted to detect escaped exotic collections from botanic gardens into adjacent native forests. Total transect length varied from 450 m to 1350 m (Table 1).

Traits studies

Traits data collected in this study were: specific leaf area (SLA), height, seed mass, dispersal method, and residence time. Traits were measured or collected for every detected individual of escaped exotic species and for 26 randomly chosen non-escaped exotic collection of botanic gardens. SLA (mm^2/mg) and plant height (m) were measured by following method suggested by Pérez-Harguindeguy *et al.* (2013). Due to technical limitation during data collection in the

Table 1. Study sites and locations of line transect distance sampling conducted to detect escaped botanic gardens’ exotic collections.

Sampling Location	Adjacent Botanic Gardens	Coordinates	Transect length (m)
Mount Gede, West Java	Cibodas Botanic Gardens	S 06^{0}44.515’ E 107^{0}00.290’	1350
Mount Tapak, Bali	Eka Karya Bali Botanic Gardens	S 08^{0}16.658’ E 115^{0}08.985’	900
Mount Slamet, Central Java	Baturraden Botanic Gardens	S 07^{0}18.096’ E 109^{0}13.905’	450
Mount Ciremai, West Java	Kuningan Botanic Gardens	S 06^{0}49.519’ E 108^{0}24.317’	650

field, not all data of height obtained from direct measurement. There were 40 percent of data of height was collected from direct measurement and the other 60 percent was collected from secondary data in available databases such as http://www.efloras.org/ and http://hear.org. The “corrected” height data from database was acquired by fitting it into a model between the 40% direct measurement data versus their median of height ranges in databases (Figure 1).

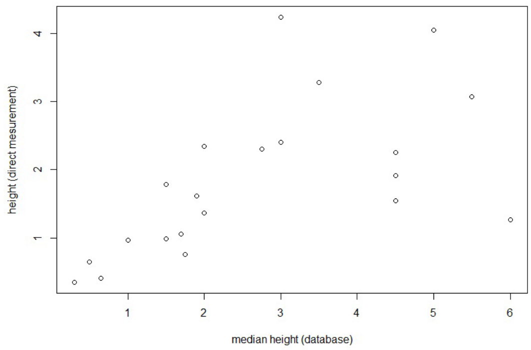

Figure 1. Scatter plot between height value from direct measurement versus height value (median) from available databases. If the minimum height value was not stated in the database, we used the median value between zero and the maximum height that was stated in the database.

Due to limited fruit availability during the survey period, secondary seed mass data for escaped and non-escaped exotics from Kew Seed Database (<http://data.kew.org/sid/>) was used for seed mass data and defined as 1000 dry seed mass (mg). Minimum residence time was obtained from botanic gardens’ collection catalogues of CBG (1930, 1963, 1977 and 1988) and BBG (1989, 1999, and 2006). Minimum residence time of exotic species from other two botanic gardens (KBG and BRBG) was acquired from botanic gardens’ official planting date records.

Dispersal method was defined as categoric variables and simplified into two categories: animal and non-animal dispersed. These categorical trait data were collected from relevant databases included <http://data.kew.org/sid/>, http://www.ars-grin.gov/>, <http://www.gbif.org>, <http://www.pfaf.org/>, and <http://www.hear.org/pier/>. Traits data with identical method was also collected from randomly selected 26 non-escaped botanic gardens exotic collections.

The retrospective logistic regression analysis was conducted to model the probability of escape of botanic gardens exotic collection into adjacent native forests based on the prescribed traits as independent variables (model 1).

$P(x) = e^{g(x)} / (1 + e^{g(x)})$ ....(model 1)

where $P(x)$ is the probability of escape of exotic collection of botanic gardens and $g(x) = a_0 + ß_1 m_i + ß_2 n_i + ß_3 o_i + ß_4 q_i + \varepsilon_i$ where m_i, n_i, o_i, and q_i were specific leaf area (SLA), dispersal method, minimum residence time, and plant height of species i respectively. The value of P(x) was equal to 1 for escaped exotics and 0 for non-escaped exotics. The Bayesian logistic regression analysis conducted in R (Team, 2013) with Bayesian framework using Just Another Gibbs Sampler (JAGS) (Plummer, 2003), called from R using package jags UI (Kellner, 2015).

Framework-based risk assessment

Risk assessment of escaped exotic was also conducted using three framework-based systems: Weed Risk Assessment (WRA) (Pheloung *et al.*, 1999), Botanic Gardens Assessment Protocol (BG-WRAP) (Virtue *et al.*, 2008), and modified BG-WRAP for tropical contexts (T-WRAP) (Junaedi, 2011). Method suggested by Onderdonk *et al.* (2010) used for WRA scoring processes.

Bayesian logistic regression analysis was also conducted to model the escape probability and utilized WRA, BG-WRAP, and T-WRAP score as independent variables (models 2, 3, and

4).

$$P(x) = e^{h(x)} / (1 + e^{h(x)}) \ldots\ldots\ldots\text{(model 2)}$$

$$P(x) = e^{i(x)} / (1 + e^{i(x)}) \ldots\ldots\ldots\ldots\text{(model 3)}$$

$$P(x) = e^{j(x)} / (1 + e^{j(x)}) \ldots\ldots\ldots\ldots\text{(model 4)}$$

where $P(x)$ is the probability of escape of exotic collection of botanic gardens and $h(x) = a_0 + ß_1 r_i + \varepsilon_i$, $i(x) = a_0 + ß_1 s_i + \varepsilon_i$, $j(x) = a_0 + ß_1 t_i + \varepsilon_i$, where r_i, s_i, and t_i are the score of WRA, BG-WRAP, and T-WRAP of species *i* respectively. The analysis procedure for model 1 was also implemented for Bayesian logistic regression analysis in model 2, 3, and 4. The deviance information criterion (DIC) values from the posterior results and area under the curve (ROC curve) were utilized to compare and visualize the reliability of all assessed models (models 1, 2, 3, and 4). The ROC curve of the model constructed using R package *pROC* (Xavier *et al.*, 2011).

RESULTS AND DISCUSSION

There were 913 escaped exotic individuals and 23 species detected from all four study sites. These escaped exotics were mostly shrubs and herbs with only several small tree species (Table 2). There were also 996 non-escaped individuals

Table 2. List of 23 escaped and 26 non-escaped exotic species collections in this study. E=escaped, N=non-escaped, KBG= Kuningan Botanic Gardens, CBG= Cibodas Botanic Gardens, BRBG= Baturraden Botanic Gardens, and BBG= Eka Karya Bali Botanic Gardens.

E/N	Species Name	Author	Family	Garden
E	*Ageratina riparia*	(Regel) R.M.King & H.Rob.	Compositae	CBG
E	*Austroeupatorium inulaefolium*	(Kunth) R.M.King & H.Rob.	Compositae	CBG
E	*Bartlettina sordida*	(Less.) R.M.King & H.Rob.	Compositae	CBG
E	*Brugmansia x candida*	Pers.	Solanaceae	BBG
E	*Brugmansia x candida*	Pers.	Solanaceae	CBG
E	*Cestrum aurantiacum*	Lindl.	Solanaceae	CBG
E	*Cestrum elegans*	(Brongn. ex Neumann) Schltdl.	Solanaceae	CBG
E	*Chimonobambusa quadrangularis*	(Fenzl) Makino	Poaceae	CBG
E	*Clidemia hirta*	(L.) D. Don	Melastomataceae	CBG
E	*Cocculus laurifolius*	DC.	Menispermaceae	CBG
E	Coffea sp.	-	Rubiaceae	BBG
E	*Dichroa febrifuga*	Lour.	Hydrangeaceae	CBG
E	*Chromolaena odorata*	(L.) R.M.King & H.Rob.	Compositae	BBG
E	*Impatiens balsamina*	L.	Balsaminaceae	BRBG
E	*Maranta lietzei*	(E.Morren) C.H.Nelson, Sutherl. & Fern.Casas	Marantaceae	CBG
E	*Montanoa hibiscifolia*	Benth.	Compositae	BBG
E	*Ophiopogon japonicus*	(Thunb.) Ker Gawl.	Asparagaceae	CBG
E	*Peristrophe hyssopifolia*	(Burm.f.) Bremek. (unresolved)	Acanthaceae	CBG
E	*Piper aduncum*	L.	Piperaceae	CBG
E	*Sanchezia speciosa*	Leonard (unresolved)	Acanthaceae	BBG
E	*Solanum giganteum*	Jacq.	Solanaceae	CBG
E	*Solanum verbascifolium*	L. (unresolved)	Solanaceae	CBG
E	*Strobilanthes hamiltoniana*	(Steud.) Bosser & Heine	Acanthaceae	CBG
E	*Zapoteca tetragona*	(Willd.) H.M.Hern.	Leguminosae	CBG
N	*Buxus sempervirens*	L.	Buxaceae	BBG
N	*Cestrum elegans*	(Brongn. ex Neumann) Schltdl.	Solanaceae	BBG
N	*Cestrum nocturnum*	L.	Solanaceae	BBG
N	*Eucalyptus globulus* subsp. *maidenii*	(F.Muell.) J.B.Kirkp.	Myrtaceae	BBG
N	*Eucalyptus robusta*	Sm.	Myrtaceae	BBG
N	*Eugenia uniflora*	L.	Myrtaceae	BBG

N	*Justicia carnea*	Lindl.	Acanthaceae	BBG
N	*Lantana camara*	L.	Verbenaceae	BBG
N	*Nerium oleander*	L.	Apocynaceae	BBG
N	*Acacia farnesiana*	(L.) Willd.	Leguminosae	CBG
N	*Asparagus setaceus*	(Kunth) Jessop	Asparagaceae	CBG
N	*Calliandra haematocephala*	Hassk.	Leguminosae	CBG
N	*Casuarina cunninghamiana*	Miq.	Casuarinaceae	CBG
N	*Casuarina equisetifolia*	L.	Casuarinaceae	CBG
N	*Cestrum nocturnum*	L.	Solanaceae	CBG
N	*Cupressus sempervirens*	L.	Cupressaceae	CBG
N	*Acacia mangium*	Willd.	Leguminosae	KBG
N	*Albizia saman*	(Jacq.) Merr.	Leguminosae	KBG
N	*Inga laurina*	(Sw.) Willd.	Leguminosae	KBG
N	*Spathodea campanulata*	P.Beauv.	Bignoniaceae	KBG
N	*Swietenia macrophylla*	King	Meliaceae	KBG
N	*Buxus sempervirens*	L.	Buxaceae	CBG
N	*Callicarpa japonica*	Thunb.	Lamiaceae	CBG
N	Hippeastrum sp.	-	Amaryllidaceae	CBG
N	*Canna indica*	L.	Cannaceae	CBG
N	*Buddleja davidii*	Franch.	Scrophulariaceae	CBG

Table 3. Estimated regression coefficients for trait-based escape probability (model 1), and framework-based escape probability model (models 2, 3, and 4). Detected effects marked with asterix (*).

Model		variables	mean	sd	95% CI	DIC
Trait-based	Full traits	*SLA	0.218	0.069	[0.106, 0.374]	39.209
		*Height	-0.689	0.271	[-1.277, -0.223]	
		*Dispersal method	2.587	1.421	[0.096, 5.667]	
		Residence time	0.017	0.020	[-0.021, 0.058]	
Trait-based	SLA only	*SLA	0.145	0.038	[0.079, 0.228]	43.742
Framework-based	WRA	WRA	0.008	0.039	[-0.069, 0.086]	71.853
	BG-WRAP	BG-WRAP	0.118	0.096	[-0.064, 0.314]	70.429
	T-WRAP	*T-WRAP	0.488	0.168	[0.183, 0.844]	61.346

from 26 species sampled in this study (Table 2). The framework-based assessment was conducted to all 24 escaped exotics and 26 non-escaped exotic collections using three frameworks: WRA, BG-WRAP, and T-WRAP.

Based on model 1 analysis (trait-based), clear effect of SLA, height, and dispersal method to escape probability was detected. For other models (models 2,3 and 4; framework-based), clear effect of T-WRAP on escape probability was detected but not for WRA and BG-WRAP (Table 3).

Full trait-based model (model 1) produced the lowest DIC value, which means that trait-based model performance is better than framework-based model in predicting the escape probability of botanic gardens exotic collections to adjacent native forests. SLA-only model also produced a smaller DIC value than framework-based models. Furthermore, among the framework-based model, T-WRAP produced the lowest DIC value, which means that T-WRAP is relatively more reliable than WRA and BG-WRAP on predicting escaped exotics from botanic gardens (Table 3). Furthermore, ROC graph visualized the better performance of trait-based (SLA only) model than framework-based model (Figure 2). In concordance with DIC value comparison, ROC curve visualizes better predictive ability of trait-based (SLA only) assessment than framework-based assessment (WRA, BG-WRAP, and T-WRAP).

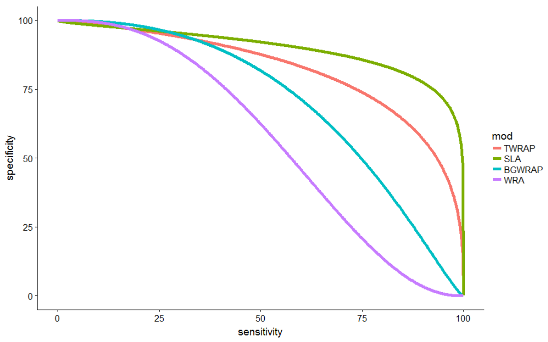

Figure 2. ROC curve of four escape probability model (trait/SLA-based, green; WRA-based, purple; BG-WRAP-based, blue; and T-WRAP-based, red).

The lower reliability of framework-based assessment system relative to trait-based might be explained by several weaknesses of the application of these framework-based systems. First, most of the framework-based assessment systems are using scoring system in the quantification processes and these scoring processes may be a subject to the epistemic and linguistic uncertainties. Second, *a priori* knowledge can also become a source of bias in the scoring procedures of risk assessment framework such as WRA (Onderdonk *et al.*, 2010). For instance, Matthews *et al.* (2017) showed that risk assessment may suggest different risk result due to the variation of the risk assessment systems and contexts. Finally, the source of uncertainty during the scoring processes may arise due to the level of details in the data and the assessor knowledge capacity. Thus, the implementation of practical guidance of the risk assessment framework application is a must to minimize bias and uncertainty in the scoring processes, the devil is in the detail (Onderdonk *et al.*, 2010).

The finding in this study indicates several promising aspects regarding invasive species risk assessment implementation. First, the fact that trait-based assessment produced more robust prediction result than framework-based indicate that trait-based assessment approach is reliable and realistic. Traits used in this study are relatively easy to measure or collect but are reliable predictors. For instance, SLA is a relatively simple trait but a good predictor for invasion likelihood because SLA indicates ecological and physiological characteristic of plants such as shade tolerance (Lusk & Warton, 2007; Poorter, 2009) and growth rate (Gibert *et al.*, 2016). Second, well established framework-based assessment system may not necessarily give reliable result. As stated before, the weakness of framework-based assessment is data demanding and this approach will become unrealistic and not reliable when those data are not available or incomplete. Lastly, simple and reliable traits for risk assessment can support managers and risk assessment user to conduct robust invasive species risk assessment under limited resources condition. Traits used in this study are relatively simple and easy to measure but produce good prediction in the risk assessment. Simple and easy to measure data will become a useful proxy to support the managers that have limited resources to conduct adequate risk assessment.

CONCLUSION

SLA, dispersal method and height are reliable predictor for escaped probability of botanic gardens exotic collection into adjacent native forest. There is no effect of residence time detected. Among all framework-based system tested in this study, only T-WRAP can reliably differentiate the escaped from non-escaped exotic collections. SLA performance is better than framework-based system on this risk assessment study, indicated by lower DIC value and visually by ROC curve. Due to its simplicity of measurement method and good predictive ability, trait-based risk assessment system can be implemented for exotic invasive rapid assessment. This rapid assessment is essential part of preventative invasive species management in Indonesian botanic gardens.

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