ECO-FRIENDLY ALTERNATIVES FOR CONTROL AND USE OF INVASIVE PLANTS IN AGROFORESTRY SYSTEMS: THE CASE OF MARABÚ (DICHROSTACHYS CINEREA) IN CUBA

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Introduction

Cuba and the shrub-like tree *Dichrostachys cinerea* (L.) Wight et Arn, known as Marabú, constitutes a unique and scaring example of the devastating consequences, when an aggressively proliferating woody shrub is introduced uncontrolled into a potentially fertile region characterized by radical changes in farming practices, government policies and international relations. Marabú was introduced into Cuba from Africa some 150 years ago, and it has since then invaded approximately 10% of the total territory in the country, equivalent to an estimated 1.14-1.5 million ha of land (Cordero, 2012; Rainsford *et al.*, 2012). The invaded areas are primarily over-exploited or unused agricultural lands. The Marabú invasion escalated dramatically after 1990, when trade relations with the Soviet Union collapsed, and when sugar cane production to a large extent was given up due to a later collapse of prices on the international sugar market. Marabú now represents a serious obstacle for improvement of Cuban food security, which is highly needed, as recent estimates point to a dependency on food imports of a staggering 75-80% of all foods consumed in Cuba (Altiery and Funes-Monzote, 2012; Graziano, 2013).

There is a justified fear that Marabú can spread to the Latin American continent, if it is not brought under control in Cuba, and major parts of the Latin American region are believed to be highly suitable for sustaining its growth. Marabú has already been detected in Florida and Arizona, USA (United Stated Department of Agriculture Database, 2012; FAO's Plant Production and Protection Division). Following climatic changes with warmer and more arid conditions, there is also a risk that Marabú or other similar plants can invade southern parts of Europe from Africa. Development of efficient global strategies to control and make use of new invasive shrubs, therefore appear to be highly needed all over the world in light of the climatic changes we are facing, and as such Cuba represents a very interesting case for the study of the behaviour of aggressive, invasive plants, and for the development of alternative strategies for their control or potential utilization.

The Cuban government has dedicated substantial attention to the control of Marabú without the use of environmentally damaging herbicides, and probably the most promising approach has been to combine heavy machinery with the subsequent use of the biomass for bioenergetic purposes (Rainsford *et al*., 2012). However, this approach is obviously restricted to easily accessible areas within reasonable distance from bioenergy plants. Complementary strategies, targeting Marabú vegetation in marginal and more remote areas, such as mountainous regions, along roadsides and in small-scale fields are urgently needed, since such areas represent a continuous source of Marabú seeds and hence new plants, which can jeopardize the attempts to control Marabú elsewhere. Present Cuban government policies attempt among other things to encourage reclamation of arable lands infested with Marabú for agricultural production in order to improve the national food security situation. However, many small-scale private cooperative farmers are deterred from engaging in such activities due to: 1) the hard and extremely time consuming (at least 5-10 years) work associated with clearing of infested areas without the use of environmentally unfriendly and expensive strong herbicides or soil compressing bulldozers, and 2) the lag-time before income can be generated from agricultural activities.

Marabú is, however, not only a plaque, but also an amazing plant, which can fix nitrogen from the air and thereby contribute to supply nitrogen fertilization and restore fertility in over-exploited agricultural soils. It produces hard-wood with qualities and a hardness equivalent to that of noble woods from tropical rain-forest trees, which are imported into many Western countries and subject to regular criticism from environmental organizations. Marabú is drought resistant and produces green matter and seed pulps almost year round, which can provide an important source of feed for (ruminant) livestock. It is already being used for production of high-quality charcoal, and there are as mentioned developments on the way for its large-scale use for bioenergy purposes (Rainsford *et al.*, 2012). Special characteristics of its carbon structure hold promise for other industrial uses (eg. activated carbon filters).

We will in the following, based on experiences in both Cuba and habitats elsewhere in the world, argue for a conceptual change, where Marabú is seen not only as a serious economic burden and a risk for improvement of Cuban food security. But rather as a plant, which holds the potential for sustaining agricultural development, and we will propose a specific role for the emerging small-scale, private cooperative sector in Cuba in complementary efforts to combat, control and utilize the potential of Marabú in areas, where other large-scale control measures, relying on eg. heavy machinery, are not feasible. The new concept is that arable lands invaded by a leguminous, drought-resistant shrub like Marabú, ranking high on the international so-called Global Invasive Species (GIS) database[1], can provide the foundation for development of economically and environmentally sustainable silvopastoral/ agroforestry systems in a controlled management system with an efficient biological controller, the goat, which is another species ranking very high on the GIS[1] database due to the ability of this browsing animal to feed on and destroy exactly plants like Marabú. The Marabú represents a potential source of precious hard-wood, fodder for ruminant livestock during the dry season, especially in (semi-) arid areas, and of nitrogen fertilization in co-cultivation systems with other (cash) crops. Our other idea, based on Danish experiences, is that incitement can be generated in the emerging private cooperative sector amongst small-scale Cuban farmers to engage in the very

[1] GIS http://www.issg.org/database/welcome

hard and time-consuming work of combating or controlling the Marabú. This by developing alternative and economically attractive market opportunities for products generated by the plant itself and by the goats employed in its biological control, and by enabling production of marketable fodder or cash crops in co-cultivation systems with Marabú.

The history of the invasion of Marabú and its current distribution in Cuba

Different invasive woody shrubs are present in Cuba, of which the most abundant are the Aroma (*Acacia farnesiana* Wight et Arn), Weyler (*Mimosa pigra*) and Marabú (*Dichrostachys cinerea* Wight et Arn). The Marabú is considered by far the most important of these species particularly in agricultural areas, due to its superior colonizing ability, its ability to adapt to and propagate in different ecosystems and due to the viability and longevity of its seeds. The Marabú is thus included amongst the highest categories of aggressive and damaging invasive species[1] in the world.

There are three different accounts of how the plant was originally introduced into Cuba. The first version states that it was brought to Cuba as an ornamental plant by a wealthy French woman living in Camagüey. The second version states that it was introduced by José Blaín on his farm “El Retiro” in Taco-Taco, Pinar del Río, to be cultivated as a botanically interesting species. The third version states that it was propagated by accident after the “10 year war” (1868-1878), when cattle farms were re-established based on imported cattle from Colombia and other places, where the plant already existed (Roig, 1915). It is, however, questionable if the plant was found on the Latin American continent at that time.

According to Cordero (2012), the Marabú has during the approximately 150 years since its introduction become the plant, which has proliferated the most in Cuba. At the turn of the 21st century, around 1.14 million ha was invaded (10% of the total Cuban territory, which represents around 18.6 % of land dedicated to agricultural activities, and it has affected around 56% of lands dedicated to livestock production).

The geographical distribution of Marabú in Cuba is not adequately documented, but the Havana municipalities appear to be among the most affected (Figure 1), but it is recognised that Marabú can be found all over Cuba (Figure 2).

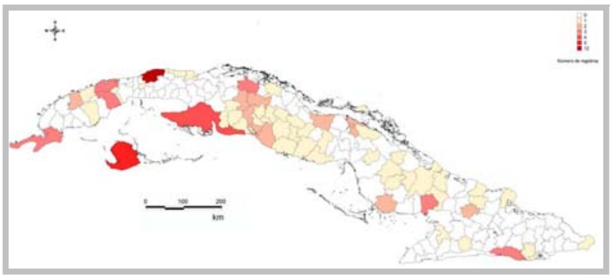

Figure 1: Incidence and occurrence of Marabú in Cuba (Regalado et al., 2012)

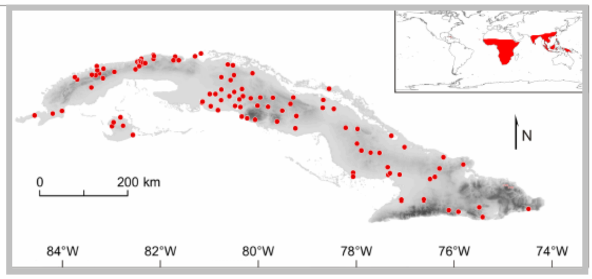

Figure 2: Spatial distribution of Marabú in Cuba (Baró & Fuentes, 2012)

The ecosystems, which have been invaded in Cuba, represent all kinds of soil types, vegetations, altitudes, and micro-climatic conditions found on the island, but Marabú appears to develop best on clay soils. It is commonly found in areas that have been abandoned for livestock or agricultural production purposes, but it can also invade agro-ecosystems in use (Baró & Fuentes, 2012). Its proliferation is associated with inadequate agricultural practices related to soil preparation, pasture and livestock herd management (Muñoz *et al*., 2009). Many natural and seminatural areas have been overwhelmingly invaded by the Marabú resulting in a loss of its natural vegetation (Figure 3A). Deforestation of the Marabú thicket, which currently takes place in Cuba, is therefore considered to be in accordance with ecological and biodiversity considerations and will help to preserve the natural Cuban biosphere (Rainsford *et al.*, 2012). Cuba, studies have been conducted with ruminant (cows, sheep) and mono-gastric (pigs, horses) animal species to determine the involvement of livestock in the propagation of the plant. These livestock species will excrete seeds in their faeces upon consumption of the Marabú fruit pods, but after the passage of the digestive tract, the germination ability of the seeds becomes improved (Muñoz *et al*., 2009), presumably due to scarification of the hard coat covering the seeds, which facilitates germination (Hashim, 1990). Consequently, excretion of seeds by livestock may be a principal reason for the continued spreading of Marabú in Cuba.

In contrast to the Cuban studies with the above-mentioned species, a Sudanese study showed that upon ingestion by goats and subsequent excretion into faeces, the germination ability of Marabú seeds was reduced by some 80% (Hashim, 1990). This may be explained by the more intense chewing behaviour of goats compared to other ruminant species, which results in a more efficient degradation of ingested feed particles, and hence a reduced size of particles excreted in the faeces (Jalali *et al*., 2012). Thereby ingested seeds would not only be scarified, but potentially complete destroyed by goats. Future studies will be needed to verify, whether goats do indeed have a special ability to destroy Marabú seeds, since this could point to a potential employment of goats in the biological control of Marabú, as discussed below.

Due to the priority of the government to guarantee food for its people (Graziano, 2013), Cuba is one of the countries, which have achieved the goal of the World Food Summit to halve the number of people suffering from starvation. However, according to official estimates a staggering 80% of foods consumed in Cuba over the 5-year period 2007-2011 were imported, associated with an average annual cost of 1700 million USD (ONEI, 2012b). This number is expected to reach 2000 million USD in 2013 (Rodríguez, 2012). It is therefore of crucial importance for the Cuban economy to improve productivity in the agricultural sector. Efficient strategies to reclaim and/or utilize arable lands infested with Marabú are therefore needed. We therefore need to understand the biology of the Marabú plant, and also what experiences have been obtained in Cuba and elsewhere in the world with respect to its control and utilization.

Nomenclature and description

The scientific name for Marabú is composed of "*Dichrostachys*", derived from the Greek words "*dis*" meaning twice, "*chroa*" meaning colour, and "*stachys*" meaning a spike, and "*cinerea*", which refers to the greyish hairs, i.e. "*Dichrostachys cinerea*" means the plant with two-coloured spike and greyish hairs. In South Africa the tree is called the ‘Kalahari Christmas tree’, but most commonly it is known as the ‘sickle bush’, because the young pods are curved like sickles. In Tropical Africa, 7 subspecies have been found, and some of them include several varieties (Ecocrop).

Dichrostachys cinerea is described as a semi-deciduous to deciduous tree up to 8-12 m tall, suckering and thicket-forming (Figure 3A), with an open crown. The bark on young branches is green and hairy, dark grey-brown and longitudinally fissured on older branches and stems, and smooth on spines formed from modified side shoots. They have characteristic strong thorns (Figure 3B), up to 8 cm long, which grow out of branches almost at right angles. Twigs have colours varying from grey, brown to violet, with prominent light lenticels. Leaves are bipinnate with 5-15 pairs of pinnae, which each bear 12-22 pairs of leaflets. Leaflets are about 8×2.5 mm wide. Flowers (Figure 3C) are very characteristic in bicoloured cylindrical, with a bottlebrush-like appearance, 6-8 cm long and fragrant. Terminal lower flowers are hermaphroditic. Upper flowers of a hanging spike are sterile, reddish or pale purple, with protruding staminodes. Pods (Figure 3D) are narrow, yellow or brown, generally twisted or spiralled, up to 100×15 mm, arranged in dense, intertwined clusters and indehiscent. There are about 4 black seeds per pod (AgroForestryTree Database).

Figure 3: The Marabú

A: forming dense thickets, where natural vegetation is eliminated
B: nasty thorns
C: beautiful bi-coloured flowers
D: intertwined clusters of pods
(Photos: MO Nielsen)

Ecology, habitat and global distribution of the Marabú

Dichrostachys cinerea is usually not frost resistant, and the frost tolerance is less on poor soils (Table 1). It is definitely drought tolerant and fire resistant, but does not tolerate waterlogging well (Venter & Venter, 1996), although it penetrates clear-cut areas far into rainforest zones. In Malaysia, it occurs in areas with strong seasonal climate, usually on poor, occasionally clayey soils, in brushwood, thickets, hedges, teak forests and grasslands. It forms dense hammocks on lateritic soils and occurs in dry deciduous forests in the Sahel region (Vogt, 1995). It is an indicator of overgrazing in low rainfall areas (Vogt, 1995). It tolerates altitudes up to 2,000 m, mean annual temperatures ranging from -2 to 50°C, and mean annual rainfalls from 200-400 mm. It grows best on deep, sandy loamy soils and tolerates a wide pH range (4.5-8.5) (Coates-Palgrave, 1988). With regards to reproductive biology, it has been found in Indonesia to flower from September-June and bear fruits from March-May, sporadically also in other months. In southern Africa the flowering season is from October-February and fruiting from May-September. The structure of the flower inflorescence suggests pollination by bats (Palmer & Pitman, 1972). The infructescence has a strong aroma, which probably attracts animals to feed on the pods. A fraction of seeds exhibit polyembryony with usually 2-3 embryos; the extent of polyembryony seems to be positively correlated with the number of seeds produced. Natural regeneration is strongest by root suckers. Within a 10 years period, one plant can produce 130 new stems in a radius of 15 m by its root suckers (Vogt, 1995). Around 1 million seeds are expected per year from an adult plant, and most of the seeds are viable (Tietema *et al*., 1992).

Table 1: Description of Marabú and its ecological requirements (Ecocrop)

Climate:	Optimal		Absolute		Soil:	Optimal	Absolute
	Min	Max	Min	Max	Depth	deep (>150 cm)	medium (50-150 cm)
Tempe-rature	15	40	10	50	Texture	medium, light	heavy, medium, light, wide
Annual rainfall (mm)	300	500	200	600	Fertility	moderate	low
Latitude	-	-	25	30	Salinity	low (<4 dS/m)	low (<4 dS/m)
Altitude (m)	---	---	-	2000			
Soil pH	5	8	4.5	8.5	Drainage	well (dry spells)	well (dry spells), excessive (dry/ moderately dry)
Light intensity	very bright	very bright	clear skies	very bright			
Climate zone: tropical wet & dry, desert or arid, steppe or semiarid							
Abiotic tolerance: fire, drought					Abiotic susceptibility: flooding		

Marabú is considered a native species in many tropical African countries (Figure 4): Cameroon, Djibouti, Eritrea, Ethiopia, Ghana, Kenya, Madagascar, Malawi, Nigeria, Somalia, South Africa, Sudan, Swaziland, Tanzania, Togo, Uganda, Zambia.

It is considered exotic ie. introduced in other countries in Africa, Arabia, tropical Asia and America: eg. Angola, Australia, Benin, Botswana, Brunei, Burkina Faso, Burundi, Cambodia, Cape Verde, Central African Republic, Chad, Comoros, Congo, Cote d'Ivoire, Cuba, Democratic Republic of Congo, Egypt, Gabon, Gambia, Guinea, Guinea-Bissau, India, Indonesia, Iran, Jamaica, Laos, Lesotho, Liberia, Malaysia, Mali, Mauritania, Mauritius, Mozambique, Myanmar, Namibia, Niger, Philippines, Rwanda, Sao Tome et Principe, Senegal, Seychelles, Sierra Leone, Thailand, Vietnam, Yemen and Zimbabwe.

Impact of Marabú on biodiversity and soil fertility in Cuba, and measures employed to control its propagation

Marabú encroaches rapidly on overgrazed, trampled ground and on old lands where the grass or other vegetation cover has been removed. Marabú has in Cuba rendered arable land unusable for any agricultural or livestock production purposes, and caused great losses in grassland yields (Muñoz et al., 2007).

The Marabú plants, when allowed to grow undisturbed, form thickets, which are so dense that they can extinguish all other plant species below (Figure 3A), and they become virtually impenetrable due to the numerous long and strong thorns, and they can shoot again from portions of the root (Vogt, 1995; ICRAF, 1992). Indirectly, Marabú infestation in grassland areas can result in overgrazing in neighbouring areas due to a reduced total availability of grazing land (Muñoz et al., 2007).

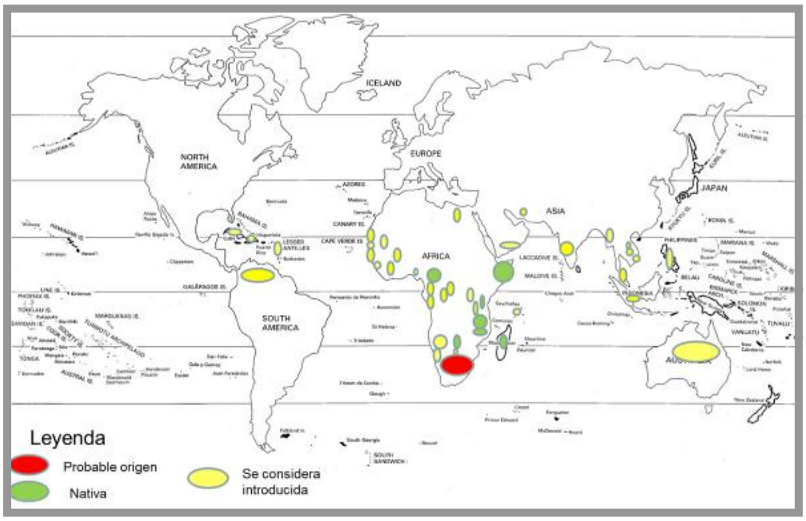

Figure 4: Global distribution of Marabú (Verdecia, 2012)

Red spot: the area of origin in Southern Africa
Green spots: areas where Marabú is now considered a native species
Yellow spots: Areas in Asia, Australia and Latin America, where Marabú is considered introduced

However, it has been reported (Núñez, 2001) that Marabú is capable of improving physical structure in the soil, provide protection against erosion caused by wind and rain, and as a legume it provides nitrogen fertilization through capture of atmospheric nitrogen and deposition in the soil. Its foliage in addition represents a significant annual contribution to soils of organic matter, and the penetration of the root system deep into the ground (up to 2 m), facilitates removal, aeration and infiltration of water deep into the soil. Upon clearing of areas infested with Marabú for years, agricultural productivity has thus been found to be improved, and it is not uncommon for farmers to leave stretches of Marabú vegetation in between fields that are cleared to benefit from these favourable impacts on soil fertility as well as from wind breaking effects.

Muñoz et al. (2007) has reported observations on the efficiency of different chemical or mechanical procedures hitherto employed in efforts to control and/or eliminate the Marabú. None of these have been completely effective, except for the use of dangerous herbicides, which are not in line with the Cuban strategies for an environmentally friendly farming approach:

Mechanical cutting: When the plant is mechanically cut, close to the ground and without applying any chemical products to the stub, it is capable of multiplying and producing up to 14 new re-growths from its roots. The cutting altitude above the ground has no effect on re-growth of the plant, nor does the season of the year or the moon phase. The only environmental factors impacting re-growth are ambient temperature and soil humidity. The frequency of cutting can reduce the speed of re-growth with time, and with a cutting frequency of 10-15 days, a small reduction in the population at each cutting can be observed after the 10^{th} cutting, but initially there is a progressive increase in growth in response to cutting. Cutting of large specimens has an effect on the production of seeds, since young plants below a height of approximately 2 m do not produce seeds (MO Nielsen, personal observation).

Chemical treatment: Good results have been obtained, when a mixture of charcoal oil or refined mineral oil, either alone or mixed with copper arsenate, has been applied to the tree stumps after cutting. Applying a mixture of 50-75% oil mixed in water on tree stumps or pruned branches was from 85-90% effective in controlling the Marabú. These procedures are, however, costly and only applicable on small plots of land.

Burning: In agreement with the reported resistance of the Marabú plant to fire (Table 1), it has not been possible to kill the plant by burning, nor has burning had any effect on the timing or quantitative re-growth of the plant, irrespective of season of the year and whether the burning was conducted after cutting (manual or mechanical) or directly without prior cutting of the plants.

Animal browsing: Promising results have been obtained, when lactating cows were introduced in a rotational system in areas, where the Marabú vegetation was cut manually at an altitude of 20-30 cm. The animals were capable of consuming the re-growth and in this way prevent the increase in density of the plants, which was otherwise observed associated with the re-growth after cutting at these heights or at ground level. The time the animals spent in a given area was determined by the state of the "pasture" area, and varied from 7-10 days in the spring to 3-5 days in the dry period, and the stocking rate was fixed at 6 livestock units/ha from the time point when the height of the re-growth had reached 15-30 cm. In addition to the prevention of Marabú re-growth, milk production of the cows was increased by 62%. Revés *et al*. (2010) have also reported promising results from an integrated semi-controlled management system with goats, where a stocking rate of 4-5 goats/ha could control the re-growth of Marabú.

It has been proposed by Manzanares *et al*. (2008) that the focus from a socio-environmental point of view should perhaps not so much be to irradicate the Marabú, but rather to solve the challenges of how to benefit from its beneficial impacts on soil fertility, whilst also conserving the environmental capital and avoid simplification of the biodiversity. This proposal is based on the documented beneficial effects of Marabú on soil fertility and the lack of control measures, which are both efficient and environmentally compatible. The potentials for utilization of Marabú in itself and as an integrated part of agroforestry/silvopastoral systems should therefore be explored.

Utilization of Marabú in Cuba

Considering the vast areas infested with Marabú, it is currently not utilized to any significant extent except for bioenergy, but a variety of potential uses are recognised.

Bioenergy production: The chemical composition of Marabú makes it highly suited for this purpose due to its dense wood with low water content and a high energy content of 4654 kcal/kg (Manzanares et al., 2008). The wood sustains a durable and clean combustion with only minor smoke and ash production (Guyat & Aguirre, 2010).

Marabú wood or branches are commonly used and with high yields either directly for production of fire wood or for production of charcoal. There is an as yet under-utilized potential for export of Marabú charcoal from Cuba, which can be marketed as eco-friendly and of high-quality. The charcoals contain only 2-6% ash and between 64-85% fixed carbon (Guyat & Aguirre, 2010). For these reasons, Marabú charcoal was ranked among the top charcoals in tests in Germany[2].

Presently, there is substantial focus on the large-scale use of Marabú for bioenergy production to substitute the dependency of imported oil. By the end of 2012, the first

[2] http://www.carbocuba.com/en/charcoal-test-marabu

European-Cuban joint venture contract in years was signed between the British company Havana Energy Ltd. and the Cuban sugar monopoly for construction of a number of 30 megawatt bioelectricity plants attached to the sugar mills around the country and based on sugar cane refuse and Marabú biomass (Frank, 2012; Rainsford *et al*., 2012). Examples of such sugar mills are the *Central Azucerero “Carlos M. De Céspedes”* and *Central Termoeléctrica “10 de Octubre”* in Camagüey. It is estimated according to Leyva *et al*. (2010) and Padrón *et al*. (2010) that:

- *“Carlos M. De Céspedes”* is surrounded by 49,050 ha of Marabú infested land equivalent to 25% out of the 196,350 ha within a 25 km radius
- *“10 de Octubre”* is surrounded by 142.328 ha of Marabú infested land equivalent to 28% out of the 502,656 ha within a radius of 40 km
- The potential bioenergy production from Marabú in these two areas alone is equivalent to the total consumption of imported oil in the Camagüey province.

Large-scale bioenergy production from Marabú is obviously only feasible in regions that are both accessible for heavy machinery and located within reasonable distance from power plants. For less accessible and marginal areas, other approaches must be applied, and this is crucial, since they represent a continuous re-infestation threat, where an adult Marabú plant can spread around 1 million seeds per year, of which 75% or more can give rise to new plants.

Wood industry: The heartwood of the Marabú is durable, medium to heavy with a density of 600-1190 kg/cm^3 (15% moisture), and has an attractive orange over red to purple colour with darker streaks, which is sharply differentiated from the yellowish-brown sapwood, which is much softer and less durable than the heartwood. The grain of the wood is straight, and the texture rather fine and even, and the wood is very resistant towards insect attacks and changes in humidity (AgroForestryTree Database; Manzanares *et al.*, 2008). But the tree has a limited size and an irregular pattern of growth with invagination of sapwood into the heartwood (MO Nielsen, personal observation). In Cuba, the Marabú wood has a reputation of being very hard and difficult to process, and the manual cutting is extremely hard due to the hardness of the wood and the unpleasant thorns. It is therefore hardly used in the wood industry, except for fence poles, which are often made from branches with little heartwood and hence not very resistant to degradation in the soil. but there is a potential for micro-industry development, which deserves to be explored.

Other uses: Baró & Fuentes (2012) report that Marabú wood has been used for paper pulp, fodder for livestock (leaves and pods), as an insecticide and for honey production, but this is not on an extensive scale, and the potential value of Marabú for such uses in Cuba has not been sufficiently explored either.

Potential functional uses of the Marabú plant – global experiences

The question to be raised at this point is whether value-chain developments based on the use of Marabú by small-scale farmers and micro-industries could be an avenue to control Marabú in marginal and less accessible areas. Marabú is utilised for many interesting purposes in particularly Africa and India, and they can roughly be classified into three overall categories: environmental control, integrated agricultural production systems, and plant-derived productions:

Integrated systems for environmental control:

Erosion prevention, stabilization and land reclamation: Marabú is widely used in eg. India for sand dune stabilization and erosion control, and the plant spacing for such purposes should be 3 × 5 m. When the plants are well-established, environmental control can be combined with harvesting of leaves and pods for fodder. Its prolific root suckers provide a natural spread for complete ground cover within a few years (ICRAF, 1992). Dense plantings help stabilize gully plugs and check-dams (ICRAF, 1992). It is recommended for use on shallow soils, arid western and subhumid alluvial plains and highly degraded calcareous wastelands (Mbuya *et al*., 1994). Owing to its strong capacity for natural regeneration, it has high potential for ravine afforestation and other soil conservation purposes on difficult sites (ICRAF, 1992).
Boundary or barrier or support: Thorn branch enclosures prevent livestock from straying at night and protect vegetable gardens, cash crops and fodder- or thatch-grass reserves from livestock. Since Marabú is difficult to control, having an aggressive weedy character, its use as a live fence is, however, very limited.
Soil improver: Marabú, being a leguminous plant, can fix atmospheric nitrogen (ICRAF, 1992).The leaves are rich in nutrients and frequently used as a green manure (Storrs, 1995). In the Sahel, particularly along riverbanks, it is said to improve soil fertility. This is interesting, since poor soil quality due to mismanagement has become a serious problem in Cuba (Jiménez Guethón & Almaguer Guerrero, 2003). According to official statistics (ONEI, 2012a) 26.4% of soils in Cuba are characterised as being seriously to very seriously eroded. Salinization affects around one million ha dedicated to agricultural activities, and compaction due to the use of heavy machinery is affecting 14.6% of the territory, including the most productive soils in the country (Jiménez Guethón & Almaguer Guerrero, 2003).

Integrated agricultural production systems:

Silvopasture and agroforestry: Marabú is highly compatible and suited for co-cultivation with certain improved arid-zone grass and forage species such as *Cenchrus ciliaris* (buffel grass), *Lasiurus sindicus* (sewan grass) and *Stylosanthes hamata*, making it well suited to silvo-pastoral systems (Roy *et al*., 1987). Plant spacing should be 8 × 8 m. It is also useful for intercropping (Ecocrop), which points to interesting possibilities of co-cultivation of Marabú with not only fodder, but also cash crops in a system with low or zero inputs of nitrogen fertilization, potentially coupled with livestock as biological controllers in a rotational grazing system. The juicy pods and leaves are rich in protein (11-15% crude protein) and minerals, and highly palatable to a wide range of animal species like cattle, sheep, goats, camels and wild African game. The plant produces shoots, leaves and pods year long, which are browsed by smaller domestic animals, and constitute an important source of nutrition particularly in the dry season and in arid areas. Pods and seeds do not contain hydrocyanic acid, minimizing the risk of poisoning animals, and although the leaves contain tannins, they do not to have any major negative impact on (nitrogen) digestion in ruminants, which could otherwise limit the use of Marabú as a fodder.
Fodder production: Marabú leaves (Pedraza Olivera *et al*., 2008) and pods (Table 2) are very nutritious and palatable to all ruminant species (Feedipedia, 2012). The protein content is reasonably high in both pods (11-18% of dry matter) and leaves (15-18%). Neutral Detergent Fibre content in dry matter is higher in pods (32-65%) than leaves (27-32%). Ca contents are high, but P contents low (Table 1). The plant retains leaves and pods late into or throughout the dry season (Feedipedia, 2012),

Apiculture: The flowers are reported to be a valuable honey source (ICRAF, 1992; Roy *et al*., 1987).

Table 2: Chemical composition and nutritional value of Marabú pods

Main analysis	Unit	Average	(Min-max)
Chemical composition:			
Dry matter	% as fed	93.0	(90.0-94.9)
Crude protein	% DM	13.5	(10.8-17.8)
Crude fibre	% DM	23.4	(19.2-26.6)
NDF	% DM	47.0	(32.3-64.6)
ADF	% DM	26.3	(25.6-26.9)
Lignin	% DM	8.0	(7.7-8.4)
Ether extract	% DM	2.2	(0.9-5.4)
Ash	% DM	5.9	(5.4-7.2)
Gross energy	MJ/kg DM	18.5	
Calcium	g/kg DM	7.4	(5.1-9.2)
Phosphorus	g/kg DM	1.8	(1.2-2.1)
Ruminant nutritive values:			
Organic matter digestibility	%	86.6	
Energy digestibility	%	84.0	
Digestible energy	MJ/kg DM	15.5	
Metabolizable energy	MJ/kg DM	12.6	
Nitrogen digestibility	%	37.2	
Pig nutritive values:			
Energy digestibility, growing pig	%	53.4	
Digestible energy, growing pig	MJ/kg DM	9.9	
NE growing pig	MJ/kg DM	5.6	

(Feedipedia, 2012)

Plant-derived productions:

Food: In addition to ruminant animals, as described above, pods and seeds from Marabú are edible for humans and other monogastric animal species (Table 2).
Fuelwood/bioenergy: As in Cuba, Marabú is commonly used for bioenergy production elsewhere in the world. For actual fuel-wood plantations a spacing of 3 x 5 m is recommended. It has a medium to slow rate of 6-8 cm/year (ICRAF, 1992), and to get maximum fuel biomass, the plants should be harvested at 10 years.
Fibre: The bark yields a strong fibre used for various applications such as twine. The debarked roots are used for strong plaiting works, such as for racks and baskets.
Timber: Due to its generally small dimensions, its reported utilization is limited to items such as walking sticks, handles, spears and tool handles. Fencing posts are durable and termite resistant, easily lasting up to 50 years (Sosef *et al*., 1998).
Ornamental: Marabú has been used as an ornamental plant due to its beautiful pink and yellow lantern flowers (Figure 3D) during early summer and the interesting branching pattern during winter. It is also a favoured plant to train as a bonsai.
Germ plasm: As previously mentioned, an adult Marabú plant can produce around 1 million seeds per year, with 50,500-66,500 seeds/kg. Under controlled conditions, more than 75% germination may be expected from quality seeds, which can be produced by taking out the seeds from pods collected as soon as they ripen on the tree, and then drying them. With orthodox seed storage behaviour; little loss occurs in viability during 26 years of hermetic storage at room temperature. At room temperature, they can be stored for up to 10 years, if kept dry and free from insects. Ash can be added to stored seed to reduce insect damage. Direct sowing of seed is also possible. The freshly collected ripe seeds take long to germinate (15-20 days) (Tietema *et al*., 1992), mainly due to the thick seed coat. Scarified seeds give better germination, and a pretreatment of 25 minutes in concentrated sulphuric acid gives optimum germination of 3-7 days for freshly collected seeds. Three-year-old seeds require only a 15 minute pretreatment for optimum germination. Artificial propagation is possible by transplanting root suckers or by using root cuttings and this is considered the easiest and usually most successful method of artificial propagation.
Medicine: Different parts of the plant are being used as medicine for a variety of ailments (Ecocrop). The bark is used in treatment of dysentery, headaches, toothaches, elephantiasis. Root infusions are taken for leprosy, syphilis, coughs, as an anthelmintic, laxative and strong diuretic. Pounded roots and leaves are used to treat epilepsy. The roots are chewed and placed on the sites of snakebites and scorpion stings. The leaves, which are believed to produce a local anaesthesia, are used for the same purpose and as a remedy for sore eyes and toothache. Leaves are taken as a diuretic and laxative, and used for gonorrhoea and boils. Powder from leaves is used in the massage of fractures. The plant is used as a veterinary medicine in India. Most of these uses are not properly scientifically documented.

The goat as a potential eco-friendly biological controller of Marabú

The goat (*Capra hircus hircus*) is of particular interest when it comes to eco-friendly biological control of the Marabú, since this animal is capable of destroying the germinating ability of Marabú seeds (in contrast to other livestock?) and control its development and maturation (incl. seed production) by feeding on the regrowth (Yayneshet *et al*., 2008; Tolsma *et al*., 1987). This potential of the goat to control unwanted vegetation under different environmental conditions has been severely underutilized in the world in general (Luginbuhl & Pietrosemoli, 2007).

Goats are classified as intermediate and highly selective mixed feeders adapted to both browsing and grazing, depending on eg. forage availability and nutritive value (Luginbuhl & Pietrosemoli, 2007). In contrast to cattle and sheep, their natural preference is to feed above the ground (up to 2 m) on vegetation like Marabú (Figure 4). As a ruminant animal, they are capable of converting fibrous Marabú biomass into highly nutritious meat and milk for human consumption, and goat meat and milk can be marketed in Cuba without the strict regulation imposed on cow milk and beef.

The goat has also been shown to be a powerful tool in poverty alleviation and to utilize scarce vegetation in areas not suitable for other forms of agricultural production. The goat is able to survive in harsher environments by feeding on a wider range of plant species than other ruminant species (Silanikove, 1997), but it is also able to induce great damage to the native vegetation due to its feeding habits, potentially leading to ecosystem degradation and biodiversity loss. This has earned the goat a very dubious reputation among environmentalists and placed it even higher in the GIS[1] database than the Marabú. The solution to the dilemma between the very efficient use of goats for environmental control and improvement of livelihoods of poor people versus their potentially very destructive impact on the environment is found in intelligent management of the goats and not in preventing the use of goats, where they obviously serve a purpose and can make a difference (Henriksen *et al*., 2007). Education and training of goats keepers combined with penalties for possible bad management may be a practical solution.

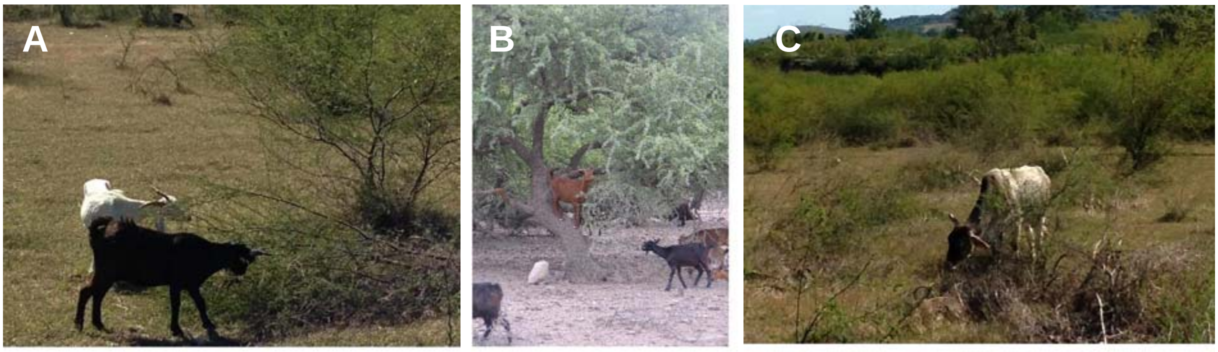

Figure 4: Goats feed on Marabú (A; Cuba) and can reach high into trees (B; Bolivia). Sheep and cattle are grazers feeding on the ground (C; Cuba) (Photos: MO Nielsen)

Potential small-scale value chain development opportunities based on Marabú

Cuba can be categorized as an agricultural country, and yet only some 15% of its population is presently engaged in primary agricultural production (Jiménez Guethón & Almaguer Guerrero, 2003). Current political efforts and economic reforms encourage development of a private, cooperative sector and reclamation of arable land for agricultural production to improve food security.

It should be evident at this point that there are huge unexploited potentials to utilise the Marabú in Cuba in new and innovative ways by developing integrated agroforestry and silvopastoral systems, combined with the use of goats as an eco-friendly biological controller. Substantial business and market development opportunities can be anticipated, both locally and internationally, which can contribute to stimulate activities necessary to control Marabú in marginal and less accessible areas, where large-scale efforts relating to bioenergy production are not feasible. All of these activities are obvious targets for developments in the small-scale private cooperative sector, where farmers and micro-industries would be key drivers:

Clearing of land infested with Marabú: can give rise to establishment of small-scale tree cutting businesses and small- and large-scale industries dedicated to processing of the biomass (charcoal and wood industries). There are no legal restrictions in Cuba for cutting and utilizing Marabú.

Agricultural production: The Marabú plant itself can be utilised as a feed for ruminant livestock, and its nitrogen fertilizing abilities can be utilised for co-cultivation with other fodder and cash crops to produce marketable animal feeds and human foods.

Goat rearing: Goats can be reared on Marabú re-growth, which represents a way to develop also landless livestock production for shepherds, and for development of specialised markets for goat meat and milk, which are not subject to the same marketing restrictions in Cuba as cow milk and meat. Goat hides and bones could potentially provide basis for development of a range of fabrication micro-industries.

Marabú timber: Hard-wood can be produced from large specimens of the plant with qualities equivalent to that of precious noble trees. Processing of the wood is difficult and with a high percentage of waste, but the wood can be purchased at a low cost, and with the price of labour in Cuba, a wood industry based on Marabú could prove competitive at the international market for specialized productions. There is no need for Forest Stewardship Council (FSC) certification of products made from Marabú growing in agricultural areas, since they are not within the FSC's competence.

Capacity development: of Cuban professionals can have spin-off value for other sectors, industries and educational institutions and provide ways to improve productivity, product quality and export opportunities in general for the country.

Private sector cooperatives as a tool to solve agricultural challenges and their potential contribution to a socially just development: Danish experiences

The experience over the last 150 years in Denmark (a social-democratic country in Northern Europe and part of Scandinavia) has demonstrated that a cooperative sector based on small-scale private farmers can provide the basis for development of highly productive and efficient farming systems and provide support for a fair societal development based on principles of solidarity and a high level of social security. The following account is based on Hansen (2013).

The Danish cooperative movement started in the 1880'ies, where important common problems gave small-scale private farmers the incentive to work together: Declining agricultural prices meant that farmers had to increase processing and added value, and a number of dairy and meat cooperatives were established. In the following years cooperatives became the major companies in almost all agricultural sectors, export shares rose to 75%, but the farms remained as individually farmer owned businesses. In recent decades Danish cooperatives have increased their size, market shares, internationalization and profits. Danish agriculture is now regarded as world leading in several areas, and this success has often been ascribed to the development based on the cooperative movement. Many parallels can be drawn between the challenges in Cuban agriculture in relation to Marabú and the historical challenges in Danish agriculture: An agricultural sector with a need to increase productivity in the food chain and with many small farmers, who can benefit from cooperating to strengthen their market power and income generation potential in order to survive and thrive.

A cooperative is a business, which is owned and controlled by the people (members), who use its services, and their benefits are distributed equitably on the basis of the use. The cooperative movement is based on a democratic system, where farmers elect members of the board, and farmers take all major and strategic decisions in the cooperative. Social responsibility and teaching of members are important parts of the cooperative system. The cooperative movement has been an important element in development of the Danish welfare system based on democracy, social security and education. Organisation into cooperatives has proven to be favourable in situations, where farmers and the farmer community face a common challenge and need to develop solutions to common problems with respect to organization, marketing or innovation, and it enables small-scale producers to benefit from the advantages of economies of scale, which the small famer or micro-industry alone cannot exploit.

Cooperatives have proven to be structurally robust, and the vertical integration, traceability, supply management etc., provide cooperatives with a competitive advantage over other types of companies also in an international context. Thus, even on the world market, Danish cooperative food companies etc. have achieved remarkable competitive strengths, and market shares considering the small size of the country (approximately 5.6 mill inhabitants and 43.000 square kilometres).

The strength of the cooperatives rely on their unique construction: Cooperatives are owned by the members – farmers - but the financial contribution is rather limited. Because farmers agree to deliver their production to the cooperative, the need for capital in the cooperative is reduced. In a way, the farmers' commitment to deliver their production to the cooperative is the major contribution from the farmers, and indeed a stable and reliable product supply is a very important asset for any company. In this way cooperatives need less capital, and the farmers can be owners of their own cooperative company without a need for huge capital input.

Lessons learnt from Danish agricultural and cooperative development

The historical lessons learnt by Danish agriculture and cooperatives might be interesting in the special Cuban context in several ways:

- The cooperative movement is based on principles of mutual support, responsability and solidarity amongst members of the cooperative and other cooperatives and can support a just development in the society as a whole.
- Cooperatives give farmers access to markets, and the vertical integration from farm-to-fork, which is a major strength in cooperatives, also enhance productivity and food security in the entire value chain.
- The cooperative sector is competitive and capable of attaining market power, and can be an active player in the globalization process through export as well as by attracting foreign investments, global strategic alliances, foreign joint-ventures etc. Partnerships with companies or group of farmers in foreign countries are common, and the concept of such cooperation is that all partners must benefit.
- The combination in Denmark of a highly competitive agribusiness with a dominance of cooperatives is a unique case. Researchers, consultants and

farmers from many countries study the Danish model in order to learn and copy from the Danish experiences. Several countries in Central and Eastern Europe adapted parts of the Danish model in the beginning of the post-communism era.

It is of utmost importance to be aware that experiences from other countries, even post-communist/socialist models, may not necessarily apply to Cuba, as Cuba's history, culture and economic experiences differ fundamentally from those of the former Soviet Union/socialist countries of Eastern Europe. Cuba has been unique in the region in its capacity to create a rather stable, but also somewhat static society with a social integration not seen elsewhere in Latin America. However, food security remains a major unsolved challenge in the Cuban society, and there is an urgent need to diversify and intensify the use of natural resources in a sustainable way, which does not lead to their deterioration (Jiménez Guethón & Almaguer Guerrero, 2003). Important questions arise in relation to whether the economic system introduced a generation ago in the 1960-70's has affected the societal dynamics and hence the macro- and micro-economic adaptability to the current process of reforms:

- How do Cubans perceive, remember and imagine work and economic activity?
- Has the former decades' tendency of very stable and secure relations between the individual subject and the work situation contributed to create a passive economic actor with reduced entrepreneurial capacity?
- Or will the current reform process be received with enthusiasm and entrepreneurial innovations?
- How will these issues impact on the transition from a government employed labour force to development of a small-scale private, cooperative sector?
- How is the private cooperative sector development and its ability to contribute to solve societal challenges perceived by Cubans?
- Is the high level of education among Cubans an asset for the economic reforms and the possibilities they imply?

Other questions arise in relation to the conceptual change we propose on the use of Marabú as a foundation for small-scale farmer and micro-industrial development:

- How will these questions and their answers affect the possibilities of creating small-scale rural enterprises in Marabú affected areas?
- How easy will it be to change the attitude toward a plant traditionally considered invasive and destructive, as well as almost invincible?
- What is the knowledge of and attitude towards the use of goats?

What the political implications will be of the current process of reforms and the improved relations to the outside world facilitating, eg. foreign investments, is another important issue beyond the scope of this paper.

Conclusions and perspectives

There is no doubt that the Marabú invasion represents a major obstacle to much needed developments and innovations in Cuban agriculture to improve food production and diminish dependency on food imports. It is also recognised that Marabú can not be extinguished (if this should be what Cuba decides to aim for) or even brought under reasonable control in the near future. However, there are huge unexploited and economically sound potentials for utilization of the Marabú, and efforts are already on the way for its large-scale use in bioenergy production to diminish dependency on oil imports. From the preceding sections it should be evident that such efforts can not stand alone, when it comes to controlling the continued spreading of Marabú in Cuba. Targeted efforts are needed in marginal and more remote areas, where large-scale efforts relying on heavy machinery are not feasible, since an adult plant can produce around 1 million seeds per year, out of which 75% can grow into new plants with the potential to invade or re-invade new areas.

The new concept, we are proposing, is that the leguminous, drought-resistant shrub, Marabú, ranking high in the GIS database[1], can provide foundation for development of economically and environmentally sustainable silvopastoral/agroforestry systems in a controlled management system with an efficient biological controller, the goat, which is also a high ranking species in the GIS[1] database, due to its special feeding behaviour, which makes it capable of controlling the propagation of exactly plants like Marabú. Future research and development activities should explore the potentials to utilize the Marabú as a source of precious hard-wood, fodder for livestock not least in (semi-)arid areas and as a nitrogen fertilizer in co-cultivation systems with other cash or fodder crops, and also how goats (or other livestock?) can be integrated into silvopastoral or landless production systems to control the propagation of Marabú, also in marginal and less accessible areas. Nitrogen and green organic matter deposited in soils by the Marabú can contribute to restore soil fertility and prevent exhaustion of soils under cultivation with zero or low input of nitrogen, as it is common practice in Cuba. Cuba strives to develop its agriculture based on organic principles. But this requires that nutrients removed from the soil with harvested crops must be returned by other means. Otherwise it is in reality not organic but exhaustion farming, which is practiced, which inevitably has reduced soil fertility as the outcome.

Danish experiences have shown that: 1) the private cooperative sector (farmers and micro-industries) is particularly well-suited to target such agricultural and societal challenges, whilst also contributing to an overall economical and socially just development, 2) it requires an economic incitement to motivate people to engage in such hard work as that required to control the Marabú, 3) this can be provided by developing alternative and attractive market opportunities for products generated by the plant itself, by the goats employed in its biological control, and by marketing of fodder or cash crops produced in co-cultivation systems with Marabú, and 4) research, development and transfer of relevant knowledge can be facilitated by collaboration and support from other countries with relevant (historical) experiences.

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