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Biofuels as Invasive Species

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Introduction

In recent years, bioenergy has drawn attention as a sustainable energy source that may offer a viable alternative to declining fossil fuel sources. Governments are looking at the potential of high-yielding crops for the production of biofuels to address shortages and to ameliorate the impacts of climate change. This approach has not been without controversy, especially in cases where food crops are used in the production of biofuels – using food to make fuel bothers many critics (Connor and Minguez, 2006; Rosegrant *et al*., 2006; Ayre, 2007; Naylor *et al*., 2007; Chakrabortty, 2008; Thomas *et al*., 2009). With regard to climate change, some analysts are of the opinion that the cultivation and conversion of food crops into biofuels requires so much energy that the savings in greenhouse gas emissions are negligible (Pimentel and Patzek, 2005; Grunwald, 2008; Searchinger *et al*., 2008). Then there is also the issue of clearing land, especially rainforests, to make way for monocultures. Forests and other ecosystems, including carbon-rich peat lands play a vital role in regulating the climate (Righelato and Spracklen, 2007; Fargione *et al*. 2008; Gibbs *et al*., 2008). However, one aspect that is often overlooked in any discussion around biofuel crops is their potential to become invasive.

After habitat destruction, invasive alien species (IAS) are already considered to be the second biggest cause of biodiversity loss worldwide. Direct impacts of invasive plant species include competition for space, nutrients, water and light, resulting in the displacement of native species. Indirect effects include changes in water-soil relations, nutrient cycling, light conditions, disturbance regimes and impacts on wildlife habitats. Hybridization between an invader and closely related native species may also lead to the loss of native species. Introduced invasive plant species are spreading at remarkable rates. For example, Babbit (1998) reported IAS to be invading approximately 700,000 ha. of land in the US every year. Introduced weeds already cause crop losses of approximately US$27.9 billion in the USA per year (Pimentel *et al*., 2001).

Global warming is expected to exacerbate the world's weed problems (Kriticos *et al*., 2003; Middleton, 2006; Low, 2008a; Raizada *et al*., 2009). Increased atmospheric CO_2 concentrations may stimulate rapid growth and high reproductive rates in weedy plant species. Invasive species such as *Bromus tectorum* L. (cheatgrass), *Pueraria lobata* Willd. (kudzu) and *Prosopis glandulosa* Torr. (mesquite) respond positively to elevated levels of CO_2 (Dukes, 2000). Extreme weather-related events and disturbance regimes are likely to increase in frequency and intensity as a result of climate change which will make many ecosystems more susceptible to invasion.

In this paper, the threat posed by the proliferation of invasive plant species as biofuel crops is assessed. This analysis is based on that of Low and Booth (2007) who mainly looked at invasive biofuel crops from an Australian perspective whereas here we attempt to assess it from a global perspective.

What are Biofuels?

The chemical energy stored in plants or animals or in the wastes they produce is called bioenergy. This energy within plant matter comes from sunlight, which converts carbon dioxide into organic compounds via photosynthesis. Any organic matter derived from plants during photosynthesis is known as biomass. During conversion processes such as combustion, biomass releases its energy, often in the form of heat, and the carbon is re-oxidised to carbon dioxide, releasing the carbon which was present in the plant (De Oliveira and de Sousa, 2007). The energy in biomass can be used directly by, for example, burning wood for heating and cooking, or indirectly, by converting it into liquids (alcohols, methyl/ethyl esters) or gaseous fuels such as hydrogen (de Oliveira and de Sousa, 2007). Most fuels used in the transport industry are liquids because vehicles require high energy density. This mainly comes in the form of bioethanol, which is produced by the action of microorganisms and enzymes during the fermentation of plant sugars or starches in a relatively simple process; or from cellulose which is a lot more difficult to break down. Biodiesel is produced from plant oils using the process of trans-esterification and is a liquid similar in composition to mineral diesel.

Bioethanol from starchy and sugar-rich crops and biodiesel from oil-containing crops are known as "first generation" biofuels. The crops used are readily converted to fuel and first generation fuel production is carried out extensively around the world today. Alcohol fuels are derived from wheat, corn, sugar beet, sugar cane, molasses and any sugar or starch from which alcoholic beverages can be made including potatoes. Feedstocks for biodiesel include vegetable oils, soy, rapeseed, *Jatropha curcas* L., palm oil, peanuts, mustard, flax, sunflower, and hemp. "Second-generation" biofuels are derived from ligno-cellulose which is the "woody" structural material of plants which is abundant and diverse and has increasing appeal because it does not divert food away from the animal or human food chain (Sims *et al*., 2008). However, fibrous components are difficult to hydrolyze to sugars and, if achieved, often yield a mixture of sugars, some of which are difficult to ferment to alcohol. The current conversion costs are also high with no technology currently available to convert ligno-cellulose to fuel on an industrial scale. Despite this, feedstocks for second-generation biofuels are already being promoted and include those plant species that grow exceptionally fast, have a high cellulose content, require low nutrient inputs, have the ability to coppice readily and can grow in a wide range of soils and climatic conditions. Species such as willows (*Salix* spp.), poplars (*Populus* spp.), gums (*Eucalyptus* spp.), mesquite (*Prosopis* spp.), and tall perennial grasses such as switchgrass (*Panicum virgatum* L.) and e-grass (*Arundo donax* L.) are actively being promoted. In addition to these, fuels derived from algae (oilgae) are known as "third-generation" biofuels. Proponents of third generation biofuels describe oil-producing algae as a biodegradable, low-input and high yield feedstock, although the theoretical yield limits of oilgae may be lower than some would suggest and the achievable yields lower still (Benemann, 2009; Walker, 2009). Most involved in research into algal fuels, however, would agree that large-scale commercial production of third generation biofuels will take years of further development, if proven feasible at a practical scale (Benemann 2008, 2009).

Why Biofuels?

Biofuel production is expanding rapidly throughout the world, and is driven by rising crude oil prices, the desire of countries to be energy independent, and concerns about climate change. Added to this is the fact that total global energy consumption is expected to grow by 50% by 2025 (Hazell and Pachauri, 2006). With oil prices increasing and future supplies uncertain, countries are seeking alternative energy sources to improve long-term energy security and reduce expensive energy import bills. President George Bush's 'Biofuels Initiative', a major component of his 'Advanced Energy Initiative,' planned to replace 75% of oil imports by 2025 (http://www.energy.gov/news/3255.htm). During a televised address to the nation of America ex-President Bush stated that America should cure its addiction to oil and turn to alternatives such as cellulosic ethanol (Herrera, 2006). According to Lovins *et al*. (2007), a domestic biofuels industry in the United States has the potential to supply ¼ of the country's oil demand and that by replacing fossil fuels with plant-derived carbohydrates it will boost farm incomes by billions of dollars per year as well as creating more than 750 000 new jobs. Peripheral benefits, especially in the developing world, include rural development, with new and profitable land-use practices providing better opportunities and long-term security for farmers and workers. It also provides an opportunity for countries with favourable land, labour and trade conditions, such as Brazil, to develop new export markets and improve trade balances.

Bioenergy already accounts for nearly 10% of total world energy supplies. It accounts for 33% of energy use in developing countries but only 3-4% in industrial countries. Biomass is the main source of household energy use for between 2 and 3 billion people in the developing world (Hazell and Pachauri, 2006). Liquid biofuels currently only represent 1.8% of total bioenergy, 1.38% of renewable energy and 0.18% of total world energy supply. Biofuels supplied 1.8% of total global transport fuel consumption in 2007, up from 0.3% in 1990 (von Lampe, 2008). The United States and Brazil remain the largest ethanol producers with 48% and 31% respectively of the global ethanol output in 2007 (von Lampe, 2008). The remaining 21% is produced in the European Union (mainly Germany and France), China, India and Canada. The European Union is currently responsible for 60% of the global biodiesel production with a significantly smaller contribution from the US, followed by Indonesia, Malaysia, Brazil, China, and others.

The growth in the biofuel industry in these countries is being fuelled largely by policies involving government regulations and subsidies, which require a component of biofuel in diesel and gasoline. According to von Lampe (2008) countries such as Belgium, Cyprus, Denmark, Estonia, Austria, Germany, Greece, Hungary and other European states wanted at least 5.75% of fuels used to be acquired from renewable energy sources by 2010. However, latest reports state that it is unlikely that this target will be reached (Licht, 2010). Japan is targeting 50 million litres of biofuels by 2011; and the USA just over 136 billion litres by 2022 (van Lampe, 2008). The target proposed by the USA includes the production of approximately 57, 79 and 61 billion litres of renewable biofuel, advanced biofuel, and cellulosic biofuel, respectively (Ethanol Industry Outlook, 2010). France intends to increase its biofuel component in domestic fuel to 10% by 2015 (von Lampe, 2008). Transport fuels in India must contain 20% biofuel by 2017 (Padma, 2008). Brazil currently requires a mandatory blend of 20 to 25% ethanol with gasoline with a minimum blending of 5% biodiesel to diesel by 2013. China's intended ethanol target for 2010 was two million tonnes of ethanol in gasoline and 10 million tonnes by 2020. Proposed targets for Tanzania include biofuel blends in transport fuel, with ethanol at 10% by volume, and biodiesel at 20% by volume (see www.bioenergywiki.net/Renewable_fuel_targets#cite_note-5 for more information on targets).

Potential Impacts of Biofuel Production

In many sectors biofuel production is seen as a green technology, much cleaner and greener than fossil fuels which are seen as polluting the environment. According to some, the term biofuels should refer exclusively to the traditional use of biological materials for fuel, such as wood, dung, bagasse and other sources. Crops grown solely for fuel production should have the prefix "agro" and not "bio" which according to critics is being used to encourage the public to see crops grown for fuel as being environmentally friendly. This may not be the case as any agricultural activity is bound to have an impact on biodiversity and there is also controversy with regard to its social and economic benefits and its contribution to carbon sequestration.

Despite the large investments in biofuels, it is very unlikely that they will make a significant contribution to global energy supply. The global energy supply is and will continue to be, dominated by fossil fuels, with oil, coal and gas currently supplying 81% of the total demand (FAO, 2008). By 2030 liquid biofuels are predicted to supply only 3-3.5% of global transport energy demand (FAO, 2008).

Global warming impacts: Carbon emissions have been increasing ever since the industrial revolution. The increase in carbon emissions has mainly been as a result of burning coal, gas, and oil. Biofuels and other forms of renewable energy on the other hand aim to be carbon neutral or even carbon negative.

The carbon emissions produced by biofuels are calculated using a technique called Life Cycle Analysis (LCA). This analysis looks at the amount of carbon dioxide and other greenhouse gases emitted during biofuel production (Pimentel and Patzek, 2005):

- Fuels consumed by farm machinery in land preparation, planting, irrigation, pruning, harvesting, storage, transport;
- The application of herbicides, pesticides, and fertilizer and the energy required to produce the chemicals; and
- That required for processing the crop into biofuel.

A 1998 biodiesel life cycle study, jointly sponsored by the US Department of Energy and the US Department of Agriculture, concluded that pure B100 (not blended) biodiesel reduces net carbon dioxide emissions by 100% compared to petroleum diesel. The majority of LCA studies have shown that biofuels provide significant greenhouse gas emissions savings when compared to fossil fuels. Studies have shown that first generation biofuels can reduce carbon emissions by as much as 60% and second generation biofuels by up to 80%, compared with using fossil fuels. In contrast, Pimentel and Patzek (2005) argued that ethanol is a net environmental and industrial loser taking about 1.15 BTU's (British Thermal Units) of input for every 1 BTU of output. In addition, recent studies have indicated that converting rainforests, peatlands, savannas, or grasslands to produce biofuels in Brazil, southeast Asia, and the US creates a 'biofuel carbon debt' by releasing 17 to 420 times more carbon dioxide than the annual greenhouse gas reductions these biofuels provide by displacing fossil fuels. Fargione *et al.* (2008) compares the production of different biofuels and assesses the 'carbon debt', or how many years it would take to pay back the carbon dioxide released at plantation establishment. There is huge variation from 0 years, in scrub prairies, to 423 years, in primary forest.

Food security impacts: Increased demand for biofuels was a contributory factor in the rises in food prices in 2007 and 2008, particularly those of corn and wheat, which resulted in price increases in food items such as pasta, bread, milk and meat. However, according to EuropaBio (2008) peaks in the price of wheat and corn are not unprecedented and in the past were related to other factors including changes in consumption patterns especially increases in meat consumption; such changes also contributed to the food price rises of 2007 and 2008. World meat production has increased by about 65% in the last 20 years (FAPRI, 2007), increasing the demand for feed (mainly cereals). Meat consumption in China alone increased from 27 to 59 kg per person per year between 1990 and 2005. According to the FAO, much of the poor performance of world agriculture in 2006 was due to disappointing cereal production. Cereal production was especially poor in Australia and the United States where it fell by 60% and 7%, respectively but production was also down in the European Union, Canada, Argentina and South Africa.

Naylor *et al*. (2007) and others report that biofuels are causing an abrupt increase in demand for agricultural commodities traditionally used for food and feed, which is placing upward pressure on crop prices. A number of studies have been completed that project future agricultural prices related to biofuels development and they generally anticipate large increases in cassava prices, moderate to large increases in maize prices, slightly smaller increases in wheat prices, small to large increases in sugar prices, moderate increases in vegetable and palm oil prices, and ambiguous effects on soybean prices as meal and oil prices move in opposite directions (Naylor *et al*., 2007).

It would therefore appear that there is still some disagreement as to the impacts of biofuel production on food production and prices, but what is much less debatable is that many of the species selected for biofuel production are already known to be invasive or potentially invasive.

Biofuels as weeds: Some biofuels possess attributes such as rapid growth rate, high yields, low water and maintenance costs, easy coppicing and an ability to grow in a wide range of habitats under a range of climatic regimes. Such attributes might make them invasive, depending on the management regime employed (Rejmánek and Richardson, 1996). Willows have been selected because of "rapid growth and wood production in young shoots, producing high yields in few years, ease of vegetative propagation, a broad gene pool and excellent ability to re-sprout after multiple harvests" (TSEC-Biosys, 2006). *Jatropha curcas* "grows quickly, is hardy, establishes itself easily even in arid land, and is drought-tolerant" (Jones, 2004). "Herbaceous and woody species are being selected, bred, and transformed for desirable agronomic traits, including tolerance to drought, salinity, and low-fertility soils, as well as increased above ground biomass and competitive ability to reduce fertilizer, irrigation, and pesticide use" (Barney and DiTomaso, 2008).

'Second-generation' biofuels are derived from the cellulose in plant cell walls BUT a commercially competitive process for converting cellulose into fuels has yet to be developed although microbial action could facilitate this. However, to facilitate this production of agrofuels, trees are being genetically manipulated for decreased lignin production (Purdue University, 2006; Chapotin and Wolt, 2007; Wolt, 2009). Lignin is an important structural polymer that is also significantly responsible for the high levels of insect and disease resistance in trees. Because lignin helps in the protection of trees from insects and diseases, trees with modified lignin will probably have to be engineered with additional traits for disease and insect resistance (Chapotin and Wolt, 2007). Poplars resistant to attack by certain species of moths have already been developed. In China more than one million genetically engineered poplars, have been planted. Increasing pest resistance in proposed biofuel crops which are already invasive could exacerbate the problem and eliminate all future attempts at biological control which is increasingly acknowledged as the most cost effective way of controlling invasive plant species in developing economies.

In the next section, I list some species from a plant family or group of plant families. These species have been proposed as potential biofuel crops but have also been recognized as being invasive or potentially invasive. There are a number of other species which have been proposed as having biofuel potential which are not listed. However, it is fair to say that many plant species which are currently considered to be invasive also have potential for biofuel production. A number of peer-reviewed papers have been published on this issue ranging in titles from "Nonnative Species and Bioenergy: Are We Cultivating the Next Invader" (Barney and DiTomaso, 2008), "Adding Biofuels to the Invasive Species Fire?" (Raghu *et al*., 2006) and "Alien alert – plants for biofuel may be invasive" (Howard and Ziller, 2008).

EUPHORBIACEAE

Many Euphorbiaceae species have been proposed as potential biofuel crops. These include species such as *Jatropha curcas* (physic nut), *Triadica sebifera* (Chinese tallow tree), *Ricinus communis* (castor-oil plant) and *Euphorbia lathyris* (caper spurge). Of the approximately 7500 species in the family, only 5% are regarded as weedy or invasive worldwide (Randall, 2002). *Jatropha gossypifolia* (bellyache bush) is considered to be one of Australia's worst weeds.

Jatropha (*Jatropha curcas* L.) Family: Euphorbiaceae

Status(es): agricultural weed, cultivation escape, environmental weed, naturalized, noxious weed, weed (Randall, 2007).

Common names: Barbados nut, bubble-bush, curcas bean, fève d'enfer, frailejón, galamaluco, grão de maluco, grand pignon d'Inde, gros ricin, fève d'enfer, jatropha, médicinier, médicinier béni, médicinier barrière, médicinier purgative, manduri-graca, mbono, physicnut, piñón, piñón blanco, pignon d'Inde, pinhão-de-cerca, pinhão-de-purga, pinhão-manso, pinhão-paraguaio, purgenut, purghère, Purgiernuß, purgingnut, purgueira, ratanjyor, ricino major, tártago, tuba (USDA-ARS, 2009).

Description: Shrub or small tree up to 6 m in height with a milky sap. **Leaves** are deciduous, alternate but apically crowded, basally cordate, 3-5 lobed in outline, 6-40 cm long and 6-35 cm broad. **Flowers** are yellowish and bell-shaped with 5-sepals. **Seed** capsules are initially green, 2.5-4 cm long, finally drying and splitting into 3 valves, which contain an oblong black seed (Morton, 1977; Little *et al*., 1974). Leaves and seeds are poisonous.

Native range: Tropical America (from USDA-ARS, 2009).

Weed status: It is widely grown as a hedge plant in many parts of the world but is listed as a weed in Brazil, Fiji, Honduras, India, Jamaica, Panama, Puerto Rico, and Salvador (Holm *et al*., 1979). It is also considered to be invasive in the Galapagos Islands (Charles Darwin Research Station, 1995), Fiji (Smith, 1981), Samoa (Space and Flynn, 2001), Tonga (Space and Flynn, 2001), and New Caledonia (MacKee, 1994). In Fiji, it is naturalized along roadsides, on open slopes, and sometimes in forest (Smith, 1981) while in Hawaii it is only "sparingly naturalized" (Wagner *et al*., 1999). In Australia, it has established in disturbed areas around old settlements (Smith, 2002). In Queensland, Australia, *J. curcas* has spread at least 80 km down one catchment, having formed a series of thickets along Emu Creek, one of them 100 x 50 m in extent (Low, 2008b). Another infestation 40-50 m across has been found along the Hodgkinson River (Low and Booth, 2007). *Jatropha curcas* is a declared weed in the Northern Territory and in Western Australia (Low and Booth, 2007). Its congener, *J. gossypifolia* is considered to be one of Australia's worst weeds (Low and Booth, 2007).

The introduction of new *J. curcas* genotypes selected for improved biofuel ability may very well enhance its invasive potential elsewhere. Considerable variation in growth, chemical composition of seed and seed traits at the level of provenance, variety or progeny can be expected in out-crossing species such as *J. curcas* (Kaushik *et al*., 2007). In 1987 and 1988, Heller (1992) tested the growth rates and yields of 13 *J. curcas* provenances in multi-location field trials in Senegal and Cape Verde and found significant differences in plant height, branches per plant and seed yield per plot. The introduction of new genotypes as biofuels with higher growth rates and yields into regions where *J. curcas* has been present and non-invasive may enhance its invasive potential.

Biofuel potential: *Jatropha curcas* seeds yield between 20-30% inedible yet high quality oil, depending on the extraction technique, and are suitable for biodiesel production (Achten *et al*., 2007). The seed-oil has also been used for illumination and lubrication, and more recently it has been touted as a potential biofuel crop. Mercedita Sombilla, who conducted an Asian Development Bank-funded study on the development of the biofuel industry in the Greater Mekong Subregion (Thailand, Vietnam, Cambodia, Laos, Myanmar and the southern part of China) identified jatropha, along with cassava and sweet sorghum, as having the most potential to be developed as sources for biofuels (Sarmiento, 2008a,b). It can also be used for making candles and soap and the cake remaining after the oil is pressed can be used as feed in digesters and gasifiers to produce biogas for cooking and in engines, or the cakes can be used for fertilizing and potentially even for animal fodder (Shyam, 2008).

The company D1 Oils has planted over 156 000 ha. of *J. curcas* in Africa, India and southeast Asia (Biopact, 2007). D1 has already secured plantation agreements in Burkina Faso, Ghana and the Philippines totaling 37 000 ha., and has the option to extend planting to approximately 990 000 further ha. of land in Burkina Faso and 5 million ha. of land in India. Nearly half a dozen states in India have set aside a total of 1.72 million ha. of land for *J. curcas* cultivation (Shyam, 2008). D1 Oils has apparently another 6 million ha. under option (roughly double the size of Belgium); and according to D1 Oils estimates, for India to reach its target of 20% bio-diesel mix, some 2 million ha. of *J. curcas* will be needed (Jones, 2004).

BP has also announced a joint venture with a biofuel tree developer to plant over 2 million acres (c. 809 000 ha.) with *J. curcas* over the next 4 years, then about 300 000 acres (c. 120 000 ha.) every year thereafter (see www.bp.com). China is also considering *J. curcas* as a biofuel crop and the Africa Biodiversity Network (2007) cites a number of jatropha projects are being considered in Africa. These include:

- Uganda and Benin are considering scaling up biodiesel production using *J. curcas*. National NGO's in Benin are projecting that they will have 240 000 ha. of *J. curcas* in production by 2012;
- Green Power East Africa has initiated its own plantings in Malawi and has trials underway in Kenya with an ultimate target at 100 000 ha. (Shyam, 2008);
- A German investor, PROKON, has begun a 10 000 ha. *J. curcas* out-grower programme in Mpanda district, southwest Tanzania. Many other investors including D1 Oils, Diligent Energy Systems and Sun Biofuels are planning to plant *J. curcas* extensively in Tanzania.
- D1 Oils has 45 000 ha. under *J. curcas* cultivation in the Chongwe District of Zambia with other minor projects throughout the country;
- Bioenergy International (Switzerland) plans to set up a 93 000 ha. *J. curcas* plantation with a biodiesel refinery and an electrification plant in Kenya.
- Other companies interested in *J. curcas* production in Africa include:
  - FPG BioFuel Botswana – www.afdevinfo.com/htmlreports/org/org_68559.html
  - SMS Biofuels Holding (Pty) Ltd in Botswana – http://sms-bio-fuel-holdings.com
  - Duelco Holdings Limited in Mozambique – www.deulco.com
  - Sun BioFuels in Mozambique, Tanzania and Ethiopia
  - Thomro Investments Ltd in Zambia – www.thomrofuels.com.

Chinese tallow tree (*Triadica sebifera* L. Small) Family: Euphorbiaceae

Status(es): environmental weed, naturalized, noxious weed, weed (Randall, 2007).

Synonyms: *Croton sebiferum* L, *Excoecaria sebifera* Müll. Arg, *Sapium sebiferum* (L.) Roxb, *Stillingia sebifera* (L.) Michx, *Triadica sinensis* Lour (USDA-ARS, 2009).

Common names: árbol del sebo, árvore do sebo, arbre à suif, boiré, candleberry-tree, chicken tree Chinese tallowtree, chinesischer Talgbaum, Florida aspen, gray popcorn tree, leiteiro, pau do sebo, popcorntree, tallowtree, vegetable tallow, white wax berry (USDA-ARS, 2009).

Description: Can grow up to 17 m tall with a stem diameter of 97 cm. **Leaves** are alternate, broad rhombic to ovate in shape with smooth edges and a long pointed tip. **Flowers** are light green and occur in terminal spike-like inflorescences up to 20 cm long. **Fruits** are three-lobed, three valved capsules, found in clusters at the end of branches (Duncan and Duncan, 1988).

Native range: Eastern Asia – eastern China, Taiwan and Japan (USDA-ARS, 2009).

Weed status: Chinese tallow has many of the attributes of invasive species namely, rapid coppicing, taproot production, and rapid growth rate. It grows in all soil types or drainage and will tolerate shade, sun, drought, floods, freezing, and is salt tolerant (GISD, 2005). In addition, the plant sap and leaves are reputed to be toxic, and the decaying leaves allelopathic. Each tree is reputed to produce 100 000 seeds per year, which are dispersed by birds and water (Low and Booth, 2007). Herbivores and indigenous insects avoid eating the leaves contributing to its invasive attributes (Lankau *et al*., 2004). It displaces native plants and forms monospecific stands where it alters nutrient cycles by enhancing productivity in ecosystems (Bogler, 2000 in IUCN/SSC – ISSG, 2005a). According to Olivier (no date) the “Tallow tree quickly becomes the dominant plant in the area it invades, causing large-scale ecosystem modification by displacing not only native vegetation but also a lot of the wildlife that co-evolved alongside it”. It is also suspected of reducing nesting sites for a variety of bird species (GISD, 2005).

It has become naturalized in the United States from South Carolina southward along the Atlantic and the entire Gulf coast, where it grows profusely along ditches and dykes. In the Houston area, it accounts for 23% of all trees, more than any other tree species and is the only invasive tree species of the 14 most common species in the area (US Forest Service and the Texas Forest Service, 2005). It is considered to be one of the 12 worst invasive species in the United States by the American Nature Conservancy (Stein and Flack, 1996). It is a declared weed in northern NSW, Australia and the Queensland government is considering declaring this plant a prohibited weed (Low and Booth, 2007).

Biofuel potential: It has been used as a seed-oil crop in Asia for the past 1500 years. The seed contains 20% oil, 24% tallow, 11% extracted meat, 8% fibrous coat and 37% shell (Duke, 1983a). On average, a 5, 10 and 20-year old tree yields 0.45, 3.38 and 11.99 kg of seeds annually (Duke, 1983a). It was for this reason that the then Bureau of Plant Industry (U.S. Department of Agriculture) established plantations of tallow along the Gulf Coast in the early 1900s to study its feasibility as an agricultural crop. At around this time it also became a popular ornamental in the USA (Rogers and Siemann, 2004). It is apparently the third most productive oil producing plant in the world, after algae and oil palm. Scheld *et al*. (1980) reported yields of 4 000 to 10 000 kg/ha, and cites estimates of 3 969 litres of oil per year as a sustained energy yield. A US Biofuel company, AgriBioFuels claims that Chinese tallow can produce 500 gallons of oil per acre (c. 765

l/ha.), compared to 48 gallons/acre (73.52l/ha.) for soybeans (www.agribiofuels.com/biofuels-market.php). There has also been interest in using this species for biofuel production in Australia (Low and Booth, 2007).

Castor-oil plant (*Ricinus communis* L.) Family: Euphorbiaceae

Status(es): agricultural weed, casual alien, cultivation escape, environmental weed, naturalized, noxious weed, weed (Randall, 2007).

Synonyms: *Ricinus africanus* Willd. , *Ricinus angulatus* Thunb. , *Ricinus armatus* Haw. , *Ricinus badius* Rchb. , *Ricinus chinensis* Thunb. , *Ricinus digitatus* Noronha , *Ricinus europaeus* T.Nees , *Ricinus glaucus* Hoffmanns. , *Ricinus hybridus* Besser , *Ricinus inermis* Mill. , *Ricinus japonicus* Thunb. , *Ricinus laevis* DC. , *Ricinus leucocarpus* Bertol. , *Ricinus lividus* Jacq. , *Ricinus macrophyllus* Bertol. , *Ricinus medicus* Forssk. , *Ricinus megalospermus* Delile , *Ricinus minor* Mill. , *Ricinus nanus* Balbis , *Ricinus peltatus* Noronha , *Ricinus purpurascens* Bertol. , *Ricinus rugosus* Mill. , *Ricinus sanguineus* Groenland , *Ricinus scaber* Bertol. ex Moris , *Ricinus speciosus* Burm.f. , *Ricinus spectabilis* Blume, *Ricinus tunisensis* Desf. , *Ricinus undulatus* Besser , *Ricinus urens* Mill. , *Ricinus viridis* Willd. , *Ricinus vulgaris* Mill. (USDA-ARS, 2009).

Common names: bafureira, carrapateiro, castor, castor-bean, castor-oil-plant, higuerilla, kasterolieboom, mamoneiro, mbarika, mbono, mdogo, mnyonyo, palma-christi, rícino, ricin, Rizinus (USDA-ARS, 2009).

Description: A fast-growing perennial shrub that can reach the size of a small tree. **Leaves** glossy deep green or reddish, alternate, 15-45 cm long, palmate, with 5-12 deep lobes and sharply toothed leaf margins. **Flowers** are reddish on the upper-side and cream coloured on the lower-side, 150 mm long. **Fruits** ovoid, softly spiny, 1-1.5 cm long, purplish-brown, three-lobed capsules. **Seeds** oblong-ellipsoid, variously mottled with brown, black and gray, bean-like (Stone, 1970).

Native range: Southeastern Mediterranean region and East Africa (USDA-ARS, 2009).

Weed status: The whole plant is toxic, with the seeds being highly toxic and lethal (Henderson, 2001). It is frequently found in riparian areas where it displaces native vegetation. It also invades abandoned fields, drainages, ditches, riverbeds, and is often common along roadsides and railroad tracks (Henderson, 2001). Seeds are dispersed by birds and mammals and may remain dormant in the soil for several years (Weber, 2003). Seedlings grow rapidly, shading out native species and producing monospecific stands. It is a well known weed in many parts of the world including Australia, southern Africa, Western USA, Mexico, and the islands of Galapagos and Hawaii (Weber, 2003). In the Northern Territory, Australia, it is a declared noxious weed (Low and Booth, 2007). It has also been recorded as being invasive on many Pacific Islands, Mexico and New Zealand (US Forest Service - PIER 2010a).

Biofuel potential: The seeds contain between 40 and 60% oil that is rich in triglycerides, mainly ricinolein. The oil is used as an additive in paints and varnishes and from World War I until the 1960s, oil extracted from the “beans” was utilized as a lubricant for aircraft. Castor oil biodiesel could also be used as a petroleum diesel additive improving both environmental and flow behaviour of the mineral fuel. Forero (n.d.) suggested that given its widespread abundance and ease of cultivation it could be used in crop substitution programs for biodiesel production in Colombia.

Comari *et al*. (2004) indicated that it has some potential as a biofuel but was far less competitive than most fossil fuels.

Caper spurge (*Euphorbia lathyrus* L.) Family: Euphorbiaceae

Status(es): agricultural weed, casual alien, cultivation escape, environmental weed, naturalized, noxious weed, weed (Randall, 2007).

Synonyms: *Euphorbia lathyrus* L., orth. var., *Tithymalus lathyrus* (L.) Hill (USDA-ARS, 2009).

Common names: caper spurge, catapúcia-menor, euphorbe épurge, gopherplant, gopher spurge, gopher plant, gopherweed, kreuzblättrige Wolfsmilch, lechetrezna, leiteira, mole plant, paper spurge, tártago (USDA-ARS, 2009).

Description: Erect biennial plant up to 1.5 m in height, with a blue-green stem. **Leaves** are lanceolate, 5-15 cm long and 1-2.5 cm wide, blue-green in colour with a pale greenish-white midrib and veins, arranged in opposite pairs. **Flowers** are green to yellow-green. **Seeds** are initially green but brown/grey when mature, produced in globular clusters (see Flora of China, 2009).

Native range: Southern Europe, northwest Africa, and eastward through southwest Asia to western China (adventive). "It is probably native only in the Mediterranean region" (Flora of China, 2009).

Weed status: It is cultivated as a medicinal or ornamental plant, escaping and self-seeding along the East and West coasts of the United States (www.hort.purdue.edu). It has been recorded as being invasive in China (Harvard University, 2007) and in New Zealand (Webb *et al*., 1988).

Biofuel potential: Nobel Laureate Melvin Calvin suggested that the "mole plant" could be the "petroleum plant". He estimated that an acre (0.405 ha.) of *E. lathyris* could produce 10 to 50 (1 590 to 7 950 litres) of oil per acre (0.405 ha.) per year. Seeds, which contain nearly 50% oil, known as oil of Euphorbia, were reported to yield more than 3 T/ha (White *et al*., 1971). It was suggested that the potential *E. lathyris* yield is equal to that of sugar cane (11.7 x 10^4 MJ ha/yr) by adding the oil yield (6.5) and the alcohol yield (5.2 x 10^4 MJ ha/yr). Marvin Bagby, the then Head of the Agriculture Department's hydrocarbon-plant research project, suggested that gopherweed was the leader among forty-five hydrocarbon-bearing plants (www.hort.purdue.edu). The potential of *E. lathyris* as a biofuel crop has recently been revived in Europe and North America (see Nemethy *et al.*, n.d. for more information on *E. lathyrus* as a biofuel crop).

POACEAE

A large number of grasses have been proposed as "second generation" biofuel crops. These include invasive species such as *Arundo donax* (giant reed), *Phalaris arundinacea* (switchgrass), *Miscanthus* species (miscanthus), *Sorghum halepense* (Johnson grass) and *Spartina* species (cordgrass). Despite their attraction as biofuels, a large percentage of grasses have become invasive worldwide with more than 500 species having being recorded as being weedy or problematic. Invasive grass species remain one of the most difficult of invasive taxa to control and often go unnoticed because of their very small and largely inconspicuous flowers.

Giant reed (*Arundo donax* L.) Family: Poaceae

Status(es): agricultural weed, casual alien, cultivation escape, environmental weed, , naturalized, noxious weed, weed (Randall, 2007).

Synonyms: *Arundo donax* L. var. *versicolor* (Mill.) (USDA-ARS, 2009).

Common names: bamboo, caña común, caña de Castilla, cana-do-brejo, cana-do-reino, canne de Provence, canno-do-reino, capim-plumoso, danubian reed, e-grass, giant Danube reed, giant-reed, giant cane, grand Roseau, Oboe reed, Pfahlrohr, spaanse-riet, Spanish-reed, wild cane (USDA-ARS, 2009).

Description: Giant reed is a large robust weed 2-6 m high; unbranched or branched above; spreading from horizontal rootstocks. **Leaves** are pale green to bluish-green, 45-60 cm long and 4-6 cm wide with large, basal ear lobes compared to those of *Phragmites australis* which are much smaller, leaf tips soft or firm not rigid and penetrating as in *P. mauritianus*.

Inflorescences are cream or brown, compact, spear-shaped, 40-70 cm long. (Henderson, 2001; Wagner *et al*., 1999).

Native range: Tropical Asia and the Mediterranean region (US Forest Service – PIER, 2010d).

Weed status: *Arundo donax* can grow on a wide variety of soil types and under a range of climatic conditions. It is considered to be one of the fastest growing terrestrial plants in the world, with nearly 10 cm/day having been recorded (Dudley, 2000). It can reach maturity in about a year and can be harvested, depending on climate, one to three times annually. Mainly grows in moist areas, such as along ditches and riverbanks, but unlike most indigenous reeds such as *Phragmites australis* in South Africa, often also occurs on roadsides and other sites away from water (Henderson, 2001). It is highly flammable and as a result increases the probability, intensity, and spread of wildfires in riparian zones. It resprouts rapidly after burning transforming native plant communities into solid stands of giant reed (Randall *et al*., 1996). It also outcompetes native species, depletes water supplies and can exacerbate flood damage (Bell, 1997). For example, every year, enough water to serve a population of about 280 000 people is lost through transpiration by e-grass growing along the Santa Ana River in the US. If this amount of untreated water was purchased from the Metropolitan Water District, it would cost approximately US$18 million at the current cost for untreated drinking water (Iverson, 1998).

It has been introduced to many countries worldwide and has become naturalized in warm temperate to tropical areas. It has a place on the International Union for Conservation (IUCN) list of 100 of the world's worst weeds (http://www.issg.org/database/species/search.asp?st=100ss). It has invaded many wetlands and rivers in Australia (Low and Booth, 2007) and in Hawaii it is naturalized in coastal areas (Wagner *et al.*, 1999). In Fiji, it is common on hillsides, in open forest, and along roadsides (Smith, 1979). California has spent more than US$25 million trying to control *A. donax* (Hundley, 2007).

Biofuel potential: It has been promoted as a potential biofuel crop in the USA and elsewhere. Dry cane yields of approximately 10, 15, and 20 MT/ha were reported respectively from infertile, partly fertile and fertile soils in Argentina. Westlake (1963) claims that *A. donax* can produce 40-75 MT/ha/yr in warm temperate and tropical regions. A US based company, Biomass Investment Group Inc. is considering planting 15 000 acres (6 070 ha.) of e-grass for biofuel production. Trials have also been undertaken for biofuel production from e-grass by a Natural Resources Management group in South Australia (Low and Booth, 2007).

Reed canary grass (*Phalaris arundinacea* L.) Family: Poaceae

Status(es): agricultural weed, casual alien, cultivation escape, environmental weed, naturalised, noxious weed, weed (Randall, 2007).

A number of other species in the genus, *P. aquatica* L. and *P. minor* Retz. are considered to be invasive in Australasia and the USA where they displace native species. The former also accumulates large amounts of dead biomass and thereby increases fire hazards (Weber, 2003).

Synonyms: *Phalaris arundinacea* var. *picta* L., *Phalaris arundinacea* f. *variegata* (Parn.) Druce, *Phalaroides arundinacea* L. Rauschert (USDA-ARS, 2009).

Common names: alpiste roseau, caniço-malhado, gardener's-garters, hierba cinta, kusa-yoshi, pasto reed, phalaris Roseau, reed Canary grass, ribbon grass, Rohrglanzgras, swamp phalaris variegated grass (USDA-ARS, 2009).

Description: Tall, perennial grass with stems that can reach 2 m in height. **Leaves** are blue-green, 0.2 to 2 cm wide and up to 0.5 m long. **Inflorescences** are arranged in dense, branched panicles that can exceed 5 to 20 cm in length. One of the distinguishing features of the genus *Phalaris* is the presence of some infertile florets. It is morphologically variable, and more than ten infraspecific categories (varieties, subspecies, forms and races) have been described. These categories are based on characteristics such as the amount of branching, leaf colour, size, shape and density of inflorescences. Differences in the height at maturity and in size, shape, and colour of the inflorescence may depend on the habitat. (GISD, 2005).

Native range: Europe, Asia, North Africa and possibly in the northwestern United States (USDA-ARS, 2009).

Weed status: Reed canary grass can be problematic, especially in wetlands and disturbed areas. The species spreads vegetatively and forms dense monospecific mats often covering large areas and impeding water flow (Weber, 2003). When it invades wetlands it suppresses native vegetation and reduces diversity. In the USA, it has invaded thousands of ha. of wetlands, displacing native species (Miler and Zedler, 2003). Its aggressive behaviour in many parts of the central and western United States may be as a result of escaped cultivars that were bred for vigour and quick growth. In southern Australia it is considered a serious wetland weed (Low and Booth, 2007).

Biofuel potential: Initially this grass species was promoted as a fodder crop with yields of 9-20 MT/ha in the US (Reed, 1976). As a result it has been investigated as a potential second generation biofuel crop in Sweden and Britain. Reported yield ranges are 3.3-5.2 ODT/ha/year in Sweden, depending on variety, to 11-19 ODT/ha/year in Switzerland (TSEC-Biosys, 2006).

Switchgrass (*Panicum virgatum* L.) Family: Poaceae

Status(es): agricultural weed, casual alien, naturalised, weed (Randall, 2007).

Many other species in the genus are invasive including *P. maximum* Jacq. and *P. repens* L. The former is a prolific seed producer and is resistant to fire while the latter is capable of producing rhizomes 6 m in length and is highly salt tolerant.

Synonyms: *Panicum virgatum* L. var. *virgatum*, *Panicum virgatum* L. var. *cubense* Griseb, *Panicum virgatum* L. var. *obtusum* Alph. Wood (USDA-ARS, 2009).

Common names: blackbent, blackwell switch grass, lowland switchgrass panic érigé, panic vierge, Rutenhirse, switch grass, tall panic grass, tall prairiegrass, thatchgrass wild redtop Wobsqua grass (USDA-ARS, 2009).

Description: It can grow up to 2 m tall with well developed, scaly rhizomes. **Leaves** are 10-60 cm long, 0.3-1.5 cm wide, usually glabrous with a prominent midrib. **Inflorescences** are 15-55 cm long, spikelets 4-5.5 mm long, ovoid, acuminate, glabrous (Wagner *et al*., 1999).

Native range: Central North America (Wagner *et al*., 1999).

Weed status: Switchgrass is very versatile and adaptable. It thrives in many climatic regimes, soil types and land conditions and spreads vegetatively via rhizomes and by seed. It is considered to be weedy or invasive in the USA, and is therefore likely to be invasive elsewhere (USDA NRCS, 2009). It has been assessed as a weed by Australian Quarantine and will not be permitted entry into Australia (Low and Booth, 2007). A number of other *Panicum* species are considered to be invasive elsewhere.

Biofuel potential: Switchgrass is rich in cellulose (42-50%), making it attractive as a source for cellulosic ethanol. Unlike corn, switchgrass is a perennial with a huge biomass output, of 6-10 tons per acre (0.405 ha.). In field trials in the UK, maximum yield was 15.4 tons/ha for a lowland ecotype (TSEC-Biosys, 2006). Switchgrass test plots have been established in many parts of the USA, as agronomists study how many tons per ha. farmers can expect to harvest for the production of biomass to make cellulosic biofuels (Cole, 2008). An Iranian firm is planning to build an ethanol plant in the Republic of Bosnia and Herzegovina which will produce 100 million gallons (378.5 million litres) of ethanol per year from switchgrass once it is fully operational (Press TV, 2007). However, there is debate about its potential as an efficient energy source.

Miscanthus (*Miscanthus sinensis* Anderss.) Family: Poaceae

Status(es): agricultural weed, casual alien, cultivation escape, environmental weed, naturalised, noxious weed, weed (Randall, 2007).

Synonyms: *Eulalia japonica* Trin., *Miscanthus condensatus* Hack., *Miscanthus purpurascens* Anderss., *Miscanthus sinensis* f. *glaber* Honda, *Miscanthus sinensis* var. *condensatus* (Hack) Makino, *Miscanthus sinensis* var. *formosanus* Hack., *Miscanthus sinensis* var.*gracillimus* Hitchc., *Miscanthus sinensis* var.*purpurascens* (Anderson) Matsum., *Miscanthus sinensis* var.*variegatus* Beal, *Miscanthus sinesis* var.*zebrinus* Beal, *Saccharum japonicum* Thunb., *Xiphagrostis condensatus* (Hack) W. Wight (USDA-ARS, 2009).

Common names: capim-zebra, Chinese silver grass, eulália, eulalia grass, maiden grass, miscanthus, porcupine grass, Schilfgras, zebra grass (USDA-ARS, 2009).

Description: It can attain a height of 3 m (rarely 4 m), forming dense clumps from a short inconspicuous underground rhizome. **Leaves** are 100 cm long and 25 mm wide. Each leaf has a silvery-white midrib with sharp tips that are re-curving (USDA Forest Service, no date). **Inflorescences** are large, showy and feather-like, pinkish-silvery in colour.

Native range: *M. sinensis* is native to Russian Federation, China, Japan, Taiwan, Republic of Korea, Philippines, and Indonesia (IUCN/SSC – ISSG, 2007).

Weed status: *Miscanthus sinensis* can tolerate compact and nutrient poor soils, including soils of various pH, heat, and drought. It is also extremely flammable, increasing fire risks substantially and can survive in temperatures as low as -26°C (USDA Forest Service, no date). It is also known to be a host of various crop diseases, including barley yellow dwarf luteovirus-MAV, barley yellow dwarf luteovirus-PAV, and cereal yellow dwarf luteovirus (Harris *et al.*, 2000). Despite the fact that *M. giganteus* (*M. sinensis* x *M. saccharifolius*) is an allopolyploid in that it does not produce seed but spreads vegetatively, it still has the potential to become invasive. Allopolyploidy does not guarantee continued sterility (Gray *et al*., 1991) and vegetative reproduction is often associated with invasiveness (Daehler, 1998; Kolar and Lodge, 2001) or directly contributes to it (Moody and Les, 2002). Common in many natural and disturbed areas, *M. sinensis* is often found in abandoned gardens, roadsides, forest edges, sides of reservoirs, and in old fields following fires (The Bugwood Network, 2003). *Miscanthus sinensis* is weedy in parts of Australia and is spreading along railway lines in New South Wales. It has also been recorded as a weed in North and South America, Europe and Asia (Randall, 2002).

Biofuel potential: The rapid growth (about 4 m/yr in Europe and 7-10 m/yr in China), low mineral content and high biomass yield of *Miscanthus* spp. make it a popular choice as a biofuel (TSEC-Biosys, 2006). It is being considered as a second generation bioenergy crop in the United Kingdom. Once established the grass can produce an annual harvest for 15 years. In addition, no pests and diseases to which *Miscanthus* spp. is susceptible in China, have been reported in the UK. Under the Energy Crops Scheme, 12 627 ha. have been planted with *Miscanthus* spp. in England and Wales (TSEC-Biosys, 2006). Yields of *Miscanthus giganteus* at two experimental sites in England ranged from 7.3 ODT ha/yr to 18.5 ODT ha/yr (TSEC-Biosys, 2006). Poland has tested a number of crops for biofuel production including *M. giganteus* and *M. sacchariflorous* (Biomass News 8, 1999). Compared with *Phalaris arundinacea* and *Panicum virgatum* the establishment phase of *Miscanthus* spp. production is more energy demanding but the high yields give this crop the best long-term energy returns (TSEC-Biosys, 2006). There have been small scale trials in the US and Canada (Low and Booth, 2007).

Spartina (*Spartina alterniflora* Loisel.) Family: Poaceae

Status(es): casual alien, cultivation escape, environmental weed, naturalised, noxious weed, weed (Randall, 2007).

Other invasive species in this genus include *S. anglica* Hubb., *S. densiflora* and *S. maritima* (Curtis) Fernald. *Spartina anglica* invades coastal lagoons, salt marshes and tidal mudflats. Intertidal mudflats and beaches can be transformed into pure stands of *Spartina*, eliminating habitats for fish, birds and invertebrates (Weber, 2003). By accumulating sediments, estuaries are widened and water flow changed. *Spartina maritima* has similar impacts.

Synonyms: *Spartina alterniflora* var. *glabra* (Muhl. ex Bigelow) Fern., *Spartina alterniflora* var. *pilosa* (Merr.) Fern (USDA-ARS, 2009).

Common names: Smooth cordgrass, salt-water cordgrass (USDA-ARS, 2009).

Description: *Spartina alternifolia* stems are 60-250 cm high and up to 2 cm in diameter at the base. **Leaves** are grey-green, 20-55 cm long and up to 5 cm wide. **Inflorescence** is a panicle 10-40 cm long with dense colourless flowers (Invasive Spartina Project, 2003).

Native range: *Spartina alternifolia* is native to eastern North and South America (USDA-ARS, 2009).

Weed status: *Spartina alterniflora* invades mudflats and channels and converts them to marshland reducing habitats for migrating shorebirds and waterfowl. This invasion increases rates of sedimentation, leading to the eventual clogging of flood control channels. *Spartina alterniflora* also hybridizes with native *Spartina* spp. in the USA and is therefore a threat to the survival of native *Spartina* spp. given the robust form and reproductive vigor of both the introduced *S. alterniflora* and their hybrids. *Spartina alternifolia* has been introduced to Asia, Australasia, Europe and the west coast of North America (Invasive Spartina Project, 2003). *Spartina anglica* has been used world-wide for coastal protection/stabilization and land reclamation. Native plant species, wildfowl and waders are excluded in invaded areas. It also threatens commercial oyster fisheries and tourism (IUCN/SSC – ISSG, 2005b). *Spartina anglica* has been introduced into Denmark, Germany, Ireland, Great Britain, North America, South America, South Africa, Australia, New Zealand and China (IUCN/SSC – ISSG, 2005b). It is a prohibited plant in Western Australia and declared as a noxious aquatic plant in Victoria (Low and Booth, 2007). *Spartina densiflora* is now present in parts of California and Washington in the US and also in Spain.

Biofuel potential: *Spartina* species are considered to have good potential as second-generation biofuels. Some experimental plantings of North American species in the United Kingdom have given yields equivalent to 15–20 tons/ha of dry matter annually. *Spartina* species are expected to produce good yields of biomass in poor soil conditions and further evaluation is continuing. (see Scott *et al*., 1990 for more information).

MELIACEAE

A family of about 550 species of trees and shrubs, including important tropical timber trees. A number of trees and shrubs in this family have been recorded as invasive elsewhere. *Cedrela odorata* on some of the Galapagos Islands (Charles Darwin Foundation, 2008), New Caledonia (MacKee, 1994), and Ghana (A.B.R. Witt, pers. obs.), *Khaya senegalensis* in Australia (Csurhes and Edwards, 1998), *Melia azedarach* on the Galapagos Islands (Charles Darwin Foundation, 2008), Fiji (Smith, 1985), New Caledonia (MacKee, 1994), and South Africa (Henderson, 2001), and *Toona ciliata* on the Hawaiian Islands (Wagner *et a*l., 1999) and in Zambia and Uganda (A.B.R. Witt, pers. obs.).

Neem tree (*Azadirachta indica* A. Juss) Family: Meliaceae

Status(es): agricultural weed, environmental weed, , naturalized, noxious weed, sleeper weed, weed (Randall, 2007).

Synonyms: *Antelaea azadirachta* (L.) Adelb., *Melia azadirachta* L., *Antelaea javanica* Gaertn., *Melia indica* (A. Juss.) Brandis (M.M.P.N.D., 2004).

Common names: Indian-lilac, margosa, margosier, neem, nimtree (USDA-ARS, 2009)

Description: Fast-growing tree that can reach a height of 15-20 m, trunk is short and may reach a diameter of 1.2 m. **Leaves** are pinnate, 20-30 cm long, with 20-31 medium to dark green leaflets about 10-12 cm long, serrate. **Flowers** are white and fragrant, drooping panicles up to 25 cm long. **Fruits** are olive-like, yellowish-white in colour (Maheshwari, 1963 in US Forest Service – PIER, 2009).

Native range: Bangladesh, India, Myanmar (USDA-ARS, 2009).

Weed status: Neem is drought resistant and thrives in sub-arid to sub-humid areas, with an annual rainfall between 400 and 1200 mm. Grows in many soil types, but thrives in well drained deep and sandy soils (US Forest Service - PIER, 2009a). It is a serious weed in northern Australia where its seeds are spread down watercourses, and by fruit-eating birds. Large infestations have also been observed in Ghana (Accra plains) and elsewhere in West Africa. It is also invasive along the south coast of Kenya and is naturalized in parts of Ethiopia (A.B.R. Witt, pers. obs.).

Biofuel potential: Neem has been grown on a commercial basis in US and elsewhere for use in agriculture and the cosmetics industry. The small seeds have, depending on the variety, an oil content of over 30% with an average oil yield per tree of 6.6 kg and 2,678 kg per ha., planted at densities of about 400 trees per ha. (Azam *et al*., 2005). Fatty acid methyl ester of oils of 26 species, including *A. indica*, were found to be most suitable for use as biodiesel meeting the major specifications of biodiesel standards of the USA, Germany and European Standard Organization and recommended for use in India (Azam *et al*., 2005).

OLEACEAE

A cosmopolitan family of about 600 species of shrubs and trees, mainly found in eastern and south-east Asia. A number of *Jasminum* and *Ligustrum* species have been recorded as invasive (Randall, 2002).

Olive (*Olea europaea* L.) Family: Oleaceae

Status(es): agricultural weed, cultivation escape, environmental weed, naturalized, noxious weed, sleeper weed, weed (Randall, 2007).

Synonyms: *Olea africana* Mill. ,*Olea chrysophylla* Lam., *Olea cuspidata* Wall. ex G. Don, *Olea europaea* subsp. *africana* (Mill.) P. S. Green, *Olea europaea* var. *cerasiformis* Webb & Berthel., nom. illeg., *Olea europaea* var. *maderensis* Lowe, *Olea ferruginea* Royle, *Olea laperrinei* Batt. & Trab., *Olea maroccana* Greuter & Burdet, *Olea sativa* var. *verrucosa* (Willd.) Roem. & Schult., *Olea verrucosa* (Willd.) Link (USDA-ARS, 2009).

Common names: azeitona, mzaituni, mzeituni, olive, olive-leaf, oliveira, Olivier (USDA-ARS, 2009).

Description: Short and squat tree, rarely exceeds 8-10 m in height. **Leaves** are oblong in shape, 2-8 cm long and 0.5–1.5 cm wide, upper surface glabrous, lower surface moderately to densely grayish or green. **Flowers** are small and white, borne in racemes arising from the axils of the leaves. **Fruit** is a small drupe 6-19 mm long, green when immature, becoming black of brownish at maturity (Wagner *et al*., 1999).

Native range: Native to the coastal areas of the eastern Mediterranean region, from Syria and the maritime parts of Asia Minor and northern Iran at the south end of the Caspian Sea (US Forest Service – PIER, 2010c).

Weed status: Grows rapidly in semi-arid to sub-humid warm-temperate regions on a range of soils (Parsons and Cuthbertson, 1992). Since its first domestication, *O. europaea* has been spreading back to the wild from planted groves. Its original wild populations in southern Europe have been largely swamped by feral plants. In southern Australia, the olive has become a major woody weed that displaces native vegetation, forming dense canopies that shade out the understorey (Motooka *et al*., 2003). Its seeds are spread by the introduced red fox and by many bird species including the introduced European Starling and the native Emu. In Hawaii, "naturalized in dry to mesic, disturbed areas" (Wagner *et al*., 1999).

Biofuel potential: The fatty-acid methyl ester of the seed oil meets all of the major biodiesel requirements in the USA, Germany and EU. The average oil yield is 4.95 kg of oil/tree or 1371 kg of oil/ha.

SALICACEAE

About 400 species of deciduous trees and shrubs, found primarily on moist soils. The genus *Salix* includes other invasive species such as *S. babylonica* L. and *S. fragilis* L. Other invasive species in the family include some *Populus* species. *Populus alba* and *P. nigra*, are both declared weeds in the Australian Capital Territory (Low and Booth, 2007) while *P. alba* and the hybrid *Populus* x *canescens* are declared weeds in South Africa (Henderson, 2001).

Willows (*Salix cinerea* L.) Family: Salicaceae

Status(es): environmental weed, naturalized, noxious weed, weed (Randall, 2007).

Synonyms: *Salix acuminata* Mill., *Salix aquatica* Sm., *Salix cinerea* f. *tricolor* Dippel (USDA-ARS, 2009).

Common names: asch Weide, graa pil, Grau Weide, gray sallow, gray willow, pussy willow, salice cerognolo, saule cendré, wierzba szara (USDA-ARS, 2009).

Description: Multi-stemmed shrub or small tree reaching 10 m in height. **Leaves** are alternate, except for the 1st pair, elliptic to obovate-lanceolate, 2-9 cm long and 1-3 cm wide, bluish grey and pubescent beneath, dull green and almost glabrous above. **Flowers**, both male and female appear as catkins on different plants, and are 2-3 cm long and 0.6-1 cm side. Female catkins are smaller and narrower than male. **Fruit** is small containing numerous tiny seeds dispersed by wind (IUCN/SSC – ISSG, 2006).

Native range: Cold and temperate regions of the northern hemisphere – Asia and Europe (USDA-ARS, 2009).

Weed status: Willow species such as *S. cinerea,* can grow on a wide range of soils and can tolerate permanent water logging, poor aeration and a pH of 3.5 making it a very hardy species (Cremer, 1999). Many willow species invade stream banks and shallow water where they obstruct and divert streams. They displace native vegetation and can cause reductions in the quality and quantity of water, often contributing to increased siltation of stream channels. The roots invade shallow stream beds by blocking spaces in between rocks leading to a loss of valuable habitat for invertebrates and fish. The increased shading along waterways reduces insect diversity and inhibits the growth of understory plants along riverbanks (Cremer, 1999).

Willows have been listed in Australia's 20 worst weeds, as they have invaded thousands of kilometers of streams and wetlands in Victoria, Tasmania, New South Wales and the Australian Capital Territory, where they worsen erosion, flooding, stream obstruction, aquatic habitat loss and water losses (Low and Booth, 2007). It is estimated that invasive willows in Australia have only invaded about 5% of their potential range (Low and Booth, 2007). *Salix babylonica* and *S. fragilis* L. have been declared as invaders in South Africa (Henderson, 2001), the former also as invasive in Fiji (Smith, 1981) and New Zealand (Webb *et al*., 1988).

Biofuel potential: "Willows have been chosen as a dedicated bioenergy crop because of rapid growth and wood production in young shoots, producing high yields in a few years, ease of vegetative production, a broad gene pool and excellent ability to re-sprout after multiple harvests. First year growth after coppice can reach up to 4 m" (TSEC-Biosys, 2006). "The willow (*Salix nigra*) is particularly promising, growing quickly and abundantly when coppiced, with meager water or fertilizer requirements" (Herrera, 2006). According to Wilkinson *et al*. (2007)**,** average UK maximum commercial yields can be above 10 oven dried tonnes (ODT)/ha/yr depending on planting density and genotype. A biodiesel plant has been planned for the eastern German city of Schwedt which will utilize a million tons of wood and other dry material per year and produce 200 000 tons of BTL diesel as a result. There are plans to obtain the increased demand for wood from willow and other fast-growing tree plantations (Wust, 2008). Poland (Biomass News 8, 1999) and China have considered using *S. viminalis* as a potential biofuel crop. A company called Pure Power Global (www.purepowerglobal.com) is studying the use of *S. viminalis* for ethanol production and is getting yields of 11 to 16 tons of ODT/ha/year. Pure Power has evaluated different hybrids, selecting seedlings for vigor and fast-growth characteristics that would double plant growth rates and biomass yields (Schill, 2008). Willows have also been suggested as a potential fuel and energy source in Australia and the United States (Low and Booth, 2007).

Poplars (*Populus alba* L.) Family: Salicaceae

Status(es): agricultural weed, casual alien, cultivation escape, environmental weed, naturalized, noxious weed, sleeper weed, weed (Randall, 2007).

A number of poplar species are considered to be invasive including *P. nigra* L. and *P. deltoides* Bartram ex Marshall.

Synonyms: *Populus alba* L. var. *bolleana* (Lauche), *Populus alba* var. *croatica* Wesm., *Populus alba* var. *nivea* Aiton (USDA-ARS, 2009).

Common names: álamo blanco, abele, gin-doro, hakuyo, peuplier blanc, Silber-Pappel, silverleaf poplar, urajiro-hako-yanagi, white poplar, witpopulier, xin bai yang (USDA-ARS, 2009).

Description: *Populus alba* can reach a height of 30 m or more. **Leaves** are dark green above with dense white hairs below, 5-12 cm long, oval to maple-leaf in shape with 3 to 5 broad teeth or lobes. **Flowers** are greenish-yellow inconspicuous and develop in slim, cylindrical flower clusters (catkins). **Fruits** are small and hairy (Wikipedia, 2009).

Native range: *Populus alba* and *P. nigra* is native to Eurasia, *P. deltoides* to North America (USDA-ARS, 2009).

Weed status: *Populus alba* can grow in a variety of soils and resprouts in response to damage. It produces large seed crops and male and female trees can spread vegetatively via root suckers. It outcompetes native tree and shrub species and interferes with community succession. It can also have an impact on water resources, with a well established tree consuming as much as 4.8 mm of water per day (TSEC-Biosys, 2006). *Populus alba* has been introduced to the United States, New Zealand, Australia, South Africa and other temperate areas. In the USA, *P. alba* hybridizes with some native poplar species (Weber, 2003). *Populus alba* and *P. nigra*, are both declared weeds in the Australian Capital Territory and have become particularly problematic in southern Australia forming dense stands along roadsides and watercourses (Low and Booth, 2007). In South Africa, *P. alba* and the hybrid *Populus* x *canescens* are declared weeds – it has been proposed that *P. deltoides* and *P. nigra* L. var. *italica* also be declared as invaders.

Biofuel potential: Poplar seeds germinate within 24h and can reach a height of 1-2 m within a year (Bradshaw *et al*., 2002). The rapid growth rate of the juvenile phase, presence of vigorous hybrids and ability to respond to short rotation coppice make it an ideal bioenergy crop (TSEC-Biosys, 2006). Poplars grown as a short rotation coppice (SRC) plantation in the UK could be harvested on a 2-5 year cycle, with plantations remaining viable for at least 30 years (TSEC-Biosys, 2006). Trial yields of 35 ODT/ha/yr for selected *P. trichocarpa* x *P. deltoides* varieties in the USA (Scarascia-Mugnozza *et al*., 1997) have been recorded.

The Office of Energy Efficiency and Renewable Energy in the US Department of Energy (DOE, 2008) is laying the groundwork for biofuels, made from fast-growing trees, shrubs, and grasses including switchgrass, hybrid poplars and willows (DOE, 2008). "Cellulosic ethanol facilities, which extract ethanol from plants such as poplars or switchgrass rather than from corn, are under construction in Pennsylvania, California, Georgia, Tennessee, New York, Illinois, Iowa, Kansas, Michigan and Louisiana" (Baker, 2008). A Californian-based company, ZeaChem plans to make ethanol from 23 000 acres of poplars (Baker, 2008).

MORINGACEAE

Species in the horseradish family are woody, often quite stout-stemmed shrubs or trees containing one genus, *Moringa* with 12 species in Madagascar, northeast and southwest Africa, and Arabia with three species spreading into India.

Moringa (*Moringa pterygosperma* Gaertn.) Family: Moringaceae

Status(es): cultivation escape, environmental weed, garden thug, naturalised, weed (Randall, 2007).

Synonyms: *Guilandina moringa* L., *Hyperanthera arborea* J.F. Gmel. , *Hyperanthera decandra* Willd., *Hyperanthera moringa* (L.) Vahl , *Moringa erecta* Salisb., *Moringa moringa* (L.) Small, *Moringa octogona* Stokes, *Moringa parvifolia* Noronha, *Moringa polygona* DC., *Moringa oleifera* Lam.., *Moringa zeylanica* Pers. (M.M.P.N.D., 2008)

Common names: Ben tree, Behn tree, Behen tree, Benzolive tree, Drumstick, Drumstick tree, Horseradish tree, West Indian ben (USDA-ARS, 2009).

Description: A small soft-wooded tree with corky bark that can reach a height of 10 m, often resembling a leguminous species at a distance. **Leaves** are grayish-green in colour, 30-60 cm long, with many small leaflets, 1.3-2 cm long, 0.3-0.6 cm wide, obovate. **Flowers** are fragrant, white, in loose axillary panicles up to 15 cm long. **Fruit** is pendent, elongate, 30-120 cm long, 1.8 cm wide, containing about 20 seeds embedded in the pith, opening by 3 valves and producing winged seeds (Duke, 1983b).

Native range: India, Malaysia, Oman, Qatar, Saudi Arabia, United Arab Emirates, Yemen (Duke, 1983b).

Weed status: *Moringa pterygosperma* is an extremely fast-growing tree, reaching a height of 2.5 m in 1-3 months under ideal conditions. It is adapted to a wide range of soil types and readily colonizes stream banks and savannah areas where the soils are well drained and the water table remains fairly high all the year round. It also coppices and pollards well (www.worldagroforestry.org). It has been introduced to many countries including Afghanistan, Bangladesh, Cameroon, Chad, Ethiopia, Gambia, Ghana, Haiti, Indonesia, Iran, Kenya, Mali, Marshall Islands, Mauritania, Nepal, Niger, Nigeria, Philippines, Senegal, Sierra Leone, Sudan, Tanzania, Uganda, Vietnam, and Zanzibar as a medicinal and food crop. It has become naturalized in southern Florida and Puerto Rico (Liogier & Martorell, 2000; IRC, 2006). There has been some naturalization on Guam (US Forest Service - PIER, 2010b) and it is considered as a garden escape on Christmas Island (Swarbrick, 1997). It has been cited as either naturalized or occasional escape or cultivated in Australia (Florabase, 2008). It has many of the attributes of invasive species and therefore has the potential to become problematic in the future, especially within the dry tropics of Australia where it is widely grown (Low and Booth, 2007).

Biofuel potential: Unlike *Jatropha curcas*, which can take anything from 3-5 years to produce its first crop, moringa can produce seeds in 1-2 years after planting. The oil from the seeds is known as “ben oil” or “behn oil” and can be used in cooking and also for illumination and cosmetics (CSIR, 1962). The seeds yield 22 to 38.5% oil. The tree can produce a maximum of 1000–2000 litres/ha/yr (Brockman, n.d.). Trials are currently underway in Australia to assess its biofuel potential (Low and Booth, 2007). A scoping plan funded through South West Catchment Council/National Action Plan into the development of industries for saline land, identified *M. oleifera* as a potentially economically feasible species for this environment (Brockman, n.d.). The Department of Agriculture-Biotechnology Program Office in Manila, Philippines, has established a Marawi City Facility that will produce biofuel from moringa seeds. Secura, an all Filipino Biotechnology Company hopes to expand its moringa plantation to 100 000 ha. (GMANews.TV, 2008). However, extracting the oil from the seeds is not easy and may need a machine-operated press.

FABACEAE

A large number of species in this family are known to be invasive. A number of Australian acacias are known to be invasive in Africa, especially in South Africa (Henderson, 2001). Other invasive species in the family include those in the genus *Bauhinia*, *Caesalpinia*, *Crotalaria*, and *Tephrosia* (Henderson, 2001; US Forest Service – PIER, 2009).

Pongamia tree (*Milletia pinnata* (L.) Panigrahi) Family: Fabaceae

Status(es): naturalized (Randall, 2007).

Synonyms: *Cytisus pinnatus* L., *Derris indica* (Lam.) Bennet , *Galedupa indica* Lam. , *Galedupa pinnata* (L.) Taub. , *Pongamia glabra* Vent., nom. illeg., *Pongamia mitis* Kurz, nom. illeg. , *Pongamia pinnata* (L.) Pierre (USDA-ARS, 2009).

Common names: Indian beech, karanja, karumtree, pongam, pongam oiltree, Poonga-oil-tree (USDA-ARS, 2009).

Description: Deciduous tree that can reach 15-25 m in height with a trunk diameter of 60 cm. **Leaves** are imparipinnate, young leaves are pinkish-red and mature leaves deep green, 5-9 leaflets. **Flowers** white to pink, paired along rachis in axillary, pendent, long racemes or panicles. **Pods** are short-stalked, oblique-oblong and flat, 1-seeded (Allen and Allen, 1981).

Native range: India to Fiji including northern Australia (USDA-ARS, 2009).

Weed status: Tolerant to water-logging, saline and alkaline soils and can withstand harsh climates and grows happily on degraded lands. The tree grows wild on sandy and rocky soils, but also on moist soil types, even in salty water. In parts of Miami, the tree is being controlled in areas where it is considered to be invasive due to the profusion of seedlings which appear from the rapidly germinating (poisonous) seeds. Of eventual greater concern to homeowners in Miami is a steadily expanding system of surface lateral roots (McLaughlin, 2005). According to Sinclair (2008), the “tree has proliferated in Brisbane because of its tenacity in tough conditions” – this is well south of its natural range. This is supported by Low and Booth (2007) who state that it seeds prolifically with high germination success near parent trees.

Biofuel potential: Trees can attain a height of 15-25 m in 4 or 5 years and bear fruit at 4–7 years. A single tree is said to yield 9–90 kg of seeds, indicating a yield potential of 900—9000 kg seeds/ha, 25% of which might be rendered as oil (assuming 100 trees/ha) (Duke, 1983c). In general, Indian mills extract 24–27.5% oil, while less efficient village crushers, 18–22% oil (Duke, 1983c). It is being investigated in India and elsewhere as feedstock for biodiesel. The Indian government has actively promoted the planting of this tree and since 2003 over 20 million trees have been planted and 45 000 farmers are now involved (www.himalayaninstitute.org). It is also being actively promoted in Cameroon where the government has identified 245 000 acres (99 147 ha.) for planting of the trees (Kane, 2007). The University of Queensland, ARC Centre of Excellence for Integrative Legume Research (CILR), has initiated trials and predicted that pongomia-derived biodiesel could meet 20% of Australia's diesel requirements with about 7000 square kilometers of plantations (Sinclair, 2008). Meeting 100% would require 35 000 square kilometers.

Mesquite (*Prosopis juliflora* (Sw.) DC.) Family: Fabaceae

Status(es): agricultural weed, cultivation escape, environmental weed, naturalized, noxious weed, weed (Randall, 2007).

A number of *Prosopis* species are invasive including *P. gladulosa* Torr. which, together with its hybrids, are invasive in Australia and southern Africa. It transforms invaded grasslands and savanna ecosystems into thorny thickets.

Synonyms: *Acacia cumanensis* Willd.,*Acacia juliflora* (Sw.) Willd., *Acacia salinarum* (Vahl) DC., *Algarobia juliflora* (Sw.) Heynh., *Algarobia juliflora* as defined by George Bentham refers only to the typical variety, *Prosopis juliflora* var. *juliflora* (Sw.) DC, *Desmanthus salinarum* (Vahl) Steud., *Mimosa juliflora* Sw., *Mimosa piliflora* Sw., *Mimosa salinarum* Vahl, *Neltuma bakeri* Britton & Rose, *Neltuma juliflora* (Sw.) Raf., *Neltuma occidenatlis* Britton & Rose, *Neltuma occidentalis* Britton & Rose, *Neltuma pallescens* Britton & Rose, *Prosopis bracteolata* DC., *Prosopis cumanensis* (Willd.) Kunth, *Prosopis domingensis* DC., *Prosopis dulcis* Kunth var. *domingensis* (DC.) Benth. Carl Sigismund Kunth's *Prosopis dulcis* is *Prosopis laevigata*. *P. dulcis* as described by William Jackson Hooker is Caldén (*P. caldenia*) (ILDIS, 2009).

Common names: algarroba, algarroba, algarrobo, bayarone, cují, negro, ironwood, mesquite, mesquitebaum, prosópis (USDA-ARS, 2009).

Description: Perennial deciduous thorny shrub or small tree, 3-10 m tall with stout stipular spines. **Leaves** are bipinnately compound with mostly two, sometimes more pairs of pinnae, 6-8 cm long, 12-25 pairs of leaflets per pinna, 6-16 mm long, 1.5-3.2 mm wide. **Flowers** greenish-yellow, sweet scented, spike-like, 5-10 cm long. **Fruits** are yellow to brown pods, cylindrical or slightly irregularly curved, usually 8-30 cm and 8-17 mm wide, 10-30 seeded. **Seeds** oval or elliptic, 2.5-7 mm long (Wagner *et al*., 1999).

Native range: *Prosopis juliflora* is native to the western USA and Mexico (USDA-ARS, 2009).

Weed status: *Prosopis* spp. are salt and drought tolerant with deep roots which tolerate dry as well as waterlogged soils. Seed production is prolific. Trees rapidly form dense thorny thickets that reduce biodiversity (Weber, 2003). Invaded grasslands are transformed to impenetrable woodlands and "forests". Loss of grass cover under canopies may also promote soil erosion. The tree resprouts easily after damage (Weber, 2003). It is naturalized in Hawaii (Wagner *et al*., 1999) where it is capable of rendering large areas impassable and displacing lower-growing plants (Motooka *et al*., 2003). Communities in Ethiopia, Kenya and elsewhere are becoming increasingly concerned about the negative impacts of *P. juliflora* which include the impact of this invasive tree on beneficial native species; encroachment onto paths, villages, homes, water sources, crop- and pastureland; and injuries due to thorns have had negative impacts on animal and human health apparently resulting in some human fatalities (Mwangi and Swallow, 2008; Maundu *et al*., 2009). Livestock owners around Lake Baringo, Kenya, claim that they now have to move 40-50km away, from where they reside, in search of grazing (Mwangi and Swallow, 2008). Crop farmers from Chemonke village, Kenya, have had to seek alternative settlement elsewhere because they have lost their land to *P. juliflora* invasions, often resulting in conflict with established communities, (Mwangi and Swallow, 2005). Surveys of local communities around Lake Baringo revealed that 85-90% of respondents to a questionnaire favoured complete eradication of invasive *Prosopis* species (Mwangi and Swallow, 2008). In another study Maundu *et al.* (2009) found that 64, 79 and 67% of respondents interviewed in the Garissa, Loiyangalani, and Baringo areas of Kenya, respectively, said that life would be better without prosopis. Over 90% of livestock owners in eastern Sudan regard invasive prosopis as a liability and pastoralists in Ethiopia refer to prosopis as the “Devil Tree”. *Prosopis juliflora* is also invasive in Eritrea, Somalia, Sudan, Egypt, Niger and other countries in Africa (Pascieznik, 1999; A.B.R. Witt, pers. obs.).

Biofuel potential: Fast growing, drought resistant, and with remarkable coppicing power, it is the ideal biofuel crop. The National Academy of Sciences (1980) found that on a 10 and 15-year rotation, expected wood yields are 50-60 MT/ha and 75-100 MT/ha, respectively. According to Ansely *et al*. (2007), treating invasive woody plants will become uneconomical in the future as fossil-fuel costs increase. A potential solution is to utlize these woody invaders for cellulosic biofuel. *Prosopis glandulosa* is a primary candidate because of abundant populations in the southern USA where yields of 13-27 megagrams/ha can be expected.

ASCLEPIADACEAE

There are about 2000 species in the family, mainly of tropical and sub-tropical origin. The stems generally exude a milky sap when damaged. Invasive species in this family also include *Araujia sericifera* and *Cryptostegia grandiflora*. The former is problematic in Australia (Csurhes and Edwards, 1998), New Zealand (Webb *et al*., 1998), and South Africa (Henderson, 2001) while *C. grandiflora* is invasive in New Caledonia (Meyer, 2007), Australia (Smith, 2002) and Ethiopia (A.B.R. Witt, pers. obs.).

Calotrope (*Calotropis procera* (Ait.) Ait. f.) Family: Asclepiadaceae

Status(es): agricultural weed, cultivation escape, environmental weed, naturalized, noxious weed, weed (Randall, 2007).

Calotropis gigantea (L.) W.T. Aiton (Giant milkweed) is another invasive plant species that has been proposed as a source of biofuel.

Synonyms: *Asclepis procera* Ait. (USDA-ARS, 2009).

Common names: aak, akund, algodão-de-seda, apple of Sodom, arbre à soie, auricula tree**,** giant milkweed, king’s crown, madar, mudar, mudarpflanze, roostertree, rubber bush, rubber tree, oscherstrauch, small crownflower, Sodom apple, Sodom's milkweed, swallowwort (USDA-ARS, 2009).

Description: Shrub or small tree up to 4 m tall with milky sap when cut or broken. **Leaves** opposite, grey-green and large, up to 15 cm long and 10 cm broad. **Flowers** white with petals purple-tipped inside and with a central purplish crown. **Fruit** grey-green, 8-12 cm long, containing numerous seeds with tufts of long silky hairs to one end (Kleinschmidt and Johnson, 1977).

Native range: India to Iran and Africa (USDA-ARS, 2009).

Weed status: Often invades beachfront dunes, roadsides, and disturbed urban plots. It roots deeply, rarely growing in shallow soils, but will tolerate soils of all textures and derived from most parent materials, as well as soils with high sodium saturation. It is naturalized in Australia, many Pacific islands, Mexico, Central and South America, and the Caribbean islands (Rahman and Wilcock, 1991). In Australia it invades roadsides, watercourses, coastal dunes and disturbed areas where it thrives on poor soils, forming dense thickets which compete with native species (Smith, 2002). It is a serious weed of the Kimberley in Western Australia, its milky sap causing contact dermatitis (Hussey *et al*., 1997). As a result it has been declared a noxious weed in Western Australia and the Northern Territory (Low and Booth, 2007). It has escaped from cultivation in Hawaii (Wagner *et al.*, 1999) and has also been recorded as invasive on the Canary Islands (Brandes, 2005). It is a declared noxious weed and/or noxious-weed seed in Puerto Rico (USDA-ARS, GRIN, 2008). *Calotropis procera* is a common roadside weed in Ethiopia and Tanzania with large numbers of plants now also being found in croplands (A.B.R. Witt, pers. obs.). In Australia, *C. gigantea* is found on roadsides, disturbed areas, watercourses, river flats and coastal dunes (Hussey *et al*., 1997). It thrives on poor soils particularly where overgrazing has removed competition from native grasses. Recorded as invasive in Fiji, Hawaii, Samoa and Australia

Biofuel potential: *Calotropis procera* has been recommended as a biofuel crop in India. It is also listed as a potential oil crop for biofuel production in the EU (van Thuijl *et al*., 2003).

MORACEAE

A family of about 1000 species of mainly large trees and shrubs that produce copious amounts of latex. A large number of *Ficus* species have been recorded as being invasive (Randall, 2002).

Breadfruit (*Artocarpus altilis* (Parkinson) Fosberg) Family: Moraceae

Status(es): casual alien, naturalized, weed (Randall, 2007).

Synonyms: *Artocarpus communis* J. R. Forst. & G. Forst., *Artocarpus incisus* L. f., *Sitodium altile* (USDA-ARS, 2009).

Common names: árbol del pan, arbre à pain, breadfruit, breadnut, breadnut tree, Brotfruchtbaum, fruta de pan, fruta-pão (USDA-ARS, 2009).

Description: Tree can reach a height of 26 m in height, trunk a width of 0.6-1.8 m. **Leaves** are evergreen or deciduous depending on climate, ovate, 23-90 cm long, 20-50 cm wide, entire at the base, deeply cut into 5-11 pointed lobes, bright green with yellow veins. **Flowers** tiny, male flowers on a drooping, cylindrical or club-shaped spike12.5-30 cm long, yellowish at first then becoming brown; female flowers massed on a rounded, green, prickly head (6.35 x 3.8 cm). **Fruit** is green at first, turning yellowish-green, yellow or yellow-brown when ripe, borne singly or in clusters of 2-3 at branch tips. **Seeds** are irregularly oval, rounded at one end, pointed at the other, about 2 cm long (Morton, 1987).

Native range: New Guinea through the Indo-Malayan Archipelago to Western Micronesia (Smith, 1981).

Weed status: It is a fast growing tree. The seedless breadfruit does well on sandy coral soils, and seeded types grow naturally on "coraline limestone" islands in Micronesia. In New Guinea, it grows wild along waterways and on forest margins in the flood plain, and often in freshwater swamps (Morton, 1987). It is believed that there is great variation in the adaptability of different strains to climatic and soil conditions, and that each should be matched with its proper environment. The Tahitian 'Manitarvaka' is known to be drought-resistant. The variety 'Mai-Tarika', of the Gilbert Islands, is salt-tolerant. 'Mejwaan', a seeded variety of the Marshall Islands, is not harmed by brackish water nor salt spray and has been introduced into Western Samoa and Tahiti (Morton, 1987). It has been recorded as being invasive in the Federated States of Micronesia (Kosrae Island) (Lorence and Flynn, 2005), Fiji Islands (Mbengga, Ngau, Ovalau, Taveuni, and Viti Levu Islands) (Smith, 1981), and Kiribati Line Islands (Teraina Island) (Wester, 1985).

Biofuel potential: All parts of the tree, including the unripe fruit, are rich in milky, gummy latex. The normal, "wild" type with seeds has little pulp while the "cultivated" and more widely grown seedless type, has more pulp.

ARECACEAE

A number of palm species have been recorded as being invasive (Randall, 2002). *Archontophoenix alexandrae* and *Caryota mitis* have been recorded as being invasive on some of the Hawaiian Islands (Daehler and Baker, 2006); *Phoenix dactylifera* on some of the Fijian Islands (Smith, 1979) and Australia (Csurhes and Edwards, 1998); and *Roystonea oleracea* on New Caledonia (MacKee, 1994).

African oil palm (*Elaeis guineensis* Jacq.) Family: Arecaceae

Status(es): naturalized, weed (Randall, 2007).

Synonyms: *Elaeis melanococca* Gaertn. (USDA-ARS, 2009).

Common names: African oil palm, Macaw fat, oil palm, apwiraiasi, dendê, nu tamara, palmiera-dendê, palmier â huile s'Afrique (GISD, 2005).

Description: Trunk is stout and solitary up to 20 m tall and 30 cm in diameter. **Leaves** are large, pinnate with 100-150 pairs of leaflets which are 60-120 cm long and 3.5-5 cm wide. **Flowers** (male) on short branches 10-15 cm long, female flowers large and borne close to trunk. **Fruits** grouped in clusters of 200-300, plum-like, ovoid-oblong, 3.5 cm long and about 2 cm wide, of various colours from orange to black when ripe (Duke 1983d).

Native range: West African coast, from Liberia to Angola. Small populations found in Madagascar.

Weed status: Invades disturbed forest; reported as invasive in Tanzania, tropical South America and a number of Pacific Islands, including Polynesia, Micronesia, Cook Islands and Hawaii (GISD, 2005). It has also escaped from cultivation in the East Usamabara Mountains, Tanzania (Dawson *et al*., 2008). Oil palm has been reported as invasive in primary forested situations in Brazil (GISP, 2008), however, evidence suggests that these reports were in fact abandoned plantations amongst secondary forest regrowth (pers. comm. J. Flood, 2009).

Biofuel potential: Cultivated for oil from the fruits and from the palm kernels. Palm oil is one of the world's important vegetable oils. Indonesia and Malaysia are the biggest producers with SE Asian production dominating the rest of the world. Crude Palm Oil (CPO) is used extensively in the food and detergent industries whilst Palm Kernel Oil (PKO) is a fine oil with properties similar to coconut oil (Corley & Tinker, 2003). According to the Wealth of India, the oil yield of oil palm is higher than that of any other oilseed crop producing 2.5 MT oil per ha per year, with 5 MT also recorded so it has high biofuel (biodiesel) potential. Hodge (1975) citing oil yields of 3,790kg/ha suggested it is the most efficient oil making plant species. Yields of semi-wild palms vary widely, usually ranging from 1.2 to 5 MT of bunches per ha. per year. One MT of bunches yields about 80 kg oil by local soft oil extraction, or 180 kg by hydraulic handpress. Estate yields in Africa vary from 7.5-15 MT bunches per ha. per year; in Sumatra and Malaysia, 15-25 MT, with some fields producing 30-38 MT. Kernel extraction yields vary from 3.5-5% or more.

Bunch yields may attain 22,000 kg/ha, of which only about 10% is oil, indicating oil yields of only 2,200 kg/ha. Higher yields are attainable. Corley (1981) suggested plantation yields of 2-6 MT/ha mesocarp oil, experimentally up to 8.5 MT/ha is possible. Averaged over the year, oil palm in Malaysia showed a growth rate of 8 g/m^2/day for an annual phytomass production of 29.4 MT/ha (Boardman, 1980). It is probable that older leaves, leaf stalks, etc., could also be harvested for biomass yield of 1-5 MT/ha. Based on energetic equivalents of total biomass produced, up to 60 barrels (9 525 litres) of oil per ha. could be obtained from this species. An energy evaluation of all the wastes from the palm oil fruit was made and it revealed that this can satisfy ca 17% of Malaysia's energy requirements. Palm oil could satisfy 20% more (Keong, 1981).

Palma del Espino, part of Peruvian conglomerate Grupo Romero, could invest up to $45 million (28.3 million Euro) in a project for biodiesel production in Peru's northern Loreto region – the project will provide for the planting of 10 000 ha of palm trees as well as for the construction of a mill for palm oil extraction and its conversion into biodiesel (Andina, 2008). China is also considering the African palm as a potential biofuel crop while Benin is considering planting 300 000-400 000 ha of oil palm in the wetlands of southern Benin (African Biodiversity Network, 2007). A 8000 ha. oil palm plantation is planned for Kigoma, Tanzania with Malaysian and Indonesian investors (African Biodiversity Network, 2007).

Recommended Policy Approaches

The Global Invasive Species Programme (GISP) and affiliated organizations warned that biofuel plants should not be introduced to new areas without having determined their likely invasiveness in the new environment (Howard and Ziller, 2008). Native species which have been grown widely in the region and have not exhibited any invasive tendencies in the past should be used in preference to introduced species. However, if a non-native species has been recommended for introduction then it is considered wise to undertake a risk assessment to determine if it has the potential to become problematic in the future.

Risk assessments support decisions on the introduction or use of a species in countries or regions. They consist of a range of questions about the biology of the species, its physical characteristics, habitat adaptations and climatic preferences and the difficulties associated with control and management (Howard and Ziller, 2008). Other questions pertain to the environmental conditions which exist in the area/region to which the plant is going to be introduced. These are generally questions about the altitude, rainfall, temperature, relative humidity, soil conditions, etc. to ascertain if there is a good match between the conditions in the native and introduced range. Each answer/response is scored and depending on the collated scores it can be ascertained if the plant has a high or low risk of becoming invasive. If the plant has a high risk, the species should not be introduced at all and alternatives should ideally be sought. If the risk is low, or if the risk is high but the authorities deem that its introduction is critical for economic development, the species could be introduced but measures should be put in place to deal with any potential escapes which should involve a rapid response mechanism to contain the further spread, followed by eradication of all individual plants growing outside of the plantation. The eradication and possible rehabilitation of the invaded areas should be at the cost of the biofuel producer/grower/investor ("polluter pays" principle).

Nevertheless, invasive species have the ability to escape and spread rapidly making it very difficult to contain them. Seeds can be dispersed by wind, water and vertebrate dispersers to areas well outside the plantation making detection very difficult. In an attempt to deal with this scenario several groups have developed best practices for biofuel production. These include the Principles and Criteria for Sustainable Biofuel Production developed by the Roundtable for Sustainable Biofuels (RSB) (http://cgse.epfl.ch/page65660-en.html) and the Principles and Criteria for Palm Oil Production developed by the Roundtable on Sustainable Palm Oil (RSPO) (http://www.rspo.org).

Twelve principles have been developed by the RSB with regard to biofuel production and include:

- That all biofuel operations shall comply with all applicable laws and regulations of the country in which the operation occurs and with relevant international laws and agreements;
- Sustainable biofuel operations shall be planned, implemented, and continuously improved through an open, transparent, and consultative Environmental and Social Impact Assessment (ESIA) and an economic viability analysis;
- Biofuel operations shall avoid negative impacts on biodiversity, ecosystems, and other conservation values. A number of criteria are listed under this principle and refer mainly to invasive species, "Criterion 7.e Biofuel operations shall prevent invasive species from invading areas outside the operation site."

Biofuel Feedstock Producers and Processors, are the operators that must comply. The minimum requirements are that;

- "Operators shall not use any species officially prohibited in the country of operation. Whenever the species of interest is not prohibited in the country of operation, Operators shall seek adequate information about the invasiveness of the species to be used for feedstock production, e.g. in the Global Invasive Species Database (GISD)."
- "If the species is recorded as highly invasive under similar conditions (similar climate, and similar local ecosystems, and similar soil types), this species shall not be used."
- "If the species has not been recorded as representing a high risk of invasiveness under similar conditions (climate, local ecosystems, soil type), Operators shall follow these specific steps:
    i. During the feedstock selection and development of biofuels, operators shall conduct a Weed Risk Assessment (WRA) to identify the potential threat of invasion. If the species is deemed highly invasive after the Weed Risk Assessment, this species shall not be used.
    ii. During the potential importation of crops, operators shall comply with all related national regulations, including the gain of an official approval or a suitable import certificate.
    iii. During feedstock production, operators shall set up management plans, which include cultivation practices that minimize the risks of invasion, immediate mitigation actions (eradication, containment or management) in case of escape of a plant species outside the operation site (possibly through the provision of a specific fund), as well as a monitoring system that checks for escapes and the presence of pests and pathogens outside the operation site.
    iv. During harvesting, processing, transport and trade, operators shall contain propagules in an appropriate manner on site and during transport."

The importation and growing of all nonnative species which are known to be invasive elsewhere and have been deemed to be a high risk species based on a Weed Risk Assessment should not be introduced and cultivated. The costs associated with invasive species, even those that are deemed to be beneficial, in most cases, outweigh the benefits that accrue from their use. However, if the introduction of an invasive biofuel crop species is deemed to be critical for economic development or other factors; then all measures as outlined by the RSB need to be followed.

Conclusions

- In recent years, bioenergy has drawn attention as a sustainable energy source that may offer a viable alternative to declining fossil fuel sources.
- In this paper, I raise the often forgotten issue of the potential invasiveness of plant species grown as biofuels; many of the proposed biofuel crops have been recognized as being invasive or potentially invasive.
- Recommended policy approaches include the use (where possible) of native species already grown widely in the region and that have not exhibited any invasive tendencies in the past.
- If a non-native species has been recommended for introduction then a Weed Risk Assessment should be conducted to determine potential invasiveness in the future.
- Further information can be obtained from the Global Invasive Species Database (GISD) and adherence to measures outlined by the Roundtable on Sustainable Biofuels (RSB) is also recommended.

References

Achten, W.M. J., Mathijs, E., Verchot, L., Singh, V. P., Aerts, R., Muys, B. (2007) Jatropha biodiesel fueling sustainability? *Biofuels, Bioproducts & Biorefining* **1**:283-291.

African Biodiversity Network (2007) Agrofuels in Africa – the impacts on land, food and forests. URL http://www.biofuelwatch.org.uk/docs/ABN_Agro.pdf (July 2009).

Allen, O.N. and Allen, E.K. (1981) *The Leguminosae.* The University of Wisconsin Press, 812 pp.

Andina (2008) Renewables – Pewru Grupo Romero moots $45 min investment in biodiesel production. Latin America News Digest (July 16, 2008).

Ansley, R.J., Stanford, R.L. and Rhodes, E.C. (2007) Biofuels from a woody invader in grasslands, Mequite (*Prosopis glandulosa*). Texas Agricultural Experiment Station, ESA/SER Joint Meeting, San Jose, California. URL http://eco.confex.com/eco/2007/techprogram/P1084.HTM z(November 2009).

Ayre, M. (2007) Will biofuels leave the poor hungry? BBC News – 2007/10/3 URL http://news.bbc.co.uk/2/hi/business/7026105.stm (May 2010)

Azam, M.M., Waris, A.and Nahar, N.M. (2005) Prospects and potential of fatty acid methyl esters of some non-traditional seed oils for use as biodiesel in India. *Biomass and Bioenergy* **29**:293-302.

Babbit, B. (1998) Statement by Secretary of the Interior on invasive alien species. National Weed Symposium, Bureau of Land Management Weed Page; 8-10 April 1998; Denver, CO.

Baker, D. (2008) Poplar trees hold promise for fuel. The Columbian (Vancouver, Washington) (July 7, 2008).

Barney, J.N. and DiTomaso, J.M. (2008) Nonnative Species and Bioenergy: Are We Cultivating the Next Invader. *BioScience* **58(1)**:64-70.

Bell, G.P. (1997) Ecology and management of *Arundo donax*, and approaches to riparian habitat restoration in southern California. In: Brock, J.H., Wade, M., Pysek, P. and Green, D. (eds). Green Plant Invasions: Studies from North America and Europe. Backhuys, Leiden, Netherlands, pp.103-113.

Benemann, J.R. (2008) *Opportunities and Challenges in Algae Biofuels Production*. A Position Paper. 15pp.

Benemann, J.R. (2009) *Microalgae Biofuels: A Brief Introduction*. 8pp.

Biomass News 8 (1999) Biomass use in Poland. URL http://www.ecop.ucl.ac.e/aebiom/biomassnews/News8/Biomass8_4.htm (July 2009).

Biopact (2007) D1 Oils has planted over 156 00 ha. of jatropha. URL http://biopact.com/2007/05/d1-oils-has-planted-over-156000.html (July 2009).

Boardman, N.K. (1980) Energy from the biological conversion of solar energy. *Philosophical Transactions of the Royal Society London* **295**:477-489.

Bradshaw, H.D. Jr, Ceulemans, R., Davis, J. and Stettler, R. (2002) Emerging Model Systems in Plant Biology: Poplar (*Populus*) as a Model Forest Tree. *Journal of Plant Growth Regulation* **19**:306-313.

Brandes, D. (2005) *Calotropis procera* on Fuerteventura. URL http://www.biblio.tu-bs.de/geobot/fuerte.html (July 2009).

Brockman, H. (n.d.) Production of biodiesel from perennials. (July 2009) Department of Agriculture and Food – Government of Western Australia. URL http://www.agric.wa.gov.au/objtwr/imported_assets/content/sust/biofuel/250507_biof.pdf

Chakrabortty, A. (2008) Secret report: Biofuels causes food crisis. Internal World Bank study delivers blow to plant energy drive. The Guardian, 3 July 2008. URL http://guardian.co.uk/environment/2008/jul/03/biofuels.renewableenergy (May 2010)

Chapotin, S.M. and Wolt, J.D. (2007) Genetically modified crops for the bioeconomy: meeting public and regulatory expectation. *Transgenic Research* **16**:675-688.

Charles Darwin Research Station. (2005) CDRS Herbarium records.

Charles Darwin Foundation. (2008) Database inventory of introduced plant species in the rural and urban zones of Galapagos. Charles Darwin Foundation, Galapagos, Ecuador.

Cole, N. (2008) Switchgrass research fields sprout agronomists study how best to harvest plants convertible to biofuel. Arkansas Democrat-Gazette (Little Rock) (June 24, 2008).

Comari, V., Tilley, D., Felix, E., Turdera, M., and Neto, M.C. (2004) Comparative energy evaluation of castorbean (*Ricinus communis*) production systems in Brazil and the U.S. In: Ortega, E. and Ulgiati, S. (eds.). Proceedings of IV Biennial International Workshop “Advances in Energy Studies”. Unicamp, Campinas, SP, Brazil. (June 16-19, 2004). pp.227-237.

Connor, D. and Minguez, I. (2006) Letter to Editor – Looking at Biofuels and Bioenergy. *Science* **312**:1743.

Corley, R.H.V. (1981) Oil palm. In: McClure, T.A. and Lipinsky, E.S. (eds.), CRC handbook of biosolar resources. vol. 11. Resource materials. CRC Press, Inc., Boca Raton, F.L., pp. 397-403.

Corley, R.H.V. and Tinker, P.B. (2003) *The Oil palm* (Fourth Edition). Blackwell Science Ltd., Oxford.

CSIR (Council for Scientific and Industrial Research) (1962) The Wealth of India – A dictionary of Indian raw materials and industrial products. New Dehli Vol. VI pp. 425-429.

Cremer, K.W. (1999) Willow Management for Australian Rivers. Natural Resource Management Special Issue, p. 2-22. URL http://www.hoadley.net/cremer/willows/default.htm (July 2009)

Csurhes, S. and Edwards, R. (1998) Potential environmental weeds in Australia: Candidate species for preventative control. Canberra, Australia. Biodiversity Group, Environment Australia. 208 pp.

Dawson, W., Mndolwa, A.S., Burslem, D.F.R.B. and Hulme, P.E. (2008) Assessing the risks of plant invasions arising from collections in tropical botanical gardens. *Biodiversity and Conservation* **17**:1979-1995.

Daehler, C.C. (1998) The taxonomic distribution of invasive plants: eco- logical insights and comparison to agricultural weeds. *Biological Conservation* **84**:167.

Daehler, C.C. and Baker, R.F. (2006) New records of naturalized and naturalizing plants around Lyon Arboretum, Mānoa Valley, O‘ahu. In: Evenhuis, N. L. and Eldredge, L. G. (eds). Records of the Hawaii Biological Survey for 2004-2005. Part 1: Articles. *Bishop Museum Occasional Papers* **87**:3-18.

De Oliviera, F.B. and de Sousa, S.S.A. (2007) Biomas-To-Liquids: A Potential Path in Brazil. Energy Tribune. URL http://www.energytribune.com/articles.cfm?aid=421 (July 2009)

DOE (Department of Energy) (2008) Department of Energy’s Office of Transportation Technologies and the Office of Power Technologies within the Office of Energy Efficiency and

Renewable. Energy from biofuels: The greening of America. URL http://bioenergy.ornl.gov/papers/misc/greening.html (July 2009).

Dudley, T.L. (2000) Noxious wildland weeds of California: *Arundo donax*. In: Bossard, C., Randall, J. and Hoshovsky, M. (eds). *Invasive plants of California's wildlands*. University California Press.

Duke, J.A. (1983a) Handbook of Energy Crops. Unpublished. URL http://www.hort.purdue.edu/newcrop/duke_energy/Sapium_sebiferum.html (July 2009).

Duke, J.A. (1983b) Handbook of Energy Crops. Unpublished. URL http://www.hort.purdue.edu/newcrop/duke_energy/Moringa_oleifera.html (July 2009).

Duke, J.A. (1983c) Handbook of Energy Crops. Unpublished. URL http://www.hort.purdue.edu/newcrop/duke_energy/Pongamia_pinnata.html (July 2009).

Duke, J.A. (1983d) Handbook of Energy Crops. Unpublished. URL http://www.hort.purdue.edu/newcrop/nexus/Elaeis_guineensis_nex.html (July 2009).

Dukes, J.S. (2000) Will the increasing atmospheric CO_2 concentrations affect the success of invasive species? In: Mooney, H.A. and Hobbs, R.J. (eds) *Invasive Species in a Changing World*, pp. 95-114. Islands Press, Washington.

Duncan, W.H. and Duncan, M.B. (1988) *Trees of the southeastern United States*. Athens, GA: The University of Georgia Press. 322 pp.

Ethanol Industry Outlook (2010) Climate of Opportunity. Renewable Fuels Association. URL http://ethanolrfa.3cdn.net/32b7ed69bd36632cb_r/m626lb0.pdf (May 2010)

EuropaBio (The European Association for Bioindustries) (2008) Biofuels Factsheet: Biofuels and Food. URL http://www.europabio.org/Biofuels/Biofuels_about.htm (July 2009)

FAO (Food and Agricultural Organization of the United Nations) (2008) State of Food and Agriculture. Biofuels: Prospects, risks and opportunities. URL http://www.fao.org/docrep/011/i0100e/i0100e00.htm (July 2009)

FAPRI (Food and Agricultural Policy Research Institute) (2007) FAPRI 2007 US and World Agricultural Outlook. URL http://www.fapri.iastate.edu/outlook/2007/ (July 2009).

Fargione, J., Hill, J., Tilman, D., Polasky, S., and Hawthorne, P. (2008). Land Clearing and the Biofuel Carbon Debt. *Science* **319:** 1235-1237.

Flora of China (2009) URL http://www.efloras.org (July 2009).

Florabase – The Western Australian Flora (2008) URL http://florabase.calm.wa.gov.au/browse/profile/19717 (November 2009).

Forero, C.L.B. (n.d.) Biodiesel from castor oil: a promising fuel for cold weather. URL http://www.icrepq.com/full-paper-icrep/222-barajas.pdf (July 2009).

Gibbs, H.K., Johnston, M., Foley, J.A., Holloway, T. Monfreda, C., Ramankutty, N. and Zaks, D. (2008) Carbon payback times for crop-based biofuel expansion in the tropics: the effects of changing yield and technology. Environmental Research Letters 3, 10pp. URL http://www.stacks.iop.org/ERL/3/034001 (January 2008)

GISD (2005) Global Invasive Species Database URL www.issg.org/database (July 2009).

GISP (Global Invasive Species Programme) (2008) Biofuel crops and the use of non-native species: Mitigating the risks of invasion. 8pp.

GMANews.TV (2008) New Marawi facility to produce biofuel from malunggay seeds. http://www.gmanews.tv/story/99206/New-Marawi-facility-to-produce-biofuel-from-malunggay-seeds.html.

Gray, A.J., Marshall, D.F. and Raybould, A.F. (1991) A century of evolution in *Spartina anglica*. *Advances in Ecological Research* **21**:1-62.

Grunwald, M. (2008) The Clean Energy Scam. TIME. URL http://www.time.com/time/magazine/article/0,9171,1725975,00.html (May 2010).

Harris, A., Small, N., Gibbs, A.J., Gibbs, M.J., Weiller, C. (2000) Viruses, Phytoplasmas and Spiroplasmas of Clonal Grasses and Their Diagnosis. Plant Biosecurity, Biosecurity Australia.

Harvard University (2007) Flora of China URL http://flora.huh.harvard.edu/china/mss/intindex.htm (November 2009)

Hazell, P and Pachauri, R.K. (2006) Overview In: Hazell, P. and Pachauri, R.K. (eds) Bioenergy and agriculture: promises and challenges. International Food Policy Research Institute.

Heller, J. (1992) Untersuchungen über genotypische eigenschaften and vermehrungs- und anbauverhahren bei der purgiernus. Dr. Kovac, Hamburg.

Henderson, L. (2001) *Alien Weeds and Invasive Plants. A complete guide to declared weeds and invaders in South Africa*. Plant Protection Research Institute Handbook No. 12. Agricultural Research Council, Pretoria.

Herrera, S. (2006) Bonkers about biofuels. *Nature Biotechnology* **24(7)**:755-760.

Hodge, W.H. (1975) Oil-producing palms of the world: a review. *Principes* **19(4)**:119-136.

Holm, L.G., Pancho, J.V., Herberger, J.P., and Plucknett, D.L. (1979) *A geographical atlas of world weeds.* John Wiley & Sons, New York.

Howard, G. and Ziller, S. (2008) Alien alert – plants for biofuel may be invasive. *Bioenergy Business* July/August 2008.

Hundley, K (2007) Power plant: Is *Arundo donax* the answer to our power problems? St Petersburg Times – 11 February 2007. URL http://www.sptimes.com/2007/02/11/Business/Power_plant_Is_Arun.shtml (July 2009).

Hussey, B.M.J., Keighery, G.J., Cousens, R.D., Dodd, J. and Lloyd, S.G. (1997) *Western Weeds. A guide to the weeds of Western Australia*. The Plant Protection Society of Western Australia (Inc.), Victoria Park, Western Australia.

ILDIS (International Legume Database and Information Service) (2009) URL http://www.ildis.org (July 2009).

Invasive Spartina Project (2003) *Spartina alterniflora* hybrids (smooth cordgrass). San Francisco Estuary Invasive Spartina Project. URL http://www.spartina.org/species/spartina-alternifolia-hy_v2.pdf (July 2009).

IRC (Institute for Regional Conservation) (2006) Floristic inventory of South Florida. URL http://www.regionalconservation.org/ircs/index.asp (July 2009).

IUCN/SSC - ISSG (Invasive Species Specialist Group) (2005a) URL http://www.issg.org/database/species/ecology.asp?fr=1&si=712&sts (July 2009).

IUCN/SSC – ISSG (Invasive Species Specialist Group) (2005b) URL http://www.issg.org/database/species/ecology.asp?fr=1&si=76 (July 2009).

IUCN/SSC – ISSG (Invasive Species Specialist Group) (2006) URL http://www.issg.org/database/species/ecology.asp?si=887&fr=1&sts= (July 2009).

IUCN/SSC – ISSG (Invasive Species Specialist Group) (2007) URL http://www.issg.org/database/species/ecology.asp?si=1121&fr=1&sts=&land=EN (July 2009).

Iverson, M.E. (1998) Effects of *Arundo donax* on water resources. *CalEPPC News* **6(3)**:10.

Johnson, M. (2007) Oil: Protecting the earth from renewable energy for 148 years. In: Economides, M.J. and Bryce, R. (eds). Energy Tribune pp. 8-9.

Jones, C. (2004) Europe adopts biodiesel – Can an African bean crack Europe's biodiesel blockage? Ecoworld – nature and technology in harmony – December 18, 2004. URL http://www.ecoworld.com/home/articles2.cfm?tid=356 (July 2009).

Kane, T. (2007) Biodiesel project started in Africa by local institute. URL http://www.riverreporter.com/issues/07-01-18/head1-biodiesel.html (July 2009).

Kaushik, N., Kumar, K., Kumar, S., Kaushik, N. and Roy, S. (2007) Genetic variability and divergence studies in seed traits and oil content of jatropha (*Jatropha curcas* L.) accessions. *Biomass and Bioenergy* **31**:497-502.

Keong, W.K. 1981. Soft energy from palm oil and its wastes. *Agricultural Wastes* **3(3)**:191-200.

Kleinschmidt, H.E. and Johnson, R.W. (1977) *Weeds of Queensland*. Government. Printer, 469 pp.

Kolar, C.S. and Lodge D.M. (2001) *Trends in Ecology and Evolution* **16**:199.

Kriticos, D.J., Sutherst, R.W., Brown, J.R., Adkins, S.W. and Maywald, G.F. (2003) Climate change and the potential distribution of an invasive alien plant: *Acacia nilotica* ssp. *indica* in Australia. *Journal of Applied Ecology* **40**:111-124.

Lankau, R.A., Rogers, W.E. and Siemann, E. (2004) Constraints on the utilization of the invasive Chinese tallow tree *Sapium sebiferum* by generalist native herbivores in coastal prairies. *Ecological Entomology* **29**:66-75.

Licht, F.O. (2010) EU member states to miss 2010 biofuel target. World Ethanol and Biofuels Report 8(18). URL http://www.agra-net.com/portal2/home.jsp?template=pubarticle&artid=1274966568430&pubid=ag072 (May 2010)

Liogier, H.A., and Martorell, L.F. (2000) *Flora of Puerto Rico and adjacent islands: a systematic synopsis* (2nd ed.). Editorial de la Universidad the Puerto Rico, San Juan, Puerto Rico, 382 pp.

Little, E.L., Jr., Woodbury, R.O. and Wadsworth, F.H. (1974) Trees of Puerto Rico and the Virgin Islands, vol. 2. Agricultural Handbook 449. USDA, Washington, DC.

Lovins, A.B., Datta, E.K., Bustnes, O-E., Koomey, J.G. and Glasgow, N.J. (2007) Winning the Oil Endgame: Innovations for profits, jobs, and security. Rocky Mountain Institute, USA.

Lorence, D.H. and Flynn, T. (2005) Checklist of the plants of Kosrae. Unpublished checklist. National Tropical Botanical Garden, Lawai, Hawai'i. 23 pp.

Low, T. and Booth, C. (2007) The weedy truth about biofuels. Invasive Species Council, 48 pp. URL www.invasives.org.au (July 2009)

Low, T. (2008a) Climate Change and Invasive Species. A Review of Interactions. Workshop Report – November 2006. Commonwealth of Australia.

Low, T. (2008b) Jatropha plans revealed. *Feral Herald* **1(17)**:4-5.

Lowe, S., Browne, M., Boudjelas, S. and De Poorter, M. (2000) *100 of the World's Worst Invasive Alien Species. A Selection from the Global Invasive Species Database.* ISSG-SSC of IUCN, 12 pp.

MacKee, H. S. (1994) Catalogue des plantes introduites et cultivées en Nouvelle-Calédonie. Muséum National d'Histoire Naturelle, Paris, 164 pp.

Maundu, P., Kibet, S., Morimoto, Y. Imbumi, M. and Adeka, R. (2009). Impact of *Prosopis juliflora* on Kenya's semi-arid and arid ecosystems and local livelihoods. *Biodiversity* 10 (2 & 3), 33-50.

McLaughlin, J. (2005). Solutions for your life – Miami-dade country. University of Florida Extension. URL http://miami-dade.ifas.ufl.edu (July 2009).

Meyer, Jean-Yves. 2007. The snake-like climber *Anodendron paniculatum* (Apocynaceae), a "new" invasive liana in the rainforests of Tahiti (Pacific Ocean). *Aliens* **24/25**:10-11.

Middleton, B.A. (2006) Invasive species and climate change. US Geological Survey Open-file Report 2006-1153. 2pp.

Miller, R.C. and Zedler, J.B. (2003) Responses of native and invasive wetland plants to hydroperiod and water depth. *Plant Ecology* **167**:57–69.

M.M.P.N.D. (Multilingual Multiscript Plant Name Database) (2004) Sorting Azadirachta names. URL http://www.plantnames.unimelb.edu.au /Sorting/Azadirachta.html (July 2009).

M.M.P.N.D. (Multilingual Multiscript Plant Name Database) (2008) Sorting Moringa names. URL http://www.plantnames.unimelb.edu.au/Sorting/Moringa.html. (July 2009).

Moody, M.L. and Les, D.H. (2002) Evidence of hybridity in invasive milfoil populations. *Proceedings of the National Academy of Sciences* **99**:14867-14871.

Morton, J.F. (1977) *Major medicinal plants*. C.C. Thomas, Springfields, IL.

Morton, J.F. (1987) Fruits of warm climates.Miami, Florida. URL http://www.hort.purdue.edu/newcrop/morton/index.html (July 2009).

Motooka, P., Castro, L., Nelson, D., Nagai, G. and Ching, L. (2003) Weeds of Hawaii's Pastures and Natural Areas; An Identification and Management Guide. College of Tropical Agriculture and Human Resources, University of Hawaii at Manoa, 184 pp.

Mwangi, E. and Swallow, B. (2005). Invasion of *Prosopis juliflora* and local livelihoods: Case study from the Lake Baringo area of Kenya**.** World Agroforestry Centre, ICRAF. Working Paper no. 3.

National Academy of Sciences (NAS) (1980). Firewood crops. Shrub and tree species for energy production. National Academy of Sciences, Washington, DC.

Naylor, R.L., Liska, A.J., Burke, M.B., Falcon, W.P., Gaskell, J.C., Rozelle, S.D. and Cassman, K.G. (2007) The ripple effect – Biofuels, food security, and the environment. *Environment* **49(9)**:30-43.

Nemethy, E.K., Otvos, J.W. and Calvin, M. (no date) Plants as a source of energy. URL http://www.anl.gov/PCS/acsfuel/preprint%20archive/Files/25_4SAN%20FRANCISCO_08-80_0216.pdf (May 2009)

Olivier, P.A. (no date) From field to factory to diesel tank – Empowering Louisiana Agriculture. A new cash crop. URL http://www.esrla.com/pdf/tallow.pdf (July 2009).

Padma, T.V. (2008) India approves biofuel rise. The New Nation: Bangladesh Independent News Service, September 29, 2008. URL http://nation.ittefaq.com/issues/2008/09/29/news0790.htm (December 2009).

Parsons, W.T. and Cuthbertson, E.G. (1992) *Noxious weeds of Australia.* Inkata Press, Melbourne/Sydney, 692 pp.

Pasiecznik, N. (1999). *Prosopis* - pest or providence, weed or wonder tree? *European Tropical Forest Research Network* newsletter. **28**:12-14.

Pimentel, D., McNair, S., Janecka, J., Wightman, J., Simmonds, C., O'Connell, C., Wong, E., Russel, L., Zern, J., Aquino, T. and Tsomondo, T. (2001) Economic and environmental threats of alien plant, animal, and microbe invasions. *Agriculture, Ecosystems and Environment* **84**:1-20.

Pimentel, D. and Patzek, T. (2005) Ethanol production using corn, switchgrass, and wood; biodiesel production using soybean and sunflower. *Natural Resource Research* **14(1)**: 65-76.

Pimentel, D., Zuniga, R. and Morrison, D. (2005) Update on the environmental and economic costs associated with alien-invasive species in the United States. *Ecological Economics* **52**: 273–288.

Press TV (2007) Iran to build Bosnia ethanol plant. Press TV, 8 April, 2007.

Purdue University (2006) GM tree could be used for cellulosic ethanol: Fast growing trees could take root as future energy source. URL http://news.mongabey.com/2006/0824_purdue2.html.

Raghu, S., Anderson, R.C., Daehler, C.C., Davis, A.S., Wiedenmann, R.N., Simberloff, D. and Mack, R.N. (2006) Adding Biofuels to the Invasive Species Fire? *Science* **313**:1742

Rahman, M.A. and Wilcock, C.C. (1991) A taxonomic revision of *Calotropis* (Asclepiadaceae). *Nordic Journal of Botany* **11(3)**:301-308.

Raizada, P., Singh, A. and Raghubanshi, A.S. (2009) Comparative responses of seedlings of selected native dry tropical and Invasive Alien Species to CO_2 enrichment. *Journal of Ecology* **2(2)**:69-75.

Randall, J.M. and Marinelli, J. (eds.) (1996) *Invasive plants: weeds of the global garden.* Brooklyn Botanic Garden Handbook 149. 111 pp.

Randall, R. (2002) *A Global Compendium of Weeds*. R.G. & F.J. Richardson, Melbourne.

Randall, R. (2007) http://www.invasive.org/gist/biglist.html.

Reed, C.F. (1976) Selected weeds of the United States. Agricultural Handbook 366. USDA, Washington, DC.

Rejmánek, M. and Richardson, D.M. (1996) What attributes make some plant species more invasive? *Ecology* **77**:1655-1661.

Righelato, R. and Spracklen, D.V. (2007) Carbon mitigation by biofuels or by saving and restoring forests? *Science* **317**:902.

Rogers, W.E. and Siemann, E. (2004) Invasive ecotypes tolerate herbivory more effectively than native ecotypes of the Chinese tallow tree *Sapium sebiferum*. *Journal of Applied Ecology* **41**:561-570.

Rosegrant, M.W., Msangi, S., Sulser, T. and Valmonte-Santos, R. (2006) Biofuels and the Global Food Balance. In: Hazell, P. and Pachauri, R.K. (eds.) *Bioenergy and agriculture: promises and* *challenges*. 2020 Focus No. 14. International Food Policy Research Institute (IFPRI), Washington, DC, USA.

Sarmiento, P. (2008a) Southeast Asia: region looks to jatropha oil as fuel source, Inter Press Service, Manila, Philippines (June 23, 2008).

Sarmiento, P. (2008b) Philippines: *Jatropha* Key to Self Sufficiency URL http://ipsnews.net/news.asp?idnews=42917 (July 2009).

Scarascia-Mugnozza G.E., Ceulemans, R., Heilman, P.E., Isebrands, J.G., Stettler, R.F. and Hinckley, T.M. (1997) Production physiology and morphology of *Populus* species and their hybrids grown under short rotation. II. Biomass components and harvest index of hybrid and parental species clones. *Canadian Journal of Forestry Research* **27**:285-294.

Scheld, H.W., Bell, N.B., Cameron, G.N., Cowles, J.R., Engler, C.R., Krikorian, A.D. and Schultz, E.B. (1980) The Chinese tallow tree as a cash and petroleum-substitute crop. In: *Tree crops for energy co-production on farms*. U.S. Department of Energy and Solar Energy Research Institute Publication, SERI/CP-622- 1086. Washington, D.C., pp. 97-112.

Schill, S.R. (2008) Pure Power offers willow cutting, crop management manual. Biomass Magazine – September URL www.biomassmagazine.com (July 2009).

Scott, R., Callaghan, T.U. and Jackson, G.J. (1990) Spartina as a biofuel. In: Gray, A.J. and Benham, P.E.M. (eds), *Spartina anglica*: A research review, ITE publication No 2, NERC, Swindon, UK.

Searchinger, T., Heimlich, R., Houghton, R.A., Dong, F., Elobeid, A., Fabiosa, J., Tokgoz, S., Hayes, D., Yu, T-H. (2008). Use of US croplands for biofuels increases greenhouse gases through emissions from land use change. *Science* **319**:1238–1240.

Shyam, AK. (2008) Biofuel – Potential future crop of farmers. URL http://www.fbae.org/our-position-biofuel_potential-future-crop-of-farmers.html (July 2009).

Sims, R., Taylor, M., Saddler, J. and Mabee, W. (2008) From 1st to 2nd generation biofuel technologies. An overview of current industry and RD & D activities. OECD/IEA. URL http://iea.org/papers/2008/2nd_Biofuel_Gen.pdf (May 2010).

Sinclair, K (2008) Branching out into biodiesel. URL http://www.news.com.au/couriermail/story/0,23739,23046031-3122,00.html (July 2009).

Smith, A.C. (1979) *Flora Vitiensis nova: a new flora of Fiji.* National Tropical Botanical Garden, Lawai, Kauai, Hawaii. Volume 1. 494 pp.

Smith, A.C. (1981) *Flora Vitiensis nova: a new flora of Fiji*. National Tropical Botanical Garden, Lawai, Kauai, Hawaii. Volume 2. 810 pp.

Smith, A. C. (1985). *Flora Vitiensis nova: a new flora of Fiji*. National Tropical Botanical Garden, Lawai, Kauai, Hawaii. Volume 3. 758 pp.

Smith, N.M. (2002) *Weeds of the wet/dry tropics of Australia - a field guide*. Environment Centre NT, Inc., 112 pp.

Space, J.C. and Flynn, T. (2001) Report to the Kingdom of Tonga on invasive plant species of environmental concern. USDA Forest Service, Honolulu, 78 pp.

Stein, B. and Flack, S. (1996) America's Least Wanted: Alien Species Invasions of US Ecosystems. The Nature Conservancy, Arlington. URL http://www.natureserve.org/library/americasleastwanted2003.pdf (July 2009).

Stone, B.C. (1970) The flora of Guam. *Micronesica* **6**:1-659.

Swarbrick, J. T. (1997) Environmental weeds and exotic plants on Christmas Island, Indian Ocean: a report to Parks Australia. 101 pp. plus appendix.

Thomas, V.M., Choi, D.G., Luo, D., Okwo, A. and Wang, J. H. (2009). Relation of biofuel to bioelectricity and agriculture: Food security, fuel security, and reducing greenhouse emissions. *Chemical Engineering Research and Design* **87(9)**:1140-1146.

TSEC-Biosys (2006) Towards a Sustainable Energy Economy URL http://www.tsec-biosys.ac.uk (July 2009).

The Bugwood Network (2003) USDA Forest Service & USDA APHIS PPQ. The University of Georgia - Warnell School of Forest Resources and College of Agricultural and Environmental Sciences - Department of Entomology. Southeast Exotic Pest Plant Council Invasive Plant Manual. Invasive Plants of the Eastern United States.

USDA-ARS, GRIN (Germplasm Recourses Network) (2008) National Genetic Resources Program, [Online Database] National Germplasm Resources Laboratory, Beltsville, Maryland. URL: http://www.ars-grin.gov/cgi-bin/npgs/html (July 2009)

USDA Forest Service (no date) Weed of the Week – Chinese silvergrass *Miscanthus sinensis* Aderss. URL http://www.fs.fed.us/fhp/invasive_plants/weeds/chinese-silvergrass.pdf (July 2009).

USDA-NRCS (National Resources Conservation Service) Plant Fact Sheet – Switchgrass, *Panicum virgatum* L. URL: http://plants.usda.gov/factsheet/pdf/fs_pavi2.pdf (July 2009).

US Forest Service - PIER (Pacific Island Ecosystems at Risk) (2009) URL http://www.hear.org/Pier/species/azadirachta_indica.htm (July 2010).

US Forest Service - PIER (Pacific Island Ecosystems at Risk) (2010a) URL http://www.hear.org/Pier/species/ricinus_communis.htm (July 2010).

US Forest Service - PIER (Pacific Island Ecosystems at Risk) (2010b) URL http://www.hear.org/pier/species/moringa_oleifera.htm (July 2010).

US Forest Service - PIER (Pacific Island Ecosystems at Risk) (2010c) URL http://www.hear.org/pier/species/olea_europaea.htm (July 2010).

US Forest Service - PIER (Pacific Island Ecosystems at Risk) (2010d) URL http://www.hear.org/Pier/species/arundo_donax.htm (July 2010).

US Forest Service and the Texas Forest Service (2005) Tree Population Characteristics. Houston's Regional Forest Report: A Report of Structure, Functions and Values.

van Thuijl E, van Ree R, de Lange TJ (2003) Biofuel Production Chains: Background Document for Modeling the EU Biofuel Market Using the Biotrans Model. URL http://www.ecn.nl/docs/library/report/2003/c03088.pdf (July 2009).

von Lampe, M (2008) Economic Assessment of Biofuel Support Policies. OECD Directorate for Trade and Industry. URL http://www.wilsoncenter.org/news/doc/brazil.oecd.biofuel.support.policy.pdf (May 2010)

Wagner, W.L., Herbst, D.R.and Sohmer, S.H. (1999) *Manual of the flowering plants of Hawaii*. Revised edition. Bernice P. Bishop Museum special publication. University of Hawai'i Press/Bishop Museum Press, Honolulu. 1919 pp. (two volumes).

Walker, D.A. (2009) Biofuels, facts, fantasy, and feasibility. *Journal of Applied Phycology* **21**: 509-517.

Webb, C.J., Sykes, W.R. and Garnock-Jones, P.J. (1988) *Flora of New Zealand, Volume IV: Naturalised pteridophytes*, *gymnosperms*, *dicotyledons*. Botany Division, DSIR, Christchurch, 1365 pp.

Weber, E. (2003) I*nvasive Plant Species of the World*. *A Reference Guide to Environmental Weeds.* CABI Publishing, Wallingford, UK.

Wester, L. (1985) Checklist of the vascular plants of the northern Line Islands. Smithsonian Institution, Washington. *Atoll Research Bulletin* **287**:1-38.

Westlake, D.F. (1963) Comparisons of plant productivity. *Biological Review* **38**:385–425.

White, G.A., Willingham, B.C., Skrdla, W.H., Massey, J.H., Higgins, J.J., Calhoun, W., Davis, A.M., Dolan, D.D., and Earle, F.R. (1971) Agronomic evaluation of prospective new crop species. *Economic Botany* **25(1)**:23–43.

Wikipedia (2009) URL http://en.wikipedia.org/wiki/Populus_alba (July 2009).

Wilkinson, J.M., Evans, E.J., Bilsborrow, P.E., Wright, C., Hewison, W.O. and Pilbeam, D.J. (2007) Yield of willow cultivars at different planting densities in a commercial short rotation coppice in the north of England. *Biomass and Bioenergy* **31**:469-474.

Wolt, J.D. (2009) Advancing environmental risk assessment for transgenic biofeedstock crops. *Biotechnology for biofuels* **2**:27.

Wust, C. (2008) New Technology foresees trees, not grain, in the tank. Spiegel Online International – 15 April 2008. URL http://www.spiegel.de/international/business/0,1518,547312-2,00.html (July 2009).