TROPICAL DRYLANDS
Volume 1, Number 1, April 2017 E-ISSN: 2580-2828
Pages: 36-42 DOI: 10.13057/tropdrylands/t010106

Species distribution model of invasive alien species *Acacia nilotica* for Central-Eastern Indonesia using Biodiversity Climate Change Virtual Laboratory (BCCVL)

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Manuscript received: 6 January 2017. Revision accepted: 23 April 2017

Abstract. *Sutomo, Van Etten E. 2017. Species distribution model of invasive alien species Acacia nilotica for Central-Eastern Indonesia using Biodiversity Climate Change Virtual Laboratory (BCCVL). Trop Drylands 1: 36-42.* Climate change may facilitate alien species invasion into new areas. This study uses Biodiversity and Climate Change Virtual Laboratory to develop a species distribution model (SDM) of *Acacia nilotica* (L.) Willd. ex Delile. based upon its naturalized distribution to project the potential distribution of *A. nilotica* throughout tropical environment of Indonesia under current and future climate conditions. Global Biodiversity Information Facility (GBIF) database was utilized to obtain the species occurrences data. The climate factors were precipitation and temperature layers, available in WorldClim current conditions (1950-2000) at 2.5 arcmin. We used Generalized Linear Model. The result was then projected to the year 2045 using RCP 8.5 greenhouse gas emissions scenarios to influence the climate model (CSIRO Mark 3.0. with 30'' resolution). Final results show that global climate change is likely to increase markedly the potential distribution of *A. nilotica* in Indonesia. By the year 2045, *A. nilotica* is most likely to spread to eastern parts of Indonesia. In general, our model performance is good (AUC = 0.82), however, like many other SDMs, it does not take into account biotic interactions as well as other environmental factors. Nonetheless, climatic suitability is an essential requirement for successful establishment of an invasive species and species distribution models that can disclose general patterns and convey useful estimates.

Keywords: *Acacia nilotica*, invasive alien species, species distribution model, climate change

Abbreviations: GCM: Global Climate Change Model, SDM: Species Distribution Model, BCCVL: Bidoversity and Climate Change Virtual Laboratory, GBIF: Global Biodiversity Information Facility, GLM: Generalized Linear Model, AUC: Area Under the Curve, ROC: Receiver-Operating Characteristics, TPR: True Positive Rate, TNR: True Negative Rate, HSI: Habitat Suitability Index, IAS: Invasive Alien Species, NTT: Nusa Tenggara Timur

INTRODUCTION

Acacia nilotica (L.) Willd. ex Delile is a small tree species widespread in the northern savanna regions of Africa, and its range extends from Mali to Sudan and Egypt. *A. nilotica* is known to be abundant in its native habitat in Africa (Brenan 1983), but no study has been specifically focused on this species. Outside of its original distribution, *A. nilotica* is considered an invasive alien species or noxious weed. In Australia, this species is found to spread along the western part of Queensland while in other states such as Western Australia, New South Wales, Adelaide and Northern Territory, this species was found in only a few numbers (Reynolds and Carter 1990). *A. nilotica* is considered to have a negative impact on savannas since adult trees of this species are tolerant to fire (Radford et al. 2001). A previous study by Burrows et al. (1991) observed that on Mitchell grasslands in Australia, *A. nilotica* was invading the grassland and forming thorny thicket formations.

A. nilotica was first introduced in Indonesia in the late 1960s in Baluran National Park in East Java. The original purpose of introducing this species was to create fire breaks to prevent the fire from spreading from Baluran Savanna into the surrounding forests. Along the time, the rapid spread of *A. nilotica* has threatened the existence of Baluran Savanna which has caused changes in some areas of the national park from open savannas to the more closed canopy areas (Djufri, 2004). If unabated, the continuing spread and over dominance of *A. nilotica* could shift the savanna into another ecosystem state such as the secondary/dry forest.

It was predicted by Global Climate change Models (GCMs) (IPCC 2007) that by the end of 21st century, global warming would cause an increase of mean temperature of about 3-4 °C, a decrease of rainfall of about 30-40%, and significant changes in seasonal as well as severe weather events. Molloy et al. (2013) stated that, at a regional scale, most species and ecological communities exist within a definable bioclimatic niche, where precipitation and temperature are among a set of variable climatic parameters that control the habitat values. If these variables change, then the habitat value for that area will also change. The task of understanding how species and communities respond to changes is crucial. Climate change may facilitate alien species invasion into new areas, particularly for species from warm native ranges introduced into areas currently marginal for temperature (Sheppard et al. 2014).

Species distribution model or SDM has the capability to assess current distribution and simulate climate-induced range shifts under different global change scenarios at the single-species and community levels (Crego et al. 2014). Therefore, the model could identify areas at risk of further invasion by invasive alien species so that pre-emptive actions could be undertaken in a plausible approach. Franklin et al. (2014) described steps in species distribution modelling as follows. Species occurrence data (such as presence-only, presence-absence or abundance) are the response variable, and environmental variables are the predictors used in a multiple regression-like modelling framework. The model can be fitted in data space using a wide variety of statistical learning methods. Estimated parameters are then applied back to environmental data layers (mapped grids) to predict the probability of species occurrences in geographical space.

SDMs has enabled conservationists to predict future landscape and has been applied in many areas of research such as for invasive species management (Webber et al. 2011), conservation and reintroduction of endangered species (Adhikari et al. 2012; Molloy et al. 2016), adaptive management of protected areas (Mairota et al. 2014), restoring landscapes connectivity (Gurrutxaga and Saura 2014) and many others. Molloy et al. (2013) did SDMs using bioclimatic variables to determine the impacts of a changing climate on the western ringtail possum (*Pseudocheirus occidentals*; Pseudocheiridae) in South-west Australia. Kritikos et al. (2003) conducted SDM using CLIMEX and predicted the potential distribution under future climate change scenarios for invasive alien species *A. nilotica* subspecies *indica* in Australia. Their results showed that the potential distribution of the species in Australia under current climatic conditions is vast and far greater than the current distribution. The authors also highlighted the impact of global climate change that may likely increase the species potential distribution in Australia and significantly increase the area at risk of invasion.

This study used Biodiversity and Climate Change Virtual Laboratory, BCCVL (http://www.bccvl.org.au/) (Hallgren et al. 2016) to develop a species distribution model of *A. nilotica* based upon its naturalized distribution in and outside of Indonesia to project the potential distribution of *A. nilotica* throughout Indonesia under current climate conditions and to assess the sensitivity of this distribution to climate change. BCCVL is a unique cloud-based virtual laboratory that provides access to numerous species distribution modelling tools; a large and growing collection of biological, climate, and other environmental datasets; and a variety of experiment types to conduct research into the impact of climate change on biodiversity (Hallgren et al. 2016). Understanding the likely potential distribution of this obnoxious plant under current and future climate scenarios will help policy makers and land managers to set up proper approaches to handling the invasion.

MATERIALS AND METHODS

Procedures

We made use of the Biodiversity and Climate Change Virtual Laboratory, BCCVL (http://www.bccvl.org.au/) to conduct the modelling analysis (Hallgren et al. 2016). Global Biodiversity Information Facility, GBIF (http://www.gbif.org/) was utilized to obtain the species occurrence data for *A. nilotica* (GBIF 2016). Global Biodiversity Information Facility (GBIF) is an international open data infrastructure funded by governments. Currently, there are various subspecies of *A. nilotica* listed in the GBIF. We chose to use the common *A. nilotica* (L.) Willd. ex Delile. as it is recorded to be present at Baluran National Park in East Java, Indonesia (Tjitrosoedirdjo 2008). The GBIF database has about 879 occurrence records of *A. nilotica* with 232 occurrences were geo-referenced. This dataset was then imported into Biodiversity and Climate Change Virtual Laboratory (BCCVL). This data of species occurrence acted as the response variable, and the predictors were the environmental variables.

In this simulation, we used WorldClim current conditions (1950-2000) at 2.5 arcmins as environmental predictors. The WorldClim collections consist of an array of global climate layers (climate grids) covering all global land areas except Antarctica. They are in the latitude /longitude coordinate reference system (not projected) and the datum is WGS84. The average monthly climate data from weather stations were used to produce the data layers. The WorldClim collection is composed of two main components, i.e. the current climate and the future climate (Hijmans et al. 2005). We selected precipitation and temperature variables because they represent important factors determining vegetation range and abundance (Krebs 1985; Van Steenis 1972), and that *A. nilotica* SDM in Australia correspond well with these climate variables (Kriticos et al. 2003). We selected seven climate variables namely maximum temperature of warmest month (B05), minimum temperature of coldest month (B06), mean temperature of wettest quarter (B08), mean temperature of driest quarter (B09), precipitation of wettest month (B13) and driest month (B14), precipitation seasonality (B15) and temperature seasonality (B04). Extreme variables are better represented by the ranges of conditions where species can occur (Crego et al. 2014).

Data analysis

The Species Distribution Model Experiment (SDM) allows us to investigate the potential distribution of a species under current climatic conditions. The BCCVL currently provides 17 different algorithms across four different categories to run species distribution model (e.g. profile model, statistical regression model, machine learning model and geographic model). In this study, we used statistical regression model namely Generalized Linear Model (GLM) to process our SDM. The GLM was used for the reason that the model accommodates regression model for data with a non-normal distribution, fitted with maximum likelihood estimation. This model produces estimates of the effect of different environmental variables on the distribution of a species. The model uses all the data available to estimate the parameters of the environmental variables and construct a function that best describes the effect of these predictors on species occurrence. The suitability of a particular model is often defined by specific model assumptions. The prediction is visualized as the suitability of a grid cell on a scale from 0 to 1, where 0 refers to very low suitability and 1 refers to very high suitability. Results from BCCVL are .tiff file which then processed further using ARC MAP 10.1. Raster value was created and classified, and then different color was given to easily enable us to different areas with different habitat suitability index.

The primary output of an SDM was a map that showed the predicted distribution of *A. nilotica* under the baseline conditions. The prediction is not really refer to where the species occurs, but rather the distribution of suitable habitat as defined by the environmental variables (in this case current climate condition) included in the model. The second output was response curve. The response curve that shows the relationship between the probability of occurrence for a species and each of the environmental variables was modelled according to the method of Richmond and Huijbers (2016). Model robustness was evaluated using the AUC (Area Under the Curve) of the ROC curve (Receiver-Operating Characteristics), which is a nonparametric threshold-independent measure of accuracy commonly used to evaluate species distribution model (Bertelsmeier and Courchamp 2014). The ROC plot is a graph of the False Positive Rate (1-Specificity) on the x-axis and the True Positive Rate (Sensitivity) on the y-axis plotted across the range of threshold probability values. The value for ROC is the area under the curve (AUC). A value of 0.5 represents a random prediction, and thus values above 0.5 indicate predictions better than random. We interpreted the AUC score as follow: a value above 0.9 is excellent, good 0.9 > AUC > 0.8, fair 0.8 > AUC > 0.7, poor 0.7 > AUC > 0.6 and fail 0.6 > AUC > 0.5 (Crego et al. 2014; Sweets 1988).

Further analysis was conducted to investigate the distribution of *A. nilotica* under potential future climatic conditions. In BCCVL this is named the Climate Change Experiment. Climate change experiment obtains a prediction of where *A. nilotica* could occur in the future under a particular climate change scenario. This analysis uses the results from the SDM experiment and projects that distribution for a certain year in the future with the climate information from one of several climate models. In this study, we selected RCP 8.5 (business as usual) greenhouse gas emissions scenarios to influence the climate model; in this case, we used CSIRO Mark 3.0 with 30" (~1km) resolution. We projected our SDM to the year 2045.

RESULTS AND DISCUSSION

Results

The potential distribution of *A. nilotica* in Indonesia under current climatic conditions is greater than the current distribution. Under the current climate, it is predicted that *A. nilotica* is most likely to spread to eastern parts of Indonesia although some parts of Java especially in the south coast of East and Central Java, also are predicted to be suitable for *A. nilotica* (Figure 1). To the eastern Indonesia, *A. nilotica* is predicted to be suitable to inhabit several sites in south-eastern Bali, southwest of Lombok, south-eastern Sumba, most of Kupang District on West side of Timor Island, and also some part of along south coast of West Papua. In West Papua, the species is predicted to be potentially suitable to inhabit (±0.64) southern coast along Merauke. Also interesting to note that small island just off the coast between Merauke and Tual is predicted by the model to be potentially suitable (±0.61) habitat for this invasive species (Figure 1). There is a trend of increasing value of mean suitability index (0.47 to 0.6) as we moved from central to eastern part of the archipelago (Figure 2).

Global climate change is likely to increase the potential distribution of *A. nilotica* in Indonesia, increasing the area at risk of invasion. Bali Island, Lombok Island (West Nusa Tenggara NTB), Sumba Island and Kupang (East Nusa Tenggara), as well as West Papua, have increased the area at risk of invasion. On Sumba Island (Figure 3), the current prediction has one area (*Baing* District in the south-eastern Sumba) where the HSI (Habitat Suitability Index) is in the range of 0.7 - 0.9, and by 2045 it is predicted that *Melolo* Sub-district in north-eastern Sumba will also have similar HSI to *Baing* District. For Kupang on the west side of Timor Island, it is detected that there will be an increase in the HSI around the Tenau and Oesau Sub-districts by 2045 (Figure 3). In general, our model performance is of good results as AUC values (0.82) are still in the range of 0.8 - 0.9 (Figure 5).

All of the chosen climate variables are responsive to *A. nilotica* distribution (Figure 4). The response curves in this plot show that the probability of occurrence of *A. nilotica* follows an optimum curve for the specific variable. *A. nilotica* occurs in areas that are very seasonal. It can grow in places with low rainfall and high rainfall (10 - 150 mm month^{-1}). It does not like extreme cold or frost, it can grow in areas where the minimum temperature of the coldest month is around 12 to 13 °C and it also grows in areas where the maximum temperature of the warmest month is around ~35 °C.

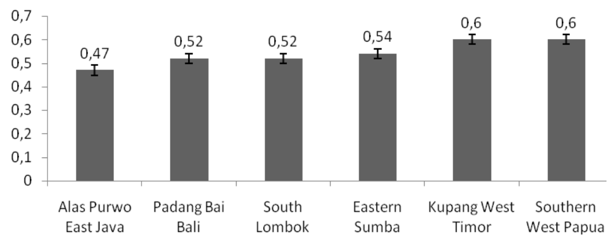


Figure 2. Mean of suitability index value for *Acacia nilotica* model using GLM in BCCVL.

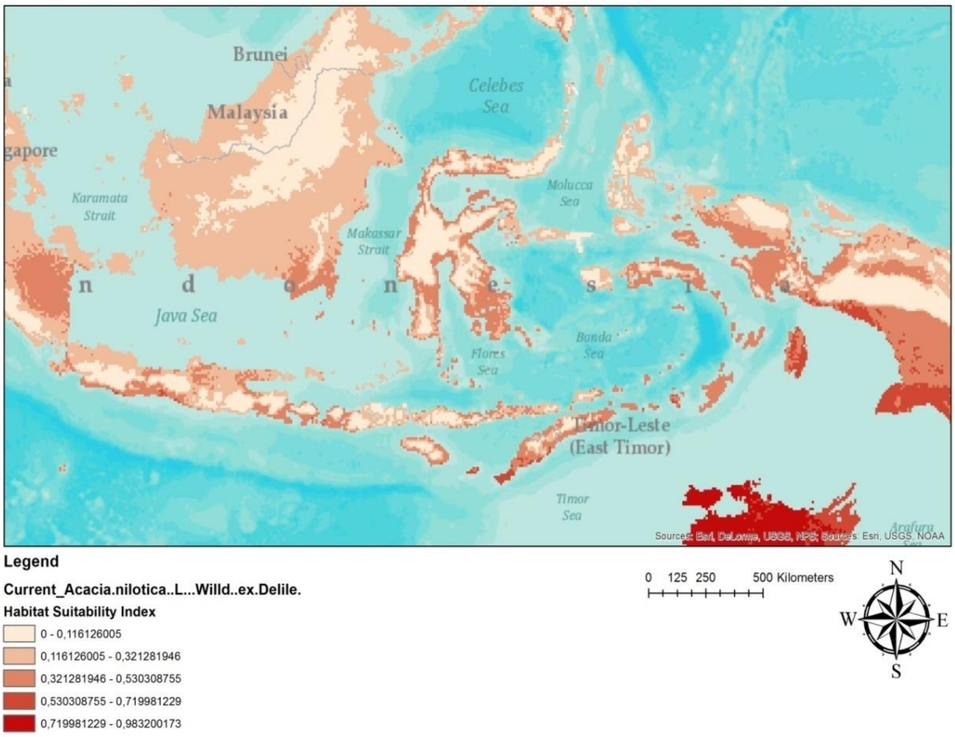
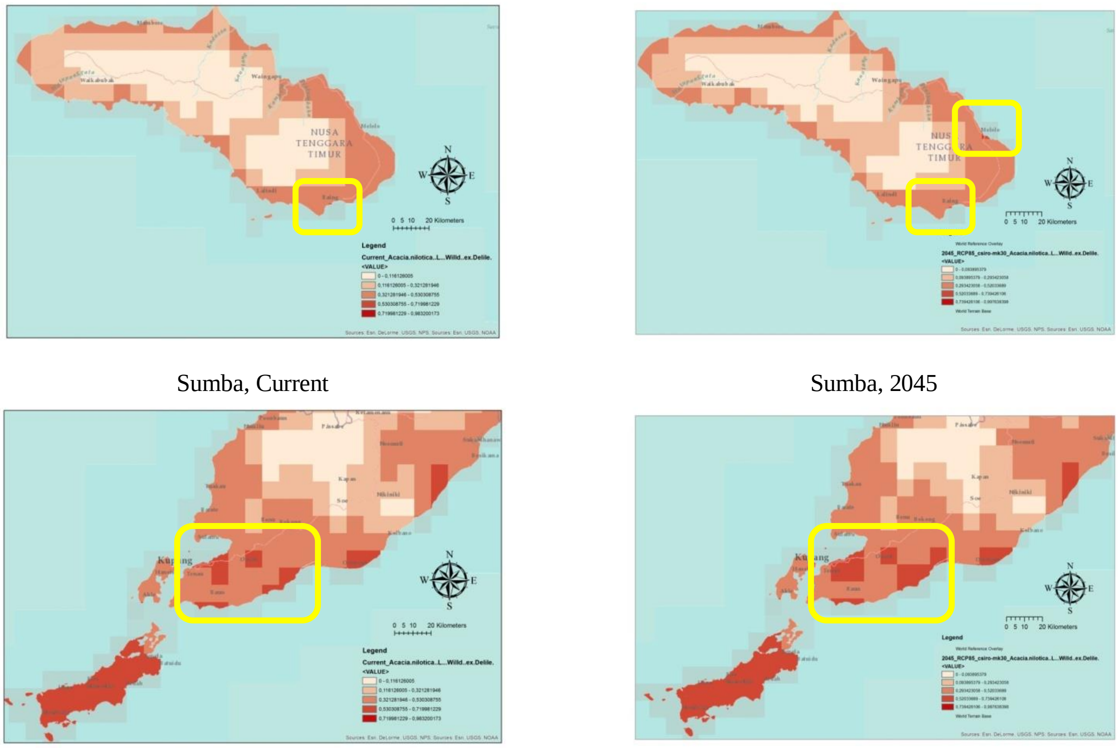


Figure 1. Predicted current distribution (habitat suitability map) of Invasive Alien Species (IAS) *Acacia nilotica* in Indonesia under current climate conditions using Generalized Linear Model (GLM) algorithm in BCCVL. Darker areas represent a higher likelihood that the species can occur.



Sumba, Current

Sumba, 2045

Kupang, Current

Kupang, 2045

Figure 3. Projection of *Acacia nilotica* species distribution/Habitat Suitability Index (HSI) on Sumba Island and Kupang, East Nusa Tenggara Province, Indonesia by 2045. Left: Predicted current distribution/current HSI. Right: Projected distribution/projected HSI in 2045. Yellow square to show to emphasize where the HSI changed.

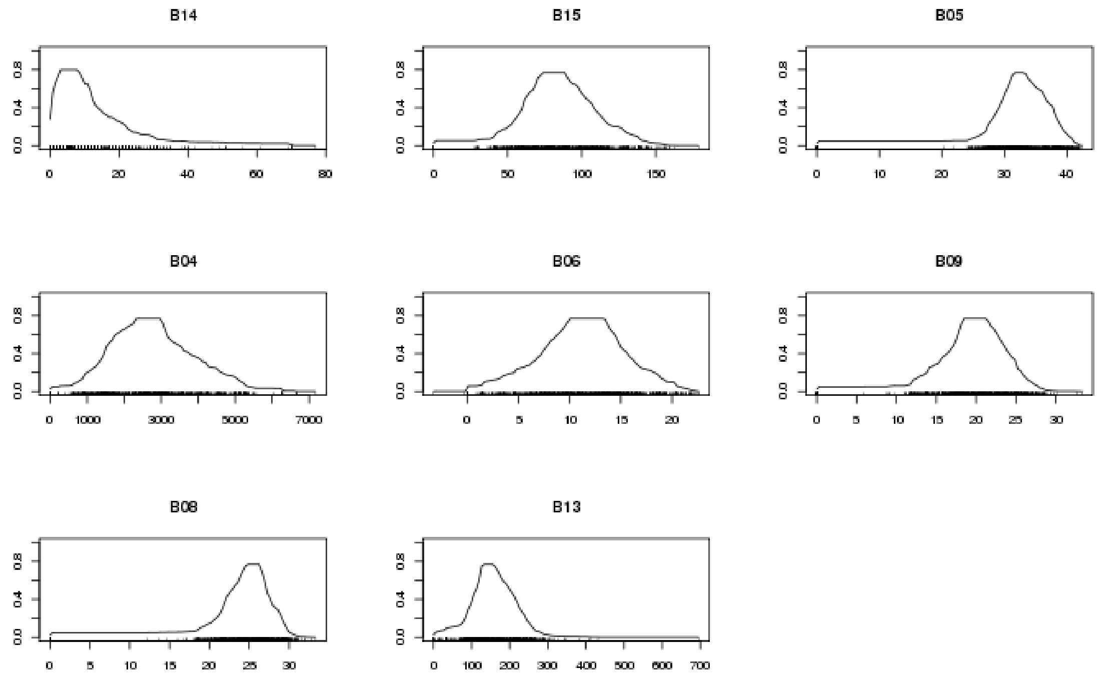


Figure 4. The response curve for *Acacia nilotica* distribution model. B05: maximum temperature of warmest month, B06: minimum temperature of coldest month, B08: mean temperature of wettest quarter, B09: mean temperature of driest quarter, B13: precipitation of wettest month, B14: precipitation of driest month, B15: precipitation seasonality and B04: temperature seasonality

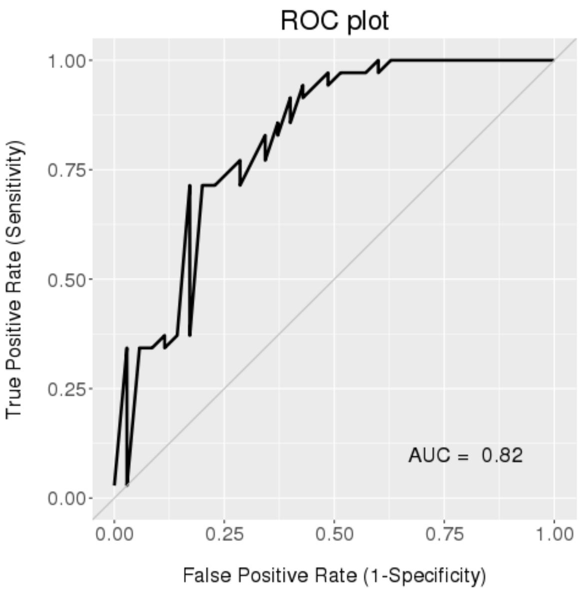


Figure 5. ROC plot which shows AUC value for *Acacia nilotica* model using GLM in BCCVL.

Discussion

The study shows that areas with the highest concentration of potential invasion of *A. nilotica* in Indonesia are mainly located along the coastline, especially in the southeast of Indonesia archipelagoes such as East Java, Bali, Lombok, Sumba, Kupang and West Papua. This result agrees with the current location of *A. nilotica* ever recorded in Indonesia in the literature and is also based on our encounter in the field. Fisher (2010) mentioned the presence of *A. nilotica* in savanna in Kupang East Nusa Tenggara Indonesia in 2010. Additionally, on our field trip to Kupang in 2015, we also noted our encounter with this thorny Acacia in savanna near a roadside to Tablolong Beach. In his expedition in 2010, Arinasa (personal communication) noted the presence of *A. nilotica* in Bali Barat National Park with the herbarium, seed and cone samples were processed and registered at the Hortus Botanicus Baliensis in Bali Botanical Garden. Previous work by Tjitrosoedirdjo (2008) also reported the spread of the species in other islands outside Java such as Timor and Papua. *A. nilotica* was reported as dominant colonizer at Baluran National Park in East Java Province and Wasur National Park in Papua (Tjitrosoedirdjo 2008). However, at a local scale, the model did not recognize Baluran National Park, at the north tip of East Java Province with high HSI and thus underestimate the occurrence of *A. nilotica* in this locality where it has been a problem for more than 20 years.

The current SDM model, when overlaid with other environmental and landscape layers, could have provided more insight. *A. nilotica* is found in savannas and grasslands at various soil types and various temperatures but is reported to be very sensitive to frost but will grow in an area where the mean monthly temperature of the coldest month is 16°C (FAO 2014). This is in line with our findings. Our model shows that *A. nilotica* habitats are very seasonal; it follows an optimum curve for the selected temperature and precipitation with a high probability in areas that have a temperature between 13 and 35 °C. This factor has some connection with land use where this species occurs which is mostly in savanna or grassland as places that have high seasonality as can be seen in Baluran National Park East Java and on Sumba Island (Bond and Keeley 2005; Sutomo and van Etten 2016). *A. nilotica* was not only found in a savanna ecosystem with the volcanic-origin type of soil as in Baluran National Park (Sutomo 2015), but also in other savannas where the soils are not of volcanic origin such as savannas in Sumba and Kupang in NTT Province. Savanna is the dominant type of land cover on Sumba Island and it is also the most burnt (Sutomo and van Etten 2016, unpublished data). Sumba Island receives an average annual precipitation of 900 mm and experience more than five months of the dry period and is located in region A (southern monsoonal region) of Indonesian climate classification region (Aldrian and Susanto 2003; Hanifah 2014). The average high temperature and low rainfall with prolonged dry season as well as local practices caused fires is more prominent in this landscape (Fisher et al. 2006; Monk et al. 2000). East Sumba District was where most of the dominant fire hotspots were detected (Sutomo and van Etten 2016, unpublished data). Our SDM also found that high HSI areas were found in East Sumba and that by 2045 the HSI is more likely to increase.

Our model projection shows a fairly small increase in potential distribution of *A. nilotica* in south-eastern parts of Indonesia by 2045 which is reasonable for a tropical climate. Our model had moderate to good performance (AUC) but yet they share a certain number of fundamental assumptions common to all species distribution models. These models do not take into account biotic interactions or microclimate conditions which may decide at a very local scale whether or not a particularly invasive species eventually becomes established in a given area (Bertelsmeier and Courchamp 2014). Nonetheless, climatic suitability is an essential requirement for successful establishment of an invasive species and species distribution models can disclose general patterns and convey useful estimates (Bertelsmeier and Courchamp 2014).

The SDM model, however, does not take into account biotic interactions and at a local scale; this interaction has been proved to have significantly affected the species of interest. For example, the interaction between *A. nilotica* with herbivores has benefited *A. nilotica*. The lowland savanna area is an important habitat for big mammal grazers such as wild buffalo, deer and banteng. Invasion of *A. nilotica* in these areas may have caused changes in the feeding behavior of these grazers and may have been causing the spread of this invasive species further in the Baluran National Park. *A. nilotica* is also unpalatable by the herbivores as this plant possesses thorny spikes on its branches which make it difficult for the herbivores to consume the leaf. However, the pods that drop to the ground are usually consumed by herbivores during the prolonged dry period when fresh shoots and grasses are scarce. At the end of the wet season toward the dry season, mature *A. nilotica* pods drop from the trees and are consumed by herbivores such as water buffalo (Tjitrosoedirdjo et al. 2013) that spread *A. nilotica* further in the national park. Sutomo et al. (2015) found that there was a large number of seeds found in buffalo dung. In approximately 100 grams of buffalo dung/dropping, there were approximately 166 seeds of *A. nilotica*. In Baluran National Park, Landsat TM image analysis shows that in fourteen years (2000 - 2014), savanna size has decreased by 1,361 ha. Meanwhile, *A. nilotica* stands to increase by 1,886 ha (Sutomo and van Etten 2016, unpublished data).

In addition, other environmental factors such as soil nutrients, land-use changes and disturbance agents such as fire also need to be used in consideration with the model. Moreover, our understandings of the capability of *A. nilotica* to adapt to the changes in these factors is still limited (but see Kriticos et al., 2003). Based on their species distribution modelling and climate change projection for *A. nilotica (*subsp. *indicia)* in Australia, it is expected that there may be increases in water-use efficiency of the species due to increased atmospheric CO^2 concentrations, which allows it to invade more xeric sites further inland and increased temperatures. *A. nilotica* is frost intolerant, grows in areas where the mean monthly temperature of the coldest month is 16° C and it can endure temperatures up to 5°C (Kriticos et al. 2003). Conservationists should not be deterred from using the predictive power of SDMs although modelling limitations apply. A dynamic SDM, based on well-surveyed populations responding to changes in known critical parameters, is one of the most excellent tools existing for conservationists to visually suggest future conditions. Users should be aware of limitations, but the model insights are a vital preliminary point for decision making (Carvalho et al. 2011).

Finally, this study is the first to model and highlight regions with a high risk of invasion by invasive alien species *A. nilotica* in the tropical environment of Southeast Asia, especially central and eastern Indonesia. Future research should endeavor at developing extrapolative modelling based on traits related to invasiveness that can be combined with the current model of estimation of geographic likelihood establishment. More research is needed on how to use SDMs in the service of informing public policy, stakeholders' scenario analysis and applied conservation (Driscol et al. 2012). When SDMs can bring together scientists, public stakeholders, and policy makers, and are used as an adaptive management tool to understand complex landscapes that are undergoing changes, only then it has achieve their full potential (Polunin 2014).

ACKNOWLEDGEMENTS

We thank School of Sciences, Edith Cowan University, Australia and Bali Botanic Gardens-Indonesian Institute of Sciences (LIPI), as well as Indonesian Ministry of Research and Technology (RISTEK). Thanks also to Sarah Richmond (Griffith University, Australia) and Lee Belbin (Atlas of Living Australia) for introducing the BCCVL.

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