Non-native plant distribution in Montserrat: Conservation and Ecological aspects.

By

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Abstract

Non-native invasive species are one of the main drivers of biodiversity loss. The urgency of addressing this global problem is increasing due to the accelerated growth and migration of human populations. Understanding the factors driving the establishment and spread of invasives is a key quest of invasion ecology in order to inform conservation management and action to successfully address this issue.

The distribution of twenty-five non-native species to Montserrat, Lesser Antilles, was recorded and mapped in order to gain insight into their spatial distribution. Because individual species and different functional groups might exhibit different spread dynamics analyses were carried out on species separately and between cultivated and non-cultivated species. Environmental and anthropogenic variables were used to investigate which had an effect on the presence of a non-native species. Prediction maps of key concern species were produced using Maxent modelling software in order to view which areas or habitats might be most at risk.

The factors responsible for species distribution on Montserrat is not clear-cut due to factors that are unaccounted for in analyses, some of these difficult to quantify. Recommendations for future research include the need to address all aspects of invasive species, not just environmental factors. The main outcomes of this study for conservation action is the identification of habitats most at risk of invasive species and species that are at high risk of establishing themselves widely. Key conservation suggestions include the continued monitoring of non-native species and divulging information in order to address the core driver: human action.

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Acronyms and Abbreviations

CBD- Convention on Biological Diversity

CHFR- Centre Hills Forest Reserve

GISD- Global Invasive species database

GISP- Global Invasive species programme

GPS- Global Positioning System

IUCN- World Conservation Union

MBA- Montserrat Biodiversity Assessment

MCHP- Montserrat Centre Hills Project

NNS- Non-native species

1. Introduction

The human need to adapt to new environments, more often than not by adapting the environment itself, is often accompanied by the movement of species outside their natural ranges (Mack *et al.*, 2000; Inderjit *et al.*,, 2005; Lockwood *et al.*, 2007). Historically, this aided migration has always occurred, from the to the acclimatization societies of the 19th century (Lockwood et al, 2007), but with the advent of increased human population growth, trade and technological advances this movement has increased exponentially (Mauchamp, 1997; Mack *et al.*, 2000; Lockwood *et al.*, 2007). In the plant realm, ornamental, food and economically important species have been intentionally introduced around the globe (Mauchamp, 1997; Pyšek *et al.*, 2004).

1.1 Invasive species: a conservation problem.

Invasive species are identified as one of the main drivers of biodiversity loss and ecosystem malfunction (e.g.: Goodwin *et al.,* 1998; Underwood *et al.,* 2003, Shuster *et al.,* 2005) with 30% of birds and 15% of plants being at risk from alien invasives (UNEP in Kairo *et al.*, 2003). The recognition that non-native species may become noxious is not a new concept and first arose in the late 18th century with even Charles Darwin giving mention to them in *The Origin of the Species* (Inderjit *et al.,* 2005). Since then a huge literature on the topic has flourished but the discipline of invasion ecology itself however is a relatively recent development (Inderjit *et al.*, 2005; Lockwood *et al.*, 2007). Impacts are experienced at ecological, economic and social levels; $1.4 trillion per year are spent globally combating non-native species (GISP, 2008), in the USA $137 billion per year (Kolar & Lodge, 2001; Lee, 2002). The role invasive species play in biodiversity loss is being increasingly recognised as evidenced by their specific mention in article 8h of the Convention on Biological Diversity: *"Prevent the introduction of, control or eradicate those alien species which threaten ecosystems, habitats or species."* Such is the urgency and magnitude of invasives that the Global Invasive Species Programme (GISP) was set up specifically to address this issue.

1.2 Vocabulary

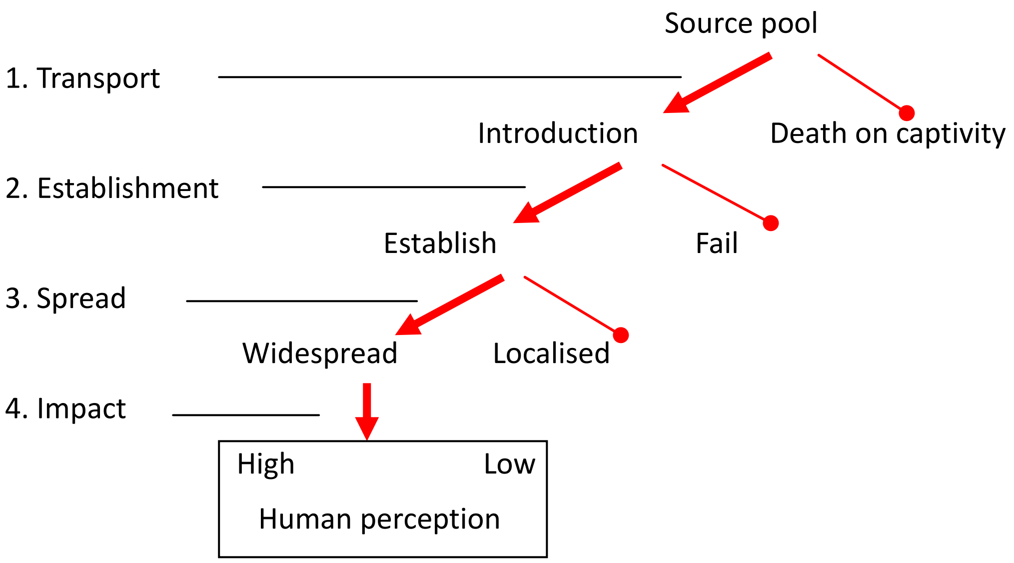
Before discussing invasive species it is important to define the terms used in this study to avoid confusion or misinterpretation. Non-native refers to a species that has been deliberately or accidentally introduced to an area from its native range (Kolar & Lodge, 2001; Pyšek *et al.*, 2004). Many synonyms exist in the literature: exotic, alien, introduced, foreign among many others (Mack, 1996; Coulautti, 2005; Lockwood *et al.,* 2007) but throughout this study the term ‘non-native’ will be used. An invasive species is applied here to a species whose establishment and spread threatens ecosystems, habitats or species (Kairo *et al.*, 2003). Those non-native species (hereafter NNS) that establish themselves in a new range but do not cause negative impacts are referred to as naturalised or non-invasive (Mack, 1996; Kolar & Lodge, 2001). Throughout the study species are referred to as 'non-native' and not 'invasive' for two reasons. First because no surveys have been carried out looking specifically at non-natives on Montserrat it is not known with certainty at which stage of the invasion process they are at, or indeed if the species are invasive. Secondly, although all the plant species are known to be invasive in other regions it is not advisable to extrapolate from this as an invasive in one range may not become invasive in another (Mack, 1996; Lockwood *et al.,* 2007; Wilson *et al.*, 2007). For these two reasons species are referred to as non-native until further analysis reveals evidence of likely invasiveness (Mack *et al.*, 2000).

1.3 Understanding the invasion process

The study of invasion provides both an opportunity to study scientific theory and inform conservation strategies (Mack, 1996; Pyšek *et al.*, 2004). A multitude of factors determine whether a species will become invasive or not (Lockwood *et al.*, 2007; van Kleunen & Johnson, 2007) and several steps are involved in the invasion process (fig. 1). Understanding the invasion process has become a main quest of invasion ecologists and conservationists (Pyšek *et al.,* 2004). Native species may become invasive if conditions change as in the case of the endemic Bermuda cedar (*Juniperus bermudiana*) which was able to spread across Bermuda after humans arrived and caused mass deforestation (Kairo *et al.*, 2003). Both biotic and abiotic factors have been identified as contributors to invasion (Lockwood et al, 2007). Several studies have shown particular biological traits of species to be associated with invasiveness (Rejmanek & Richardson, 1996; Goodwin *et al.,* 1998; Kleunan & Johnson, 2007). Abiotic factors such as environmental variables and anthropogenic actions have been identified as facilitators of the presence and success of invaders (Lockwood *et al.,*, 2007). Despite most research focussing on biological traits and habitat disturbance (Parendes & Jones, 2000) determining the key factors and their interplay to allow predictions to be made has proven to be a challenge (Rejmanek & Richardson, 1999).

Only a small percentage of introduced species are able to overcome the barriers to their establishment (Mack *et al.,*, 2000; Kolar & Lodge, 2001; Lockwood *et al.,* 2007). However, humans have aided invasion mainly through the facilitation of the first step in the invasion process: the transportation of species allowing to overcome otherwise insurmountable barriers such as the Atlantic ocean (Mack, 1996). This facilitation is only likely to increase meaning that it is increasingly urgent to deepen the understanding of NNS in order to prevent detrimental impacts on ecosystems and their components (Mack, 1996; Fitzpatrick & Weltzin, 2005; Zhu *et al*., 2007).

Figure 1. Schematic representation of the invasion process showing the four main stages and the possible outcomes of each stage.



1.4 Importance of studying invasion

A report from the Joint Nature Conservation Comittee (JNCC) to the Nature Conservancy on Invasive Species in the Caribbean (Kairo *et al*, 2003) highlights the necessity of compiling data on the nature of invasive species: their biology, ecology, distribution and impacts. Throughout the UK Overseas Territories (UKOTs) it is known that invasive plant species are present but the threat and abundance of these is not known (Varnham, 2006) and so research is needed in order to devise habitat management and species action plans (Underwood *et al.*,, 2003). The distribution of invasive plants on Montserrat has not yet been studied thoroughly (Hamilton *et al.*, 2008) and so any studies on the non-native flora will enhance conservation plans.

Because documentation and studies on failed invasions are rare (Mack *et al.*, 2000; Kolar & Lodge, 2001; Lockwood *et al.*, 2007) knowledge on factors that hinder plant invasion is lacking, one side of prediction. It is therefore important to study all non-native species and not just those that are known invasives in order to pre-empt potential invasions.

1.5 Study scope

This study focuses on the second and third stages of the invasion process -establishment and spread- in order to provide data and information from which management action can be built from. NNS, both those that are renowned invasives and those of uncertain status, are surveyed in this study to fulfil the following aims:

1. Investigate which factors, biotic and abiotic, affect the presence of non-native species.
2. Record and map the spatial distribution of key non-native species on Montserrat.
3. Predict the potential distribution of these non-native species.
4. Provide information and support for conservation action regarding non-native species.

1.6 Thesis structure

Because both the disciplines and literature of invasion ecology is vast an overview of the main invasion ecology theories and approaches regarding the establishment and spread of NNS will be given in the background. To place the study in its conservation context and to understand the current NNS issue on Montserrat a brief summary of its history, its biodiversity and conservation issues is given.

The results present an overview of species distribution in habitats and disturbance types based on the similarity of their non-native species composition. Because addressing each NNS individually is beyond the scope of this study the results will focus on key species considered to pose the greatest risk based on findings. How well the aims of the study were achieved and further possible avenues for research will be considered in the discussion. Although the ecological theory is an interesting aspect it is important that findings from this study are placed within the conservation context on Montserrat in order for them to be translated from paper to action. The discussion will therefore elaborate on the results by focussing on specific species and place findings in the context of possible conservation options for Montserrat.

2. Background

2.1 Understanding invasives and their invasion

It is not possible to discuss invasion ecology studies without an understanding of the hypotheses that may form the basis of these studies. Many hypotheses to explain why and how species become invasive exist (table 1). It is likely that the distribution of NNS result from a combination of these hypotheses. Several approaches have been used in an attempt to predict species invasiveness to come up with solutions that will maximize accuracy in order to allow conservation action to be cost and time efficient. Some of the main approaches are described below; those that involve manipulation of the environment or species will not be discussed here (Mack, 1996 provides an overview of this approach). These approaches are used to address one or more of the factors thought to be driving species establishment and spread.

Table 1. Brief description of some of the main hypotheses proposed to explain the establishment and spread of non-native species (NNS).

Hypothesis	Description	Mechanism	Interaction scale
Resource fluctuation (RFH)	Change in resource availability facilitates invasion	Ecological	Community
Invasional facilitation (IFH)	Interactions between NNS promote invasion	Ecological	Community
Human commensal (HCH)	Species that are commensal with humans are the most successful	Ecological	Species
Selection for invasion ability (SIAH)	Anthropogenic factors have driven the evolution of invasive genotypes in some species.	Evolutionary	Population
Enemy release (ERH)	Competitors and enemies of NNS fail to accompany them during introduction giving NNS a competitive advantage.	Ecological	Population

Taken and adapted from Inderjit *et al.*, 2005, table 1, p. 25

2.2 Species lists

Lists of known invasive species have often been used to extrapolate to other ranges (Mack, 1996) and have proved successful in some cases (Pyšek *et al.*, 2004). Lists may also be useful to determine the social history of a species such as its use by humans; this can provide hypotheses to explain the distribution of species. Issues arise if this approach is used in isolation due to the multitude of factors that contribute to species invasion success, factors that may be present or absent in the range being predicted to. Merely studying known invasives may also lead to potential invasives being overlooked (Mack, 1996).

2.3 Biological traits

Using biological traits as a means of predicting the invasiveness of a species is particularly appealing due to the relative ease of screening a species for those 'indicator' traits (Mack,1996). However, there is debate as to how reliable biological traits can be as there is not a set of traits that can be applied to all species (Mack, 1996). Despite few studies having investigated the same set of characteristics there is generally consensus among studies in relation to the direction of the relationship between a particular trait and invasiveness (Kolar & Lodge, 2001). Rejmanek and Richardson (1996) use several biological characteristics to model whether a plant species is likely to be invasive and found that seed size, short intervals between large seed crops and short juvenile period were reliable indicators. A review by Kolar and Lodge (2001) on studies investigating biological traits found that terrestrial plant traits that tended to be indicative of invasiveness were small seed size, vegetative propagation and short juvenile periods.

A limiting factor of using biological traits as indicators of invasiveness is the availability of information for each species (Goodwin *et al.*, 1998). Another important consideration in data analysis is choosing the appropriate measure to quantify NNS. When investigating the effect of residence time on NNS Pyšek and Jarošík (2005) used two measures of to quantify NNS: frequency and range. Frequency indicates how common a species is but provides no spatial distribution information whereas range indicates how widespread a species is. Most studies (e.g.: Lloret *et al.,* 2005) used only one measure but it is best to use more than one because results obtained vary according to the response variable as found by Pyšek and Jarošík (2005).

Biological traits must be placed within the ecological and social context of the range a species is in. Species that do not have the expected biological traits of an invader may become invasive due to lack of predators, diseases and competitors (Mack, 1996). Also the establishment and propagation of a species may be aided by anthropogenic disturbance.

2.4 Disturbance

Disturbance can be defined as "any relatively discrete event in time that disrupts ecosystem, community or population structure and changes resources, substrate availability, or the physical environment" (White & Picket, 1985, p.7 in Lockwood *et al.,* 2007). According to the RFH disturbances change the resources available to species, particularly the case in terrestrial plants

(Inderjit *et al.,* 2005). Disturbance is able to promote plant invasions by removing barriers to their colonisation success (Parendes & Jones, 2000). Road and rivers are disturbances that may not only provide entry points for species via an altered physical environment (Parendes & Jones, 2000; Lockwood *et al.,* 2007) but facilitate species dispersal (Parendes & Jones, 2000).

Despite many studies having shown disturbance to be a factor promoting invasion (Parendes & Jones, 2000; Inderjit *et al.,* 2005) there is evidence of the opposite effect (Lockwood *et al.*, 2007). Baret *et al.* (2006) found that areas with the greatest amount of invasion had a lower NNS richness than areas that were less invaded suggesting that monocultures were developing in heavily invaded habitats.

2.5 Environmental variables

The relationship between the presence of a species and environmental variables, the species' niche, is the basis for ecological niche modelling (Guisan *et al.,* 2002; Fitzpatrick & Weltzin, 2005), a technique that has been widely applied in predicting species' distributions (Pearson *et al.,* 2007). This technique has recently been applied to predicting the range of invasive species although it has had limited application in modelling non-native plant species (Townsend Peterson *et al.*, 2003).

The idea of niche modelling together with the existence of powerful computer software has given rise to a range of prediction modelling techniques (see table 2 for a list of the main models) each with different success rates and uses (Mack, 1996: Elith *et al*., 2006). It is possible to either extrapolate from the native range to the new range ("forward" prediction) or from the current invaded range in a region to other parts of the same region not yet known to be invaded (Fitzpatrick & Weltzin, 2005). Many studies match the climate a species occupies in its native range to the climate in its new range to predict where it could spread to (Mack, 1996; Fitzpatrick & Weltzin, 2005). Limitations of predicting from one range to another is the potential that the niche of origin is not maintained in the new range (Fitzpatrick & Weltzin, 2005) or that constraints placed upon a species in another range are no longer present.

Table 2. Summary of some modelling methods in existence with the main method used and the type of data required. P- presence data; A- absence data; PA- presence and absence data needed.

Name	Method	Type of data used
BIOCLIM	Climatic envelope model	P
DK-GARP	Genetic algorithm	P-A
MAXENT	Maximum entropy algorithm	P
GAM	Generalised additive model- regression analysis	PA
GLM	Generalised linear model- regression analysis	PA

Adapted from Elith *et al.,* 2006, table 4, p.135.

Maxent is a software modelling programme that uses the 'maximum entropy' distribution probability function to predict the location of species based on environmental variables. Several studies have found this software to be superior to others (Elith *et* al., 2006; Pearson *et al.*, 2007). Only presence data is required to create a model which assigns each grid-cell a species presence probability based on environmental suitability (Phillips *et al.*,, 2006; Phillips and Dudik, 2008) Constraints are placed on the probability distribution based on the environmental parameters of the grid-cell presence record (Phillips et al, 2006; Townsend Peterson et al, 2007) attempting to recreate the boundaries of the ecological niche (Fitzpatrick & Weltzin, 2005). The environmental variables are input as girds with the value of a variable for each grid-cell (Phillips and Dudik, 2008). A small number of presence records, which may occur if a species is a nascent immigrant (Zhu *et al*., 2007) is not a limiting factor as Maxent can create prediction models based on as few as two presence samples although for optimum results it is best to have at least five samples (Pearson *et al*., 2007).
An important aspect of prediction mapping is testing how accurate the model is yet this is not commonly applied in most studies (Fitzpatrick & Weltzin, 2005). The accuracy of the model is tested using presence points that were not used in the modelling procedure: 'test' data (Pearson *et al.*, 2007). The amount of data to set aside as test data is defined as a percentage Phillips *et al.*,, 2006). The output from a test of model accuracy is the omission errors: the amount of range that did not overlap with a test presence location (Townsend Peterson *et al.*, 2003; Fitzpatrick & Weltzin, 2005). Jacknife tests are used to test the contribution of each environmental variable to the model allowing the variables which best predict the distribution of the species to be identified. Three Jacknife tests are run: one on the gain each variable brings to the prediction model, one on the gain each variables provides when the model is applied to test data; the last runs models using one variable at the time and tests the AUC value of each model (Phillips *et al.*, 2006).

2.6 Community analyses

2.6.1 Simmilarity indices

One of the most common ways of comparing habitats based on NNS composition is using diversity indices such as the Shannon and Simpson (Wearne & Morgan, 2004). When abundances of species is not recorded however it is not possible to use these abundance-based indice; similarity indices have therefore proven to be a useful method for comparing species composition in these situations (Parendes & Jones, 2000; Wearne & Morgan, 2004; Chao, 2005). By determining the similarity it will be possible to see if certain disturbance and habitat types have particular groups of species associated with them. This in turn can provide insight into the dispersal mechanism and factors reponisble for the presence of each species or groups of species. The Sørensen dissimilarity index (sometimes referred to as the Bray-Curtis index for binary data; Chao, 2005) was chosen as it was developed specifically from incidence data (Chao, 2005). Although the Mountford index is best for presence-absence data it takes into account pseudo-absences (particularly useful for herbarium data) which skews the data if absences are true absences (Vegan R documentation, 2008).

The Sorensen index is calculated from:

$$\frac{2C}{(A+B)} * 100$$

where A=number of species present in site 1

B= number of species present in site 2

C= number of species present at both sites

A value of 0 indicates two sites are completely similar and 1 indicates they are completely dissimilar (Looman & Campbell, 1948 in Vegan R documentation, 2008).

2.6.2 Ordination and clustering

Clustering techniques are often used in plant ecology as a means of detecting vegetation communities (Shaw, 2003) and have also been applied to a limited extent in plant invasion ecology (Baret *et al.*, 2006). It provides an easily interpretable output of the classification of the dataset and this is one of the reasons it is a popular technique (Shaw, 2003). However, clustering analysis may not have enough strength as an analysis on its own due to the lack of significance testing and subjective nature of its interpretation which is why an ordination technique should be use to complement it (Shaw, 2003). Because of this ordinations are more common in the invasion literature than clustering techniques (Honnay *et al*., 2002; Underwood *et al*., 2004; Freeman *et al*., 2007).

Non-metric multidimensional scaling (NMDS) was developed by Kruskal in 1964 but has had limited application as an ordination technique within invasion ecology despite evidence of its superiority to other ordination techniques (Fasham, 1977; Kenkel & Orlóci, 1986; Hochstedler *et al.*, 2007). Datasets that are non-parametric and contain many zero values, as are presence-absence data, can be reliably analysed using this technique (Parendes & Jones, 2000; Hochstedler *et al.*, 2007). Study sites are ordered in a multi-dimensional space according to the similarity of their species composition to other sites so that sites which have similar floristic compositions are clustered in the ordination diagram (Parendes & Jones, 2000; Shaw, 2003; Hochstedler *et al.*, 2007). Using this technique, Parendes and Jones (2000) were able to identify NNS communities along different road types. Wearne and Morgan (2004) identified similarities in native species composition according to the invasion level of sites by *Cystisus scoparius.* This method is also chosen in place of other more common ordination methods when it is not known which environmental variables the NNS are responding to or the shape of the species response curve to these variables (Fasham, 1977).

2.7 Study area

Montserrat is a 104km^2 island of the lesser Antilles in the Eastern Caribbean (62° 12′ west, 16° 45′ north) (fig. 2). Despite its small size Montserrat possesses several habitat types from Elfin woodland at the highest altitudes through wet, mesic, dry, littoral forest, thicket to scrub in the driest areas (Hamilton *et al*., 2008). Within these there are a variety of land uses which reflect Montserratian history the main ones being agriculture (abandoned and current), grazing and residential areas. Most of the wet forest and Elfin woodland, two habitats that harbour endangered species and are vulnerable themselves, are located within the Centre Hills (fig.3). The climate is tropical with an average relative humidity of 75% (Brussel, 1997) and rainfall between 110-210cm (Young & Hilton, 2008). Salt laden trade winds occurring in the north and east of the island contributes to localized desert condition (Brussel, 1997) resulting in different vegetation communities (Hamilton *et al*., 2008). This together with intensive forest clearance and grazing has caused soil erosion in the Northern Silver Hills (fig.3 a) (Hamilton *et al*., 2008).

The Caribbean is considered one of the world's biodiversity 'hotspots' (Conservation International, 2007); Montserrat is home to eight globally threatened species (including two plant species) and potentially 78 plant species of global conservation concern (Young *et al*, 2008; Hamilton, 2008). Oceanic island ecosystems, where the flora and fauna have evolved in isolation from strong competitors and predators (GISD, 2008), are the most vulnerable to disturbance: over 70% of all extinctions have occurred on islands (Kairo *et al.*, 2003; Varnham, 2006). These disturbances include alien invasives which are among the greatest threats to oceanic island biodiversity (Mauchamp, 1997), Montserrat is no exception.

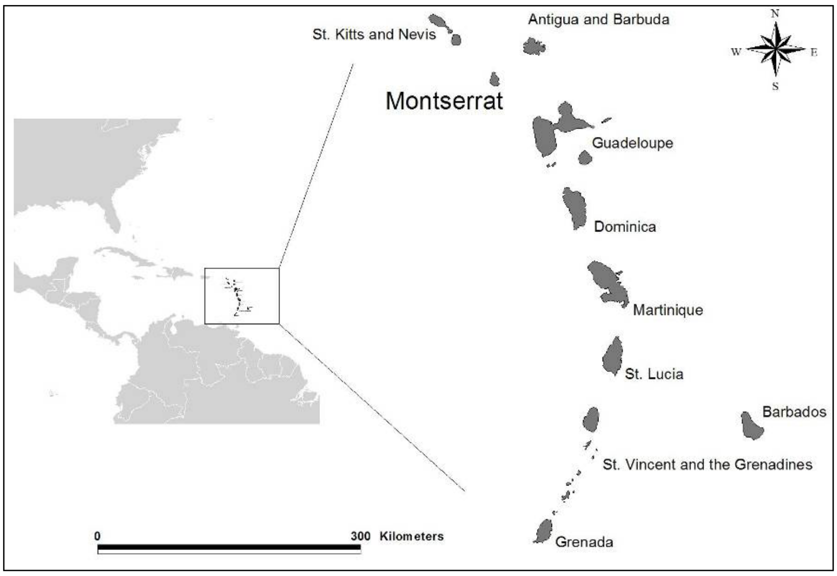


Figure 2. Location of Montserrat within the world and the Lesser Antilles.
Taken from Young & Hilton (2008), fig. 2.1, p. 30.

As well as the threats common to worldwide biodiversity (climate change, habitat loss and fragmentation, invasive species) Montserrat's biodiversity has recently suffered from natural disasters, most notably in the form of volcanic eruptions. The first volcanic eruption in 1995 led to two-thirds of the 12000 inhabitants fleeing and most have not returned; the present population is approximately 5000. Many species' habitats were destroyed or at best significantly restricted in range, this includes those of the eight globally threatened species (Young & Hilton, 2008**)**.

2.7.1 History

Montserrat has been inhabited by several groups of peoples, one succeeding the other. The structure of present-day vegetation has been influenced by how each group of people altered the biodiversity of the island has affected present day vegetation, including non-native flora. This change suffered by the vegetation communities can be seen in fig. 3.

The Arawaks, an Amerindian tribe, arrived at the island in around 400AD by from Venezuela (Brussel, 1997). The Caribs, a feared tribe, arrived on Montserrat in the 1500s driving the Arawaks away to avoid massacre. The earliest known name for Montserrat is the Carib one: 'Alliouagana' meaning 'land of the prickly bush' (Brussel, 1997) most likely due to the spiny acacia shrubs that can be found in abundance in lower-lying areas. Unlike the Arawaks who maintained a shifting

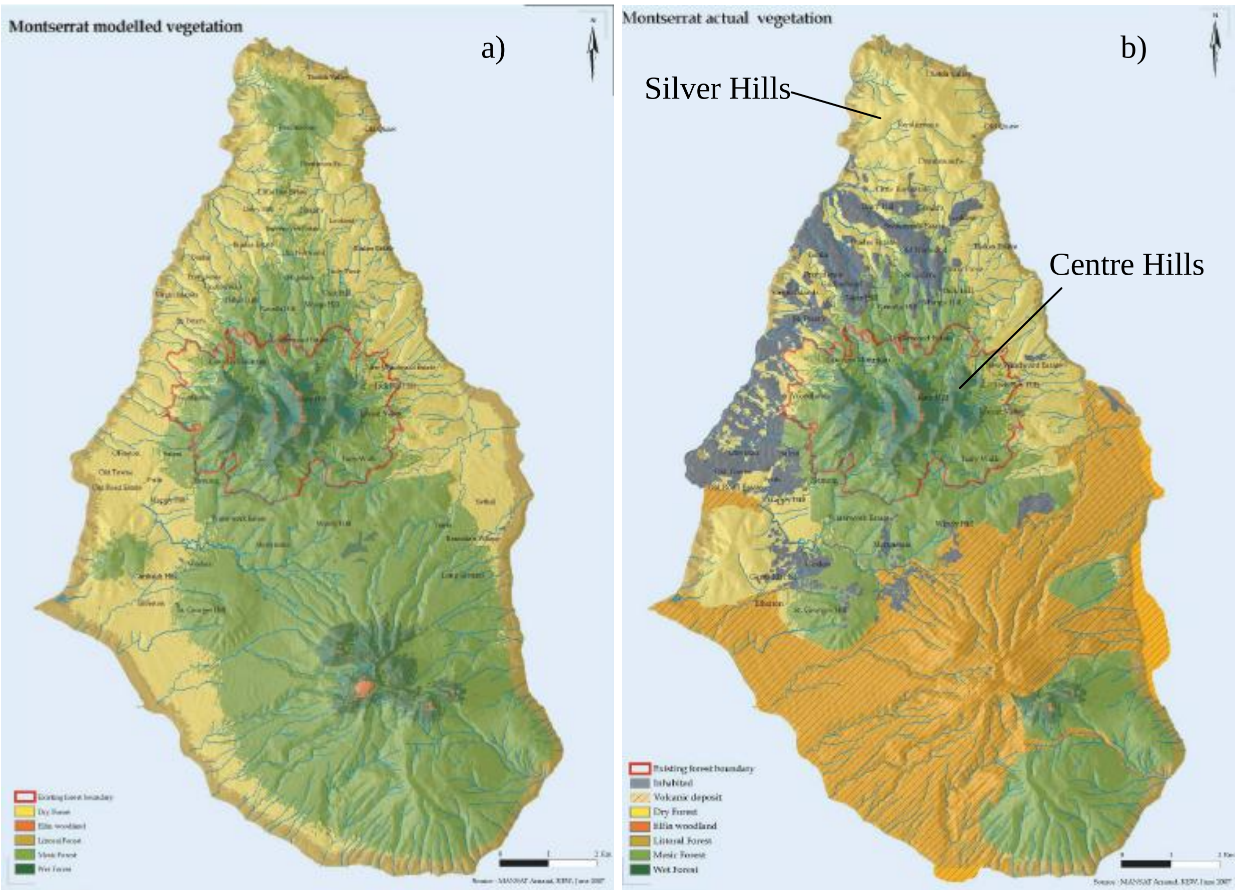


Figure 3. Modelled vegetation on Montserrat before the arrival of humans (a) and present day vegetation (b).

agriculture society in coastal areas the Caribs practiced shifting and permanent agriculture in the higher altitude forests as well (Brussel, 1997). The Caribs introduced many plant species including guava (*Psidium guajava*) and the calabash tree (*Crescentia cujete*) both important crop plant species (Brussel, 1997) the former currently a major invasive problem in areas of its non-native range (ISDB, 2008).

Although Montserrat was 'discovered' by Columbus, bestowing the island with the name Montserrat, the British, arriving in the 17th century, were the first white settlers. Within this time widespread forest clearance occurred for agricultural purposes resulting in one-third of the forest being lost (MBA, 2008). Colonialists brought with them African slaves to work on sugar and tobacco plantations; 523 slaves were living on the island by 1672 (Brussel, 1997). After emancipation in 1838, former slaves being poor and having no land tenure continued to work for estate owners in near-slavery conditions. Some were given land parcels on which subsistence farming took place (Hamilton, pers. com).

Previously to the volcanic eruption agriculture, along with tourism, was the main source of income (Oldfield, 1987). Neem (*Azadirachta indica*), the 'miracle tree' was planted in the 1980s (Kairo *et al.,* 2003) as it was thought that it would bring great economic benefit due to the multitude of products that can be harvested from it (Brussel, 1997; James, 2007). It did not take off however (Hamilton, pers. com) and this species now poses a potential invasion problem. After the volcanic eruption of 1995 the Southern part of the island, where most of the agricultural land is found, became (and still is) an exclusion zone. Further abandoned agricultural land can be found within the Centre Hills reserve (fig. 3 a) where agricultural practices, among other resource uses, are restricted (Young & Hilton, 2008).

2.7.2 Non-native flora

There are 149 known introduced species to Montserrat (Hamilton *et al*., 2008) twenty-eight of these were surveyed in this study (for a full list of species with brief descriptions see table 1 and box1, appendix A). Some of these are known to be particularly aggressive invaders. *Leucaena leucocephala,* placed in the "100 worst" list of invasives by the GISD, has been widely introduced for forestry and agricultural purposes (National Research Council (NRC), 1984; GISD, 2008). It is an extremely fast-growing species and uses include: reforestation, soil improvement, timber, firewood, agroforestry, forage and fences (NRC, 1984; Cook *et al.,* 2005). Contrastingly, *L. leucocephala* has been advocated as a reforestation species where forest degradation has occurred and where invasive grasses are taking over as *L. leucocephala* is able to outcompete them (NRC, 1984). This zealous introduction has lead to this species becoming a widely distributed invasive species and its damaging effects on local flora are now becoming apparent (GISD, 2006). The impacts of the volcanic eruption are not only direct but through the forced abandonment of agricultural land cultivated species are now able to spread. This is particularly the case with guava (*Psidium guajava)* which is known to spread into surrounding areas once farms are abandoned (Hamilton *et al*., 2008).

2.7.3 Conservation on Montserrat

As well as being party to several international obligations (table 3) national species protection acts exist including the Plant Protection Act. This regional act aims to prevent the introduction of plant pests and diseases through import permits, control measures and eradication (Kairo *et al.*, 2003). Although originally set-up to protect agricultural resources, its benefit can also extend to the conservation of biodiversity on Montserrat (Kairo *et al.*, 2003). The Centre Hills Project was established in 2005 with as its aims: conducting a socioeconomic assessment of the Centre Hills, review environmental legislation, establish an outreach programme, begin an assessment of the Centre Hills's biodiversity and ecological research (Young, 2008). The legislation to implement the CBD on Montserrat is currently being developed (Clubbe, pers. com).

Table 3. Montserrat's international, regional and national conservation obligations. Information compiled from Oldfield, 1987 and Kairo *et al.*, 2003.

International	National/Regional
CITES	Plant Protection Act
Bonn	Turtle Ordinance
Whaling	
Ramsar	
World Heritage	

Although it is established that invasives are adding to the threats species are facing on Montserrat the distribution and full threat of invasive plant species is unknown (Hamilton *et al*., 2008). It is therefore necessary to assess and quantify the likely impacts of these on native biodiversity. Environmental and species action plans will need information on invasive's distribution and spread in order to implement successful conservation action (Underwood, *et al.*, 2003).

3. Methods

Field data was collected throughout five weeks from 10th May to 19th June 2008. A short pilot study was conducted (10th May to 13th May) to test the data collection methodology and identify study areas. The target list of twenty-eight species, representing twenty-eight genera and twenty-one families, was compiled using expert knowledge, literature information of invasive species lists of the Caribbean region (Kairo *et al.*, 2003), a newly compiled non-native flora of Montserrat (Hamilton, M., Clubbe, C., Robbins, S. K. & Bárrios, S., 2008) and observations during the pilot study.

3.1. Study areas

All recording was located in the north and centre of the island as the southern part is currently an exclusion zone. Eight habitat types as identified by RGB Kew on prior visits, were chosen for sampling. These habitats and their defining characteristics are presented in table 4.

Table 4. Habitat categories used for transects with climate charactersitics and typical species present. Adapted from table 3.4, p.49-50 of MBA, 2008.

Habitat	Characteristics
Beach	Coastal Vegetation influenced by wind and salt spray. Typical taxa: *Cordia sebestena,Argusia gnaphaloides, Ipomoea pes-caprae, Coccoloba uvifera, Ernodea littoralis, Strumpfia maritima, Suriana maritima*.
Wet forest	Medium/Large tree dominated vegetation >5m tall in high elevations with high rainfall. Typical taxa: *Elaeocarpaceae, Phyllanthus spp., Podocarpus coriaceus, Asplundia spp., Orchidaceae, Marcgravia umbellate, Arecaceae, Sloanea spp.*
Mesic forest	Medium/Large tree dominated vegetation >5m tall in mid elevations with medium rainfall. Typical taxa: *Begonia obliqua, Araceae, Lauraceae, Inga laurina, Eugenia spp., Piper spp., Mangifera indica, Thunbergia spp., Sida spp., Solanum spp., Stachytarpheta spp.*
Dry forest	Medium/Large tree dominated vegetation >5m tall in lower elevations with low rainfall. Typical taxa: *Capparis spp., Bursera simaruba, Tabebuia spp., Apocynaceae, Casearia spp., Hymenaea courbaril, Samanea saman, Bunchosia spp., Swietenia spp., Chiococca alba, Guaiacum officinale, Cedrela odorata.*
Thicket	Large shrub/small tree dominated vegetation 2.5-5m tall in lower elevations with low rainfall Typical taxa: *Cordia spp., Bourreria succulenta, Oplonia microphylla, Cassine xylocarpa, Piscidia carthagenensis, Pithecellobium unguis-cati, Pisonia spp., Coccoloba spp., Verbenaceae*.
Scrub	Shrubby vegetation 0.5-2.5m tall in lower elevations with low rainfall Typical taxa: *Comocladia dodonaea, Agavaceae, Croton spp., Galactia spp., Acacia spp., Malpighia linearis, Stigmaphyllon spp., Tetramicra canaliculata, Melochia spp., Jacquinia armillaris,Corchorus aestuans*.
Riparian	Includes both moving fresh water and riparian habitat that are no longer viable through disturbance. Typical taxa: *Phytolacca rivinoides, Heliconia caribaea, Salicaceae,* Ferns., *Mangifera indica, Casuarina equisetifolia, Terminalia catappa.*
Anthropogenic	Landscape modified and maintained through human activity.

3.2 Field sampling

Transects were walked with a presence/absence NNS recording site of 5 metre radius at 30m intervals. From the pilot study it was seen that the potential length of transects in habitats differed and it was therefore necessary to establish a standardised transect length that could be undertaken in every habitat in order to have a comparable sample size for each habitat. For this reason, transects of 300m (resulting in 10 recording points per transect) were carried out in each habitat with a total of 10 transects per habitat (totalling 70 transects and 700 recording sites). It was attempted to situate transects in a manner to 1) avoid spatial auto-correlation and 2) capture a representative sample of topographic and climatic conditions (Townsend Peterson *et al.,* 2003).

Field data was recorded in ArcPad 7.0 on a hand-held computer (Fujito-Siemens N560) with integrated GPS software so that the location of each recording point had assigned geographic coordinates. GPS was also used to measure the 30m intervals between recording points. Further recording points, totalling 1407, were taken to be used in mapping the species' distributions; these could not be used in statistical analyses as they were highly clustered and a disproportionate amount were undertaken in dry and mesic forest. Unless otherwise mentioned all analyses were carried out using the 70 transects or 700 recording points. When transects were used in analyses all recording points within a transect were grouped (Honnay *et al.*, 2002) effectively providing 70 recording sites for the whole study area.

3.2.1 Disturbance type

Each recording point was assigned one of twelve disturbance categories during data recording. Three of these categories (high, medium and low) were used if disturbance was not caused by a land-use change but by human presence or use of the area. If no disturbance was present then it was recorded as 'none'. For a definition of each disturbance type see table 5.

3.2.2 Variables

GPS was used to record altitude at each recording point. Ground percentage cover, canopy cover and canopy height were recorded at the same time by visual estimation. Canopy cover was measured as the percentage cover of vegetation above head height. Canopy height was measured as the maximum height of vegetation above head height. The GPS location of each NNS present was input into ArcMap GIS software (Montserrat 1958 British West Indies Grid geographical projection) to construct distribution maps. Other layers added were: roads, rivers, inhabited areas and environmental grid layers. These layers were created and obtained from Royal Botanic Gardens (RBG) Kew. The distance to roads, rivers and inhabited area of each NNS point was calculated by joining the sample point layer with these layers and then calculating the straight-line distance of each point to the closest road, river and inhabited area. Slope, aspect, direction of flow and distance to coast were also calculated for each point by extracting the value of these environmental grid layers to all NNS presence points. All these variables were obtained in order to investigate if a relationship exists between these variables and the presence of a NNS.

The range size of each species was calculated in ArcGIS using all recording points (not just those from transects) by the nearest neighbour method using the Euclidian distance. This was used as one of the response variables when investigating possible effects of biological traits on species distribution following Pyšek and Jarošík (2005).

Table 5. Disturbance categories used for sample points and their defining characteristics.

Disturbance	Characteristics
Current agriculture	Land currently under cultivation
Old agriculture	Abandoned agricultural land no longer farmed
Grazing	Land with livestock grazing
Infrastructure	Area where a public service is present e.g.: water pipes.
Road	A tarmac or dirt road used by vehicles.
Trail	Paths outside anthropogenic areas used by pedestrians.
Residential	Areas with housing or buildings
Volcano	Areas that have been disturbed by severe ashfall or are submerged in ash.
High	Area that is heavily visited or used e.g.: rubbish dumped
Medium	Area which is frequently visited or disturbed
Low	Area which is rarely visited or disturbed
None	No visible natural or anthropogenic disturbance

Adapted from table 3.4, p.49-50 of MBA, 2008.

3.3 Biological Traits

Few were the traits where information was available for every species and so the traits investigated were chosen based on a combination of findings from previous studies and the data available for each species in this study. Following Rejmanek and Richardson (1999) and Goodwin et al (1999) the attributes chosen were: seed size, plant height, leaf size and seed number per fruit. These attributes were tested against range size and total frequency to see if biological attributes could account for the NNS abundance on Montserrat.

3.4 Data analysis

3.4.1 Overall NNS distribution

An analysis of variance (ANOVA) was used to test if overall NNS richness was significantly different among habitats and disturbance types and to test if there is an interaction between habitat and disturbance. Total species richness was log-transformed in order to fulfil the normality assumption of an ANOVA. A Spearman's rank correlation was applied to test if the amount of disturbance types present within a habitat and NNS richness are correlated. These tests were applied to reveal if species are more abundant in certain habitats and disturbance types. If a significant correlation exists between number of disturbance types and NNS richness then this will suggest that the amount of disturbance may also be a factor influencing overall NNS frequency.

Pearson rank correlation tests were applied to the percentage occupancy of a habitat or disturbance category by a NNS and the NNS species richness to see if similar effects as those found in Baret *et al*'s (2006) study were occurring which would indicate that more heavily invaded areas are dominated by a few species. All statistical analyses were carried out in the R package, 2.7.1.

3.*4.2 Single NNS distributions*

In order for statistical tests on individual species to have sufficient power only NNS with over 30 presence records could be analysed (Crawley, 2005). This was not a limitation however as the species of greatest interest had over this number of presence points. Significant differences in individual species' distributions among habitats and disturbance types were tested for using a Kruskal-Wallis test following Honnay *et al.*, 2002. Significant results will indicate that a species is significantly more abundant in certain habitats and disturbance types allowing priorities to be made in terms of which habitats are most at risk of a particular NNS and should be targeted or monitored.

3.4.3 Non-native community analysis

A hierarchical cluster analysis was used to group non-native species based on the transects they ocuppy following Baret *et al.*, 2006. A species dissimilarity matrix was constructed using the Sorensen index in the R package Vegan 1.14-9. (Okansen *et al*, 2005) to construct the cluster diagram. Several trees were made with different linkage types in order to decide which tree was most appropriate; there was no difference in the groupings made. It was decided to use McQuitty linkage as this is the most appropriate for vegetation data (Shaw, 2003). Habitats and disturbance categories were also clustered following the same method.

Non-metric multidimensional scaling (NMDS) was used to order transects according to their species composition and complement results from the clustering analysis. This will indicate if transects within the same habitat or disturbance types have similar NNS compositions and reveal which species are most closely associated with particular transects. Species presence/absence was transformed into the proportion presence of the species per transect and a Sorensen dissimilarity matrix constructed using the R package Vegan following Parendes & Jones, 2000. By using the Sorensen index the ordination of sites does not take into account species abundance but composition only (Zechmeister *et al*, 2007) which is appropriate for the presence/absence data collected. The significance of the NMDS ordination of sites along the axes was tested using a multivariate analysis of variance (MANOVA) with the Pillai-Bartlett test statistic following Zechmeister *et al.*, 2007 as was the ordination of species. Because NMDS is a non-parametric ordination method it is unadvisable to draw main conclusions from this analysis (Shaw, 2003) but it does reveal patterns in the dataset that would otherwise go unnoticed in other statistical techniques. Habitat and disturbance were fitted to the NMDS as environmental vectors to reveal if either could explain the ordination of the transects along the axes (Okansen, 2005).

3.4.4 Variables affecting NNS presence and frequency

It was decided to use regression analyses on the environmental variables instead of using an ordination technique such as CCA (e.g.: Freeman *et al*., 2007) because it is not known which variables best explain the presence or absence of NNS.

Binomial multivariate regressions (GLM following Guisan *et al*., 2002) were used to investigate if the relationship between different environmental variables and non-native species presence is significant. A model with all variables was run initially and then simplified using the “step” function in R 2.7.1. Models used the 700 individual recording points and not the transects in order to be able to carry out analyses with the environmental variables. This will provide insight into which factors most affect NNS presence.

Average height, seed size, seed number per fruit and leaf size were tested against relative abundance and range size follwing Pyšek and Jarošík (2005). Individual linear regressions were carried out for each variable instead of a multiple regression due to the low number of response variables (25 species).

For each of the regression analyses two regressions were carried out one including all species and one with cultivated species removed. Cultivated species removed were: *Azadirachta indica, Carica papaya, Crescentia cujete, Hedychium spp., Hevea brasiliensis, Mangifera indica* and *Psidium guajava*. This second analysis was carried out as species whose distribution has been directly facilitated by humans are likely to have different factors driving their distributions. A difference in significance or significant variables in either regression will indicate this.

3.4.6 Prediction mapping

The environmental grids used with their abbreviations are listed in table 6. These grids have been created by the GIS unit at RBG Kew. For all models the parameters recommended by Phillips et al 2006 were used: 25% test percentage, regularisation multiplier of 1, 500 iterations and a convergence threshold of 10^{-5} (for further details on these parameters see Phillips et al 2006).

Prediction maps were created for *B. pinnatum, C. madagascariensis, L. leucocepahala, M. indica, P. guajava, S. plicata* and *W. trilobata.* These species were chosen because they are known invasives in other ranges with *C. madagascariensis, L. Leucocepahala* and *P. guajava* being particularly aggressive (GISD, 2006). To map the predicted range size the Maxent prediction output (in ASCII format) was input into ArcMap as floating-point grids following Peterson *et al*, 2007. This maps the occurrence probability from 0 to 100 of a species at each site (in this case the site is a 10m by 10m grid cell). The sum of all probabilities was calculated to identify which non-native species are predicted to be most widespread. These maps were overlayed with the Centre Hills Forest Reserve (CHFR) boundary. This will indicate how susceptible the CHFR is to NNS establishment and spread.

Different models were run for each individual species with different environmental inputs in order to find the best model for each species. The best model was chosen based on the highest test AUC value (Peterson *et al*., 2007). A Pearson's rank correlation test was applied to verify that sample size had no effect on test AUC value (Elith et al., 2007).

Predictions were also run for all non-native species combined, cultivated non-native species alone and non-cultivated species alone. A Spearman's rank correlation test was applied to indicate if the variables that best determine the distribution are significantly different between these groups of species.

Table 6. Maxent input variables for prediction mapping of NNS.

Variable	Abbreviation	Variable	Abbreviation
Irradiation level at 2 pm	2pm	Degrees from North	aspect-n
Irradiation level at 5 pm	5pm	Degrees from East	aspect-e
Irradiation level at 8 pm	8pm	Degrees from South	aspect-s
Soil moisture accumulation	accum	Degrees from West	aspect-w
Digital elevation model	dem	Distance to north-east coast	dist-ne
Slope (%)	slope	Distance to the north coast	dist-north
Water-flow direction	waterflow	Distance to the south coast	dist-south
Shortest distance to coast	dist-coast	Distance to the west coast	dist-west

4. Results

4.1 Species frequency

Three species were recorded an insufficient number of times and so data analysis was carried out using twenty-five out of the twenty-eight target list species. *Acacia nilotica* was not present in any of the transect points (most likely missed due to the difficulty of correctly identifying legumes when not in flower or fruit (Estrada & Martinez, 2003) and so to be precautious it was decided to exclude this species instead of recording it as 'absent'. Species that were recorded only once, namely *Ziziphus mauritania* and *Nicotiana tabacum*, were not included in analyses as they provide insufficient data.

Five species (*Bryophyllum pinnatum, Cryptostegia madagascariensis, Leucaena leucocephala, Mangifera indica, Psidium guajava* and *Wedelia trilobata*) account for over 69% of all presence records (fig. 4). All other species individually accounted for less than 5% of the presence records (fig.4) indicating an uneveness in non-native species composition on Montserrat.

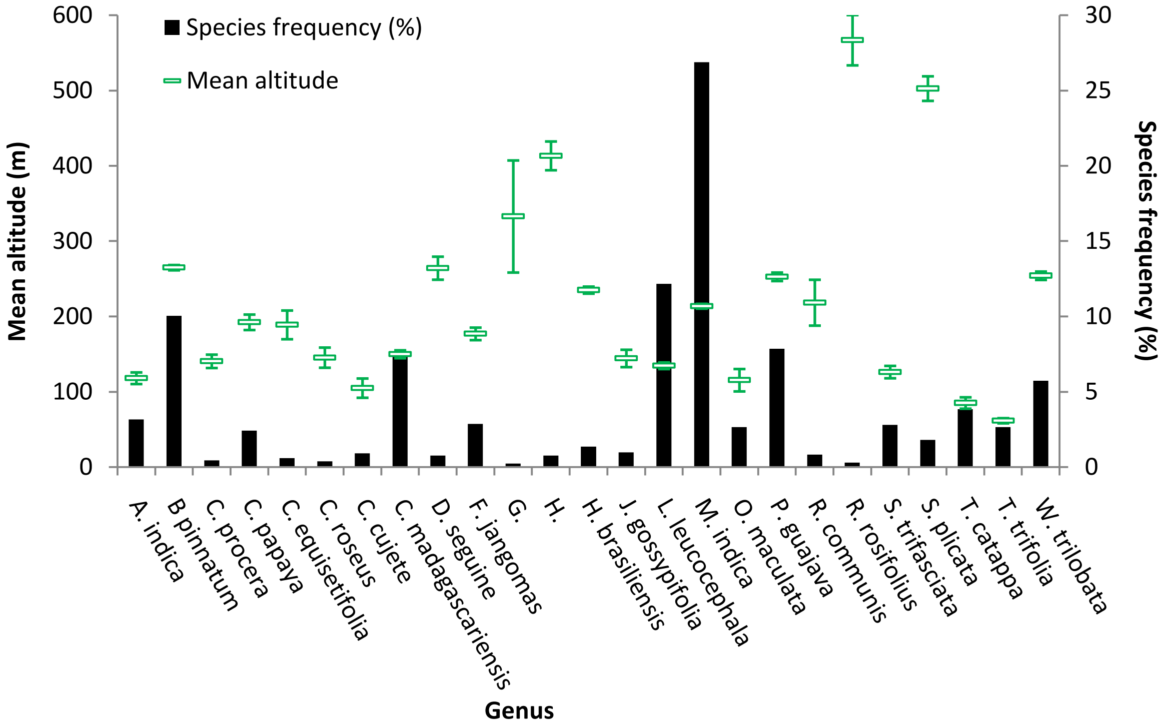


Figure 4. Species percentage frequency of occurence and mean altitude (± 1SE) of each species' presence location.

Most species were found between 100m to 300m (fig. 4) but this does not necessarily indicate that most non-native species are located at these altitudes as the sampling effort was greater within this altitude range. However, certain species were predominantly found above or below the 100-300m altitude band. *Rubus rosifolius* and *Spathoglottis plicata* were recorded at the highest altitudes (average of 566m ± 66 (*n*= 4) and 502 ± 32 (*n*= 24) respectively) whereas *Terminalia catappa* and

Triphasia trifolia at the lowest altitudes (85m ± 15.1 (*n*=51) and 61m ± 6.9 (*n*=35) respectively).

4.2 Overall distribution pattern of NNS

Anthropogenic areas had the greatest proportion of non-natives present (fig.5) yet dry forest and mesic forest had the highest NNS richness (21 and 20 respectively; fig. 5). Old agriculture had the highest NNS richness (21) whereas only two species altogether were found in areas where there was no disturbance: *M. indica*. and *P. guajava.*

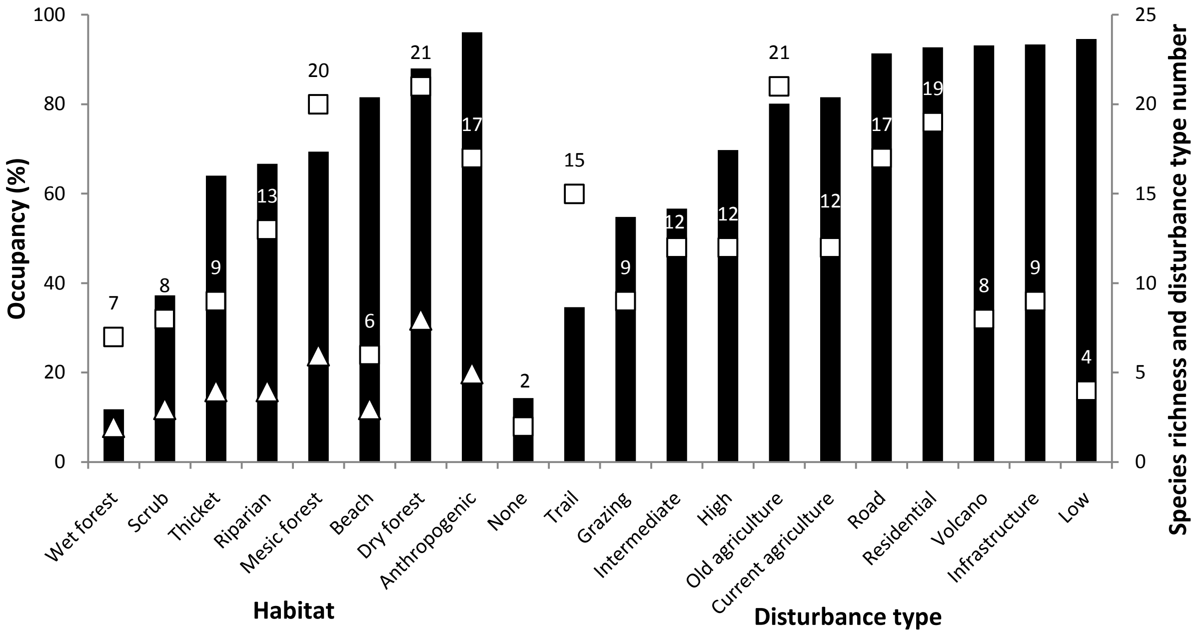


Figure 5. Overall percentage presence of non-native species in each habitat and disturbance type with non-native species richness (U) and total number of disturbance types (T). Percentage presence is the proportion of presence points in each habitat.

In areas of low disturbance a NNS was present 94% of the time which is similar to areas with infrastructure, volcanic disturbance, roads and residentail areas. NNS occupancy was lowest in the wet forest and areas with no disturbance. Although there was a positive correlation between the NNS richness and the percentage occupancy of a habitat or disturbance category these were not significant (*p*>0.05, cor=0.5328555 and 0.4334683 respectively) likely due to insufficient sample points. When the same correlation is carried out but with habitats and disturbance categories together then a significant positive correlation exists (*p*<0.05, t = 2.1043, df = 18, cor=0.4443285; see fig.1, appendix B, for correlation plots) suggesting that the areas with a greater occupancy by NNS have a higher NNS richness.

There was a significant difference between the NNS richness in different habitats ($F_{7,63}$= 5.0, p<0.001) and between disturbance types ($F_{11,59}$= 2.3, p< 0.05). When an ANOVA with the interaction between habitat and disturbance is undertaken there is no significant effect of this interaction on non-native species richness ($F_{9,43}$=0.775, p>0.05) and there is no longer a singificant effect of disturbance type ($F_{11,43}$= 0.602, p>0.05). Overall non-native species richness within a habitat is positively correlated with the number of disturbance types present (Spearman's rank, s=4.5804, p<0.001). This suggests that it is the amount of disturbance present rather than the type of disturbance that influences the overall presence of non-native species in an area. However, individual species responded differently to both habitat and disturbance and so it was necessary to investigate these individually.

4.3 Individual species distributions

Oeceoclades maculata is the only species whose frequency either among habitats or disturbance types is not significantly different (table 7). *Flacourtia jangomas*'s frequency in different habitats is not significantly different but it is among different disturbance types. All other species have significant frequency differences among habitats but only three other species differ significantly in their frequency among different disturbance types (*Carica papaya* and *Psidium guajava* along with *F. jangomas*; table 7). 81% and 73% of the *Bryophyllum pinnatum* and *Cryptostegia madagascariensis* recorded was in thicket habitat and 77% and 75% of their presence records are in grazing areas (see fig. 2 in appendix B for individual species distributions among habitats and disturbance categories).

Azadirachta indica and *Leucaena leucocephala* are most frequent in anthropogenic and dry forest areas (42% and 34%; 40% and 42% respectively). Both were most frequent in areas with residential disturbance likely a reflection of their proposed use as economically important species. *Flacourtia jangomas*is most frequent in dry (42%) and mesic forest (34%) although this was not significant (table 1). However, it is significantly more frequent in areas disturbed by former agriculture(36%) suggesting that it had its uses as fencing. *Psidium guajava* was most frequent in dry forest areas along with *Carica papaya* (50% for both) and in old agricultural areas as was *M. indica* (61% and 35% respectively) (see fig. 2 in appendix B).

4.4 Community analyses

Clustering analysis separated the 25 species into 8 main groups (table 8) with two species in their own group: *Hevea brasiliensis* and *Ricinus communis*. The major fruit crops (*Carica papaya, Mangifera indica* and *Psidium guajava*) are grouped together whilst other economically important species, with the exception of *Crescentia cujete*, are in groups 7 and 8 (see fig. 3 appendix B for cluster diagram).

Table 7. Results of Kruskal-Wallis test of species distribution among habitats and disturbance types. Non-significant values are indicated as n.s.

	Habitat			Disturbance		
Species	**dF**	χ^2	***p***	**dF**	χ^2	***p***
Azadirachta indica	7	15.2	0.0337	10	16.5	n.s.
Bryophyllum pinnatum	7	29.1	0.0001	10	6.95	n.s.
Carica papaya	7	17.9	0.0122	10	26.3	0.0018
Cryptostegia madagascariensis	7	17.0	0.0176	10	5.68	n.s.
Flacourtia jangomas	7	12.5	n.s.	10	24.12	0.0040
Leucaena leucocephala	7	19.1	0.0080	10	16.2	n.s.
Mangifera indica	7	30.7	<0.0001	10	11.7	n.s.
Oeceoclades maculata	7	7.54	n.s.	10	5.02	n.s.
Psidium guajava	7	20.1	0.0054	10	17.0	0.0491
Sansevieria trifasciata	7	23.6	0.0013	10	12.7	n.s.
Terminalia catappa	7	15.9	0.0262	10	14.1	n.s.
Triphasia trifolia	7	16.5	0.0200	10	15.2	n.s.
Wedelia triloba	7	24.2	0.0011	10	14.5	n.s.

Table 8. Cluster diagram of species according to transects occupied based on the Sorensen distance.

Group	Species
1	*Hedychium; C. equisetifolia; C. roseus; C. procera; Gigantochloa*
2	*H. brasiliensis*
3	*O. maculata; R. rosifolius; S. plicata.*
4	*C. cujete; C. madagascariensis; B. pinnatum; J. gossypifolia.*
5	*R. communis*
6	*D. seguine; F. jangomas.*
7	*T. catappa; A. indica; T. trifolia.*
8	*S. trifasciata; C. papaya; W. trilobata; P. guajava; M. indica; L. leucocephala.*

Table 9. Grouping of habitats and disturbance types based on their non-native species composition.

GROUP	HABITAT	GROUP	DISTURBANCE
1	Dry forest	1	Grazing
	Anthropogenic	2	Low
2	Mesic forest		None
	Riparian	3	Infrastructure
3	Scrub		Volcano
	Thicket	4	High
4	Wet forest		Medium
5	Beach	5	Current agriculture
		6	Trail
			Old agriculture
		7	Residential
			Road

Table 9 shows the clustering of habitats and disturbance types according to their species composition based on the Sorensen dissimilarity index. The non-native species composition in beach habitat was the most dissimilar to all other habitats. Wet forest also has a highly dissimilar non-native species composition to all other habitats mainly due to the presence of *Spathoglottis plicata* and *Rubus rosifolius* as *S. plicata* was also recorded only in mesic and dry forest and *R. rosifolius* in mesic forest. The non-native species composition of scrub is most similar to that of thicket with six species in common and five that are only found in one of the habitats. Dry forest and anthropogenic habitat have fifteen species in common and six species unique to one resulting in their group having the lowest dissimilarity value (fig. 4, Appendix B for cluster diagram). Non-native species composition in residential areas was most similar to the composition in roads, they share all but two species. None and low disturbance had similar species compositions.

The MANOVA test on the ordination values of each transect along the NMDS axes was significant ($F_{1,54}$=11.3, $p<0.0001$) with axis 1 being significant but not axis 2 ($F_{1,54}$=16.9, $p<0.001$ and $F_{1,54}$=3.34, $p>0.05$ respectively). The stress value was 18.9 and the ordination was two-dimensional which is within the expected range of 2-4 dimensions for vegetation data (Zechmeister *et al*, 2007). Three out of five transects undertaken in wet forest were most floristically similar to each other (fig. 6 a). The other two transects are most similar floristically to mesic, ripirian and dry forest transects. Transects undertaken in thicket were most similar to each other and to two scrub transects reflecting the clustering analysis. Anthropogenic and dry forest transects were ordered in the centre of each axis together with riparian and all but one of the mesic forest transects which again reflects the groups formed by the clustering analysis. Beach transects were also ordered to the centre of axis 1 but were spread out along axis 2. Two of these transects had the most similar non-native species composition to each other but other beach transects were most similar to transects from other habitats. One transect in mesic forest was highly different from all other transects.

The lack of defined groups of transects in the ordination diagram indicates that areas within the same habitat type do not necessarily have the most similar non-native species composition. Fig. 6 b) shows the ordination of the same transects but overlayed with disturbance type instead of habitat type. All transects undertaken in road, residential, current agriculture were ordered towards the centre of both axes indicating that these transects are the most similar floristically reflecting the grouping of road and residential transects in the clustering analysis. The NNS composition similarity of transects with the same disturbance, particularly those within old agriculture, grazing and high disturbance, is low as shown by the lack of ordination clusters formed.

When species are overlayed on the ordination it can be seen that some are closely associated with

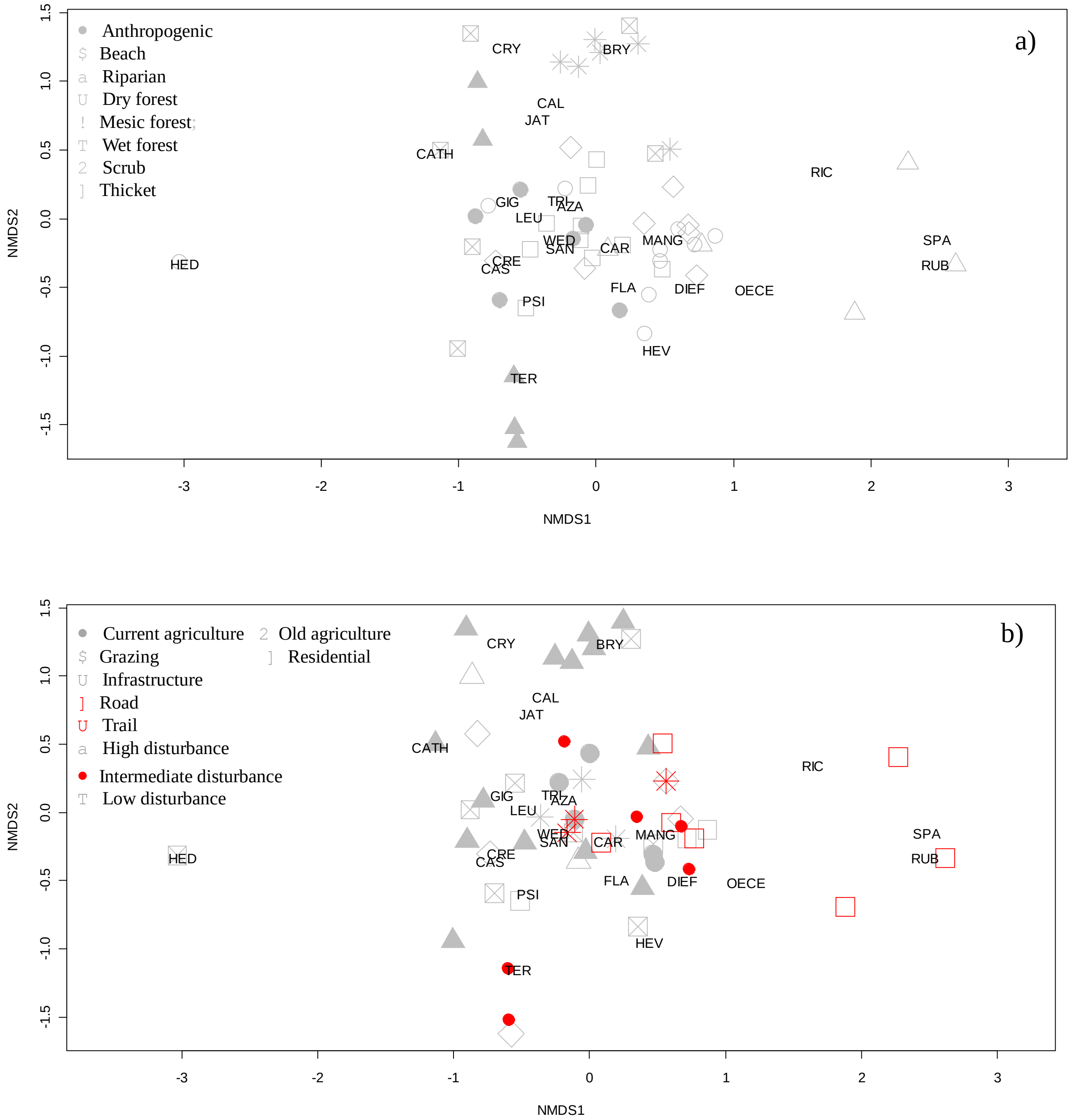


Figure 6. Non-metric multidimensional scaling (NMDS) ordination of transects according to non-native species presence/absence overlayed a) habitat type and b) disturbance showing which species are most associated with each transect.

particular habitats or disturbance types. A MANOVA showed that species ordination is significantly associated with axis 2 but not 1 ($F_{1,24}$=4.46, $p<0.05$ and $F_{1,24}$=2.54, $p>0.05$ respectively). *Spathoglottis plicata* and *R. rosifolius* are both strongly associated with wet forest from their position on the ordination diagram (fig. 6). *Bryophyllum pinnatum, C. madagascariensis*, *C. procera*, *C. roseus* and *J. gossypifolia* seem to form a group that is associated most with thicket, scrub and grazing disturbance . When looking at disturbance type these species are associated with grazing, old agriculture and beach transects (fig. 6 b).

When habitat and disturbance types were fitted to the ordination both had a significant relationship with the ordination (r^2 =0.4287,p< 0.0001; r^2= 0.3192 , p< 0.05 respectively) suggesting that the habitat type has a greater effect on NNS composition than disturbance type emphasising earlier results of the ANOVA and Kruskal-Wallis tests where habitat had a more significant effect than disturbance.

4.5 Environmental variables

Models that best explain the presence of all NNS, non-cultivated species alone and cultivated species alone contain different variables (table 10). Because the reponse variable is NNS presence/absence a variable influences the *probability* of a NNS being present and not the *abundance* of NNS. Five variables are included in models of both non-cultivated species and cultivated species although the direction of the relationship changes . The closer an area is to road and an inhabited locations the more likely a cultivated species is to be found whereas the opposite is true for a non-cultivated species. Canopy height does not seem to be involved in determining whether a non-cultivated species is present but is positively associated with the presence of NNS overall and cultivated species. The distance to a river and slope are only determining factors in the non-cultivated species model. The only variable that is different between the model for all NNS and one for only cultivated species is distance to road. There is a lower probability that a non-cultivated NNS will be present on steeper slopes but cultivated species do not seem to be dependent on slope.

Table 10. Environmental variables in the model that best explains the presence of all NNS (AIC= 1622, R^2=0.26) non-cultivated species only (AIC= 1075, R^2=0.38) and cultivated species only (AIC=1127, R^2=0.26).

VARIABLE	All species		Non-cultivated species		Cultivated species	
	Estimate	***p***	**Estimate**	***p***	**Estimate**	***p***
Altitude	-0.00172	0.006008	-	-	-0.00568	0.003818
Slope	-	-	-1.99E-02	0.0228	-	-
Aspect	0.004107	<0.001	5.68E-03	>0.0001	0.002383	>0.001
Distance to river	-	-	5.35E-03	>0.0001	-	-
Distance to road	-	-	2.11E-04	0.00892	-0.00018	0.027439
Distance to coast	0.003067	<0.001	5.94E-04	>0.001	0.000966	>0.001
Distance to inhabited area	0.000851	<0.001	9.03E-05	0.15145	-0.00057	0.000115
Canopy height	0.098307	<0.001	-	-	0.116701	>0.001
Canopy % cover	-0.04091	<0.001	7.86E+00	>0.001	-0.03397	>0.001
Ground % cover	-0.0359	<0.001	-4.85E-02	>0.001	-0.01817	>0.001

4.6 Biological traits

As shown in table 11 no significant relationship was found between the biological traits of a species and its proportion abundance or range size (p>0.05 for all traits) suggesting that the presence of species is not determined by the species' life history. The relationship continued to be not significant with cultivated species removed (table 2). Although not significant there are differences in test values between regressions carried out against range and frequency with frequency having slightly larger R^2 values and lower p-values.

Table 11. Results of linear regressions of range size (km^2) and frequency of non-native species with four biological traits.

Variable	All non-native species				Cultivated species removed			
	Range size		Frequency		Range size		Frequency	
	R^2	*p*	R^2	*p*	R^2	*p*	R^2	*p*
Height (cm)	<0.01	0.779	0.06	0.278	<0.001	0.936	0.10	0.271
Seed size (mm)	0.02	0.582	0.10	0.146	0.01	0.711	0.02	0.618
Number of seeds produced per fruit	<0.01	0.861	0.04	0.387	<0.01	0.908	<0.01	0.895
Leaf area size (cm^2)	<0.001	0.916	<0.01	0.776	<0.001	0.98	0.06	0.379

4.7 Species predictions

4.7.1 Models

The number of presence samples did not affect the AUC value (p>0.5, cor=0.137 see fig. 5 appendix B for graph) so it was possible to carry out predictions unrestricted of sample size. For all but two species the best model (based on the test AUC) was one that included all variables (fig. 9). The models with the highest AUC for *L. leucocephala* and *M. indica* included all but one variable: distance to north-east coast and distance to the north coast respectively.

The distribution of overall non-natives on Montserrat is best predicted by the distance of a location to the east coast (fig. 9) with this variable contributing 20% to the prediction. Variables best predicting the location of non-cultivated species is similar with distance to the North-East coast contributing slightly more than distance to the east coast (20% and 18% respectively; fig.9). Cultivated species, however, were predicted best by different variables with distance to the west coast having the greatest contribution (24%). Variables that contribute the most to cultivated NNS and non-cultivated NNS were significantly different ones ($p<0.001$, S=160, rho=0.803). This indicates that the factors driving the distribution of different species groups differ supporting the results from the multivariate regression.

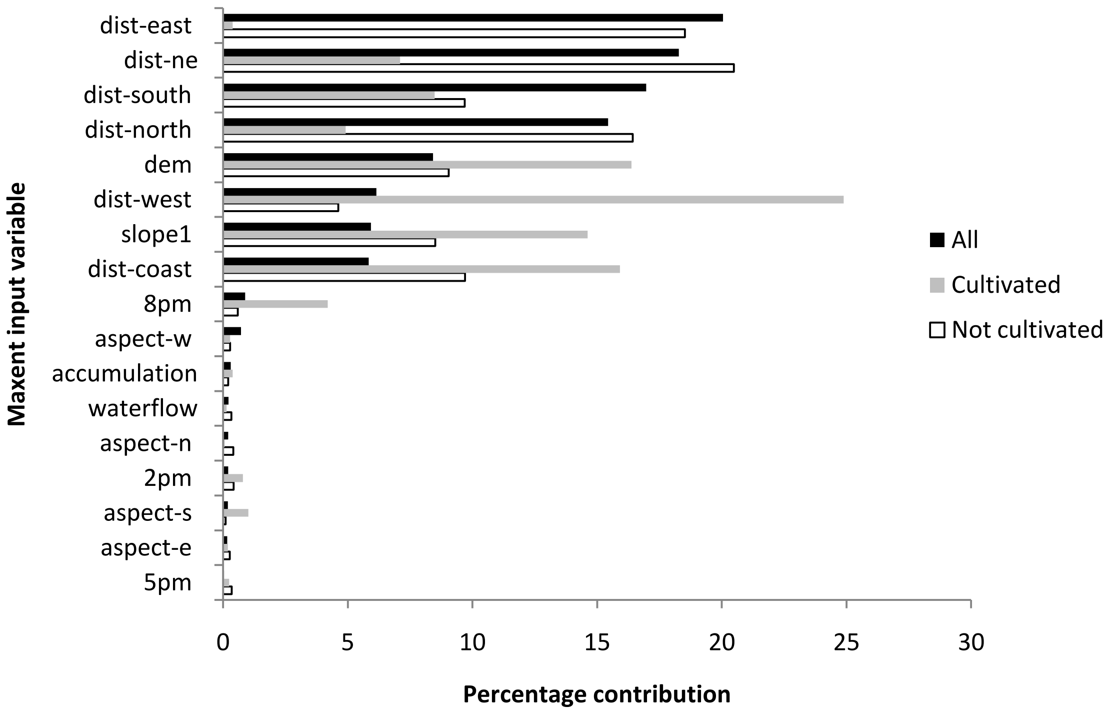


Figure 9. Percentage contribution of each environmental variable to the Maxent prediction of all non-native species, cultivated species and non-cultivated species on Montserrat.

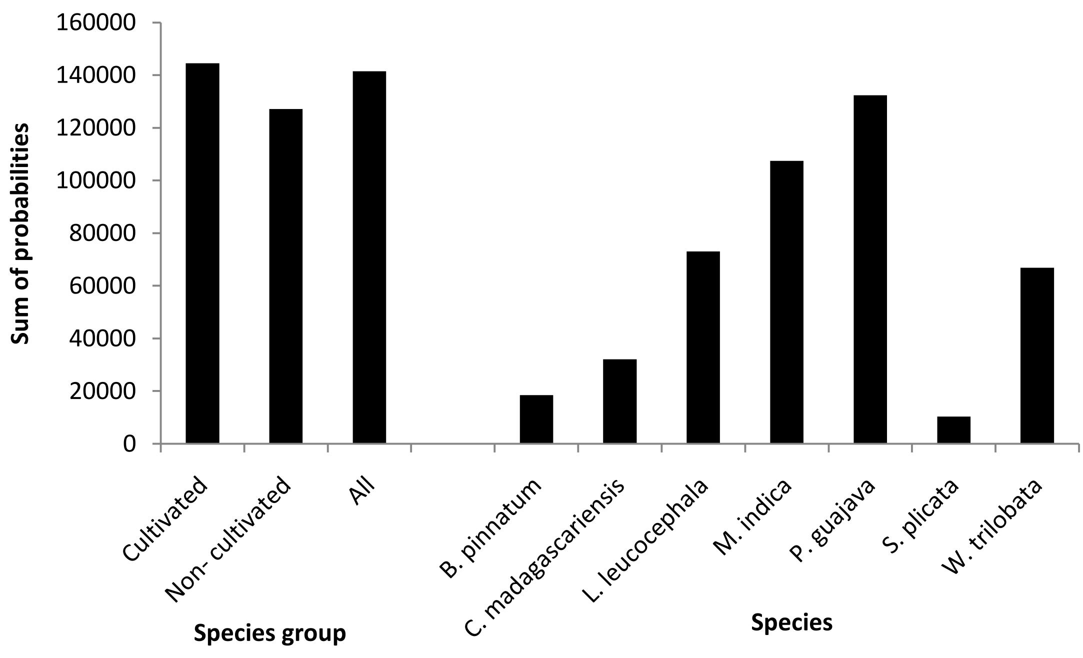


Figure 10. Sum of prediction probabilities for different groups of species and individual species.

4.7.2 Predicted range

The predicted range size differed for each species (fig. 11) with *P. guajava*, *M. indica* and *L. leucocephala* having the highest mean probability and sum of all probabilities indicating that these

NNS have the potential to be the most widespread.

Prediction maps for *L. leucocephala* and *M. indica* have sharp cut-off points indicating that the variables input for these species may not be the most appropriate ones and that further variables may need to be included. For all species but *L. leucocephala* the variables that contribute most to the prediction are distance to the South and North coast; *L. leucocephala* is best predicted by the distance to the North-East coast (See table 1, appendix B). It can be clearly seen that *B. pinnatum*'s and *C. madagascariensis*'s distribution is restricted to the northern part of the island where it is driest although the latter species has the potential to spread along the whole north-west coast. The areas with the highest likelihood of ocurrence for *M. indica, P. guajava* and *W. trilobata* are towards the centre of the island spreading towards the CHFR. *Leucaena leucocephala* seems to be restricted to areas of low to mid elevation. Although *S. plicata* has the smallest predicted distribution range it is predicted to be and has been recorded in this study within the CHFR and at the highest elevation in the Elfin Woodland.

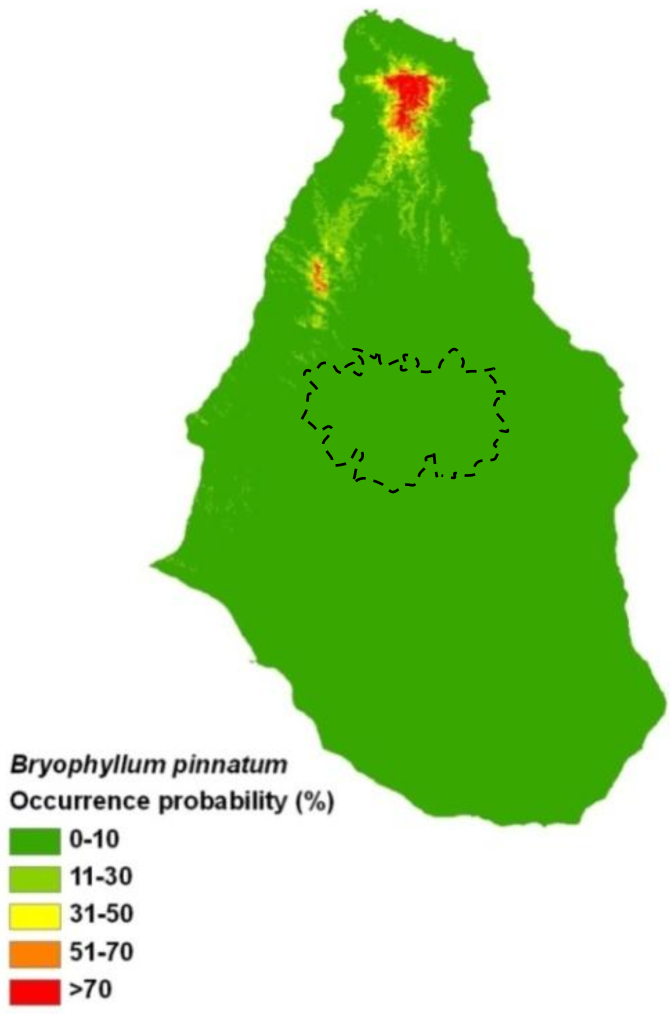
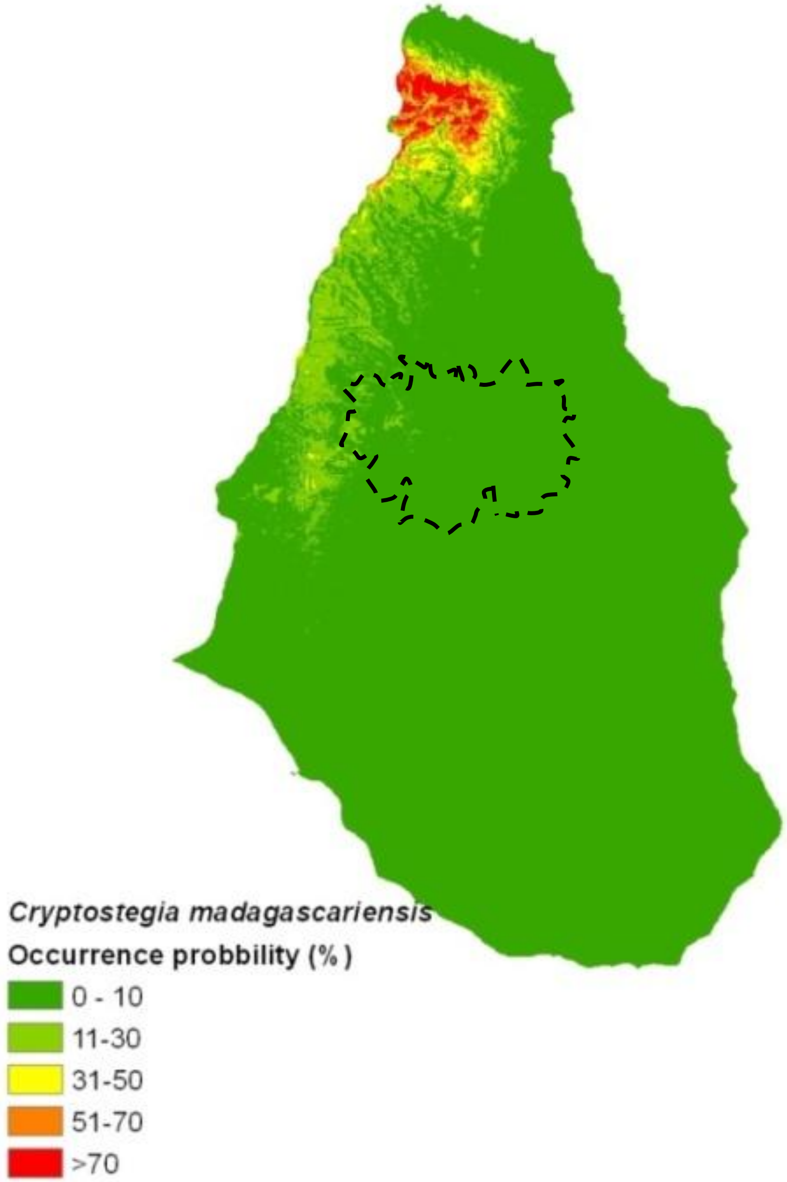


Figure11 . Prediction maps for *B. pinnatum, C. madagascariensis, L. leucocepahala, M. indica, P. guajava, S. plicata* and *W. trilobata* showing CHFR boundary (- - - -) and occurrence probability as a percentage



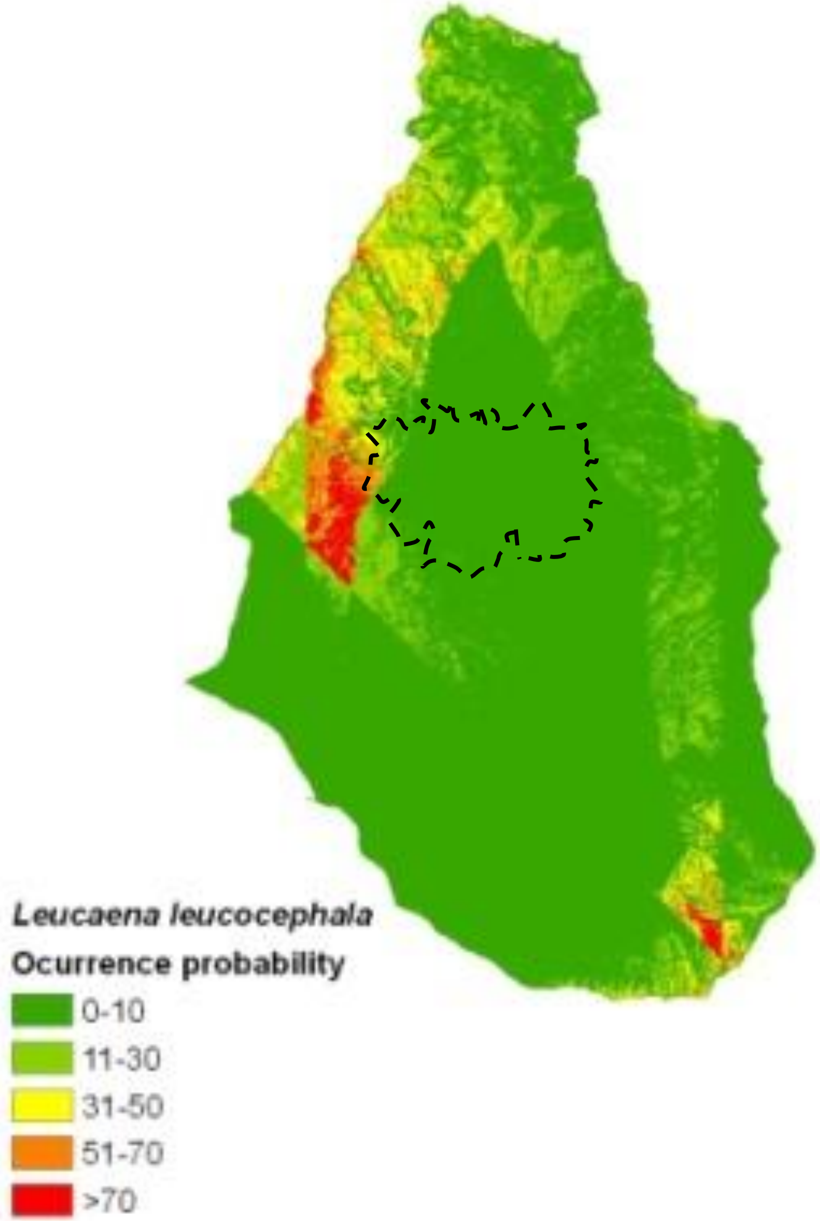
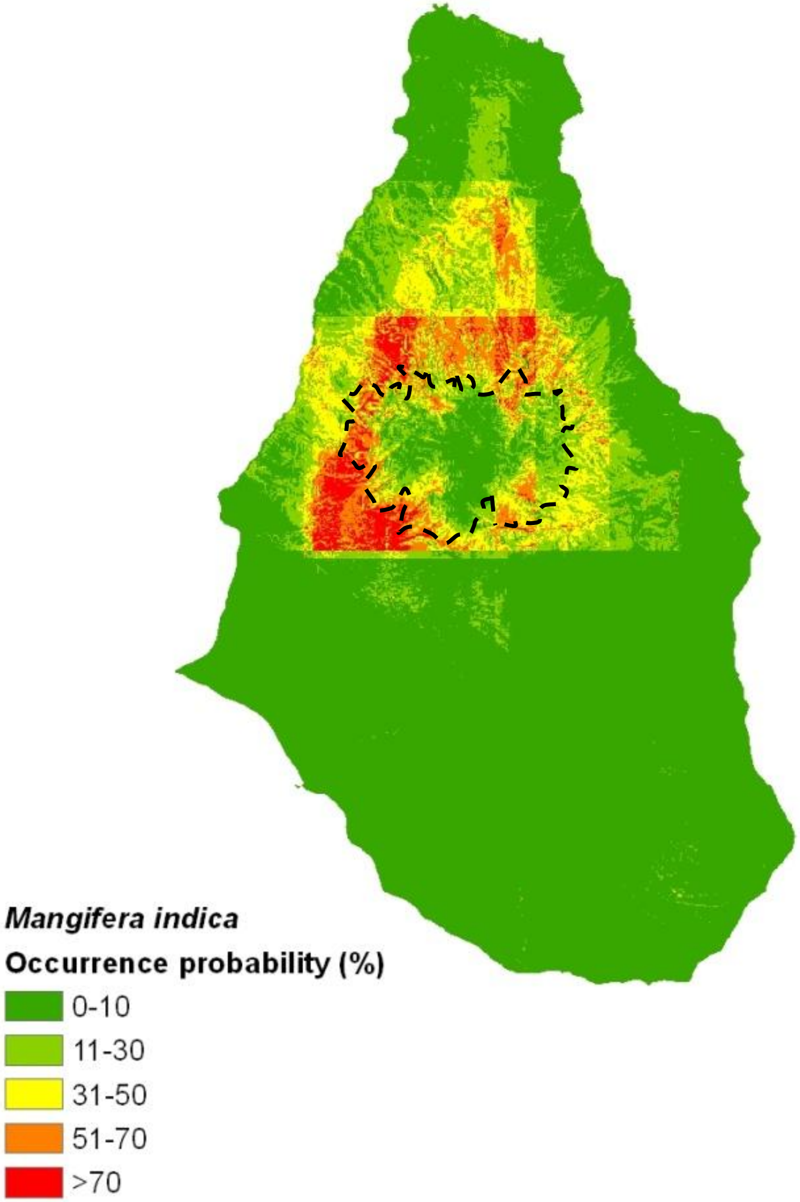


Figure 11 . cont.



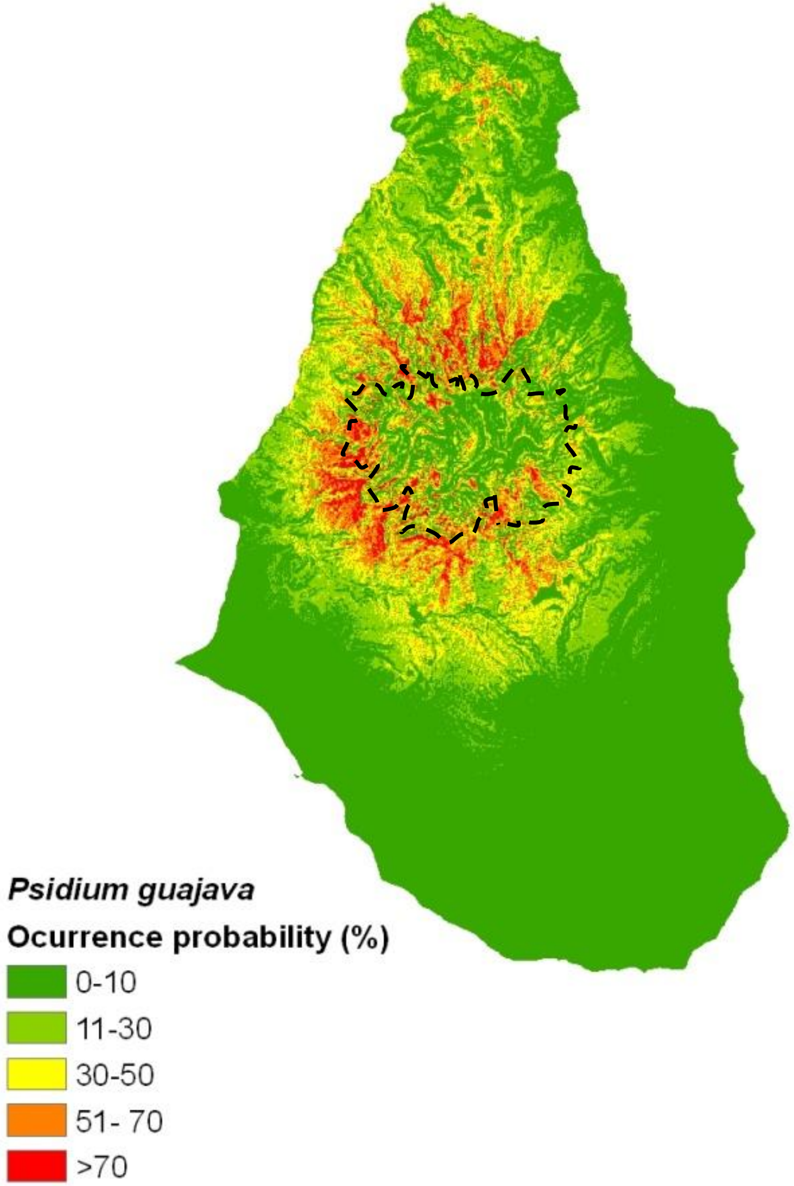


Figure 11 . cont.

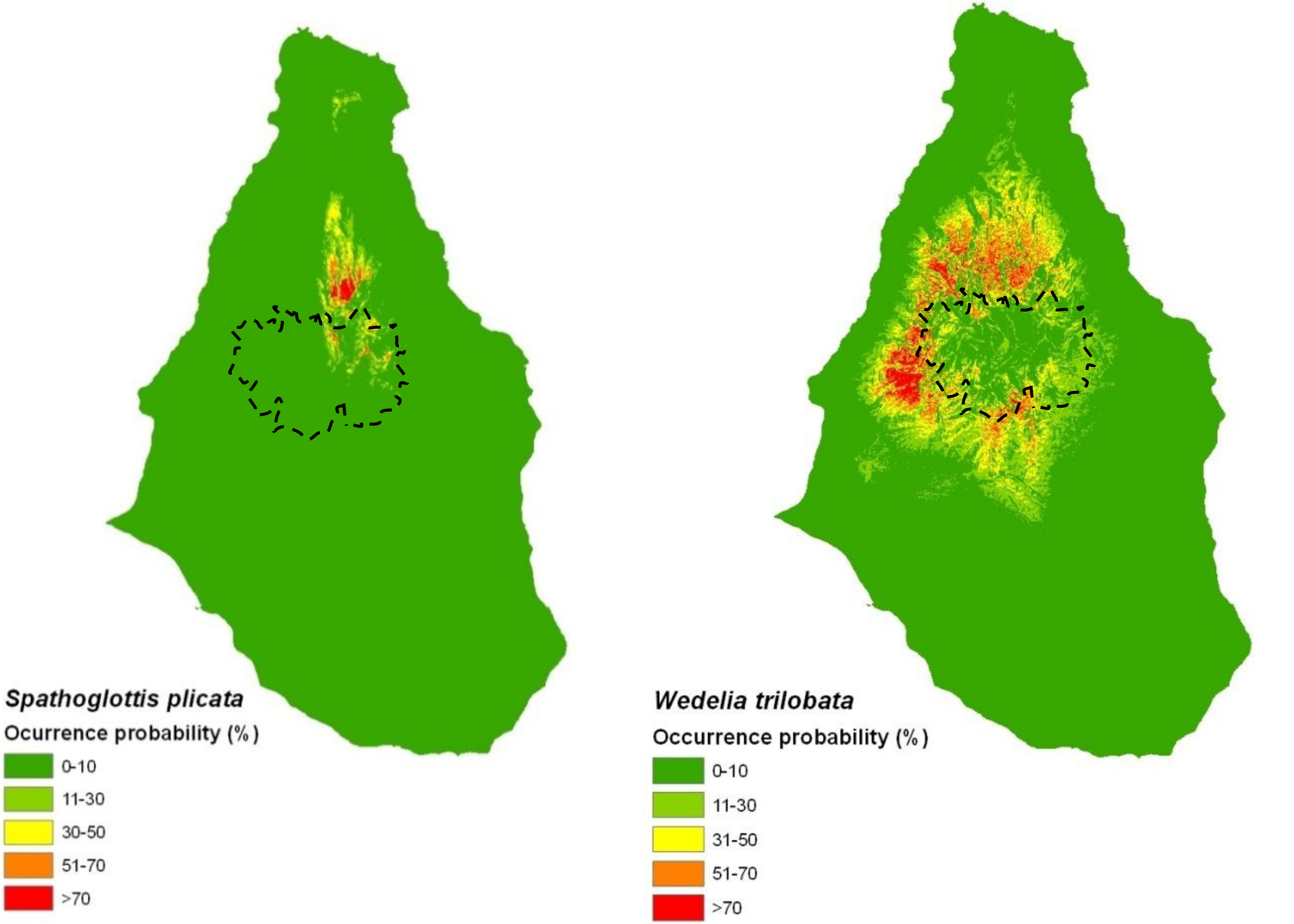


Figure 11 . cont.

5. Discussion

5.1 Overall NNS distribution

The habitat heterogeneity hypothesis proposes that some areas have a higher species richness due to the greater variety of habitat types (Báldi, 2008). Myklestad & Saetersdal (2004) (in Báldi, 2008) found that native species richness was correlated with habitat diversity. The significant positive correlation between NNS richness and number of disturbance types indicates that where the disturbance matrix is more diverse there are more opportunities for the establishment of non-native species. This is further supported by the lack of significant interaction between habitat and disturbance suggesting that it is not individual disturbance types that affects the amount of NNS that establish in an area. The size of each habitat is also a factor that needs to be considered; if habitat area size is correlated with NNS richness then size may be the main determining factor (Báldi, 2008). In the analyses of species richness per habitat the same number of sample points was used for each habitat so size is a factor that can be ruled out. It could be said that habitats with a greater variety of disturbances simply have a greater amount of disturbance yet anthropogenic, which is a more modified habitat than either dry or mesic forest, had a significantly lower NNS richness and number of disturbances than either of the former two habitats. This would need to be further investigated by sampling all disturbance types in all habitats in order to be able to compare them equally.

From a conservation perspective this study has highlighted that lowland habitats are at a greater risk from NNS than highland habitats corresponding to Baret *et al*'s (2006) findings. As in other Caribbean islands lowland habitats have suffered the greatest impacts from human occupancy (Young, 2008; Maunder et al, 2008) and on Montserrat habitats in this area have the greatest NNS richness. Several endangered plant species, *Swietenia mahagoni*, *Guaiacum officinale* and *Rhizophora mangle*, occupy these areas which currently have no protection (Hamilton *et al.*, 2008). The presence of known destructive invaders, namely *C. madagascariensis* and *L. leucocephala*, in these areas requires urgent attention in order to prevent further deterioration of these habitats.

The lack of large difference between NNS communities in different transects could be an indication of the homogeny of the overall NNS community. This could also be an effect of sampling as the target list consisted mainly of common NNS and McKinney and & La Sorte (2007) found that these abundant NNS were shared more often between different sites than rarer NNS. This could be tested for by sampling a larger diversity of the NNS community.

5.2 Individual NNS

As all sampling (with the exception of twenty recording points in the southern tip of Montserrat) was undertaken in the north and centre areas the ability to deduce accurately the invasive risk of NNS of Montserrat as a whole is limited. However, for the areas that were surveyed, which includes the CHFR, it will be possible to inform conservation decisions.

The two most widespread and frequent NNS, *P. guajava* and *M. indica*, have a long history of cultivation on Montserrat. However, unlike *M. indica, P. guajava*, known to be an aggressive invader by its fast growth rate and shading out other species (GISD, 2008), is a greater threat. From the predicted distribution the habitats that are most at risk are mesic and wet forest not only because this is where the spread is predicted but because these habitats contain vulnerable and endangered species.

The greatest concern from *M. indica* is its indirect effect on the ecosystem by providing a food source for rats allowing them to survive and proliferate (Young & Hilton, 2008). The management options for this species are not as clear-cut as may be the case with other NNS because it is also an important species for native flora and fauna. Eradication of the species, a solution that is usually perceived as the ideal one (Zavaleta *et al*, 2001), is likely to have detrimental effects on the ecosystem as well as be unpopular among the public. The endemic orchid, *Epidendrum montserratense*, often found growing on old mango trees (Hamilton *et al.*, 2005) and native bat species which feed on the mango fruit (Pederson *et al.*, 2008) would be but two endangered species that would suffer from their removal.

Some patterns seen in the data are explained by the type of species and its use. The fact that the most frequent species were those with a known human use provides support for the human-commensal hypothesis of invasion (Inderjit et al, 2005). On Montserrat humans have facilitated species invasion by not only directly introducing them but by indirectly providing opportunities for spread by disturbances such as roads. *Leucaena leucocephala*' s ability to grow in dry areas with poor soils means it is a prime coloniser of disturbed areas (NRC, 1984) and this is reflected in *L. leucocephala*'s current and predicted distribution in this study. The spread of other species on Montserrat is unlikely to have been aided by humans such as *R. rosifolius* and *S. plicata* which were found at the highest elevation in areas rarely frequented by humans (Martin, 2008, pers. com). Although the dispersal mechanisms of NNS on Montserrat has not been studied from observation in the field it is likely that *R. rosifolius* is being dispersed by birds highlighting the importance of considering all components of the ecosystem. This is also necessary for any conservation action as a modification in one species may affect others in the ecosystem (Zavaleta *et al.,* 2001).

The orchid *O. maculata* was originally introduced to Brazil from Africa as an ornamental species but has found its way to the Caribbean most likely via wind (Acevedo-Rodriguez, 1996). This suggests that it has potential to occupy a large range on Montserrat although within this study it accounted for 3% of all NNS recorded. However, this species may be at the lag stage of its invasion process (Mack, 1996) as it is a relatively recent arrival to the Caribbean (Hamilton, *et al.,* 2008). *Spathoglottis plicata* is a concern because it has been located within the highest altitudes of the wet forest; dispersal could be facilitated by occasional hikers though these areas. Gaining more information on the dispersal of these species would be both of scientific interest and of use in preventing further spread of these species.

Bryophyllum pinnatum and *C. madagascariensis* are both species of dry habitats whose establishment seems to be facilitated by disturbance by their frequent occurrence along roadsides (Vieira et al, 2004; PIER, 2008) and this was reflected in this study. These two species are closely associated in terms of spatial distribution either because they have similar dispersal dynamics or they could be facilitating each other following the invasional facilitation hypothesis (Inderjit et al, 2005).

Casuarina equisetifolia and *Ziziphus Mauritania* are considered 'major invasive threats' to the whole Caribbean region (Kairo *et al.,* 2003). *Ziziphus mauritania*, recorded only once throughout the study, is unlikely to be a threat on Montserrat although because southern areas have not been surveyed it is not possible to affirm this accurately. The relative frequency of *C. equisetifolia* was only 0.6% (eight presence points) but this is likely to be an under-representation as from observations it is known that this species is frequent in the south of the island (Clubbe and Hamilton, 2008, pers. comm.). This species is a threat in waiting as it is highly dipersable due to its small seeds and has toxic effects. It is also a resistant species as evidenced by the lack of leaf shedding after the 2003 volcanic explosion (Montserrat Centre Hills Project (MCHP) Newsletter, 2008). Complete removal of this species would be the ideal solution as in areas where it was originally planted for amenity purposes it can be replaced by native species. However, removal is a costly process and other non-native species might benefit from its removal so a thorough assessment would be required (Zavaleta *et al.,* 2001).

5.3 Factors driving NNS distribution

5.3.1 Environmental variables

The distribution of non-cultivated NNS is likely to be dictated more heavily by natural processes, e.g.: wind, animals, than that of their cultivated counterparts and from this study it is suggested that rivers and slopes are the variables that most heavily determine the presence of a non-cultivated NNS whereas these are not limiting factors in the distribution of cultivated species. It is not possible to extract with certainty the variables that are most responsible for NNS distribution due to the synergistic or antagonistic effects that variables have on each other.

5.3.2 Biological attributes

The lack of correlation between biological traits and species frequency or range size is unexpected considering most studies have found some traits to be significant (see Kolar & Lodge, 2001). The simplest conclusion to draw is that these attributes are not the main factors in determining the distribution of the species. Goodwin et al (1999) found that height was not significantly correlated with range size and suggested that other biological attributes are responsible for the range size and abundance of NNS. Using a model incorporating seed mass, juvenile period and interval between large seed crops to predict invasiveness of species, Rejmanek and Richardson (1999) found that invasive species with large seed masses that were dispersed by vertebrates were incorrectly classified as non-invasive.

The lack of significant relationship of biological traits with known cultivated species removed highlights the importance of propagule pressure and residence time. To test this the spatial distribution of each species needs to analysed in conjunction with known introduction locations (sufficiently detailed data for this might not be available however). Traditionally the highest human population density has been in southern areas of the island with mainly agricultural practices occurring in the north and centre of the island. An important factor in determining the area occupied by a non-native, both in terms of size and location, is the time of introduction (Lockwood et al, 2007) as longer established plant species tend to be more widespread (Kolar & Lodge, 2001; Pyšek *et al.*, 2004). No data was available for the time of introduction into Montserrat of each species but it is likely that the propagule pressure has been much less in the north of the island and has only increased in recent years since the volcanic explosion meaning plants have not yet had enough time to spread.

Most studies looking at biological characteristics use species datasets of over one-hundred species (Goodwin *et al.*, 1999; van Kleunen & Johnson, 2007). However, Rejmanek and Richardson (1997) looked at 24 species of pine and found significant effects of biological traits. Because the species they used are well known species information on several biological characteristics was available allowing them to test a greater variety of characteristics in order choose between which variables had the most significant effect.

Regressions against range and frequency, although not significant, provided different results supporting the findings of Pyšek and Jarošík (2005). It is therefore important to take into account the response variable that is being used to determine factors influencing NNS abundance.

5.4 Further research

5.4.1 Distribution of NNS

Understanding which factors contribute to the distribution of NNS is confounded and it is not possible to accurately state which factors are driving the distribution. For this further studies would be needed and further analyses could be applied to the data. The AIC for the models indicating which variables had the greatest effect on NNS presence were high and the amount of variation explained low suggesting that further variables are needed to account for the presence of NNS. Incorporating a measure for disturbance level into the models might yield further insights. It was not possible to adapt the data in this study because disturbance was assigned as a broad category and it is not known what the relative disturbance was between recording points.

The effects of the volcanic eruption on NNS distribution and spread have not been addressed in this study due to the inability to sample within areas most affected by the volcanic eruption and time constraints. However, this is an important issue to address for conservation on Montserrat from the aspect of the colonising of these areas by NNS. This will have to be formally quantified but from observations in the field it was seen that the species newly growing in areas disrupted by the volcano were NNS particularly *L. leucocephala*, *T. catappa* and *W. trilobata*. Members of the Asteraceae family are able to tolerate initial stressful conditions and from studies in Hawaii these are among the first colonisers of new volcanic deposit (del Moral & Grishin, 1999). *Wedelia trilobata* could therefore be more widespread than is predicted and should be further monitored.

Although the Sorensen index is appropriate for the present data-set values in the dissimilarity matrix created reflect the insensitivity of using presence-absence data. When the dataset is in binary format a there are more values below 0.5 (i.e.: more similar) than when the dataset is in abundance format (see table 2 appendix B). A mantel test using Spearman rank showed that the two matrices of dissimilarity values were significantly different (statistic r: 0.4972, $p < 0.001$). Using abundance data may therefore result in a more realistic representation of NNS but there is a trade-off with time. However, efficient sampling is important in any discipline particularly in conservation where both time and financial resources are scarce. Recording the presence or absence allowed a greater number of recording points to be undertaken ensuring sufficient replication and allowing a larger area to be covered (Shuster *et al.*, 2005). The trade-off in this study between sampling intensity and range size (Shuster *et al.*, 2005) is a positive one as a greater area was covered improving the accuracy of the NNS distribution mapping which can be used to inform conservation action.

Despite trying to place transects at distances to avoid auto-correlation in certain habitats, such as thicket, this was difficult due to the location and size of the habitat which is mainly restricted to the north of the island. A preliminary Moran's I test (carried out in ArcMap 9.0) showed that overall recording points non-natives were clustered (Moran's Index = 0.587912, Expected Index = -0.000679, Variance = 0.000372, Z Score = 30.510973). Spatial autocorrelation might be contributing to the results and to allow for this an autocorrelation coefficient needs to be integrated into the statistical analyses by using spatial autoregressive models following Dark, 2004.

5.4.2 Mapping

Although the prediction maps yielded applicable results the outputs from the prediction could be further analysed. Because the dataset comprises ‘true-absences’ it would be possible to test the prediction model using these instead of using only the test data. Maps could be further manipulated by overlaying habitat types (or other conservation units of interest) on the predicted range and calculating the percentage of each that is facing NNS occupancy in order to quantitatively assess invasiveness potential.

Spatial autocorrelation may be introducing bias into the prediction models in Maxent by (Pearson *et al.,* 2007). It would be possible to account for this by choosing test presence points and then removing all other points that were within a certain distance of it following Pearson *et al.,* (2007). They chose a distance of $10km^2$ based on the climatic and topographic conditions; due to Montserrat’s small size a considerably smaller distance would be needed ($10km^2$ is the length of Montserrat). However, because it is NNS that are being mapped an over-prediction is not as much of an issue as it would be if predicting the range of an endangered species, a precautionary approach is preferred to one that involves remediation.

Because flora and fauna are rarely free of human interaction and invasion pathways of species vary depending on their social and biological aspects it is not possible to predict the distribution of a species by looking solely at environmental factors (Fitzpatrick & Weltzin, 2005). Other factors need to be looked at such as the species characteristics; anthropogenic influence and interactions with other species in the ecosystem (Fitzpatrick & Weltzin, 2005). Producing a grid with a disturbance value at each co-ordinate would be time-consuming and probably unfeasible but grids could be made using disturbance surrogates such as distance to roads or population centres. The best way to model the impact of disturbance on NNS presence would be in spatial mapping software such as ArcGis where areas can be defined according to disturbance type/level and the likely presence or abundance of non-natives predicted.

5.5 Next steps

Because eradication or management programs are costly continued monitoring of NNS on Montserrat is required in order to detect any changes in NNS frequency and pre-empt any spread.

By surveying not only NNS that are likely to be invasive this study can set a basis for continued monitoring in order to identify any emerging invasive risks previously not envisaged. Investigation into the impacts that invaders are having on the native biodiversity and environment together with distribution information can inform conservation plans to manage these invaders and prevent future invasion. A better understanding of the NNS interaction with the native and non-native biodiversity will also be necessary before undertaking solutions such as removal (Zavaleta *et al.,* 2001). Maxent's ability to use a low sample size and user-friendliness may prove to be a particularly useful tool for determining the potential spread of NNS that are currently at low frequencies or have lower detectabilities than other NNS. This continued monitoring could be used to carry out risk assessments on NNS that emerge as high threats. identify priorities will help Montserrat to implement legislation necessary for the CBD and for the Global Strategy for Plant Conservation.

Although controlling and monitoring NNS is often seen as the main component of invasive species management plans the underlying cause of invasions, human actions, must also be addressed especially in the face of rising human population and migration. Raising awareness about NNS must therefore be a core part of the management process. The species description list in appendix A could serve as a basis for a 'users guide' to NNS on Montserrat. This should highlight both the risk to biodiversity and the economy in terms of agriculture and tourism. This guide needs to be concise and targeted to the correct audience; a guide with all NNS, even one with all 25 species in this study would dilute the message. Priority species need to be chosen, using findings from this study as a starting point.

The current distribution and frequency of potential invasive species on Montserrat is not yet at a level where all habitats are immediately threatened but given the location and spread rate of certain species it is an impending scenario. Implementing action targeted at NNS can be integrated with the existing programme of the MCHP in order address this issue now and prevent the reduction of Montserrat's biodiversity to 'biomonotony'.

6. References

Acevedo-Rodriguez, P. (1996) Flora of St. John, US Virgin Islands. *Memoirs of the New York Botanical Garden* **78:** 1 -581.

Báldi, A. (2008) Habitat heterogeneity overrides the species–area relationship. *Journal of Biogeography* 35: 675–681.

Baret, S., Rouget, M., Richardson, D. M., Lavergne, C., Egoh, B., Dupont, J. & Strasberg, D. (2006) Current distribution and potential extent of the most invasive alien plant specis on La Reunion (Indian Ocean, Mascarence Islands). *Austral Ecology,*31: 747-758.

Bhowmik, P. C. (2005) *Characteristics, significance, and human dimension of global invasive weeds.* Invasive Plants: Ecological and Agricultural Aspects. Ed. Inderjit. Birkhäuser, Verlag/Switzerland.

Brussel, D. E. (1997) *Potions, Poisons and Panaceas- An ethnobotanical study of Montserrat.* Southern Illinois University Press, Carbondale and Edwardsville, USA.

Center for Aquatic and Invasive Plants (2008) Aquatic, Wetland and Invasive Plant Particulars and Photographs. University of Florida. <http://aquat1.ifas.ufl.edu/node/22>

Conservation International (2007) Biodiversity Hotspots <www.biodiversityhotspots.org>, accessed 05/04/08

Convention on Biological Diversity (1992) <http://www.cbd.int/convention/convention.shtml>, accessed 25/05/08.

Colautti, R. I. (2005) In search of an operational lexicon for biological invasions. *Invasive Plants: Ecological and Agricultural Aspects*. Ed. Inderjit. Birkhäuser, Verlag/Switzerland.

Cook, B.G., Pengelly, B.C., Brown, S.D., Donnelly, J.L., Eagles, D.A., Franco, M.A., Hanson, J., Mullen, B.F., Partridge, I.J., Peters, M. and Schultze-Kraft, R. (2005) *Tropical Forages.* CSIRO, DPI&F(Qld), CIAT and ILRI, Brisbane, Australia. <http://www.tropicalforages.info/key/Forages/Media> accessed 06/07/2008

Crawley, M. (2005) *Statistics: An Introduction using R*. John Wiley and Sons, Ltd, .

Dark, S.J. (2004) The biogeography of invasive alien plants in California: an application of GIS and spatial regression analysis. *Diversity and Distribution* 10: 1-9.

del Moral, R & Grishin, S. Y. (1999) *Chapter 5: Volcanic Disturbances and Ecosystem Recovery*. Ecosystems of Disturbed Ground. Walker, L.R. (Ed.). Elsevier, Amsterdam.

Elith, J., Graham, C.H., Anderson, R.P., Dudik, M., Ferrier, S., Guisan, A., Hijmans, R.J., Huettman, F., Leathwick, J.R., Lehmann, A., Li, J., Lohmann, L., Loiselle, B.A., Manion, G., Moritz, C., Nakamura, M., Nakazawa, Y., Overton, J.M., Peterson, A.T., Phillips, S., Richardson, K., Schachetti Pereira, R., Schapire, R.E., Soberón, J., Williams, S.E., Wisz, M. & Zimmermann, N.E. (2006) Novel methods improve predictions of species' distributions from occurrence data. *Ecography*, **29**: 129–151.

Estrada, A. E. & Martinez, A. (2003) Los Generos de Leguminosas del Norte de Mexico. Botanical Research Institute of Texas, Texas, USA.

Fasham, M. J. R. (1977) A comparison of nonmetric multidimensional scaling, principal components and reciprocal averaging for the ordination of simulated coenoclines and coenoplanes. *Ecology* 58: 551-561.

Fitzpatrick, M. C. & Weltzin, J. F. (2005) Ecological niche models and the geography of biological invasions: a review and a novel application. *Invasive Plants: Ecological and Agricultural Aspects*. Ed. Inderjit. Birkhäuser, Verlag/Switzerland.

Freeman, J. P., Stohlgren, T. J., Hunter, M. E., Omi, P. N., Martinson< M., Chong, G, W. & Brown, C. S. (2007) Rapid assessment of postfire plant invasions in coniferous forests of the Western United States. *Ecological Applications*. 17(6): 1656-1665.

Global Invasive Species Database (2008) <http://www.issg.org/database>

Global Invasive Species Programme (GISP) (2008) Highlights of the Global Invasive Species Programme (GISP) at the 9th Conference of Parties (COP9) of the Convention on Biological Diversity (CBD), Bonn, Germany, 19-30 May 2008.

Goodwin, B.J., McAllister, A.J. &Fahrig, L. (1999) Predicting Invasivenss of Plant Species Based on Biological Information. *Conservation Biology* 13(2): 422-426.

Guisan, A., Edwards Jr., T.C. & Hastie, T. (2002) Generalized linear and generalized additive models in studies of species distribution: setting the scene. *Ecological modelling* 157: 89-100.

Hamilton, M., Clubbe, C., Robbins, S. K. & Bárrios, S. (2008) *Chapter 3: Plants and habitats of the Centre Hills and Montserrat.* Ed. Young, R. P. A biodiversity assessment of the Centre Hills, Montserrat. Durrell Conservation Monograph No.1

Hochstedler, W. W., Slaughter, B. S., Gorchov, D. L., Suander, L. P. & Stevens, M. H. H. (2007) Forest floor plant community response to experimental control of the invasive biennial, *Alliaria petiolata* (garlic mustard). *Journal of the Torrey Botanical Society* 134: 155-165.

Inderjit, Cadotte, M. W. & Colautti, R. I. (2005) *The ecology of biological invasions: past, present and future.* Invasive Plants: Ecological and Agricultural Aspects. Ed. Inderjit. Birkhäuser, Verlag/Switzerland.

Institute of Pacific Islands Forestry (2008) Pacific Island Ecosystems at Risk (PIER), <www.hear.org>, accessed 20/08/2008.

James, A. (2007) *An Illustrated Guide to Dominica's Botanic Gardens.* Forestry, Wildlife & Parks Division, Botanic Gardens. Roseau, Dominica.

Kairo, M., Ali, B., Cheesman, O., Haysom, K. & Murphy, S. (2003) Invasive Species Threats in the Caribbean Region. CAB International report to the JNCC

Kenkel, N. C. & Orlóci, L. (1986) Applying metric and nonmetric multidimensional scaling to ecological studies: some new results. *Ecology* 67(4): 919-928.

van Kleunen, M. & Johnson, S. D. (2007) Effects of Self-compatibility on the Distribution Range of Invasive European Plants in North America. *Conservation Biology* 21(6): 1537-1544.

Kolar, C. S. & Lodge, D. M. (2001) Progress in invasion biology: predicting invaders. *TRENDS in Ecology & Evolution* 16 (4): 199-204.

Kruskal, J. B. (1964) Multidimensional scaling by optimizing goodness of fit to a nonmetric hypothesis. *Psychometrika* 9(1): 1-27.

Lloret,F., Medail, F., Brundu, G., Camarada, I., Moragues, E., Rita, J., Lambdon, P. & Hulme, P.E. (2005) Species attributes and invasion success by alien plants on Mediterranean islands. *Journal of Ecology*, 93: 512-520.

Looman, J. & Campbell, J. B. (1948) Adaptation of Sorensen's K for Estimating Unit Affinities in Prairie Vegetation. *Ecology*, 41 (3): 410-416.

Mack, R. N. (1996) Predicting the Identity and Fate of Plant Invaders: Emergent and Emerging Approaches. *Biological Conservation* 78: 107-121.

Mack, R.N., Simberloff, D., Lonsdale, W. M., Evans, H., Clout, M. & Bazzaz, F.A. (2000) Biotic Invasions: Causes, Epidemology, Global Consequences and Control. *Ecological Applications* 10(3): 689-710.

Mauchamp, A. (1997) Threats from Alien Plant Species in the Galapagos Islands. *Conservation Biology* 11(1): 260-263.

Maunder, M., Leiva, A., Santiago-Valentin, E., Stevenson, D. W., Acevedo-Rodriguez, P., Meerow, A. W., Meija, M., Clubbe, C. & Francisco-Ortega, J. (2008) Plant Conservation in the Caribbean sland Biodiversity Hotspot. *Botanical Review* 74*:* 197-207.

McKiney, M. I. & La Sorte, F. A. (2007) Invasiveness and homogenization: synergism of wide dispersal and high local abundance. *Global Ecology and Biogeography* **16:** 394-400.

Montserrat Centre Hills Project (MCHP) Newsletter, 2008. MALHE

National Research Council (1984) *Leucaena: Promising Forage and Tree Crop for the Tropics.* Second edition. National Academy Press, Washington, D.C.

Oldfield, S. (1987): *Fragments of Paradise: a guide for conservation action in the UK Dependent Territories*. Pisces Publications, Oxford.

Okansen, J. (2008) Vegan: R functions for vegetation ecologists. <http://cc.oulu.fi/~jarioksa/softhelp/vegan.html>

Parendes, L. A. & Jones, J. A. (2000) Role of Light Availability and Dispersal in Exotic Plant Invasion along Roads and Streams in the H.J. Andrews Experimental Forest, Oregon. *Conservation Biology* 14(1): 64-75.

Pearson, R.G., Raxworthy, C. J., Nakamura, M. & Townsend Peterson, A. (2007) Predicting species distributions from small numbers of occurrence records: a test case using cryptic geckos in Madagascar. *Journal of Biogeography* 34: 102-117.

Pedersen, S. C., Young, R.P., Morton, M. N. & Masefield, W. (2008) Chapter 7: Bats of the Centre Hills and Montserrat Ed. Young, R. P. A biodiversity assessment of the Centre Hills, Montserrat.

Phillips, S. J., Anderson, R. & Schapire, R. (2006) Maximum entropy modelling of speciesgeographical distributions. *Ecological Modelling* 190: 231-259.

Phillips, S. J. & Dudik, M. (2007) Modeling of species distributions with Maxent: new extensions and a comprehensive evaluation. *Ecography* 31: 161-175.

Pyšek, P. & Jarošík, V. (2005) Residence times determines the distribution of alien plants. *Invasive Plants: Ecological and Agricultural Aspects*. Ed. Inderjit. Birkhäuser, Verlag/Switzerland.

Pyšek, P., Richardson, D. M. & Willimason, M. (2004) Predicting and explaining plant invasions through analysis of source area floras: some critical considerations. *Diversity and Distributions*, 10: 179-187.

R documentation. (**200**8) Dissimilarity Indices for Community Ecologists- Vegan package.

Rejmanek and Richardson (1996) What attributes make some plant species more invasive? *Ecology* 77 (6): 1655-1661.

Shaw, P. J. A (2003) *Multivariate Statistics for the Enviromental Sciences*. Hodder Arnold, London.

Shuster, W.D., Herms, C.P., Frey, M.M., Doohan, D.J., Cardina, J. (2005) Comparison of survey methods for an invasive plant at the subwatershed level. *Biological Invasions*. 7: 393-403.

Townsend Peterson, A., Papes, M. & Eaton, M. (2007) Trasferability and model evaluation in ecological niche modelling; a comparison of GARP and Maxent. *Ecography* 30: 550-560.

Townsend Peterson, A., Papes, M. & Kluza, D. A. (2003) Predicting the potential invasive distributions of four alien speciesin North America. *Weed Science* 51: 863-868.

Underwood, E. C., Klinger, R., Moore, P.E. (2004) Predicting paterns of non-native plant invasions in Yosemite National Park, California, USA. *Diversity and Distributions* 10: 447-459.

Underwood, E., Ustin, S., DiPietro, D. (2003) Mapping nonnative plants using hyperspectral imagery. *Remote Sensing of Environment* 86: 150–161.

Varnham, K. (2006) Non-native species in UK Overseas Territories: a review. *JNCC Report No. 372*

Vieira, M.F., Leite, Oliveira, M.S.O., Grossi, J. A. S., Alarenga, E.M. (2004) Biologia Reprodutiva de *Cryptostegia madagascariensis* Bojer Ex Dence. Periplocoideae, Apocynaceae), Especie ornamental e exotica no Brasil. *Bragantia, Campinas* 63(3): 325-334.

Wearne, L. J. & Morgan, J. W. (2004) Community-level changes in Australian sub-alpine vegetation following invasion by the non-native shrub *Cytisus scoparius*. *Journal of Vegetative Science* 15: 595-604.

Young, R. P. & Hilton, G. M (2008) *Chapter 2. Background to the Centre Hills biodiversity assessment*. Ed. Young, R. P. A biodiversity assessment of the Centre Hills, Montserrat.

Young, R. P. & Hilton, G. M. & Martin, L.(2008) *Chapter 1: Biodiversity of the Centre Hills: importance, key features, conservation priorities and recommended actions*. Ed. Young, R. P. A biodiversity assessment of the Centre Hills, Montserrat.

Zavaleta, E. S., Hobbs, R. J. & Mooney, H. A. (2001) Viewing invasive species removal in a whole-ecosystem context. *TRENDS in Ecology & Evolution* **16(8):** 454-459.

Zechmeister, H.G., T. Dirnböck, K. Hülber & M. Mirtl, C. (2007) Assessing airborne pollution effects on bryophytes – lessons learned through long-term integrated monitoring in Austria. *Environmental Pollution* 147(3): 696-705.

Zhu, L., Osbert, J. S., Sang, W., Zhenyu, L. & Ma, K. (2007) Predicting the spatial distribution of an invasive plant species (*Eupatorium adenophorum*) in China. *Landscape Ecology* 22:1143-1154.

APPENDIX A

Table 1. Species surveyed, their origin and reason for being introduced. The local name refers to the species names in Montserrat, for those that the local name is unknown the common name is given in italics. Agricultural refers to plant species that are harvested but not for human consumption. When the reason for introduction is unknown this is due either to the species having several important uses or not known to having been deliberately introduced. Data was compiled from expert knowledge, herbarium information (ALUKA and Kew Herbarium), online databases (Center for Aquatic and Invasive Plants and CSIRO) and literature.

Species	Local name (*common name*)	Origin	Reason for introduction	Synonyms of scientific name
Acacia nilotica	*Gum*	Africa	Unknown	
Azadirachta indica	Neem	Southern India	Agricultural	
Bryophyllum pinnatum	Love-bush	Madagascar	Household	Kalanchoe pinnatum
Calotropis procera		Indian sub-continent	Agricultural	
Carica papaya	Papaya	Tropical America	Food	
Casuarina equisetifolia		Australia	Amenity	
Catharanthus roseus	*Madagascar periwinkle*	Madagascar	Unknown	
Crescentia cujete	Calabash	Central America	Household	
Cryptostegia madagascariensis	Purple Allamanda	Madagascar	Ornamental	
Dieffenbachia seguine	Dumb cane			
Flacourtia jangomas			Unknown	
Gigantochloa	Bamboo	Old World Tropics	Agricultural	
Hevea brasiliensis	Rubber Tree		Agricultural	
Jatropha gossypifolia			Unknown	
Leucaena leucocephala	Leucaena	Mexico and Central America	Animal fodder	*Leucaena glauca*, *Mimosa leucocephala*
Mangifera indica	Mango	Tropical Asia	Food	
Nicotiana tabacum	Tobacco		Agricultural	
Oeceoclades maculata		Tropical africa	Unknown	
Psidium guajava	Guava	Central America to northern South	Food	

		America	
Hedychium spp.	Ginger		Food
Ricinus communis	Castor Oil Plant		Agricultural
Rubus rosifolius			Food
Sansevieria trifasciata	Mother in laws tongue		Amenity
Spathoglottis plicata		Asia	Ornamental
Terminalia catappa	(West) Indian Almond	Indian sub-continent	Food
Triphasia trifolia	Sweet lime	China	Unknown
Wedelia trilobata	Sage grass	Tropical America	Unknown
Ziziphus mauritiana	*Jujube*	Africa	Food

Box 1. Description of non-native species surveyed on Montserrat. Information is not complete for all species. All photographs taken by S. Stow.

***Azadirachta indica*- Neem**
Family: Meliaceae
Native to: Southern India

History on Montserrat: Hailed as a 'miracle tree': planted due to its potential economic value as several products can be gained from it such as insect repellant, medicine and timber (Brussel, 1997; James, 2007). Currently used on a small scale with some people utilising the leaves as pesticide for the household (Martin, pers. comm.) and also as a source of nectar for honey bees (Nixon, pers. comm.).

Key Identification features: Fragrant white/yellow flower; compound leaves; serrated leaflets

***Bryophyllum pinnatum*- Love bush, Love leaf, Leaf of Life**
Famliy: Crassulaceae
Native to: Madagascar

History on Montserrat:
Used in the household as soap (Fenton, pers. comm) and can also be used

Figure 2 Flower of *Bryophyllum pinnatum*.

swelling. Tea made from the flowers is said to have opiate-like effects (Brussel, 1997).

Figure 3 ***Bryophyllum pinnatum*** **seed capsules.**

Invasive risk:

Small seeds which are wind dispersed allowing it to spread easily.

Key identification features:

Succulent mid-green leaves with red edges; tubular light red flowers

Calotropis procera

Famliy: Apocynaceae

Native to: Indian sub-continent

History on Montserrat:

Recorded very few times, always in small numbers and by human settlements. However, some have been recorded away from human settlement such as in the Silver Hills. It was most likely intentionally introduced for harvesting of its fiber that can be made into cloth (Britannica Encyclopedia online).

Figure 4 Calotropis procera flowers and leaves.

Key identification features:

Large round leaves with obvious light green veins; bright purple flowers; soft flesh green fruit.

Figure 5 Calotropis procera fruit.

***Carica papaya*- Pawpaw**

Family: Caricaceae

Native to: Tropical America

History on Montserrat:

Cultivated for human consumption. Also reputed to have healing properties for kidney problems, ringworm and insect stings. The black seeds can be used as a substitute for black pepper (Brussel, 1997).

Key identification features:

Smooth lobed leaves (unlike castor oil that has rough stems); fruit and flowers emerge from main stem under leaves; fruit ripen from green to bright orange; bright orange flesh with round black seeds. Male and female parts are located on different plants resulting in different flowers.

Figure 6 Carica papaya leaves and fruits.

Figure 7 Carica papaya unripe fruits.

Figure 8 Carica papaya fruits eaten by a bird.

Casuarina equisetifolia-

Family: Casuarinaceae

Native to: Australia

History on Montserrat:

Widely planted over the world for amenity and infrastructure purposes. Planted to reduce soil erosion.

Invasive risk:

Its biological characteristics make it a very resistant plant: produces many small winged seeds that have a wide dispersal range by wind and water; establishes readily on disturbed areas except those prone to flooding; very resistant to salt spray. It grows rapidly altering the light, temperature and soil climate reducing the habitat suitability for other plant species. It can also directly inhibit growth of other species due to the chemicals it exudes from its leaves. (Global Invasive Species Database, 2008).

Key identification features:

Needle-like leaves; fruits1-2cm cones; distinctive noise as the wind passes through the branches.

***Catharanthus roseus*- Madagascar periwinkle (12 o'clock)**

Family: Apocynaceae

Native to: Madagascar

History on Montserrat:

Introduced as an ornamental plant in gardens and on a smaller scale to harness its medicinal uses. Tea made from leaves and roots to treat strains, cancer, diabetes, high blood pressure.(Brussel, 1997).

Key identification features:

Bright pink flowers with five petals

***Crescentia cujete*- Calabash**

Family: Bignoniaceae

Native to: Central America

History on Montserrat:

Introduced by the Carib indians around the 1500s (Brussel, 1997). Important tree in the Caribbean due to its large fruit and medicinal uses (James, 2007). The fruit is inedible but used to make various parephenalia e.g.: bowls; the seeds are cooked and eaten (Brussel, 1997).

***Figure 9 Crescentia cujete* fruit; note it is growing from the branch as are the leaves.**

Key identification features:

Leaves and fruit grow from branches; large green fruit.

***Cryptostegia madagascariensis*- Purple Allamanda**

Family: Apocynaceae

Native to: Madagascar

***Figure 11 Cryptostegia madagascariensis* buds, flowers and leaves.**

***Figure 10 C. madagascariensis* open seed pod with seeds.**

History on Montserrat:

As in other parts of its non-native range it was originally introduced as an ornamental garden plant and then escaped into the wild.

Invasive risk:

Known to be dominant in disturbed areas due to its ability to grow over other vegetation. Produces many seeds.

Key identification features:

Large 5-petalled purple flowers with no odour; if leaf, petal or stem cut a white substance exudes; large seed pods containing many seeds with long white filaments for wind dispersal.

***Dieffenbachia seguine*- Dumbcane**

***Figure 12 Dieffenbachia seguine.* Note vegetative stems on ground.**

Family: Araceae

Native to:

History on Montserrat:

Roots,stems, leaves boiled with bait as rat poison. Stems and petioles can indice abortion. Planted along the boundaries of plantations.

Invasive risk:

Propagates well from cut stems

Flacourtia jangomas

Family: Salicaceae

Native to:

***Figure 14 Flacourtia jangomas* fruit.**

***Figure 13 F. jangomas* buds and flowers.**

History on Montserrat:

Fruits can be eaten raw and are also eaten cooked in sweet dishes (Brussel, 1997).

Key identification features:

Small white flowers; fruits ripen from green to red; flowers and fruit grown at leaf base; leaf edges serrated; leaves arranged alternately on branched.

***Gigantochloa spp*- Bamboo**

Family: Poaceae

Native to: Old World Tropic

History on Montserrat: Introduced as an ornamental plant (observed in gardens) and for its use in utensil making: cups, fishing poles, furniture (Brussel, 1997). There is also a medicinal benefit as all parts can be boiled and the tea drunk to cure colds.

Key identification features:

Long stems with distinctive rings;

***Hedychium spp.*- Ginger**

Family: Zingeberaceae

Native to:

History on Montserrat:

Introduced for cultivation as a food crop. The roots are used as a spice and beer is also made from them (Brussel,

Figure 15* Flower and leaf of *Hedychium spp.

1997).

***Hevea brasiliensis*- Rubber**

Family: Bignoniaceae

Native to:

History on Montserrat:

Introduced as a cash crop. Now is no longer harvested.

Key identifcation features:

Large dark-green leaves; very tall (up to 30m) with straight trunks; fruit and flowers grow from stems so gives stems a 'knobbly' appearance; when bark cut exudes thick white-yellow substance (the 'rubber').

***Figure 16 Hevea brasiliensis* top branches with leaves and flowers growing from stems.**

***Figure 17* Cut bark of *H. brasiliensis* exuding 'rubber'.**

Leucaena leucocephala

Family: Leguminosae- mim

Native to: Native to Mexico and Central America

History on Montserrat:

Likely to have been introduced as a fast-growing livestock feed and hedge.

Invasive risk:

Produces many seeds and establishes itself quickly particularly in disturbed areas.

Key identification features:

Seed pods located at end of stems- 'finger-like'; white 'pom-pom' flowers, sometimes yellow.

***Mangifera indica*- Mango**

Family: Anarcardiaceae

***Figure 18 Mangifera indica* flower and leaves.**

Native to: Tropical asia

History on Montserrat:

Introduced as a food crop, often planted at the edge of plantations for food (Martin, pers. comm.). The fruit has a variety of uses eaten not only raw but also made into preserves. The leaves are used to treat: intestinal worms, colds, sinus, coughs, arthritis, asthma. The bark and leaves can be used to make a yellow bye (Brussel, 1997).

Invasive risk:

This tree is a food source for a variety of animals, not least humans. The potential range of dispersal of its seed it therefore great. Its largest threat is not so much its direct impact on native flora and fauna but more the food source that it provides to rats.

Key identification features:

Large round fruits which ripen from green to orange-red; long and narrow dark green leaves with mid-green veins; small yellow to pink flowers arranged around a spike.

***Nicotiana tabacum*- Tobacco**

Family: Solanaceae

Native to:

History on Montserrat:

Cultivated for various uses as observed by Brussel (1997): tea from leaves as a sedative and for colds; fresh or dried leaves used as a bandage for wounds and blisters; heated leaves serve to relieve pain; chewing leaves sooths toothache and when smoked has an antispasmtic effect.

Oeceoclades maculata

Family: Orchidaceae

Native to: Africa

Figure 19Leaves of Oeceoclades maculata.

History of Montserrat:

Sparsely distributed when recorded and usually in low numbers. Exception was transect from Soldier Ghaut to Oriole Walkway where there was a relatively high total amount despite beaing sparsely distributed.

Invasive risk:

Potential invasive as seems to occupy disturbed areas.

Key identifcation features:

Mottled leaves of mid and dark green; flowers white

***Psidium guajava*- Guava**

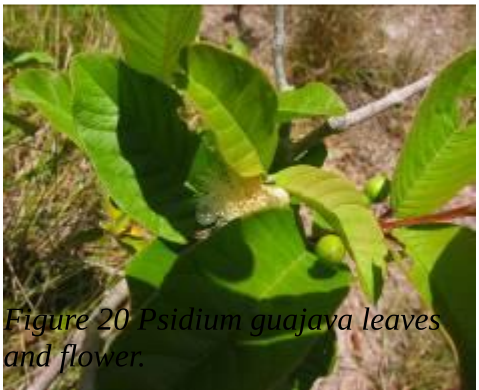


Figure 20 Psidium guajava leaves and flower.

Family: Myrtaceae

Native to: Central America from Mexico to northern South America, and Lesser Antilles (GISDB)

History on Montserrat:

Major crop plant.

Invasive risk:

Known to be a major threat in other areas of its range as is able to spread quickly when not cultivated.

Key identification features:

Round fruit; white flowers with many stamen; leaves and stems rough;

***Ricinus communis*- Castor-oil Plant**

Family: Euphorbiaceae

Native to:

***Figure 21 Ricinus communis* fruits and yellow flower on bottom left.**

***Figure 22 Ricinus communis* leaf.**

History on Montserrat:

Recorded in areas that have been under cultivation.

Tea from leaves for high blood pressure, skin raches, stomach distress, and fevers. Leaves heated for painand swelling. Poison in seeds giving gastroenteritis.

Rubus rosifolius

Family: Rosaceae

Native to:

Figure 23Rubus rosifolius fruit and leaves.

History on Montserrat:

Brussel (1997) recorded this plant as being used to treat diarrhea using the leaves and roots. The berries by contrast have a laxative effect although they are used to make jam etc.

Key identification features:

Bright red berries; leaves with five serrated leaflets ;small spines.

***Sansevieria trifasciata*- Mother in Laws Tongue**

Family: Dracaenaceae

Native to:

History on Montserrat:

Planted for amenity purposes.

Key identification features:

Sword-shaped succulent leaves to 1m growing in clumps; mottled mid-green and light-green; edges with red-brown colour.

Figure 24Sansevieria trifasciata leaf.

Jatropha gossipifolia

Family: Euphorbiaceae

History on Montserrat:

Unknown

Key identification features:

Three-lobed dark red leaves, 5-petalled small red flowers.

Figure 25 Jatropha gossypifolia leaves, flowers and young fruit.

Spathoglottis plicata

Family: Orchidaceae

Native to: Asia

History on Montserrat:

Escaped from cultivation in Puerto Rico and is spreading throughout the caribbean (MBA, 2005). Introduced as an ornamental garden plant due to its attractive pink flowers.

Key identification features:

Long leaves; deep pink flowers; can grow to 1m; usually growing from ground.

Invasive risk:

Potential to out-compete and shade out native plants.

Figure 27 Spathoglottis plicata growing in abandoned farmland.

Figure 26Spathoglottis plicata gorwing in upper wet forest.

***Terminalia catappa*- (West) Indian Almond**

Family: Combretaceae

Native to: Indian sub-continent

Figure 28Terminalia catappa leaves, fruits and flower spikes.

History on Montserrat:

Introduced as a fruit crop.

Invasive risk:

Fruits are eaten by animals, particularly fruit bats (James, 2007) and so have the potential to be diespersed widely.

Key identification features:

Large leaves; fruits

***Triphasia trifolia*- Sweet lime**

Family: Rutaceae

Native to: China

Figure 29 Triphasia trifolia ripe fruit.

History on Montserrat:

The berries are edible and their juice is reported to be used as a substitute for nail polish (Martin and Daley, pers. comm). The leaves and fruits can be made into a beverage and a treatment for cold when boiled (Brussel, 1997).

Invasive risk:

Can form thickets and shade out lower-lying vegetation.

Key identification features:

Figure 30Triphasia trifolia leaves.

Shrub to 1.5m tall; leaves formed of three leaflets with the middle leaflet being significantly larger; spines present at base of leaf; fruits shaped like small lemons ripen from green to red; if fruit or leaf cut there is a distinctive sweet citrus odour.

***Wedelia trilobata*- Sage grass** (Scriber) or **Graveyard grass**(Gambi)

Figure 31 Wedelia trilobata flowers and stems trailing up a tree trunk.

Family: Asteraceae

Native to: Tropical America

History on Montserrat:

Brussel (1997) recorded that the leaves, flowers and stems have been made into tea to treat asthma, colds and also to induce abortion. This plant may have been brought over for cultivation or have been accidentally introduced from seeds.

Invasive risk:

Forms dense mats and grows over other ground vegetation ultimately shading it out.

Key identification features:

Bright yellow daisy-like flowers

APPENDIX B

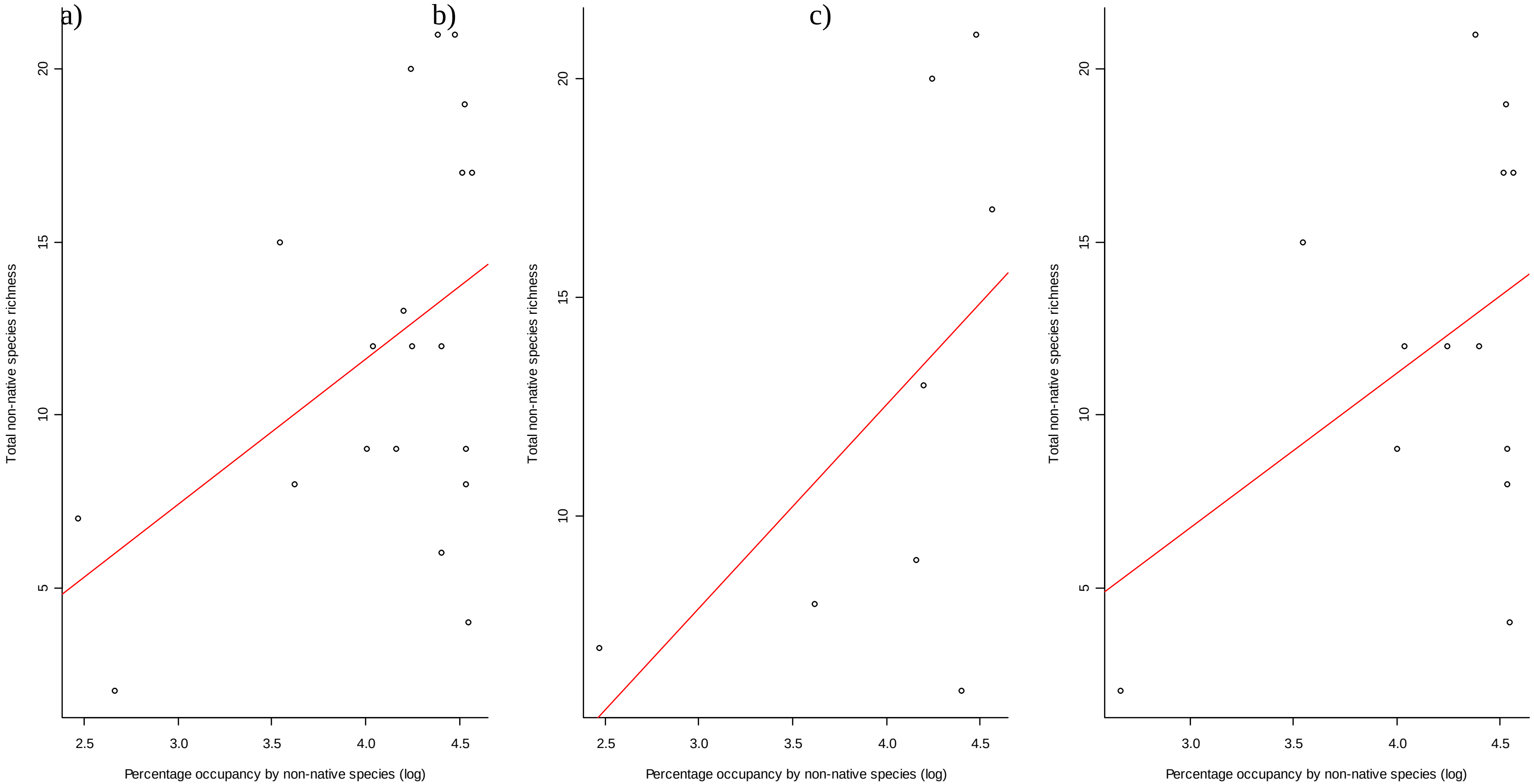
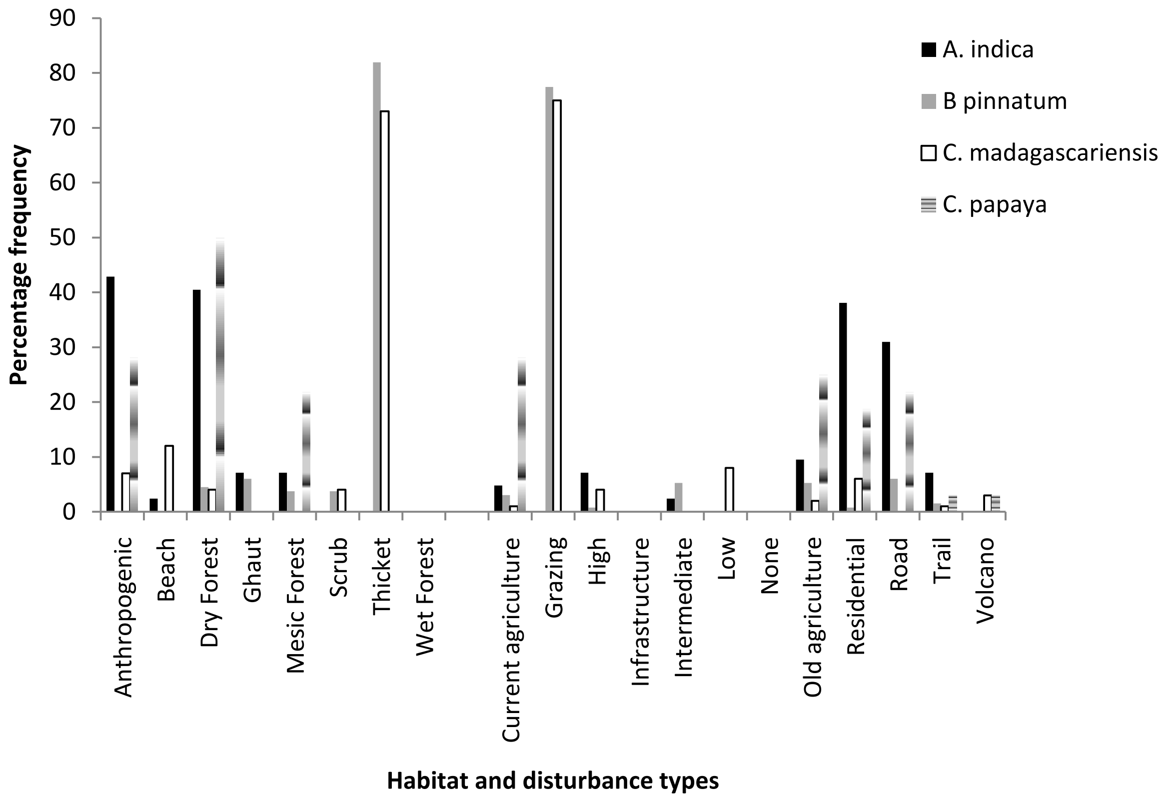


Figure 32. Correlation plot with best-fit line between NNS richness and percentage occupancy of a) both habitat types and disturbance categories (cor=0.444,dF=18, R^2=0.197, p=<0.05); b) only habitat types (cor=0.532, dF=6, R^2=0.283, p>0.05) and c) only disturbance categories (cor=0.433, dF=11, R^2=0.188, p>0.05).



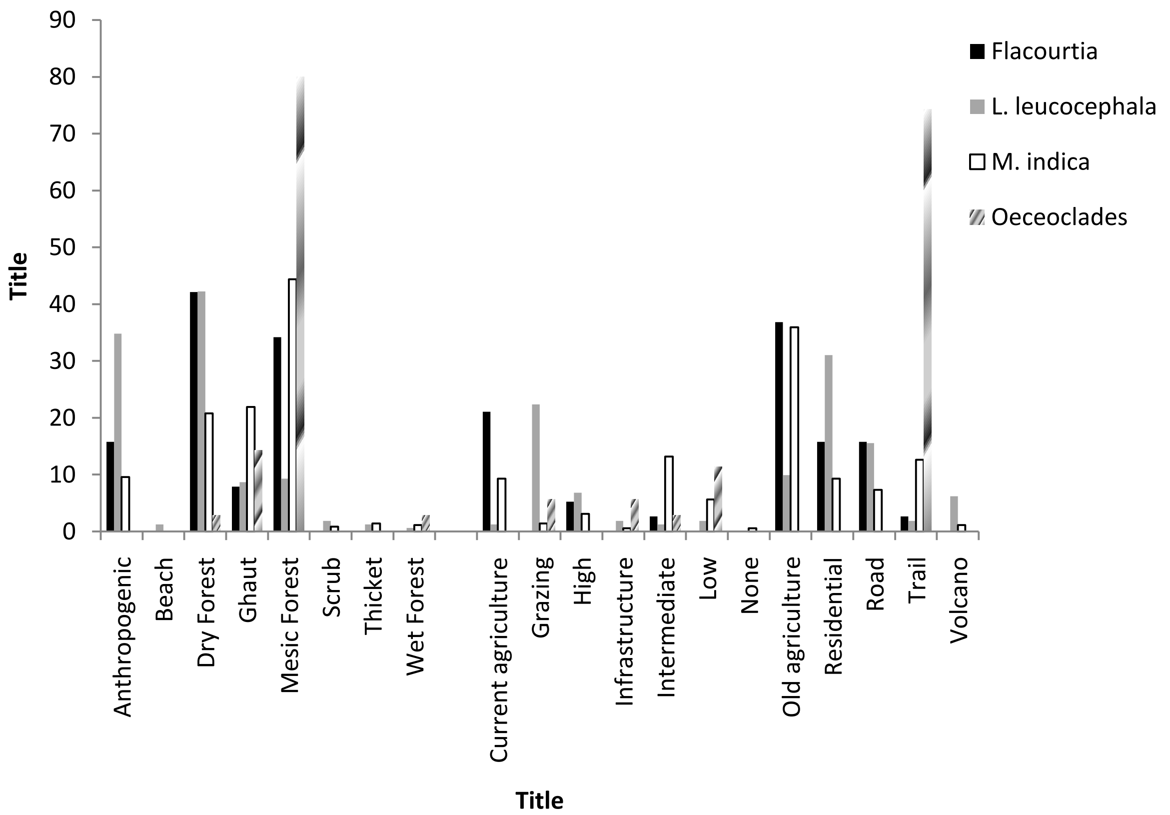
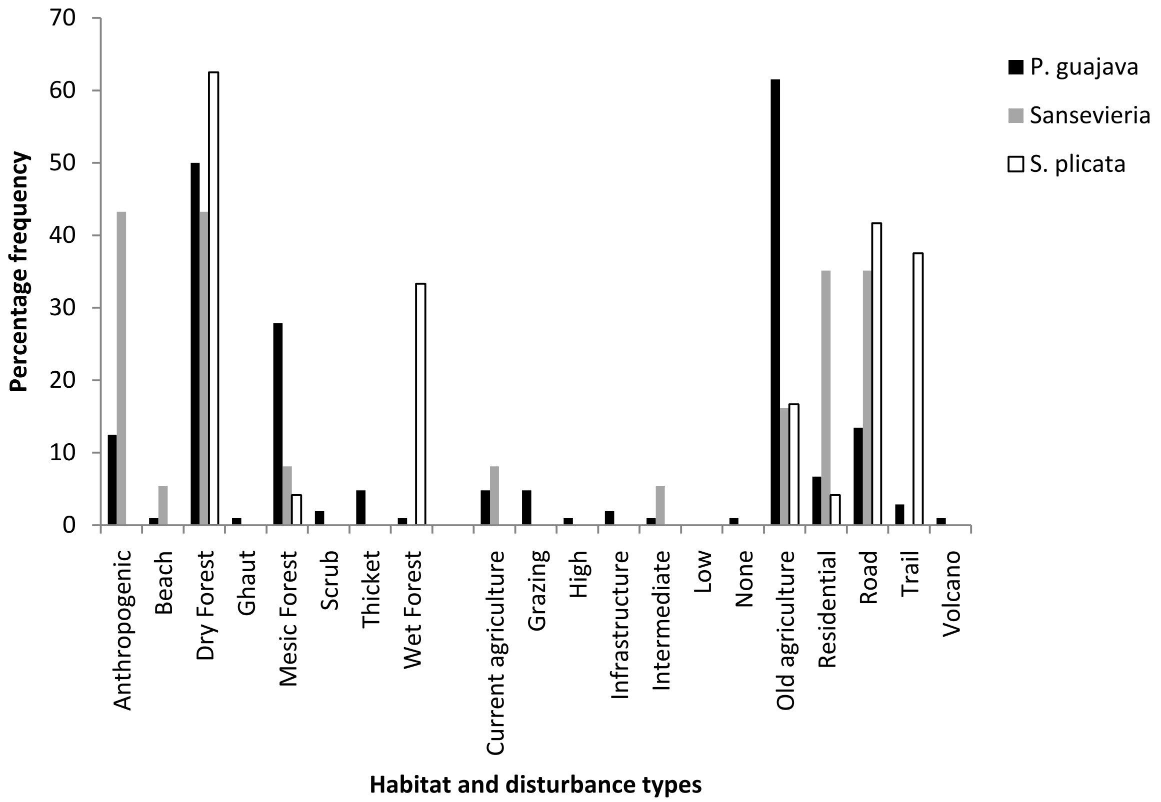


Figure 33. Frequency distribution of species with over 30 presence points in the eight habitat types.



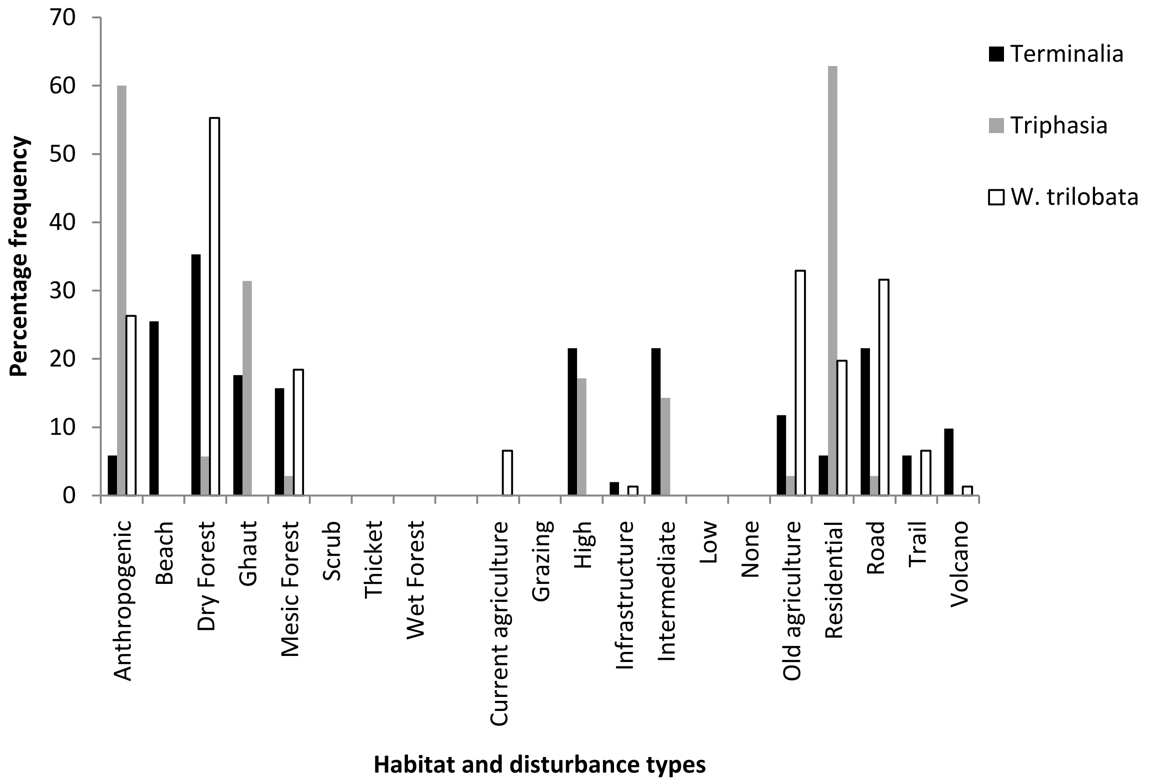


Figure 34. cont

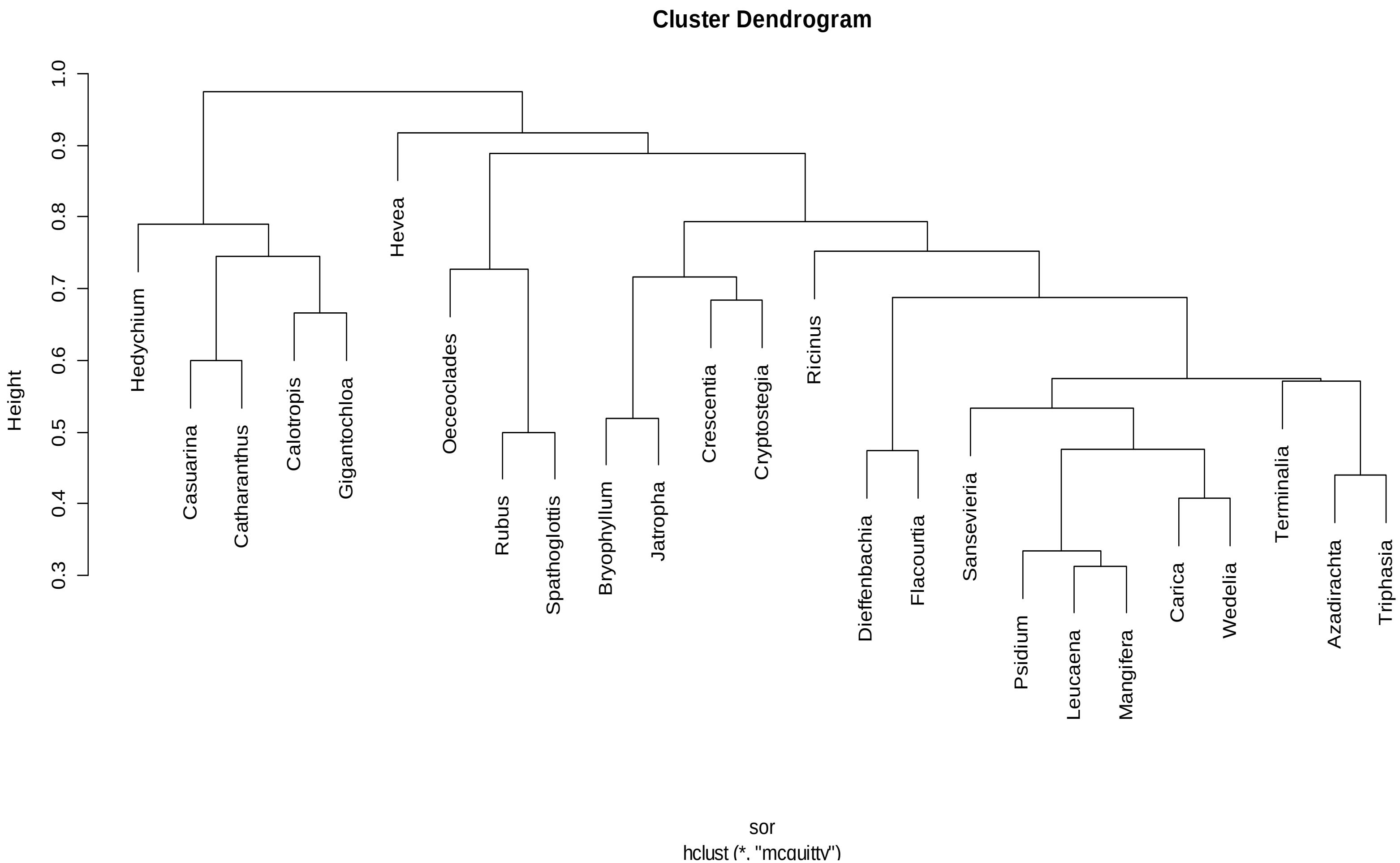


Figure 35 Cluster diagram of the 25 species based on the transects they were present in.

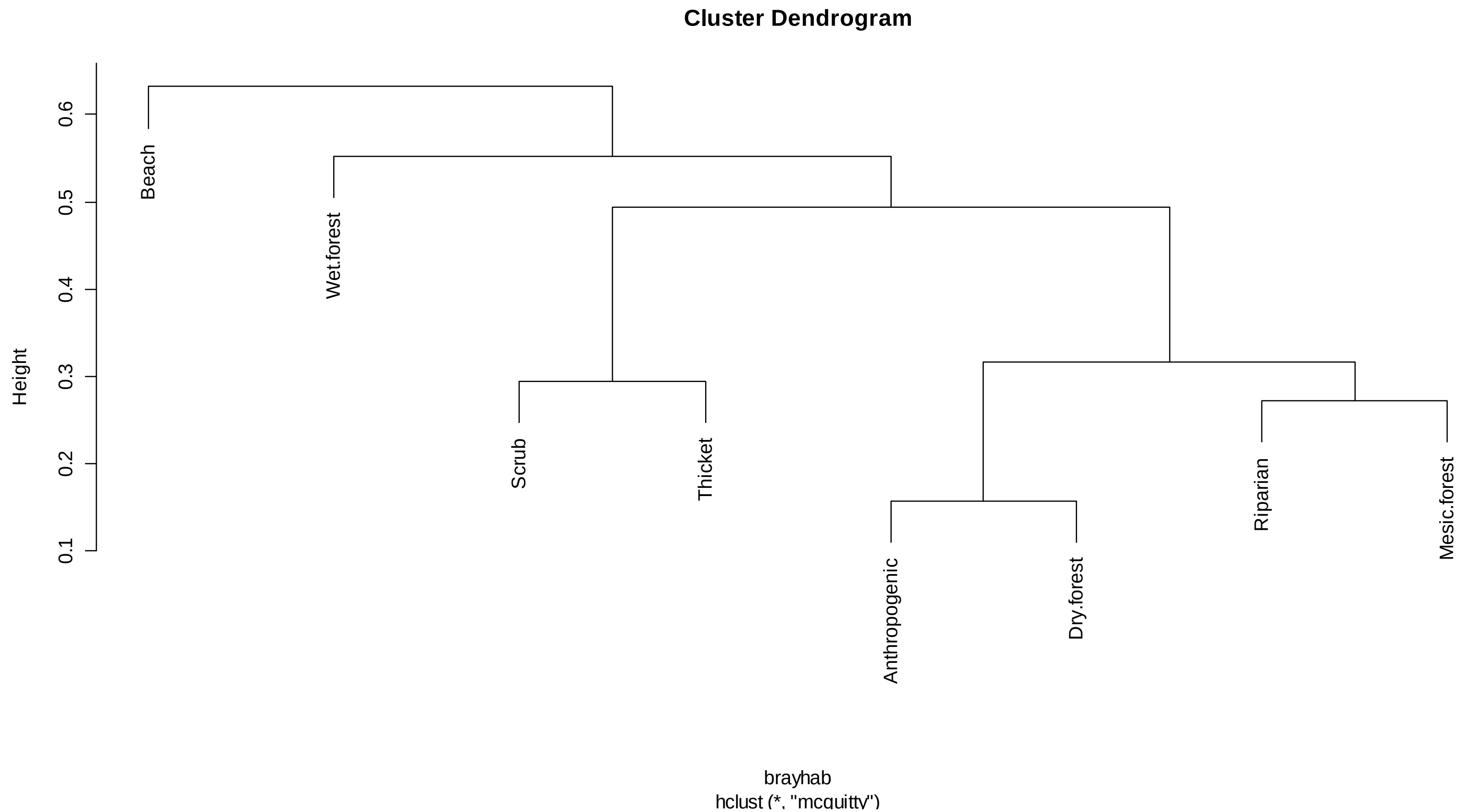


Figure 36 Cluster diagram of the eight habitats based on their species composition using the Sorensen index.

Table 1. Contribution of each variable, as a percentage, to the prediction of NNS distributions from Maxent models. See table 6, p. 21 for definition of variables.

Variable	B. pinnatum	C. madagascariensis	L. leucocephala	M. indica	P. guajava	S. plicata	W. trilobata
2pm	1.3708	0.1384	2.7048	0.03	1.1462	0	0.9708
5pm	0.1334	0.0322	0.6481	0.395	3.5361	4.3076	5.6284
8pm	0.2103	0.9087	0.3033	1.2892	2.1252	0.4875	4.4672
accumulation	0.1783	0.4035	0.9716	1.3074	1.5666	0.4303	0.1319
aspect-e	0.1936	0.1642	0.5907	0.1652	0.6593	0.0998	0.4946
aspect-n	0.4057	0.254	0.33	0.4642	1.7518	0	1.8043
aspect-s	0.1173	0	0.1367	0.3514	0.1521	0	0.6622
aspect-w	0.2701	0.2234	1.1935	0.1913	1.461	0	0.0596
dem	10.0239	2.3257	1.8776	5.2821	10.6858	21.2129	8.9173
dist-coast	14.9925	1.2555	20.0778	21.9536	6.3655	20.8182	21.3762
dist-east	8.1957	7.2334	1.9223	10.4262	5.3391	7.0074	16.0433
dist-north	25.0922	48.2143	5.1185	29.0536	22.8968	32.9633	10.3282
dist-south	25.9615	24.1088	6.7476	16.1844	8.9028	3.9791	23.1698
dist-west	0.9148	2.1875	14.2025	4.4645	11.4974	0	0.0554
dist-ne	10.0607	8.7832	35.6973	2.8879	6.0982	0.2989	0.7344
slope	1.1547	2.2057	7.037	4.7693	15.8067	7.9257	4.8225
waterflow	0.7245	1.5614	0.4406	0.7847	0.0096	0.4693	0.3338

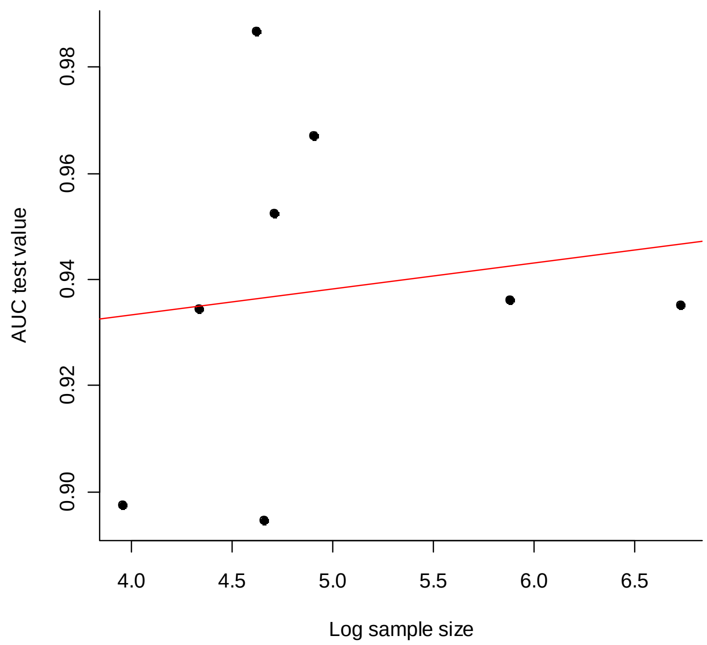


Figure 37 Correlation of log sample size against AUC test value. R^2=0.0188, df=6, p>0.05, cor=0.137.

Table 2. Total number of Sorensen values in a dissimilarity matrix made from abundance and binary data.

Sorensen index value class	Abundance data	Binary data
1-completely dissimilar	22	22
0-completely similar	0	7
Less than 0.5	53	347
0.5 or greater	476	141

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