Final Project report for the ‘Mitigating the Threat of Invasive Alien Species (IAS) in the Insular Caribbean project: Black River IAS Pilot Project’

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1. Introduction

The Black River morass is the largest freshwater wetland ecosystem in Jamaica and the second largest in the Caribbean. It is a biologically diverse and extremely complex natural wetland ecosystem that supports a large number of plants, animals and natural communities. The Morass support high levels of endemic species which are severely threatened by anthropogenic disturbance owing to their relatively small size and accessibility to human encroachment. In recognition of its value as a reservoir of endemic biodiversity, and its contribution to the livelihoods of local communities, the Black River morass will be designated as a protected area in 2015. It was also designated as a Ramsar site in 1997, signifying that it is a wetland ecosystem of international importance. The Ramsar designation should provide both the impetus for national action and the framework for international cooperation geared towards the conservation and sustainable use of this important wetland. To date however, the threats to the Black River morass remain unchecked (selective removal of trees, burning, the cultivation of marijuana and habitat encroachment), resulting in the continued loss or degradation of various habitat types. Conservation of the swamp forest is challenged by on-going human impacts (e.g., tree cutting, fires) and is compounded by the establishment of two exotic plant species that are at different stages of invasion. Although it may be possible to eradicate the more recently introduced invasive, *Melaleuca quinquenervia*, the other invasive, *Alpinia allughas*, is now firmly established. *A. allughas* has displaced most of the native swamp flora adjacent to the tributaries that feed the morass, and is now the dominant vegetation in the upper region of the lower morass. The remnant patches of swamp forest have not escaped the progression of ginger, with smaller patches seeming to be more susceptible to invasion. Even larger patches have been adversely impacted, as *A. allughas* has established itself around the edges and in tree gaps found within patches. Low light levels found in the understorey of the larger swamp forest patches have apparently prevented *A. allughas* from becoming established; however, gaps created by the removal of valuable tree species provide a point of entry for the establishment of *A. allughas*, and may therefore precipitate the demise of a given forest patch. Therefore, the aim of this pilot project was to determine suitable methods for controlling the two major plant invasives found in the Black river lower morass. A secondary aim was to ascertain the impact of these plant invasives on swamp forest diversity and regeneration.

1.1 Project Objectives

To meet the stated aims, the objectives of the Pilot were:

1. To determine the impact of *A. allughas* on the native biodiversity of the Lower Black River Morass;
2. To determine a method of treatment most appropriate for management of the *M. quinquenervia* in the Lower Black River Morass;
3. To ascertain the impact of the *A. allughas* on swamp forest regeneration in the Lower Black River Morass;
4. To determine which mechanical control treatment is the most suitable for management of the invasive ginger *A. allughas* in the Lower Back River Morass.

1.2 Component/Activities of the Pilot Project 1: The impact of A. allughas on the native biodiversity of the Lower Black River Morass

The implementation of the Black River Pilot falls within the ambit of a much larger conservation effort that is ongoing in the Morass. As a measure of continuity, these activities will become a part of long term monitoring of the swamp forest.

1.2.1 Component/Activity 1a: Baseline Survey

The status of biodiversity within invaded and un-invaded swamp forest patches will be compared to determine the impact of the invasive ginger *A. allughas* on biodiversity. The following activities will need to be completed:

1. Plot Establishment: permanent sample plots will be used to (i) determine the impact of the invasive ginger on the diversity, structure and status of swamp forest trees and (ii) provide a baseline for the continuous tracking of the fate of trees found within the last remaining patches of swamp forests.
2. Floral Surveys: All trees (≥ 2 cm DBH) found within each plot will be tagged, identified and measured (diameter at breast height (DBH) and height). Also dendrometer bands will be placed on selected individuals to determine growth rates over the long term.
3. 3-D mapping of the forest plots: A terrestrial laser scanner (TLS) will be used to measure DBH, height, volume and crown area (and other structural measures) of all the trees sampled, and will be used to sample trees within the newly established plots. The use of the TLS will be dependent on the accuracy of the measurements derived from the scan scene in relation to the field survey. Thus, DBH data collected from the PSPs will be regressed against DBH data collected using the TLS.

1.2.2 Component/Activity 1b: Habitat mapping and IAS Detection using remote sensing (a coupled sensor approach)

Currently, the distribution and extent of all the various habitat types, IAS and marsh grasses (and the impacts of the IAS at the landscape level) are unknown. Thus, the extent and distribution of the various habitats, IAS, and marsh grasses will need to be accurately mapped. To date, efforts have been geared towards coarse mapping of landscape level features because at present the high cost, and the poor spectral and spatial resolution of available remotely sensed images are the limiting factors. High-resolution Geoeye 1 images of the lower Black River Morass recently obtained was collected by recording the reflection of four different wavelengths of light from the earth surface. The recorded wavelengths include the blue, red, green and near infrared (or NIR) spectrum of light. While this can be used to discern the presence of the invasive ginger, the bandwidth of the various spectrum of light recorded is too wide to discern the various grass species, the other IAS, *M. quinquenervia*, and small patches of *A. allughas*. Also, despite the 1- m resolution, the spatial resolution is still not sufficiently high enough to determine structural or vegetative features. Furthermore, to effectively control *M. quinquenervia* requires information from both the landscape the local levels. Landscape level data such as the current distribution/extent and location of infestations, and local level data on structural parameters such as tree height, DBH and density are needed to formulate a comprehensive control strategy. Consequently, the distribution, extent and structural parameters of all the habitat types and the IAS found within the Lower Black River Morass will be determined using a coupled sensor approach.

There is a need, to determine the distribution of all the habitat types and the various IAS. To date four small patches of *M. quinquenervia* have been identified, however it is unsure if others are present. Of those identified two can be accessed, while the status of the other two stands is yet to be confirmed as access to these sites is at present impossible. The best means by which to identify and locate individual trees and other stands of *M. quinquenervia* is through the use of high resolution, hyperspectral images. This can be achieved by first generating the unique spectral signature of the *M. quinquenervia* from the hyperspectral images, then by using this unique spectral reflectance to identify and map the *M. quinquenervia* infestation.

A vertical take off and landing VTOL, unmanned aerial vehicle (UAV) affixed with a hyperspectral camera, and an airborne laser scanner (ALS) will be used to collect all the landscape level data for the Lower Black river Morass. The hyperspectral camera will be used to determine the unique reflectance of the target IASs and determine crown shape, while the ALS will provide auxiliary data such as tree height. A similar approach was used to detectand map invasive species in a Hawaiian rainforest (see Asner et al. 2008). Using data from both sensors, the density, height, and DBH (using allometric relationships between crown size, tee height and DBH) can be derived. Additionally, the UAV will allow for the collection of this data, whenever they are needed, thus the project will not be limited by image availability.

This activity will be funded by the Forest Conservation Fund and the MacArthur foundation, and represents a value added exercise. The information generated can then be used to formulate IAS management, control and/or eradication strategies for the entire morass.

1.3 Component/Activities of the Pilot Project 2: Experimental control of M. quinquenervia in the Lower Black River Morass

The methods of controls used are dictated by the degree of infestation (Bodle *et al.* 1994). We have identified four patches of *M. quinquenervia,* the current extent of the infestation is unknown, but appears to be minimal. Because of the risk of spreading the seeds of *M. quinquenervia* (which can remain viable for 1 - 7 years) mechanical removal will not be attempted. Chopping is not recommended as it will lead to stress and the trees respond to stress by shedding their seeds. A tree or branches of a tree will desiccate when stressed by freezing, drought, fire, herbicide treatment or breakage. At such times, a single tree may release as many as 20 million seeds (Woodall, 1981). Ideally it would be preferred if seeds are not spread throughout the area. However, if the trees are allowed to die where they stand, we will only need to conduct frequent checks below the canopy (or in a clearly defined area). Additionally, if tree numbers are relatively low, and with a small canopy size, we can place shade cloth below the canopy around the base of the trees (at a height of approximately 1-m) to catch most of the dispersed seeds. Cutting and burning is not recommended because *Melaleuca* is fire adapted, and its regeneration is enhanced by burning and cut stumps (with and without roots) can coppice. While the cuts stumps can be treated with herbicides to prevent coppicing this method of contol is less successful than the frill and girdle technique. Furthermore, the cut stump method of control is also more labour intensive and is only used when it is not desirable, for reasons of safety or aesthetics, to leave dead trees standing (Lakeland and Meisenburg 2008).

The seeds can be spread by removing the cut branches, and despite their low viability, this should be minimized. Thus the frill and girdle application methods with herbicides will be used (Langeland and Meisenburg 2008)**. All herbicides used for *M. quinquenervia* control have very low toxicity to wildlife and low risk to humans** (Langeland and Meisenburg 2008). These are generally used for outlier trees or for large stands where aerial application is not desirable. It is much more labor intensive than aerial application but non-target damage is minimal compared to aerial application.

Proposed method

Depending on the size of each patch, three plots will be established within each of the four patches of *M. quinquenervia* that we have identified (the size of the plot will depend on how many plots can be accommodated in each patch). Despite the distance between the patches, these can be regarded as blocks within a randomized block design. Therefore, t three plots will be established in each of the four identified patches, giving a total of 12 plots. Pre-treatment assessment includes measurement of diameter at cutting height (provisionally this will be 0.5 meters above the ground), density per plot, and water depth. A machete will be used to cut through the bark deep enough to expose the living tissue just inside the bark (cambium layer) right around the entire trunk. Cuts will be made in a downward direction so that the severed bark is left to contain the herbicide mixture. A hand-held spray bottle will be used to apply the herbicide to the girdle in sufficient quantity until the tissue is thoroughly wet. The surfactant used will either be those recommended by the manufacturers or added by manufacturers at the time of purchase.

One of the following herbicide treatments (three will be selected, and one will be applied to each treatment; four herbicides were named because their use in the experiment is subject to availability) will be applied to the trees within one of each plot either at rates recommended by the herbicide manufacturer or diluted as follows:

1) 50% solution of Picloram/ 2,4-D
2) 50% solution Hexazinone
3) Imazapyr in a 50% solution with water (this is considered to be the most consistently effective when using the frill and giggle methods of application)
4) 25% solution that contains 3-4 lb per gallon glyphosate acid and 25% solution that contains 2 lb imazapyr acid per gallon with a methylated see-oil surfacant.

The trees will be monitored every 3 months for two years. The time taken for a tree to die and the percentage mortality will be noted. Trees will be presumed dead if the cambium is dark brown at all points checked on the trunk. All seedlings found within the plots will either be uprooted (if seedling densities are low) or cut (using the cutter) repeatedly every 3 months until they have died. One method of control for seedlings is foliar application of herbicides. This method however will affect non-target species, and depending on the application levels and time of year, it may seep into the soil, the surface water or washed out to the river or areas with large bodies of standing water. The seedlings do no have a stump; as such there will not be enough surface area to apply the herbicides after cutting. The most successful application will be applied to the rest of the trees found within the patches.

1.4 Component/Activities of the Pilot Project 3: The impact of the A. allughas on swamp forest regeneration in the Lower Black River Morass

1.4.1 Assessing the impact of A. allughas on the swamp forest regeneration

The dynamics and ecophysiology of native tree seedlings found within patches currently being invaded by *A. allughas* (three patches in total) will be assessed. It is assumed that the patches are dying because *A. allughas* is outcompeting seedling and saplings, and possibly arresting some (or all) stages of the regeneration cycle. Thus experiments will allow for the assessment of the impacts of competition with *A. allughas* on seedling survival, growth, recruitment and eco-physiology of native tree species within the morass. Seedling ecophysiology will be determined using an infrared gas analyzer. This will be used to determine the best way control *A. allughas* in the recently invaded patches, and ways to enhance the vigour of affected tree species.

Therefore, 3, 20 × 20-m plots will be established within three swamp forest patches invaded with *A. allughas*. These plots will be further subdivided into 16, 5 × 5 m sub-plots. Within each plot, 5 sub-plots will be randomly selected for seedling assessments. One of the following treatments will be applied randomly to the five selected subplots within one of each of the three plots:

1) No removal
2) Repeated removal of the ginger and trenching within the sub-plots, and shading using a 90% shade cloth every three months for 2 years.
3) Repeated removal without shading

Seedlings found within the five subplots of each treatment plot will be tagged, and seedling growth (RCD and height) and ecophysiology will be measured every six months for a period of 2 years. Similarly, we will tag and measure the growth and ecophysiology of *A. allughas* found within the subplots. Understorey light conditions will also be measured every six months for a period of 2 years. In the shaded experiments, seeds that are dispersed on the shade cloth will be identified, counted and weighed. Once collected and assessed, the seeds will be placed under the shade cloth within the sub-plots in which they were collected and their positions flagged. This is to ensure that the seeds dispersed within the subplots can be quantified. The germination and survival of these seeds will be assessed.

Additionally, five seed traps measuring 1 × 1 m will be placed within five randomly selected subplots, within the three plots of each block located in the invaded patches and within two plots of each block located in the uninvaded patches to measure seed rain. The seeds will be identified, counted and weighed. They will be potted and used as a seed source for our germination and restoration trials. The sub-plots selected for this assessment will not be used for seedling assessments. The assessment of seed rain will be used to determine the effects of the invasion on seed dispersal. Also, seed weight is a useful indicator of successional status/functional types (bigger seeds = climax species, smaller seeds = pioneers), and will indicate which species are actively producing seeds, and the quantity of seed production.

1.5 Component/Activities of the Pilot Project 4: The control of A. allughas and the rehabilitation infected swamp forest patches

1.5.1 Component/Activity 4a: Germination experiments

The objective of the germination experiment is to determine the percentage germination of seeds from target species, and in instances where germination rates are low, test different scarification methods to assess germination potential. The experiment will help to determine if this is a viable method for generating propagules.

A nursery will be constructed in Black River. Germination experiments will be conducted using seeds collected from seed traps or from within the swamp forest patches. If germination cannot be achieved by direct sowing, scarification or other methods of breaking dormancy will be attempted. Potting experiments using wildlings (seedlings collected from the wild) will also be conducted.

1.5.2 Component/Activity 4b: Control of A. allughas

The mechanical removal of *A. allughas*, will be assessed as a possible method of control. Repeated mowings was found to be a successful mechanical method of controlling kahili ginger in Hawaii and therefore this method will be investigated. In the Hawaiian experiment, the shoots were cut using a weed cutter and resprouted shoots were cut again when they were 12 inches in length. A 90% control was achieved in approximately one year, although complete control may require several years (Tunison 1991). Small patches of ginger will be used and other plots will be established at the edges of ginger infestation for this experiment. Specifically four blocks consisting of 3, 20 × 20 m plots will be established and the following treatments will be applied:

1) Cutting and trenching every three months for two years and covering with dark "chicken curtain/blinds" (with 0 % light transmissibility)
2) Cutting and trenching every 3 months for two years.
3) Cutting and trenching once.

The number and height of *A. allughas* stems will be assessed after two years (where possible).

1.5.3 Component/Activity 4c: Control of A. allughas and forest rehabilitation

Rehabilitation experiments will be established in two patches that are completely over-run with *A. allughas*. These are patches with only a few remnant trees, and with the canopy completely lost. Specifically, 2, 20 × 20 m plots will be established and the following treatments will be applied:

1) Cutting of the ginger, trenching to remove rhizomes, and planting of native forest species.
2) Cutting of the ginger, trenching to remove rhizomes, cover with 90% shade cloth, and the planting of selected forest seedlings below the shade cloth.

The growth, mortality and eco-physiology of the planted seedlings will be assessed. The seedlings will be monitored every week for the first month. Seedlings that die within the first month of the establishment of the experiment will be replaced. Initially, seedling performance will be monitored after every 2 weeks during the first and second months and once per month after the second month for a period of one year. They will then be monitored every three months for the second year. This experiment will commence in April 2011 for two years.

2. Component/Activity 1: Impact of *Alpinia allughas* on native biodiversity of the Black River Morass

2.1 Baseline survey

2.1.1 Methods

The following were established and assessed:

1. 20, 60 x 20 m permanent sampling plots (PSPs), that were established in four blocks of 5 plots (10 of which were established in 2006) in the largest swamp forest patch (Patches 1 & 2; Figure 1);
2. 7 additional 20 x 20 m PSPs during the period April – August 2011. Three were established in a patch overrun with *A. allughas* (Patch 3), and four were established in a small patch completely surrounded by *A. allughas* (Patch 4; Figure 1);
3. A single PSP (Patch 5; Figure 1) in an infected patch (1, 20 x 20 m);
4. 21, 20 x 20 m plots in four patches in Burnt Savanna in January – August 2012 (Patches 6, 7, 8 & 9; Figure 1).
5. 9, 20 x 20 in plots in a patch located along the Gayle River in February – April 2013 (Patch 10; Figure 1).

All plant species were identified using voucher specimens collected from the field and matching them with reference specimens in the Department of Life Sciences' herbarium.

2.1.2 Preliminary results

In total, 20, 20 x 60, and 38, 20 x 20 m PSPs were established, covering a total area of 3.92 ha. A total 14,336 trees ≥ 2 cm DBH (diameter at breast height, i.e. 1.3 meters from the ground) representing 25 plant families were sampled within the plots. Approximately 43 species (including 2 unidentified specimens) of which 10 were endemics and 8 were introduced species. Fabaceae and Myrtaceae were the best-represented families, with 5 species each. There was an uneven distribution of species richness throughout all plots sampled (Figure 2a). *Grias cauliflora*, was the most abundant species recorded (Figure 2b), but it was confined to the two largest forest patches, whereas the remaining top ten abundant tree species were found in all forest patches assessed. A check of the International union for the Conservation of Nature (IUCN) red list (Ver. 2.8. 1998) indicated that of the species encountered, five endemics have a vulnerable/threatened conservation status (*Bactris jamaicana*, *Comocladia velutina*, *Roystonea princeps*, *Wallenia erythrocarpa* and *Wallenia sylvestris*). However, the conservation status of approximately 80% (34 species) of the species were not evaluated. The parish of St. Elizabeth is referred to as one of the last or only remaining localities where these species are found (Adams 1972). Moreover, of notable interest is the presence of the invasive African oil-palm (*Elaeis guineensis*), which is considered as one of the World's top 100 invasive plant species (Global Invasive Species Database 2014). Several other invasive plants species were (understorey trees) within the sample plots (eg. *Syzygium jambos*) or while conducting other surveys (several invasive grasses and aquatic plants). Several native species (e.g. *Cecropia peltata*, *Calophyllum calaba, Calyptranthes chytraculia*) were not previously recorded in either the swamp forest patches or the riparian forests of the BRLM.

A sample-based rarefaction curve (which is a plot of species richness for a specific number of individual samples) (Figure 2c) showed that cumulative tree species sampled did not reach the total number of expected species. Two estimators of total species richness, corrected for unseen species in samples (Chao and first order Jack-knife) estimated at total of 61±13 (s.e.) and 57 ± 4 (s.e.) plant species in all the patches sampled. A cluster dendrogram used to investigate the similarities/differences among the different patches based on tree species richness and abundance indicated that three patches with high densities of invasives (*A. allughas*: patch 5 and *Elaeis guineensis*: patches 7, 8 and 9) were similar, with patch 5 being the most dissimilar of the 4 patches (Figure 3a). Additionally, patches 3 and 4, both of which has *A. allughas* present in the understorey and are surrounded by *A. allughas* were also very similar. A preliminary analysis of the relationship between *A. allughas* and measures of tree structure and diversity indicated that *A. allughas* density was significantly ($P = 0.016$) higher in patches with lower tree basal area (the area occupied by the stem of each tree) (Figure 3b). There was no significant relationship between other measures of structure (tree abundance/density) and tree diversity; therefore *A. allughas* effects/impacts/invasion was related to tree structure and not tree species composition of a patch.

2.1.3 Additional activities

A total of 2500 dendrometer bands were made, and placed on trees > 5 cm DBH in 2013. This will be used to monitor tree growth and to determine if there are growth differences among the various species and swamp forest patches and to determine the effects of *A. allughas* and the African oil-palm infestation on long-term tree growth.

2.1.4 Future Activities

Biodiversity data from the plots are currently being analyzed. These analyses include assessing the differences/similarities in measured characteristics among the swamp forest patches such as DBH class distributions, diversity, density etc. An ordination, specifically a non-metric dimensional scaling (NMDS) ordination, will be used to determine the impact of *A. allughas* and other factors on these characteristics (such as size of patches, presence of other invasives, etc). The findings from this assessment will be published in 2 – 3 research papers, that will be submitted to various peer reviewed journals by April 2014 for review. Additionally, the PI is currently exploring the use of a terrestrial laser scanner to collect structural and other data on trees (height, DBH, volume, area of crown, density, location) and structural data on other plant types within our plots.

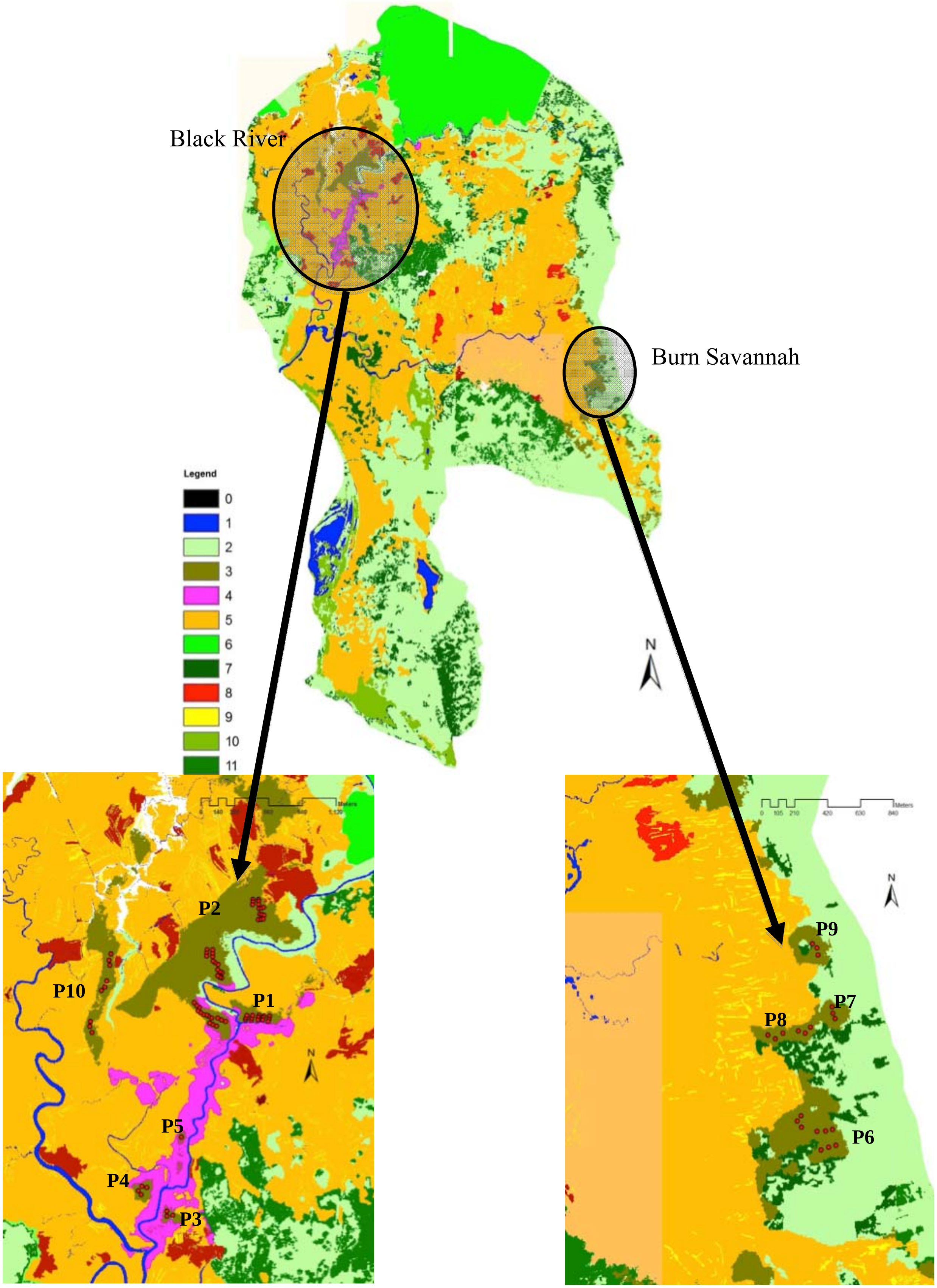
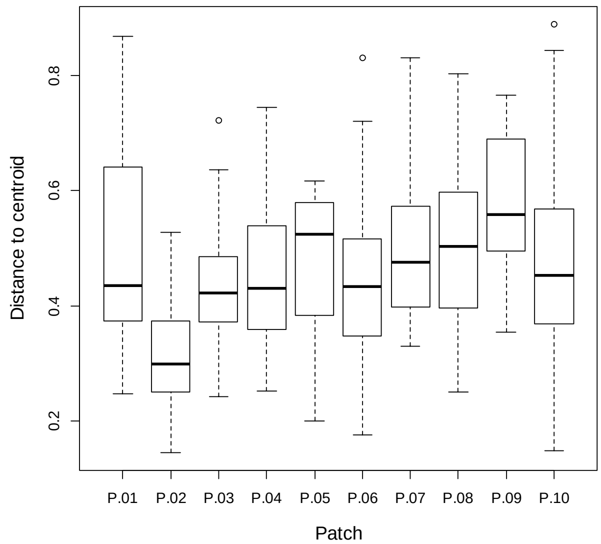


Figure 1. Classified image of the Black River Lower Morass study site showing plot locations (center of each 20 x 20 m and center of each 20 x 20 m subplot for the 60 x 20

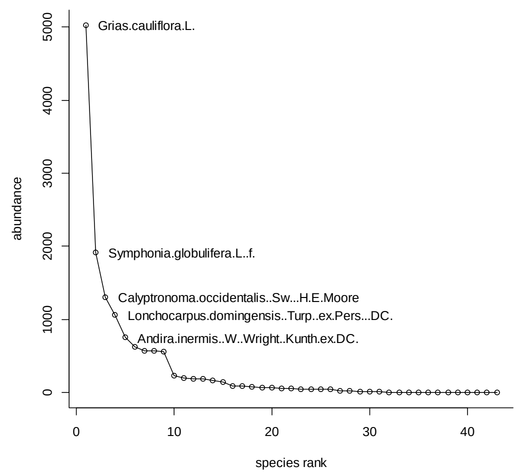
m plots). The land cover classes include: 0- background; 1- water/river; 2 - bare ground/grasses/non-vegetation (also includes areas in white); 3 - swamp forest patches (brown); 4 - *Alpinia allughas;* 5 - morass grasses; 6 – agriculture; 7 - other woody vegetation; 8 – burning; 9 - marijuana cultivation; 10 & 11 – mangroves.

(a)



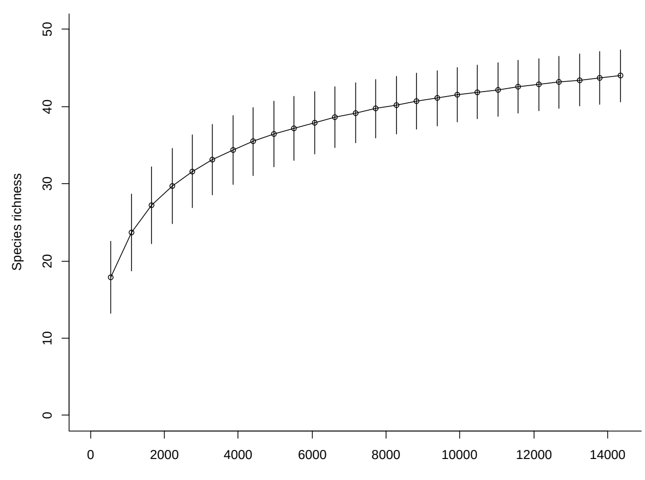
Distance to centroid
0.2
0.4
0.6
0.8
P.01
P.02
P.03
P.04
P.05
P.06
P.07
P.08
P.09
P.10
Patch

(b)



abundance
0
1000
2000
3000
4000
5000
Grias.cauliflora.L.
Symphonia.globulifera.L..f.
Calyptronoma.occidentalis..Sw...H.E.Moore
Lonchocarpus.domingensis..Turp..ex.Pers...DC.
Andira.inermis..W..Wright..Kunth.ex.DC.
0
10
20
30
40
species rank

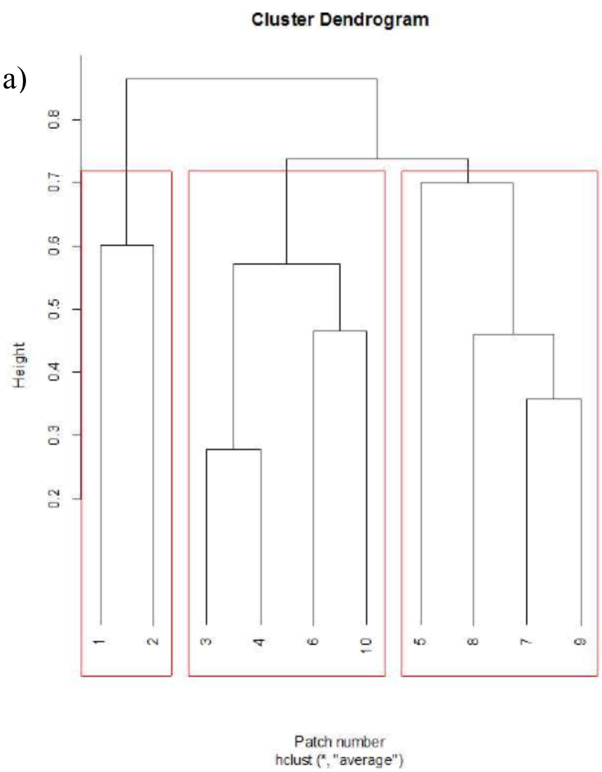
(c)



Species richness
0
10
20
30
40
50
0
2000
4000
6000
8000
10000
12000
14000
Pooled individuals

Figure 2. a) Species accumulation curve for all swamp forest patches sampled, b) abundance rank curve for all the most common species in the BRLM swamp forest patches and c) beta diversity differences among the forest patches.

a)



b)

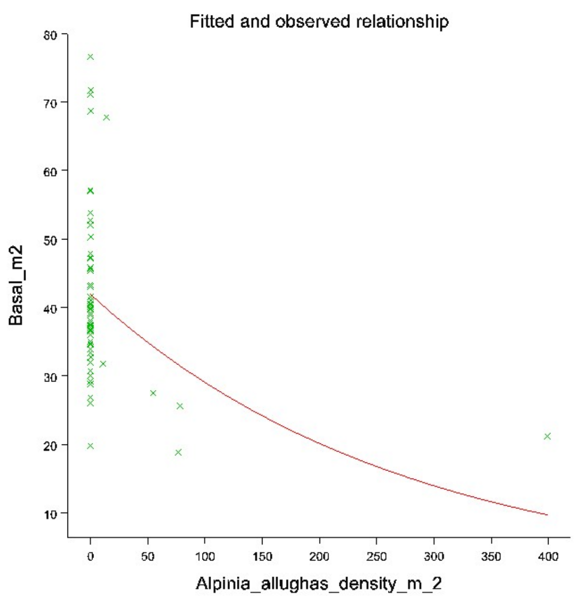


Figure 3. a) Cluster dendrogram used to investigate the similarities/differences among the different patches (patch numbers and a descripion of disturbance levels are presented in figure 1), based on species richness and abundance and b) observes (x) and predicted (line) values obtained from a generalized linear model used to assess the relationship between *A. allughas* density and average plot basal area.

2.2 Landscape level survey: maps of the state of the ecosystem and location of IAS in the Black River Lower Morass

2.2.1 Methods

This activity was primarily funded by the MacArthur foundation (computer hardware and software), and funding from the Black River IAS project was used to purchase two survey grade GPS units. To date, aerial photographs from 1941 and satellite images from 2001 (IKONOS) and 2009 (Geoeye) have been classified. The Geoeye images were donated by the Geoeye foundation. The 1942 images (1:50,000 scale; taken between December 1941 and January 1942) were scanned using a Musteck flatbed scanner and the Leica Photogrammetry Suite (LPS) software package was used to orthorectify the images (i.e. append a coordinate system to the images using aerial triangulation) to correct for distortions.

The orthorectified 1941 aerial photographs and the satellite images were classified using an object based image analysis (OBIA). Specifically, we used the object based image classification software eCognition to classify the images. The software allows for the input of additional data such as digital surface models (DSMs; for the 1941 images we used a DSM derived from stereo-pairs of the 1941 images, while for the satellite images we used a DSM that covered the entire island), to improve the classification process. A number of different statistical methods such as a support vector machine (SVM), random forest and a logistic regression were used to classify the images. Additionally, a textural analysis was used to improve the classification of the black and white images. Misclassifications were manually corrected.

2.2.2 Preliminary results

To date the threats to its existence of the BRLM remain unchecked, resulting in the continued loss or degradation of various habitat types (Figure 4). Our research has confirmed that the BRLM has been reduced by 31% (1941 – 2001), and some constituent habitat types have fared especially poorly: the swamp forests declined by 80% from 1941 – 2001 and accounted for 2% of the Ramsar defined area in 2001 (down from 10% in 1941) and are now restricted to 20 small fragmented patches in the lower morass, all of which are in various states of degradation. Terrestrial ‘forest’ vegetation declined by 57% since 1941 and accounted for 8% of the Ramsar defined area in 2001; approximately 98 – 99.5% of this could be classified as severely degraded in 2001.The herbaceous marshland has declined by 12% and accounted for 38% of the Ramsar defined area in 2001. Both IASs were not present in 1941, and presently account for < 1% of the Ramsar defined area in 2001. There is a need to determine the rate of spread of both IASs (see below) and to identify additional areas of infestation in the upper morass, which can be a source of propagules if the IASs are controlled or eradicated in the lower morass.

2.2.3 Future activities

The classifications have been expanded to include remotely sensed images for the years 2009 (Geoeye Images), 1951, 1961 and 1980 (aerial photos). Additionally, satellite images (Landsat) for the years 1982, 1985, 1989, 1995, will also be classified. The aim of this assessment was to map the distribution of the invasive ginger from the time it can be first detected using remotely sensed images and determine its rate of spread, and use this information to predict the areas that will likely be invaded if the spread of the ginger is not controlled. The mapping exercise will be expanded to include the upper Morass, and increase the area of interest in the lower morass, in support of the 'Strengthening the Operational and Financial Sustainability of the National Protected Area (PA) System Project', administered by NEPA. A final map will be generated and will be used for zoning of the new protected area and for other purposes. Additionally, there are established populations of *A. allughas* and *M. quinquenervia* in the upper morass; therefore, their current distribution will be mapped.

2.2.4 Accuracy assessment

An accuracy assessment (AA) is required to determine the accuracy of the maps derived from the classification exercise, an extensive ground truthing exercise is required to generate ground control points (GCPs) for the AA. To date most of the ground truthing exercises have been conducted at sites that could either be accessed by boat or motor vehicle. GCPs from remote locations across the lower morass are required for the AA and the collection of GCPs at remote locations will commence in April 2014. This activity is scheduled to coincide with a comprehensive assessment of peat volume, the distribution of marsh grasses and an assessment of tree and plant above and below ground biomass in the BRLM. To reduce the cost and to maximize our efforts, the ground truthing exercise will be conducted simultaneously with abovementioned activities.

2.2.4 Other activities

The remote sensing platform is yet to be delivered due to issues with the supplier, and because of the length of time it took to gain approval for renewing/granting of an export licence by the United States Department of Commerce. A license was required before the UAV and the Geo-Reg software (needed for rectification of the hyperspectral images) can be shipped to Jamaica. The software was delivered in September 2012, and the export license/permit for the UAV was successfully renewed on February 10, 2014. Therefore the unit should be shipped by March 2014.

In anticipation of the delivery of the remote sensing platform, Mr Prospere explored the use of hyperspectral data in discriminating plant species in the BRLM. Specifically, Mr Pospere explored several methods/techniques that can be used to discriminate 46 plants species found in the BRLM using their spectral reflectance curve. Some of the methods that were used were not previously used for this purpose. Mr Prospere successfully discriminated plant species native to the BRLM, and several invasives (Figure 5).

Therefore, this method will be used map the location of both native plants species and several plant invasives in the BRLM, using data from our hyperspectral camera.

The results of the current and expanded mapping exercise will yield approximately 5 - 6 research papers that will be submitted to various peer-reviewed journals.

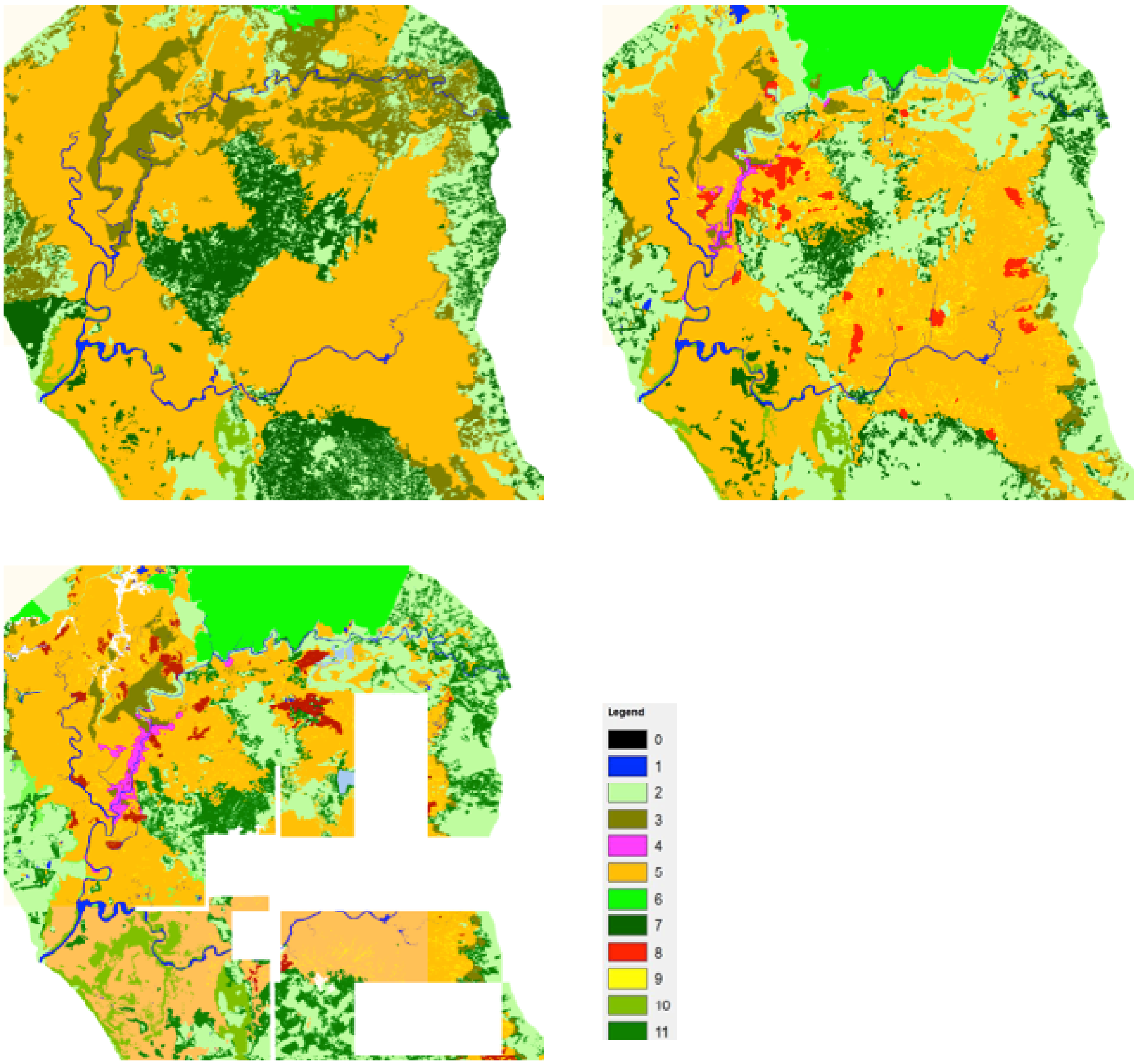


Figure 4. Preliminary results from our classification exercise for the years 1941 (top left), 2001 (top right) and 2009 (bottom left). The 2009 classification is incomplete. The area of interest will be expanded to include additional years and the upper morass and both marine and terrestrial components in the lower morass. The land cover classes

include: 0- background; 1- water/river; 2 - bare ground/grasses/non-vegetation (also includes areas in white); 3 - swamp forest patches (brown); 4 - *Alpinia allughas;* 5 - morass grasses; 6 – agriculture; 7 - other woody vegetation; 8 – burning; 9 - marijuana cultivation; 10 & 11 – mangroves.

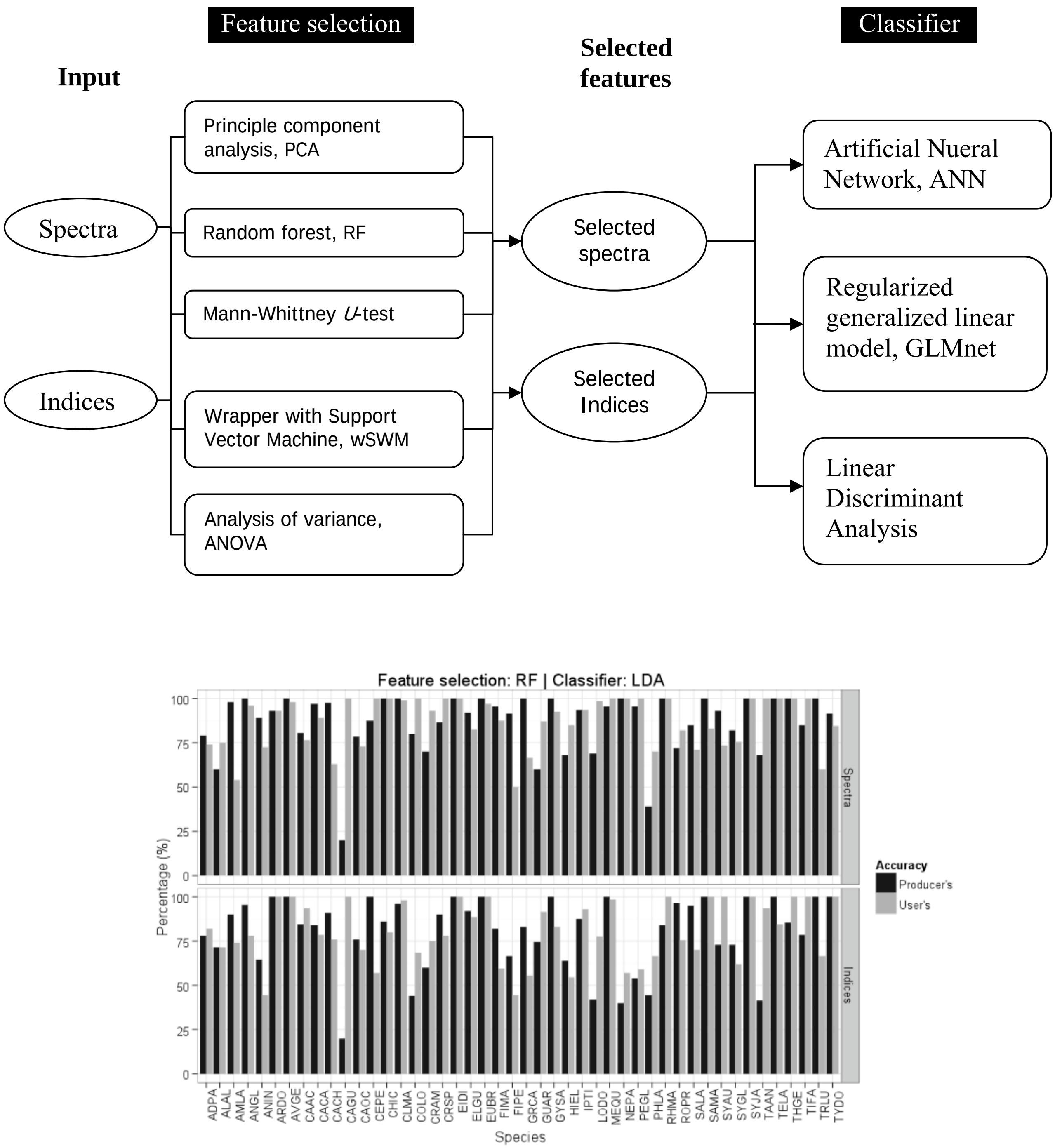


Figure 5. Flow chart outlining the methods used to discriminate 46 plant species from the Black river Lower Morass using their spectral reflectance (top) and the ability of various

methods to accurately discriminate 46 plant species from the Black River Lower Morass is determined by their producer's and user's accuracy (bottom).

3. Component/Activity 2: *Melalecua quinquenervia* control

3.1 Methods

The proposed method was modified (the 12 plots were included in one patch and he size of the plots were reduced) and the herbicides used for the control experiment were chosen based on availability and effectiveness. In February 2012, 12 experimental plots were established according to a randomized block design in the first patch of *M. quinquenervia* (Figure 7). Specifically, three blocks consisting of four 10 x 10 m plots each were established.

Machetes were used to frill the trees (cut a ring around the circumference of the trunk), after which the herbicides were applied using a spray bottle. The trees in the control plots were also frilled, but no herbicides were applied. The treatments were applied on April 16 and April 17, 2012. The treatments applied to one plot in each block were:

1. 50% Arsenal
2. 50% Roundup and 25% Arsenal
3. 50% Velpar
4. Control

Various treatments were applied to a second patch (Figure 7) of *M. quinquenervia* trees over a period of three days (February 11 – 13, 2013). Eight plots in this experiment were burnt (the fire was probably started by individuals cultivating marijuana); therefore the effects of burning, girdling and various herbicides treatments on the trees were assessed. A third patch (Figure 7) of *M. quinquenervia* was accessed using our amphibious ATV on March 12, 2013. However, only six plots (and not 12 plots) were established. The site was also in very close proximity to extensive marijuana cultivations; consequently a path around these cultivations had to be found. Ultimately, one of the growers to provided a path to the third patch. The fourth patch (Figure 6) was not accessed due to safety concerns.

3.2 Preliminary results

A total of 1033 trees were sampled throughout all the treatment plots. The application of both the Arsenal and Arsenal and round up herbicides resulted in 100% mortality of trees in the first experiment. The application of Velpar resulted in 22.6% mortality of *M. quinquenervia* trees, while the control plots recorded 0% mortality. The results of an ANOVA for a randomized block design indicated that the effects of the treatments were significant ($P < 0.001$). Also mortality in the Arsenal and Arsenal and round up treatments were significantly higher than the Velpar treatments and the control plots ($P < 0.001$ for each comparison, respectively). Tree mortality in the latter two treatments was not found to be significantly different ($P = 0.058$).

In the second experiment, the results were the same ($P < 0.001$ overall; for all comparisons, $P < 0.001$ and for Velpar vs control plots $P = 1.0$). Burning had no effect on tree survival/mortality. The application of both the Arsenal and Arsenal and round up herbicides resulted in 98.96% and 100% mortality, respectively, of trees. The Velpar treatment plots and the control plots both recorded 0% mortality and the percentage mortality was not significantly different between the two (P = 1.0). For the final experiment, the application of Round up resulted in 100% mortality, while the control plot recorded 0% mortality. Also an ANOVA indicated that this result was significant ($P < 0.001$).

3.3 Future work

The final assessment will be conducted in March 2014 and a manuscript will be prepared for submission to a peer-reviewed journal for publication. The remainder of the herbicides will be applied to all trees in the three patches. Each patch will be divided into a grid, consisting of plots of equal sizes (approximately 10 x 10 meters) and systematically apply the treatments to each grid, until it is applied to every tree. This exercise will commence by January 2015.

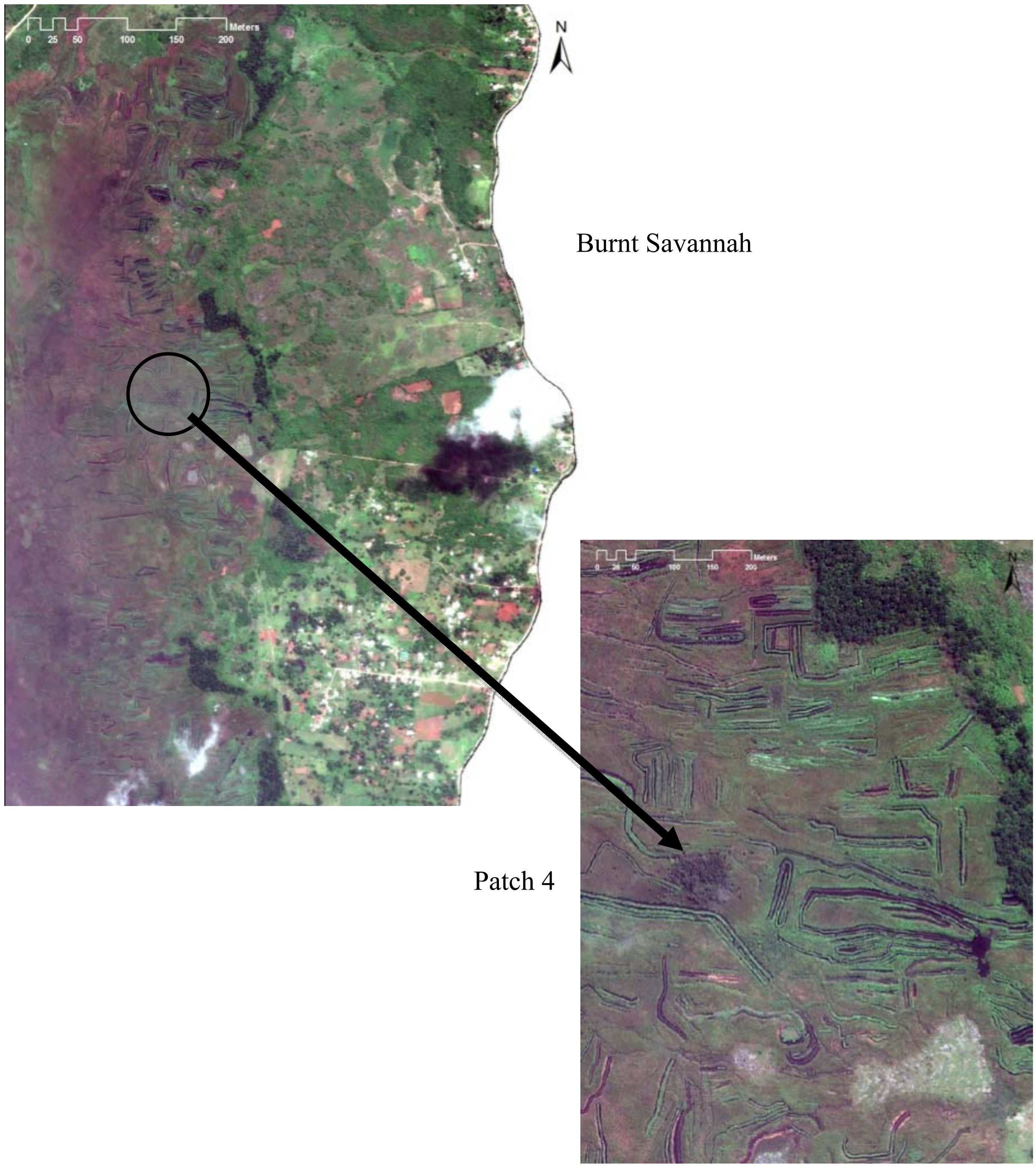


Figure 6. The fourth patch of *Melaleuca quinquenervia* located near Burnt Savanna, Black River, that was not accessed due to safety concerns (extensive marijuana cultivations).

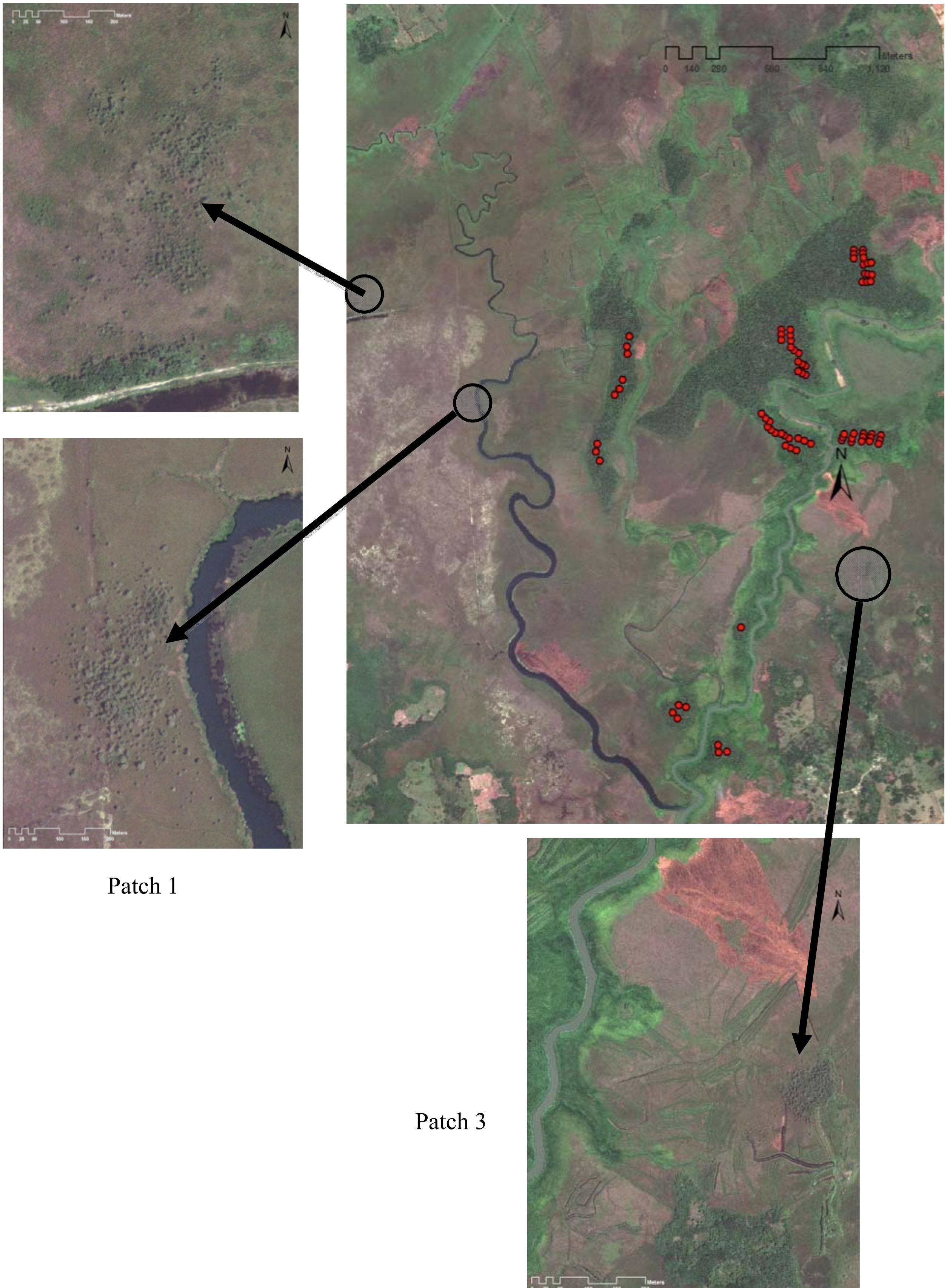


Figure 7. Natural colour satellite images showing three patches of *Melaleuca quinquenervia* where the control experiments were established in the Black River Lower Morass.

4. Component/Activity 3. Impact of *A. allughas* on swamp forest regeneration

4.1 Method

The proposed method was modified because the graduate student/research/field technician responsible for this activity left the Black River IAS project before these experiments could be established. Fortunately, a field assistant was trained and he was now responsible for collecting seedling data. The establishment of the proposed experiments required a suitably qualified research/field technician or graduate student, and the project was unable to recruit a suitable replacement.

Therefore, to assess the impact of *A. allughas* on swamp forest regeneration, particularly regeneration by seed, we established a total of 250, 5 x 5 m seedling quadrats nested within the larger 20 x 60 m and 20 x 20 m plots. Specifically, the following were established:

1. 5 randomly selected 5 x 5 m quadrats in each 20 x 20 meter subplots of the 20 x 60 m plots. For two blocks, seedling quadrats were established within four 20 x 60 plots while for the remaining two blocks, seedling quadrats were established within two 20 x 60 m plots;
2. 5 randomly selected 5 x 5 m quadrats were established in two of three 20 x 20 m PSPs established in a patch overrun with *A. allughas*, and two of the four 20 x 20 m PSPs established in a small patch completely surrounded by *A. allughas*;
3. 5 randomly selected 5 x 5 m quadrats were established in the single PSP in an infected patch (1, 20 x 20 m);
4. 5 randomly selected 5 x 5 m quadrats were established in two of three 20 x 20 m plots established in two small patches in Burnt Savannah;
5. 5 randomly selected 5 x 5 m quadrats were established in two of 6, 20 x 20 m plots established in a patch in Burnt Savannah;
6. 5 randomly selected 5 x 5 m quadrats were established in three of 9, 20 x 20 m plots established in a patch in Burnt Savannah.

No seedling quadrats were established in the plots established close to the Gayle River. Hemispheric photographs (Figure 8) were taken in the middle of each plot during seedling assessments. This will be used to assess the understorey light climate. Seedlings were tagged and measured (root collar diameter and height) in 8, 20 x 60 m plots over a period of three months (January – March 2011). However, because the research technician/graduate student left the project after our first census, only new and older seedlings sampled within all seedling quadrats during subsequent censuses were tagged and recorded (by our field assistant) as being either dead or alive during the periods June – September 2011, January – March 2012 and June – August 2012. Due to financial constraints, seedling assessments were discontinued after August 2012. However, a final assessment is planned for the period March – June 2014. A comparison between the diversity and density of seedlings, and understorey light conditions will be used to determine the possible effects of *A. allughas* on swamp forest regeneration.

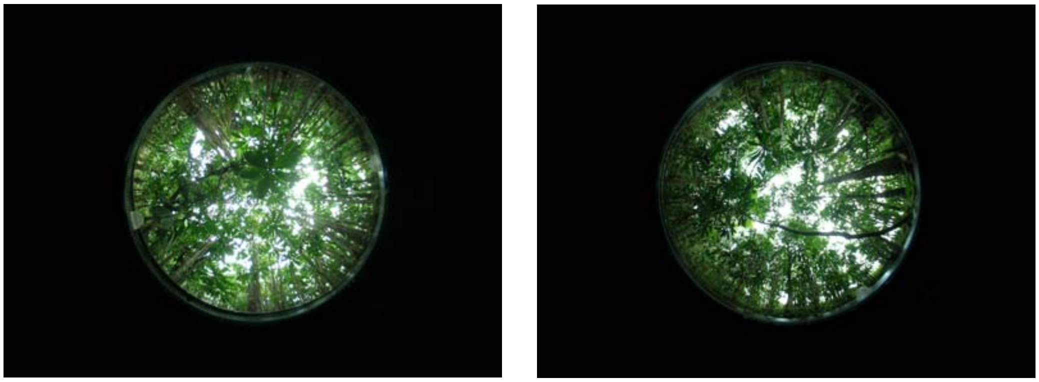


Figure 8. Hemispheric photographs taken at the center of the seedling quadrats.

4.2 Preliminary results
In total, approximately 250 seedling quadrats were established, covering a total area of 6250 m^2 or 0.625 ha. This represents a very intensive sampling effort. Most of the data collected over the two year period have not been collated; but approximately 100,000 individual seedlings from approximately 10 – 20 species were sampled. Understorey light, and the density, diversity, mortality, survivorship and recruitment of seedlings differ will be assessed to determine if they are different among the patches, and to determine the impact of *A. allughas* infestation on these variables. This assessment will be completed in August 2014 and the results will be submitted for publication in peer-reviewed journals.

4.3 Seed traps
To assess whether *A. allughas* affects the ability of trees to produce seeds, 50, 1 x 1 m seed traps were placed in a subset of PSPs on June 2012 and 6 additional seed traps were placed in plots established by the Gayle River on March 2013. A total of 56 seed traps within our PSPs. Initially, the seed traps were checked on a monthly basis from July 28, 2012; however, this activity could not be sustained, and was discontinued due to financial constraints. Monthly assessments recommenced in April 2013 but were discontinued again by August 2013, because the PI who was now responsible for data collection was not unable to continue the assessments due to other commitments (overseas travelling) and severe financial constraints. We hope to recommence monthly assessments in April 2014 for a period of one year.

5. Component /Activities 4: The control of *A. allughas* and the rehabilitation infected swamp forest patches

The following activities were not implemented:

1. Establishment of native species nursery,
2. Germination experiments,
3. Mechanical control of *A. allughas*
4. Forest Rehabilitation post control of *A. allughas*,

Activities 1, 2 and 4 were not implemented because of financial constraints. The number of field staff employed by the Black River IAS project was reduced because of budgetary constraints. Also, the project simply did not have the finances to build and maintain a nursery or to start the rehabilitation experiments. Regarding the mechanical control of *A. allughas*, the ATV was purchased in 2011 but was not delivered until 2012. The cutter and plow were purchased and delivered in 2012 but had to be stored in Kingston, because were unable to secure them in Black River. A trailer (used to transport and store the cutter, plow and the ATV) was purchased and shipped to Jamaica in September 2012; however it did not clear Jamaican customs until January 2013. It took an additional three months to obtain the requisite documents need to transport the trailer to our field site. As a result, both pieces of equipment were transported to Black River using the trailer in April 2013, but they could not be transported up river because the project's jon boat was stolen in September 2012. The cost to transport either the cutter or the plow up river was approximately $100 USD one-way (per trip), and due to financial constraints, this activity was suspended until the project's PI/manager had adequate finances to either build a barge to transport both units up river, purchase a new boat or cover the cost of transporting them by boat over the period of one month. This activity is currently delayed until April 2014, with a slated completion date of January 2015.

6. Adaptive Management Plan for Black River Lower Morass

Again, due to financial constraints an adaptive management plan was not drafted. Additionally, in the original IAS project document, $10,000 USD was budgeted to cover the cost of a consultant who would be responsible for drafting the management plan. Because our budget was reduced we initially thought that this activity was no longer considered as a target and also the project PI specifically requested that this target should not be included in the TOR that was signed by the Department of Life Sciences and NEPA because the Black River IAS project would not generate sufficient information to draft a management plan (see Appendix 1). But this target was not amended on the TOR. In any event, a management plan will be drafted for both the upper and lower morass, the cost of which will be borne by the 'Strengthening the Operational and Financial Sustainability of the National Protected Area (PA) System Project'.

7. Constraints

The project commenced one year after the scheduled start date, and was beset by numerous technical and other challenges; these challenges were detailed in previous reports. Most notably, the project was under under-funded; therefore our budget was completely exhausted by April 2012. As a result, all project activities undertaken since April 2012, had to be funded out of pocket at a cost of approximately $70,000 USD. Therefore the project failed to meet some targets due to a combination of factors mentioned above. Some of the challenges that were faced were expected, given the nature of field based research. However, other issues such as the theft of the project boat and an outboard engine was not anticipated, and as a result, the implementation of some activities (e.g. the *A. allughas* control experiment where the boat was needed to transport the cutter and the plow up river) was delayed. Despite the challenges, some of the projected targets were met, and despite the financial constraints, additional targets will be met by August 2014.

The PI opted to invest in the acquisition of equipment that can reduce the PI's dependency on field staff and to automate data collection and the establishment and maintenance of field experiments, to ensure that project activities are sustainable. Consequently, although some of the proposed targets were not met, project activities will continue beyond the life of this project and will proceed with minimal financial input. The PI has been actively seeking funding to expand some activities and to undertake new initiatives and it is hoped that funding can be secured in the near future.

8. Lessons learnt and recommendations

The proposed administrators must state explicitly, possible funding restrictions when engaging potential partners prior to submitting a project proposal for funding. UNEP and CABI were disingenuous regarding their overtures to the manager/PI of the Black River project. The PI was not informed of possible funding restrictions and was told that equipment could be purchased using grant funding. Additionally, there was no opposition from UNEP or CABI when the proposal, which included line items for purchasing equipment, was submitted to the GEF. However, after using matching funds put forward by the Black River IAS PI to secure funding, they reneged on what they had agreed to purchase.

Also UWI is a very capable research institution and has its own financial oversight. Therefore funding for the Black River IAS could have been administered directly by UWI (despite their tardiness with payments and reimbursements). Moreover, the PI has been conducting research at the target site since 2004 and knows what is needed to successfully implement the Black River IAS project in such a challenging. Furthermore, UWI's regional and international standing means that partnerships can be secured with other universities; therefore if technical assistance is required it can easily be procured. The technical oversight provided by CABI left much to be desired. Despite their vast experience working in other countries, they have not previously worked in Jamaica, at a similar site or tackled similar invasives. Therefore the unnecessary technical oversight resulted in the delay of project activities for a period of one year and significantly affected PI's ability to successfully conclude the activities of this project. The delay was significant; the Black River IAS project had ample field staff to complete the baseline assessments within one year and implement *A. allughas* control experiment by the second year. However the delay resulted in one of the project's two graduate student/research seeking and securing gainful employment (after being unemployed for period when the project was delayed). Therefore the project was forced to pay a premium price for field/research assistants and could not benefit from the graduate student assistantship provided by the Department of Life Sciences to help offset graduate student's expenditures. Additionally, funding was available cover the cost of shared project personnel; but due to the delay, this project was completed, and we were forced to pay for the full salaries of these personnel.

The project also suffered from having too many micro-managers. This affected the start date of the project as the project PI. After devising the project method with the local project administrator (NEPA), the PI had to prove that he was competent enough to devise and implement an IAS project at a site where he has been conducting research for past 10 years. Furthermore, because the UNEP and CABI insisted that the equipment that were included in the project proposal could not be procured due to their high costs, the project had to procure cheaper and less capable equipment, specifically, a less capable ATV. The PI originally sought to purchase a more capable but expensive ATV capable of self-propulsion on water. Instead the project had to settle for a less capable unit that had to be significantly modified, at a cost, to ensure that it could be used to access remote sites. As such, in addition to the late start, the project lost approximately 18 months procuring and modifying the ATVs, and this also resulted in the theft of an outboard that was purchased to propel the ATV on water. In the end, two ATVs had to be purchased (because the cost of one more expensive unit could not be shared), and in the end, both ATVs cost approximately 1.5 times as much as the preferred ATV.

In any case the project was under funded because the level of funding requested was not granted for the three complimentary projects. This meant that the Black River IAS pilot project and the two other complimentary projects funded by the MacArthur Foundation and the Forest Conservation Fund were treading on a financial tight rope. Consequently additional expenditures increased the cost of implementing the project activities beyond what was budgeted. As a result, two years after the project commenced some of the proposed field activities could not be implemented while others were discontinued due to severe financial constraints. The lesson learnt here is that the PI should never agree to implement projects that cost approximately 40% more than the total budget granted. Or, project targets should be revised to reflect the budget. The PI was confident that additional funding could be secured within the timeframe of the pilot to cover cost overruns, but this never materialized. Consequently some of the project activates had to be funded out of pocket, to ensure that project activities could be sustained.

So the recommendations include:

1) External funders must explicitly state funding restrictions while developing project proposals with local partners.
2) The PI for similar projects that are complex in nature and are being conducted in challenging environments must be granted greater latitude over how project funding is spent and the best and most appropriate methods/equipment to be used to achieve the project objectives.
3) Therefore in the future, pilot projects should be administered as a consultancy. If this is done, deliverables can be agreed prior to the start of the project, to ensure that the cost for each deliverable is adequately met. The consultant would then be free to employ whatever methods he/she deems adequate to complete the objectives of the consultancy.
4) Too many micro-mangers spoil the broth especially for PIs from an institution like UWI. PIs based at UWI are already faced with burdensome and tardy grant administration. Adding further layers of administration and mico-management only serves to impede the progress of any project.

Citations

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Appendix 1. Email from the PI to the then HOD of Life Sciences outlining that he did not agree to develop an adaptive management plan.

From: **Kurt McLaren** kurt.mclaren@uwimona.edu.jm
Subject: Re: MOU with the IAS Project and the UWI
Date: 1 February 2011 08:58
To: WEBBER,Mona K mona.webber@uwimona.edu.jm

Mona,
Sorry for the late comments. I did not agree to this:
3.2.7 Develop an Adaptive Management Plan for the Lower Black River Morass focusing on target IAS;

We will develop an adaptive management plant but this is for our MacArthur project. The information that is being collected/research that will be conducted by the IAS project will not give us sufficient data/information to develop such a plan.

Also for section 3.2.3, we are using this fund to help cover the habitat surveys. There are important equipment that we need, which they refused to procure for this project. So we solicited funding for the equipment from Macarthur and the FCF. The equipment will be used to collect data that can be used by both projects and will not be dedicated to the IAS. The IAS project is expected to stand on it's own, hence we have included line items in the IAS project to purchase all the necessary equipment needed for this project.

Kurt

On 11 Jan 2011, at 17:53, WEBBER,Mona K wrote:

> Colleagues,
> I was sent these docs. this afternoon. I will review and comment to NEPA ASAP. However, If you wish to review as please see attached.
> Please send me any comments you wish to add.
> Thanks a lot,
> Mona
>
> **From:** English, Nelsa [mailto:Nelsa.English@nepa.gov.jm]
> **Sent:** Tuesday, January 11, 2011 02:18 PM
> **To:** WEBBER,Mona K
> **Subject:** MOU with the IAS Project and the UWI
>
> Good Afternoon Dr. Webber,
>
> Please see attached a Draft of the Memorandum of Understanding and supporting documents drawn up for agreement between NEPA's Mitigating the Threat of Invasive Alien Species in the Insular Caribbean Project and the UWI, Mona's Department of Life Sciences regarding the UWI's implementation of 3 pilot projects on behalf of the Project. Kindly review same and return comments by 26 January 2011.
>
> Please note that a printed copy of the document will be delivered by Bearer.
>
> We look forward to hearing from you soon.
>
> Cheers
> Nelsa
>
> **Nelsa English-Johnson (Mrs.)**
> National Project Coordinator
> Mitigating the Threat of Invasive Alien Species Project
> National Environment & Planning Agency
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