Applications of the IUCN Red List in evaluating global extinction risk of timber tree species

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Abstract

Anthropogenic deforestation and habitat degradation are major pressures on biodiversity. The world's wild-growth timber tree species additionally face pressure from unsustainable and illegal harvest practices. Despite the threats to these economically valuable species, our understanding of their extinction risk remains incomplete and outdated. In fact, many timber tree taxa are marketed under trade names only, making it difficult to identify those most at risk. An additional challenge is presented by limited data and the pressing need for rapid species assessment in order to inform conservation actions. However, the use of 'big data' is coming to the fore in ecological research, and offers a valuable chance to meet international assessment targets such as those of The Global Strategy for Plant Conservation (GSPC), which call for knowledge of the conservation status of all known plant species to guide conservation actions (GSPC Target 2), in addition to sustainable harvesting of all wild-sourced plant-based products (GSPC Target 12), by the year 2020 (CBD, 2012).

This thesis therefore aimed to identify timber tree taxa in trade at the species level; to assess utility of occurrence records from the Global Biodiversity Information Facility (GBIF) in timber species range mapping; to assess current extinction risk of a priority subset of timber tree species by applying the IUCN Red List (Red List) of Threatened Species Categories and Criteria; and, lastly, to evaluate the uncertainty of these preliminary Red List assessments.

Consolidation of open-access timber lists produced a 'working list' of 1,578 angiosperm timber taxa in trade. GBIF records were demonstrated to be a suitable low time-cost resource with which to estimate species extent of occurrence and prioritise

range-restricted timber tree species for Red List assessment. In addition to GBIF datasets, Global Forest Change (GFC) satellite imagery was found to be a valuable resource for assessing timber tree species range size, habitat fragmentation, and population trends over time. Preliminary Red List assessments conducted for 324 timber tree species suggest that some 69% may be threatened with extinction if current rates of deforestation persist.

Although GBIF and GFC 'big data' were found to introduce some uncertainty into timber tree Red List categorisations, quantitative comparison to assessments conducted using 'expert' datasets suggested that categorisations were not greatly impacted. Furthermore, these evaluations illustrated the scarcity and inaccessibility of more traditional sources of Red List assessment data for timber tree species. It is evident that if we are to meet GSPC and other conservation targets for timbers and other at-risk, poorly-known tree taxa, we must recognise that open-access 'big data' repositories represent a powerful opportunity for Red Listing.

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Author's declaration

I confirm that this thesis is the result of my own work with the following exception of the report detailed below. Additional datasets and material used in this thesis have been fully referenced and acknowledged throughout.

Chapter 2 is published as a report in collaboration with three co-authors. It was conceived by JM and ACN and researched and written by JM. SO and MR provided commentary, review and support. The report is accessible online as follows:
Mark, J., Newton, A. C., Oldfield, S. and Rivers, M., 2014. A Working List of Commercial Timber Tree Species. Botanic Gardens Conservation International. [Online]. Available from: http://www.bgci.org/news-and-events/news/1175/

"*The loss of even one species diminishes the Earth's store of biological diversity for, once eliminated, a species cannot be recovered or regenerated. All possibilities the species had for bettering life are gone...*"

Francisco Dallmeier

–

"*The clearest way into the universe is through a forest wilderness.*"

John Muir

1 Introduction

1.1 Literature Review

1.1.1 Global biodiversity loss

It is widely recognised that human activity is irreversibly affecting the environment at an unprecedented rate and at a global scale (Pimm, 2009; Butchart *et al.*, 2010; UNEP, 2012). The human population now exceeds seven billion, fuelling demand for raw materials, land conversion and energy production. Livestock pasture and cropland now cover some 37.4% of terrestrial land area (Foley *et al*., 2011). Fossil fuel combustion, agriculture, and industrial processes emit billions of tonnes of carbon dioxide, methane, and nitrous oxide per annum, disrupting regulation of Earth systems including the carbon and nitrogen cycles and annual precipitation (IPCC, 2007; UNEP, 2012).

Human activity not only affects regulation of abiotic processes, but also biological systems in the form of ecosystems (UNEP, 2012) and biodiversity – that is, the variety of life on Earth, ranging from the chemical composition of genes to highly complex ecosystems (United Nations, 1992). Rapid human population growth, industrialisation and globalisation over the last two hundred years are thought to have accelerated species extinction rates 1,000-10,000 times above background levels (Purvis *et al*., 2000b; Pimm, 2009). Anthropogenic activities threaten the natural world through habitat fragmentation and destruction, pollution, and over-exploitation of natural resources. Globalisation facilitates spread of alien invasive species through increased international travel and trade (Secretariat of the Convention on Biological Diversity, 2010; UNEP, 2012). Alongside climate change, these stressors act synergistically as the principal drivers of biodiversity loss (Brook *et al.*, 2008).

1.1.2 Monitoring the state of plant biodiversity

In 2002, the Convention on Biological Diversity (CBD) compiled a framework of indicators to monitor the state of global biodiversity at the level of genes, species and ecosystems. The pressures acting on biodiversity were also monitored, and the aim was to use the resulting data to assess progress towards a series of global conservation targets. At this time, the 193 Parties to the Convention committed to "…*achieve by 2010 a significant reduction of the current rate of biodiversity loss…*" as part of the United Nations Millennium Development Goals (Stuart and Collen, 2013). Despite varying degrees of progress (Butchart *et al*., 2010), internationally-agreed targets continue to be set, with the latest targets set for 2020 and 2050 (Sparks *et al*., 2011).

Operating alongside the CBD's Aichi Biodiversity Targets for 2020, the Global Strategy for Plant Conservation (GSPC) is the key international action plan focused specifically on long-term sustainable management and conservation of the world's plant resources (CBD, 2012). Targets 2 and 12 of the GSPC call for knowledge of the conservation status of all known plant species to guide conservation actions as well as sustainable harvesting of all wild-sourced plant-based products, by the year 2020 (CBD, 2012).

A recently published study by Beech *et al*. (2017) determined, for the first time, that 20% of all angiosperm and gymnosperm plant species were represented by trees, of which there are 60,065 species currently known to science. When referring to trees, this thesis uses the definition of "tree" agreed upon by the Global Tree Specialist Group (GTSG) of the International Union for the Conservation of Nature (IUCN): "*A woody plant with, usually, a single stem growing to a height of at least two metres or, if multi-stemmed, then at least one vertical stem five centimetres in diameter at breast height*" (Beech *et al*., 2017). This thesis focuses on the threat to trees exploited for timber.

1.1.3 The value of timber trees

A timber tree is one felled for its wood for use in construction or production of wooden items such as flooring, furniture, musical instruments and carvings. Felled trees may be traded in the form of primary wood products such as roundwood or smaller, cut logs (sawnwood), or in the form of finished products such as veneer, boards, plywood or wooden objects (ITTO, 2012). Currently, trade in timber products contributes an estimated 468 billion dollars annually to global GDP (The World Bank, 2004), supporting multi-million dollar construction, furniture and paper industries.

Trees used for timber are valued by world markets and national governments for their wood, yet their other contributions to human well-being remain largely overlooked (FAO, 2012; Oakes *et al*., 2012). In addition to producing timber for construction and furniture industries, these species are integral parts of the forest ecosystems that provide the plethora of goods and services upon which modern society relies, including pollination, water filtration, bacterial breakdown of waste, and genetic potential in the form of untapped biodiversity (Millennium Ecosystem Assessment, 2005; UNEP, 2005b; Díaz *et al*., 2006).

Some tree species, including some timber tree species, play key roles within the forest ecosystem, as foundation (defining community structure and controlling key dynamics) or keystone (exerting a disproportionately large effect on community dynamics in relation to its local abundance) species (Ellison *et al*., 2005), or as canopy dominants. Decline or disappearance of such species disrupts entire species communities (Friends of the Earth International, 2013), altering ecosystem function with potentially damaging consequences for human economy, health and well-being (Díaz *et al*., 2006; Secretariat of the Convention on Biological Diversity, 2010). However, despite their value, timber tree species face numerous threats, chiefly deforestation and over-exploitation.

1.1.4 Threats to timbers: The global deforestation crisis

Forests are among the most biodiverse ecosystems on the planet (Newton *et al*., 2003). Collectively, tropical and temperate forests cover 31% of total land area (FAO, 2010), providing habitat for more than 50% of all terrestrial species (UNEP, 2005a). They are also vital to the maintenance of biogeochemical processes and provision of raw materials (Millennium Ecosystem Assessment, 2005), and provide fundamental subsistence for over 350 million people (Newton *et al*., 2003; FAO, 2012). The human population as a whole depends upon forests for fundamental services as diverse as the regulation of atmospheric gases, carbon sequestration, and primary production (Millennium Ecosystem Assessment, 2005; FAO, 2012). Additionally, some forests are attributed cultural, religious or spiritual importance (Millennium Ecosystem Assessment, 2005). The extinction of a tree species is, in itself, a form of habitat degradation with ecosystem-wide consequences. Yet, in spite of this inherent importance, forest ecosystems remain highly threatened by deforestation and degradation (Hansen *et al.*, 2010; FAO, 2012).

Deforestation results in a two-fold loss of biodiversity; directly through the clearance of tree taxa, and indirectly by fragmenting and degrading the habitat of associated animal and plant species (UNEP, 2009). Abiotic impacts of deforestation include release of sequestered carbon dioxide and other greenhouse gases and diminished capacity of terrestrial carbon sinks; disruption to localised climate regulation, which may result in drought; degradation of forest watersheds; increased risk of landslides and flooding due to loss of soil integrity; and disruption of natural fire regimes (IPCC, 2007; UNEP, 2009; Gill *et al.*, 2013).

In their summary of progress towards the Convention on Biological Diversity's 2010 conservation targets, Butchart *et al.* (2010) noted that despite a significant increase in area of forest under Forest Stewardship Council certification (an indicator of sustainable management) since 1995, this trend has decreased in recent years. Rates of deforestation remain high, with gross global forest cover declining by 2.3 million square kilometres from 2000 to 2012 (Hansen *et al*., 2013).

Advances in remote sensing technology allow global forest cover to be mapped and changes monitored using high-resolution satellite imagery (see Hansen *et al*., 2013 for the most recent global maps using Landsat data at a 30-metre resolution). However, it is not yet possible to differentiate at a species level using satellite imagery, making population monitoring of individual tree species difficult over large land areas that cannot be covered by drones or low-flying aircraft. Satellite remote sensing data have been incorporated into the Global Forest Resources Assessments (FRAs) carried out by the Food and Agriculture Organisation of the United Nations (FAO) at five-year intervals using national and regional datasets (FAO, 2010). However, the reliability of FRAs for long-term monitoring has been called into question owing to variation in the quality of the datasets used, varying definitions of different land cover types, and incomplete country reporting (Grainger, 2008).

The primary sources of tree species population data are the networks of forest plots recorded by numerous disparate research groups in the field. The impressive spatial coverage of such networks in the Amazon was recently demonstrated by ter Steege *et al.* (2013), presenting data from 1,170 plots covering approximately six million hectares of lowland forest. However, in some instances, plot networks can be unavoidably restricted by national borders or impenetrable areas. As yet, there is no single repository for global plot network data, and such data have not been consolidated globally for suites of species, such as trees harvested for timber.

Large-scale deforestation has several drivers, including forest clearance for agriculture (such as palm oil, livestock ranching, coffee and cocoa); biofuel plantations; infrastructural development; and extraction of raw materials including timber (Newton, 2008; de Lacerda and Nimmo, 2010). Additional degradation may occur from unsustainable harvest of valuable non-timber forest products such as medicinal plants and invertebrates, fuelwood, rubber, latex and fibre.

1.1.5 Threats to timbers: The international timber trade

International trade in wood is documented as early as 3,000 BC in the Mediterranean and North Africa, but the timber trade only became truly global in the seventeenth and early eighteenth century, following European colonisation of the Americas (Peck, 2001a). Today, trade in tropical timber is centred in the Asia-Pacific region, where the largest producers are Indonesia, Malaysia, Papua New Guinea and the Solomon Islands. Other major producers are Brazil, India and Nigeria (ITTO, 2012).

Logging of primary (non-plantation) forest plays a significant role in deforestation; the FAO reported over 1,760 million cubic metres of logged wood removed from forests in 2005 (FAO, 2010). Removal and transport of cut timber also puts pressure on forest biodiversity, as logging roads open up previously inaccessible forest tracts to other extractive industries, illegal loggers and poachers (Abernethy *et al*., 2013). Poor bio-controls on internationally-traded wood products can facilitate spread of alien invasive species, including pests and pathogens (IUCN, 2001a; Hulme, 2003; Burgiel *et al.*, 2006).

The harvesting of timber from plantations has increased substantially in the last decade (ITTO/CBD, 2011) but, in terms of biodiversity loss, it is notable that a significant proportion of the non-plantation (natural, old-growth forest) trees exploited for timber are tropical hardwoods (ITTO, 2012; Friends of the Earth International, 2013). These species may take decades to reach reproductive maturity. This means that over-harvesting of juveniles significantly impacts recruitment and prevents population recovery. Purvis *et al*. (2000a) found that species with long generation times, late sexual maturity and low reproduction rates are more vulnerable to extinction at low population densities, such as are brought about by unsustainable logging. Populations with very few individuals remaining may be considered 'functionally extinct' – their contribution to ecosystem function is greatly reduced (Brook *et al*., 2008), and their reduced gene pool may preclude recovery (Purvis *et al.*, 2000a, 2000b).

1.1.6 Conservation status of timber trees

In 1998, Oldfield *et al*. published the first extinction risk assessment of the world's tree taxa, estimating that some 10% were threatened with extinction (Oldfield *et al*., 1998; Newton and Oldfield, 2008). *The World List of Threatened Trees* (Oldfield *et al*., 1998) was pioneering in scope, categorising over 7,300 tree species as globally threatened on the IUCN Red List of Threatened Species (Red List) – the most comprehensive database of global assessments of species extinction risk – and drawing policy attention to trees as conservation priorities. Since then, there has been little addition to the number of tree taxa with comprehensive extinction risk assessments. The IUCN Red List currently contains assessments of over 70,000 species of plant, animal, fungi and protista (IUCN, 2014), and is considered the international standard for species conservation status assessments. However, a search of the IUCN Red List database in January 2014 yielded only 8,671 species classified by life history as trees (IUCN, 2014). A recent review by Newton and Oldfield (2008) suggests that some 95% of these assessments originate from *The World List of Threatened Trees*, together with a global assessment of conifers (Farjon and Page, 1999; Farjon and Filer, 2013) and an assessment of the endemic flora of Ecuador (Valencia *et al*., 2000).

The 1998 assessments used Red List Categories and Criteria Version 2.3 (Oldfield *et al*., 1998). The assessments were therefore based on expert knowledge and trade figures available at the time, and did not involve distribution mapping. Previous versions of the Categories and Criteria are not directly comparable with the current Red List Version 3.1 (Mace *et al*., 2008), which has higher quantitative thresholds for threatened categories and requires quantitative distribution maps.

Approximately one fifth of the species assessed in *The World List of Threatened Trees* had 'timber' listed as a use (Oldfield *et al*., 1998). With the exception of some of the conifer species assessed in 1999 by Farjon and Page and updated by Farjon and Filer in 2013, and assessments of some timber tree species as part of assessments of other groups, e.g. Betulaceae, Theaceae, Ebenaceae and oaks, these remain the only comprehensive assessments of conservation status of the world's timber tree species to date. Re-assessment with current Red List thresholds is urgently needed.

An additional challenge is the fact that 'timber' is a fluid identifyier of a group of tree species; as populations of the most prized timber tree species are depleted or protected from loggers by trade sanctions or regional conservation, market demand shifts to 'look-a-likes' and species with similar wood properties (Oldfield and Osborn, January 2014, pers. comm.). The tree species identified as timbers by Oldfield *et al.* in 1998 are therefore unlikely to be the only ones in trade today. A review of the wider timber trade and conservation literature is also an urgent requirement before 'timber' tree assessments can be made with confidence.

1.1.7 The evolving IUCN Red List

The IUCN began listing at-risk birds and mammals in Red Data books in the 1950s, raising the profile of the world's most threatened fauna among the general public and in policy circles. Coverage was extended in the 1970s, with the aim of including all higher vertebrates and representative groups of fish, plant and invertebrate species. Assessments relied on expert opinion, and as such were highly subjective, with no mechanism in place to ensure assessments were distanced from commercial interests or personal motivations (Mace *et al*., 2008). Categories of threat and uncertainty were first introduced in the 1970s, and reviewed in the early 1980s (Fitter and Fitter, 1987) to be more representative and applicable across different taxonomic groups, and more robust and less reliant on subjective judgement. The first quantitative assessment assessment criteria were proposed by Mace and Lande (1991) for three threat categories (Critical, Endangered and Vulnerable). These were adopted by the IUCN within Red List Version 2.3 (Mace *et al*., 2008), and have undergone periodic reviews. The current Red List Categories and Criteria (Version 3.1) were published in 2001 and, to date, remain unchanged, though the official guidance for their application is more regularly updated (IUCN Standards and Petitions Subcommittee, 2017).

Version 3.1 of the Red List has nine Categories, from Not Evaluated to Extinct, (see below). Only three of these nine Categories, Vulnerable, Endangered, and Critically Endangered, denote a species as 'Threatened' (IUCN, 2001b):

> **Not Evaluated (NE)** – The taxon has not yet been assessed using the Red List Criteria.
>
> **Data Deficient (DD)** – There is insufficient information available for an assessment to be made. If the taxon is very poorly studied, then further research is needed. Alternatively, if the taxon has been studied but the assessor cannot yet make an assessment, there may be a need for specific data, for example on abundance or range size.

Least Concern (LC) – The taxon does not meet thresholds for Vulnerable, Endangered or Critically Endangered, and is not close enough to these thresholds to be classed as Near Threatened.

Near Threatened (NT) – The taxon does not meet Criteria thresholds for Vulnerable, Endangered or Critically Endangered, but is close to qualifying for a Threatened Category, or will qualify in the near future.

Vulnerable (VU) – The taxon meets thresholds for Vulnerable on any of the Criteria A-E, and therefore faces a high risk of extinction in the wild.

Endangered (EN) – The taxon meets thresholds for Endangered on any of the Criteria A-E, and therefore faces a very high risk of extinction in the wild.

Critically Endangered (CR) – The taxon meets thresholds for Critically Endangered on any of the Criteria A-E, and therefore faces an extremely high risk of extinction in the wild.

Extinct in the Wild (EW) – The taxon is only known to survive in cultivation, captivity or in populations that have been naturalised far outside of its historic native range, determined through exhaustive surveys appropriate to the taxon's life cycle and life form.

Extinct (EX) – The taxon is not present in cultivation, captivity or in naturalised populations outside of its historic native range, and there is no reasonable doubt that the last individual of the taxon has died. This must be determined through exhaustive surveys appropriate to the taxon's life cycle and life form.

Assessments are made based on five quantitative Criteria, A-E. Any one of these Criteria may qualify a species for a Threatened Category (IUCN Standards and Petitions Subcommittee, 2017). The Red List Categories are as follows (IUCN, 2001b):

A - *Population reduction* (past, present or projected), measured over the longer of ten years or three generations.

B - *Declining geographic range*, in the form of severely fragmented, limited or extremely fluctuating area of occupancy and / or extent of occurrence.

C - *Small population size* and decline, fragmentation or fluctuations.

D - *Very small or restricted population* determined by number of mature individuals and / or restricted area of occupancy.

E - *Quantitative analysis* indicating high probability of extinction in the wild within 100 years' time.

1.1.8 The cost of conservation and the use of 'big data' in meeting GSPC targets

With current extinction risk of the world's timber tree taxa largely unknown, we cannot prioritise individual timbers for conservation action or trade sanctions even in the face of the ongoing major threats of deforestation and unsustainable exploitation. With this in mind, meeting GSPC 2020 Targets 2 and 12 becomes vital for these economically and biogeochemically valuable trees.

However, conducting IUCN Red List assessments requires sufficient information on a taxon's generation length, population size and trends over time, occurrence, occupancy, and habitat quality throughout its global native range. Data scarcity may be compounded for timber tree taxa, as they are globally-widespread and occur either in exploited stands or, if not yet reached by loggers, in inaccessible forest. Therefore, regular and exhaustive ground-truthing to support IUCN Red List assessments is impossible for the majority of timber tree taxa.

Time-cost of conducting Red List assessments is high. Juffe-Bignoli *et al*., (2016) estimate that, for the year 2013, total funds and volunteer hours used by the IUCN Red List amounted to US$ 4,785,729, and 2,474 days (at a time-cost of US$ 504,085) respectively. The poor species-specific exploitation documentation indicates that, for timbers, time-cost is likely to be particularly high. How then can we speed up the Red List assessment process for tree taxa, including timbers, to meet GSPC 2020 Targets, and to allow for regular re-assessment as extinction risk of these taxa, and our knowledge and understanding of that risk, changes over time?

In recent years, large repositories of biological records, satellite imagery, and regional forest plot records have been published, open-access, online. Such datasets are collectively termed 'big data', and are increasingly being used for various aspects of conservation, including species distribution mapping and extinction risk assessment. Datasets from the open-access species distribution record repositiory, The Global Biodiversity Information Facility (GBIF) have been used to map species ranges (e.g. Ficetola *et al.*, 2014). Satellite imagery of change in global forest cover over recent years, available from the Global Forest Change (GFC) repository (Hansen *et al*., 2013) has recently been used to conduct preliminary IUCN Red List asessments for forest-dependant vertebrates (Tracewski *et al*., 2016). Such datasets present an opportunity to conduct rapid IUCN Red List assessments of timber tree taxa. However, issues of data reliability, particularly concerning records from GBIF, have been raised (Yesson *et al*., 2007; Hjarding *et al*., 2014), and it is not yet known whether such datasets would be fit for purpose for timbers.

1.1.9 A summary of knowledge gaps and research needs

Global biodiversity is in crisis, with extinction rates up to 10,000 times higher than background rates. Trees harvested for timber face threats on two fronts: deforestation and unsustainable exploitation for their wood. Despite their importance to ecosystems, human livelihoods and commerce, timber tree taxa are poorly-documented under scientific nomenclature, making their identification in trade and harvest reports difficult. Additionally, the current extinction risk status of the majority of timber tree taxa remains a mystery, as past assessments using the IUCN Red List Categories and Criteria are sparse or outdated. There is, therefore, an urgent need to identify timber tree taxa currently in trade and conduct up-to-date Red List assessments for this valuable group.

However, IUCN Red List assessments are costly in terms of the data requirements, person-power and time needed to apply the Categories and Criteria to each study taxon. Large datasets (so-called 'big data') from open-access data repositories such as GBIF and GFC have been used in range mapping and extinction risk assessments for other groups, and may represent a chance to speed up and streamline the Red Listing process for timbers. However, there are known caveats to such an approach, and we do not yet know whether it is suitable for timber trees – a globally widespread set of tree taxa, grouped by their use rather than by taxonomic or regional similarities. In order to meet the fast-approaching GSPC 2020 Targets for tree taxa, it is likely that use of 'big data' will become necessary. It is therefore important to evaluate the opportunities and limitations of this approach to Red Listing for trees.

Lastly, all IUCN Red List assessments contain a degree of uncertainty, and use of 'big data' may compound this. For taxa as potentially at-risk and as commercially-valued as timbers, it becomes even more important that assessment uncertainty be analysed, to ensure that extinction risk categorisations are as reliable as possible, and that any uncertainties are known and understood. This thesis addresses these knowledge gaps through the research aims, questions and objectives presented in the Research Outline below.

1.2 Research Outline

1.2.1 Research aims

- Identify tree taxa traded for timber, to the level of Latin binomial or trinomial (this aim is addressed in Chapter 2).
- Assess the utility of species distribution records from the Global Biodiversity Information Facility (GBIF) in timber tree range mapping (this aim is addressed in Chapter 3).
- Assess current extinction risk of a subset of the world's commercially-traded timber tree species by applying IUCN Red List Categories and Criteria, Version 3.1 (this aim is addressed in Chapter 4).
- Evaluate the uncertainty of the preliminary Red List categorisations made in Chapter 4 (this aim is addressed in Chapter 5).

1.2.2 Research questions and objectives

Question 1: How many angiosperm tree taxa are currently harvested and traded for timber?

This research question is addressed by meeting the following objectives:

1a. Select a series of source lists of timber tree taxa, identified by Latin binomial or trinomial, produced by relevant organisations in the conservation, government and commercial sector spheres.

1b. Consolidate these lists into a unified 'working list' of angiosperm timber tree taxa in trade, including only those taxa that appear in two or more source lists.

Question 2: Are species distribution records from the Global Biodiversity Information Facility (GBIF) sufficient for use in calculating timber tree species' IUCN Red List extent of occurrence (EOO) and area of occupancy (AOO)?

This research question is addressed by meeting the following objectives:

2a. Assess coverage, species representation, and sources of bias for cleaned and refined timber tree species distribution records downloaded from GBIF.

2b. Using a random subset of timber tree species, assess reliability of species distribution information from GBIF datasets in comparison to information from floras and regional experts.

2c. Assess reliability of using GBIF data to calculate extent of occurrence (EOO) and area of occupancy (AOO) for timber tree species, and investigate whether these EOO and AOO values are sufficient for use in reliably prioritising timber tree species for full IUCN Red List assessment on the basis of range restriction.

Question 3: How many of the world's wild-harvested, angiosperm timber tree species are currently threatened with extinction, according to IUCN Red List Categories and Criteria Version 3.1?

This research question is addressed by meeting the following objectives:

3a. Prioritise a subset of timber tree species for Red List assessment, on the basis of species range size and, where available, previous IUCN Red List assessments of threat.

3b. Determine which of the world's commercially traded timber tree species are threatened with extinction by applying the IUCN Red List Criteria to make preliminary extinction risk categorisations.

Question 4: How uncertain are the IUCN Red List categorisations that were made in Chapter 4 using open-source distribution record and deforestation datasets?

This research question is addressed by meeting the following objectives:

4a. Obtain distribution records / range maps, quantitative information on logging harvest and timber trade, information on the advent of current rates of deforestation, and information on the minimum and maximum limits of seed dispersal distance, for as many of the Chapter 4 study species as possible, either directly from taxonomic or regional experts or from published studies.

4b. Re-apply Criteria A and C, over time-periods appropriate to the beginning of current rates of deforestation in the tropics and subtropics, to all Chapter 4 study species and compare the resulting categorisations to those made in Chapter 4.

4c. Re-apply the Red List Criteria based on information on species exploitation, for as many study species as the available logging and trade data allow, and compare the resulting categorisations to those made in Chapter 4.

4d. Assess availability, coverage and reliability of species distribution records / maps provided or published by taxonomic and regional experts in comparison to GBIF datasets used in Chapter 4. Additionally, assess extent of occurrence, area of occupancy (EOO), area of forested range, and sub-criterion B1 (EOO) categorisation under ‘expert’ versus GBIF records datasets.

4e. Re-apply Criterion B, sub-criterion (a) (severe fragmentation), using minimum and maximum seed dispersal distances estimated using the ‘dispeRsal’ function in RStudio, and compare the resulting sub-categorisations under these dispersal distances with the corresponding sub-categorisations produced in Chapter 4.

1.2.3 Thesis structure

This thesis consists of an introduction (Chapter 1), followed by four data chapters each addressing a key research aim (Chapters 2-5). Each data chapter contains its own discrete introduction, methods, results and discussion sections. Chapter findings and conclusions are linked in a final discussion (Chapter 6). An outline of structure and chapter content is given below.

Chapter 1: Introduction

This chapter provides a comprehensive review of the relevant literature and identifies the knowledge gaps that are addressed in this thesis. The Introduction provides context and justification for the thesis, and presents the research aims and objectives used to address these knowledge gaps.

Chapter 2: Identifying timber tree taxa in trade: A working list of commercial timber trees

This chapter reviews and consolidates numerous lists of timber trees identified by Latin binomial or trimonial, to create a unified working list of tree taxa commercially traded for timber. This working list is used as the basis for all further research presented in Chapters 3-5. This chapter addresses Research Question 1 and Objectives 1a and 1b.

Chapter 3: Applications of GBIF data in assessing extinction risk of timber trees

This chapter evaluates the reliability and applicability of species distribution records from the Global Biodiversity Information Facility (GBIF) in distribution mapping and extinction risk assessments of tree species traded commercially for timber. GBIF datasets for a subset of timber tree species are analysed for quality, sampling coverage and bias. Within this subset, GBIF spatial data are compared to range information from floras and taxonomic and regional experts. This chapter addresses Research Question 2 and Objectives 2a, 2b and 2c.

Chapter 4: IUCN Red List extinction risk assessments of timber tree species

This chapter presents up-to-date extinction risk assessments for a subset of 324 timber tree species, prioritised on the basis of range-restriction and / or previous 'Threatened' Red List status, through application of the IUCN Red List Categories and Criteria Version 3.1. This chapter addresses Research Question 3 and Objectives 3a and 3b.

Chapter 5: Assessing the uncertainty of IUCN Red List categorisations for timber tree species using open-source and expert datasets

The chapter evaluates the uncertainty of the Red List categorisations carried out in Chapter 4, by comparing Red List assessment outcomes produced using Chapter 4 open-access datasets to outcomes produced using expert-provided and other published, peer-reviewed datasets, in a series of case studies. Analysis includes use of a Bayesian Belief Network to quantify the likelihood of different category outcomes when using different input datasets. This chapter addresses Research Question 4 and Objectives 4a, 4b, 4c, 4d and 4e.

Chapter 6: Discussion

The Discussion reflects on the research findings of Chapters 2-5, presents conservation conclusions, evaluates the success of this thesis in addressing the knowledge gaps presented in Chapter 1, and makes recommendations for the direction of future research.

1.2.4 Research ethics

As this research did not involve studying humans or other vertebrate subjects, ethical issues were minimal and restricted to data provenance and usage. The majority of the datasets used in this thesis are open-source, and the repositories and / or authors have been fully referenced. All closed-source datasets, such as the species distribution records from expert collections used in Chapter 5, are used with prior agreement of the dataset owners who are gratefully acknowledged as such. Bournemouth University's Research Ethics e-module and an Ethics Checklist were completed and approved.

1.3 References

Abernethy, K. A., Coad, L., Taylor, G., Lee, M. E. and Maisels, F., 2013. Extent and ecological consequences of hunting in Central African rainforests in the twenty-first century. *Philosophical transactions of the Royal Society of London. Series B, Biological Sciences*, 368, 20120303.

Beech, E., Rivers, M., Oldfield, S. and Smith, P.P., 2017. GlobalTreeSearch: the first complete global database of tree species and country distributions. *Journal of Sustainable Forestry*, 16, 1-36.

Brook, B. W., Sodhi, N. S. and Bradshaw, C. J. A., 2008. Synergies among extinction drivers under global change. *Trends in Ecology & Evolution*, 23 (8), 453-460.

Burgiel, S., Foote, G., Orellana, M. and Perrault, A., 2006. Invasive Alien Species and Trade: Integrating Prevention Measures and International Trade Rules. Washington D.C.

Butchart, S. H. M., Walpole, M., Collen, B., van Strien, A., Scharlemann, J. P. W., Almond, R. E. A., Baillie, J. E. M., Bomhard, B., Brown, C., Bruno, J., Carpenter, K. E., Carr, G. M., Chanson, J., Chenery, A. M., Csirke, J., Davidson, N. C., Dentener, F., Foster, M., Galli, A., Galloway, J. N., Genovesi, P., Gregory, R. D., Hockings, M., Kapos, V., Lamarque, J-F., Leverington, F., Loh, J., McGeoch, M. A., McRae, L., Minasyan, A., Hernández Morcillo, M., Oldfield, T. E. E., Pauly, D., Quader, S., Revenga, C., Sauer, J. R., Skolnik, B., Spear, D., Stanwell-Smith, D., Stuart, S. N., Symes, A., Tierney, M., Tyrrell, T. D., Vié, J-C. and Watson, R., 2010. Global Biodiversity: Indicators of Recent Declines. *Science*, 328 (5982), 1164-1168.

CBD, 2012. Global Strategy for Plant Conservation: 2011-2020. Richmond, United Kingdom: Botanic Gardens Conservation International.

Díaz, S., Fargione, J., Chapin III, F. S. and Tilman, D., 2006. Biodiversity loss threatens human well-being. *PLoS Biology*, 4 (8), 1300-1305.

Ellison, A. M., Bank, M. S., Clinton, B. D., Colburn, E. A., Elliott, K., Ford, C. R., Foster, D. R., Kloeppel, B. D., Knoepp, J. D., Lovett, G. M., Mohan, J., Orwig, D. A., Rodenhouse, N. L., Sobczak, W. V, Stinson, K. A., Stone, J. K., Swan, C. M., Thompson, J., Holle, B. Von and Webster, J. R., 2005. Loss of foundation species: consequences for the structure and dynamics of forested ecosystems. *Frontiers in Ecology and the Environment*, 3 (9), 479-486.

FAO, 2010. Global Forest Resources Assessment 2010. Rome: Food and Agriculture Organization of the United Nations.

FAO, 2012. State of the World's Forests 2012. 10th ed. Shaw, J. (ed.). Rome: Food and Agriculture Organization of the United Nations.

Farjon, A. and Filer, D., 2013. An atlas of the world's conifers: an analysis of their distribution, biogeography, diversity and conservation status. Brill.

Farjon, A. and Page, C., 1999. Conifers status survey and conservation action plan. Gland: International Union for the Conservation of Nature.

Ficetola, G. F., Rondinini, C., Bonardi, A., Katariya, V., Padoa-Schioppa, E. and Angulo, A., 2014. An evaluation of the robustness of global amphibian range maps. *Journal of Biogeography*, 41 (2), 211-221.

Fitter, R. and Fitter, M., 1987. The Road to Extinction. Fitter, R. and Fitter, M. (eds.). Gland, Switzerland: International Union for the Conservation of Nature.

Foley, J. A., Ramankutty, N., Brauman, K. A., Cassidy, E. S., Gerber, J. S., Johnston, M., Mueller, N. D., O'Connell, C., Ray, D. K., West, P. C., Balzer, C., Bennett, E. M., Carpenter, S. R., Hill, J., Monfreda, C., Polasky, S., Rockström, J., Sheehan, J., Siebert, S., Tilman, D. and Zaks, D. P. M., 2011. Solutions for a cultivated planet. *Nature*, 478 (7369), 337-342.

Friends of the Earth International. 2013. From policy to reality: "Sustainable" tropical timber production, trade and procurement. Friends of the Earth International. [Online]. Available from: http://www.foei.org/resources/publications/publications-by-subject/forests-and-biodiversity-publications/from-policy-to-reality. [Accessed: February 2014].

Gill, D., Magin, G. and Bertram, E., 2013. Trees and climate change: A guide to the factors that influence species vulnerability and a summary of adaptation options. Cambridge, UK: Fauna & Flora International, 1-16.

Global Biodiversity Information Facility (GBIF). [Online]. Available from: http://www.gbif.org/. [Accessed: November 2013 - January 2014].

Grainger, A., 2008. Difficulties in tracking the long-term global trend in tropical forest area. *PNAS*, 105 (2), 818–823.

Hansen, M. C., Stehman, S. V and Potapov, P. V., 2010. Quantification of global gross forest cover loss. *Proceedings of the National Academy of Sciences of the United States of America*, 107 (19), 8650–8655.

Hansen, M., Potapov, P., Moore, R., Hancher, M., Turubanova, S., Tyukavina, A., Thau, D., Stehman, S., Goetz, S., Loveland, T., Kommareddy, A., Egorov, A., Chini, L., Justice, C. and Townshend, J., 2013. High-resolution global maps of 21st-century forest cover change. *Science*, 342 (6160), 850-853.

Hjarding, A., Tolley, K. A. and Burgess, N. D., 2014. Red List assessments of East African chameleons: a case study of why we need experts. *Oryx*. Available from: doi:10.1017/S0030605313001427.

Hulme, P. E., 2003. Biological invasions: winning the science battles but losing the conservation war? *Oryx*, 37 (2), 178-193.

IPCC, 2007. Climate Change 2007: Synthesis Report. IPPC, 12-17. [Online]. Available from: http://www.ipcc.ch/pdf/assessment-report/ar4/syr/ar4_syr.pdf. [Accessed: December 2013].

ITTO, 2012. Annual Review and Assessment of the World Timber Situation 2012. Yokohama, Japan.

ITTO / CBD, 2011. ITTO/CBD collaborative initiative for tropical forest biodiversity - Programme document. ITTO / CBD, 1-46.

IUCN, 2001a. Global Strategy on Invasive Alien Species. McNeely, J., Mooney, H., Neville, L., Schei, P. and Waage, J. (eds.). Gland, Switzerland, and Cambridge: International Union for the Conservation of Nature.

IUCN, 2001b. IUCN Red List Categories and Criteria. Version 3.1. Gland, Switzerland and Cambridge, United Kingdom: IUCN Species Survival Commission, IUCN.

IUCN, 2014. IUCN Red List of Threatened Species Version 2013.2. [Online]. Available from: www.iucnredlist.org [Accessed: 3 January 2014].

IUCN Standards and Petitions Subcommittee, 2017. Guidelines for Using the IUCN Red List Categories and Criteria. Version 13. Prepared by the Standards and Petitions Subcommittee. Downloadable from: http://www.iucnredlist.org/documents/RedListGuidelines.pdf.

Juffe-Bignoli, D., Brooks, T.M., Butchart, S.H., Jenkins, R.B., Boe, K., Hoffmann, M., Angulo, A., Bachman, S., Böhm, M., Brummitt, N. and Carpenter, K.E., 2016. Assessing the cost of global biodiversity and conservation knowledge. *PLoS ONE*, 11 (8), e0160640.

de Lacerda, A. E. B. and Nimmo, E. R., 2010. Can we really manage tropical forests without knowing the species within? Getting back to the basics of forest management through taxonomy. *Forest Ecology and Management*, 259 (5), 995-1002. [Online]. Available from: doi:10.1016/j.foreco.2009.12.005 [Accessed: 4 October 2013].

Mace, G. M., Collar, N. J., Gaston, K. J., Hilton-Taylor, C., Akçakaya, H. R., Leader-Williams, N., Milner-Gulland, E. J. and Stuart, S. N., 2008. Quantification of extinction risk: IUCN's system for classifying threatened species. *Conservation Biology*, 22 (6), 1424-42.

Mace, G. M. and Lande, R., 1991. Assessing Extinction Threats: Toward a Reevaluation of IUCN Threatened Species Categories. *Conservation Biology*, 5 (2), 148-157.

Millennium Ecosystem Assessment, 2005. Ecosystems and human well-being: Synthesis (Millennium Ecosystem Assessment). Ecosystems, 5 (281), Washington, D.C.: World Resources Institute, 1-100. [Online]. Available from: doi:10.1196/annals.1439.003.

Newton, A. C., 2008. Conservation of tree species through sustainable use: how can it be achieved in practice? *Oryx*, 42 (2), 195-205.

Newton, A. and Oldfield, S., 2008. Red Listing the world's tree species: A review of recent progress. *Endangered Species Research*, 6, 137-147.

Newton, A., Oldfield, S., Fragoso, G., Mathew, P., Miles, L. and Edwards, M., 2003. Towards a global tree conservation atlas. Cambridge, United Kingdom, 0-18.

Oakes, N., Leggett, M., Cranford, M. and Vickers, H., 2012. The Little Forest Finance Book. Oxford: Global Canopy Programme.

Oldfield, S., Lusty, C. and MacKinven, A., 1998. The World List of Threatened Trees. Cambridge: WCMC, IUCN.

Peck, T., 2001a. Historical Perspective. In: The international timber trade, Woodhead Publishing Limited, 7-15. [Online]. Available from: doi:10.4135/9781452205540.n1.

Pimm, S. L., 2009. Climate disruption and biodiversity. *Current Biology*, 19 (14), 595-601.

Purvis, A., Gittleman, J. L., Cowlishaw, G. and Mace, G. M., 2000a. Predicting extinction risk in declining species. *Proceedings of the Royal Society of London, Series B*, 267, 1947-1952.

Purvis, A., Jones, K. E. and Mace, G. M., 2000b. Extinction. *BioEssays*, 22 (12),1123-1133.

Secretariat of the Convention on Biological Diversity, 2010. Global Biodiversity Outlook 3. Montreal.

Sparks, T. H., Butchart, S. H. M., Balmford, A., Bennun, L., Stanwell-Smith, D., Walpole, M., Bates, N. R., Bomhard, B., Buchanan, G. M., Chenery, A. M., Collen, B., Csirke, J., Diaz, R. J., Dulvy, N. K., Fitzgerald, C., Kapos, V., Mayaux, P., Tierney, M., Waycott, M., Wood, L. and Green, R. E., 2011. Linked indicator sets for addressing biodiversity loss. *Oryx*, 45 (3), 411-419.

Stuart, S. N. and Collen, B., 2013. Conserving Biodiversity in a Target-Driven World. In: Collen, B., Pettorelli, N., Baillie, J. E. M. and Durant, S. M. (eds.), Biodiversity Monitoring and Conservation: Bridging the Gap between Global Commitment and Local Action. John Wiley & Sons Ltd., 441-438.

Ter Steege, H., Pitman, N. C .A., Sabatier, D., Baraloto, C., Salomao, R. P., Guevara, J. E., Phillips, O. L., Castilho, C. V., Magnusson, W. E., Molino, J-F., Monteagudo, A., Nunez Vargas, P., Carlos Montero, J., Feldpausch, T. R., Coronado, E. N. H., Killeen, T. J., Mostacedo, B., Vasquez, R., Assis, R. L., Terborgh, J., Wittmann, F., Andrade, A., Laurance, W. F., Laurance, S. G. W., Marimon, B. S., Marimon, B-H., Guimaraes Vieira, I. C., Amaral, I. L., Brienen, R., Castellanos, H., Cardenas Lopez, D., Duivenvoorden, J. F., Mogollon, H. F., de Almeida Matos, F. D., Davila, N., Garcia-Villacorta, R., Stevenson Diaz, P. R., Costa, F., Emilio, T., Levis, C., Schietti, J., Souza, P., Alonso, A., Dallmeier, F., Duque Montoya, A. J., Fernandez Piedade, M. T., Araujo-Murakami, A., Arroyo, L., Gribel, R., Fine, P. V. A., Peres, C. A., Toledo, M., Gerardo, A. A. C., Baker, T. R., Ceron, C., Engel, J., Henkel, T. W., Maas, P., Petronelli, P., Stropp, J., Eugene Zartman, C., Daly, D., Neill, D., Silveira, M., Rios Paredes, M., Chave, J., de Andrade Lima, D., Jorgensen, P. M., Fuentes, A., Schoengart, J., Cornejo Valverde, F., Di Fiore, A., Jimenez, E. M., Penuela Mora, M. C., Fernando Phillips, J., Rivas, G., van Andel, T. R., von Hildebrand, P., Hoffman, B., Zent, E. L., Malhi, Y., Prieto, A., Rudas, A., Ruschell, A. R., Silva, N., Vos, V., Zent, S., Oliveira, A. A., Cano Schutz, A., Gonzales, T., Nascimento, M. T., Ramirez-Angulo, H., Sierra, R., Tirado, M., Umana Medina, M. N., van der Heijden, G., Vela, C. I. A., Vilanova Torre, E., Vriesendorp, C., Wang, O., Young, K. R., Baider, C., Balslev, H., Ferreira, C., Mesones, I., Torres-Lezama, A., Urrego Giraldo, L. E., Zagt, R., Alexiades, M. N., Hernandez, L., Huamantupa-Chuquimaco, I., Milliken, W., Palacios Cuenca, W., Pauletto, D., Valderrama Sandoval, E., Valenzuela Gamarra, L., Dexter, K. G., Feeley, K., Lopez-Gonzalez, G. and Silman, M. R., 2013. Hyperdominance in the Amazonian Tree Flora. *Science*, 342, (6156), 325.

The World Bank, 2004. Sustaining Forests: A Development Strategy. Washington D.C.: The International Bank for Reconstruction and Development/The World Bank [online]. Available from: doi:10.1016/0304-3878(77)90033-5.

Tracewski, L., Butchart, S. H. M., Di Marco, M., Ficetola, G. F., Rondinini, C., Symes, A., Wheatley, H., Beresford, A. E. and Buchanan, G. M., 2016. Toward quantification of the impact of 21st-century deforestation on the extinction risk of terrestrial vertebrates. *Conservation Biology,* 30, 1070-1079.

UNEP, 2005a. Ecosystems and human well-being: a framework for assessment - Executive Summary (Millennium Ecosystem Assessment). Washington DC: Island Press.

UNEP, 2005b. Ecosystems and human well-being: Current state and trends, Volume 1 (Millennium Ecosystem Assessment). Hassan, R., Scholes, R. and Ash, N. (eds.). Washington DC: Island Press.

UNEP, 2009. Vital Forest Graphics. Lambrechts, C., Wilkie, M. L., Rucevska, I. and Sen, M. (eds.). The United Nations Environment Programme; The Food and Agriculture Organization of the United Nations; The United Forum on Forests. UNEP / GRID-Arendal.

UNEP, 2012. Global Environment Outlook 5: Summary for policy makers. Nairobi.

United Nations, 1992. Convention on Biological Diversity. United Nations.

Valencia, R., Pitman, N., Leon-Yanez, S. and Jorgensen, P., 2000. Libro Rojo de las plantas endemicas del Ecuador. 2000th ed. Quito: Pontificia Universidad Catolica del Ecuador.

Yesson, C., Brewer, P. W., Sutton, T., Caithness, N., Pahwa, J. S., Burgess, M., Gray, W. A., White, R. J., Jones, A. C., Bisby, F. A. and Culham, A., 2007. How global is the global biodiversity information facility? *PLoS ONE*, 2 (11), e1124.

2 Identifying timber tree taxa in trade: A working list of commercial timber trees

2.1 Introduction

It is widely recognised that human activities are placing global biodiversity under increasing pressure (Butchart *et al*., 2010; UNEP, 2012). Tropical and temperate forests are amongst the world's most biodiverse ecosystems (Newton *et al*., 2003), supporting over 50% of all terrestrial species (UNEP, 2005). Forests also provide a multitude of ecosystem services, including maintenance of vital biogeochemical processes such as nutrient cycling, carbon sequestration, water filtration and localised climate control (Millennium Ecosystem Assessment, 2005). Some 350 million people around the world rely on forests for everyday subsistence (FAO, 2012), and timber, food and medicinal forest species support multimillion dollar industries (The World Bank, 2004). However, this wealth of biodiversity and ecosystem services remains at risk from deforestation and forest degradation (Hansen *et al*., 2010).

One of the first steps towards safeguarding forest biodiversity is to identify the species most at risk. To address this knowledge gap, Target 2 of the Global Strategy for Plant Conservation (GSPC) calls for "*an assessment of the conservation status of all known plant species*" by 2020 (CBD, 2012). Currently, conservation status assessments meeting the globally-recognised standards of the IUCN Red List (IUCN, 2014) have been carried out at the global level for approximately only 4% of known plant species (Sharrock, 2012). There is therefore an urgent need to conduct such assessments, particularly for 'useful' plants, including tree taxa valued for their timber.

The World Bank estimates that the trade in timber products contributes some $468 billion annually to global GDP (The World Bank, 2004). Timber trees also provide numerous critical ecosystem services. However, despite the escalating threats to timber species from land conversion, illegal trade and unsustainable logging, we lack up-to-date conservation status assessments for many of these species. A compounding problem is the lack of documentation regarding which tree species are actively being harvested for commercial trade. There is currently no unified database of commercially harvested timber tree species, though numerous different lists exist with varying degrees of overlap.

This chapter addresses the research question: *How many angiosperm tree taxa are currently harvested and traded for timber?* To do so, it provides a composite working list of timber tree taxa currently harvested and traded commercially on the timber market, by integrating different species lists from seventeen different sources. Each taxon is listed by scientific binomial or trinomial and by family. The sources used to compile the working list are described, together with information on the author and/or publishing organisation of each source, and where it can be accessed.

Furthermore, much of the information in this chapter was published as an online report in November 2014 on the websites of Botanic Gardens Conservation International (available from: http://www.bgci.org/news-and-events/news/1175) and The Global Tree Campaign, where it is intended to be of use to taxonomists; botanical, conservation and ecological researchers; timber-sourcing organisations; woodworkers; and other interested parties. The publication aims to provide an integrated list of open access (or easily accessible) sources supplying information on commercial timber tree species.

2.2 Methods

2.2.1 Nomenclature

The names that timbers are traded under do not always follow conventional scientific notation. Rather, it is common to trade a species under genus name only, or by a common/trade name which can differ between countries and regions. For example, *Aquilaria malaccensis* may be traded as '*Aquilaria*' or simply as 'agarwood'. Trade lists of timber trees described by full Latin binomial are therefore in the minority. This presents a problem when identifying timber species so, to maximise reliability, this working list is compiled from only those sources that list taxa by full Latin binomial or trinomial.

2.2.2 List compilation

Taxa lists were extracted from seventeen online, open-access sources produced by international development, conservation and forest certification organisations; consultants on the timber trade; national forestry departments; taxonomists; and woodworkers, from the commercial, scientific, conservation, government and, in the case of woodworking, public community sectors (see **Table 2.1** for a description of each source). In selecting sources, it was assumed that online, open-access lists would be more up-to-date than paper sources, and would thus best reflect current trade. Lists were combined using Microsoft Excel 2010.

The original intention was to base this working list on the timber species previously assessed for the IUCN Red List, primarily those included in *The World List of Threatened Trees* (Oldfield *et al*., 1998). However, after consultation with TRAFFIC – the wildlife trade monitoring network – (Oldfield and Osborn pers. comm., 2014) and IUCN (Goettsch and Hilton-Taylor, pers. comm., 2014), it became apparent that these previous assessments may not accurately reflect species currently in trade. It was concluded that a more representative list should be compiled using more recent data, including timber taxa listed on the Appendices of the Convention on International Trade in Endangered Species of Wild Flora and Fauna (CITES) (CITES, 2013); trade reports; and publications from conservation organisations. The current integrated list (**Appendix A, Table A1**) is based on such sources.

In addition to the well-known timber trade authorities CITES, TRAFFIC, the International Tropical Timber Organisation (ITTO) and L'Association Technique Internationale des Boix Tropicaux (ATIBT), it was decided to include species lists from organisations with a focus on legal sourcing of timber, including Nature Ecology and People Consult (NEPCon), the Forest Stewardship Council (FSC), Greenpeace and the World Wide Fund for Nature (WWF). The former two organisations work directly with private sector sourcing companies, therefore should be indicative of what is actually in trade.

Lists from independently-run databases such as woodexplorer.com and thewooddatabase.com, used by taxonomists and woodworkers interested in identifying commercial timber products to species level, were also consulted. Some of these resources are regularly updated and may benefit from crowd-sourcing user's comments to rapidly detect and correct errors.

2.2.3 Data cleaning and taxonomic checks

The composite list was cleaned to remove duplicates, genus-only listings and common/trade names. The Plant List (2013) was used as a taxonomic reference to check for synonymy and spelling errors.

2.2.4 Source ranking

To check reliability, attempts were made to trace initial origin and authors of each species list used, initially through an online literature search and then by directly contacting the organisation providing the list in question. In a few cases it was impossible to determine exact origins. Therefore, each species was ranked by the number of sources in which it was featured. Taxa appearing in only one resource were excluded from the final published working list. By listing only those taxa appearing in two or more resources, we minimised the chance of erroneously including non-timbers.

2.2.5 Removals

This list focuses on angiosperm timbers only, as conifers were comprehensively assessed in 1999 (Farjon and Page, 1999) and updated in 2013 (Farjon and Filer, 2013). Conifers were removed from the compiled list using *The Conifers Database* (Farjon, 2013) for taxonomic reference.

Table 2.1 Resources used to compile working list of commercial timbers

Resource name	**Organisation / Author**	**Date published / version used**	**Will resource be updated in future?**
CITES Appendices I, II, III	Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES)	2013	Yes - CITES member states convene every 3 years at a Conference of the Parties (CoP). Amendments to Appendices I & II must be made at a CoP. Species may be added or removed from Appendix III at any time.
Resource description	The CITES Appendices are lists of species of fauna and flora, including some timber tree species, that are or may soon become threatened with extinction. CITES affords these species different levels of protection from over-exploitation by regulating their commercial trade.		
Available from	http://www.cites.org/eng/app/appendices.php		

Good Wood Guide	Greenpeace	2004	Not updated
Resource description	Consumer guide listing traditionally-harvested timbers together with more sustainable, FSC certified alternatives. Provides information on IUCN Red List status of the 'traditional' species.		
Available from	http://www.greenpeace.org.uk/MultimediaFiles/Live/FullReport/6759.pdf		

FSC Species Terminology	Forest Stewardship Council (FSC)	2007	Not updated
Resource description	A compilation of tree species commonly used in international trade, giving both scientific and common names, as well as synonyms. Updates discontinued. For more information, please contact FSC.		
Available from	FSC_STD_40_004b_V1_0_EN_FSC_Species_Terminology.pdf		

Good Wood Guide Checklist	Friends of the Earth; Fauna and Flora International	2013	Not updated
Resource description	Consumer guide to sustainably-sourced wood for construction (or similar) projects. Lists timber species by common and scientific name, and provides information on uses, geographic origin and global threat status (according to the IUCN Red List and CITES).		
Available from	http://www.foe.co.uk/campaigns/biodiversity/resource/good_wood_guide/wood_timber_types_a_to_g.html		

Resource name	Organisation / Author	Date / Version	Will resource be updated in future?
An assessment of tree species which warrant listing in CITES	Hewitt, J	2007	Not updated
Resource description	Report prepared for Milieudefensie (Friends of the Earth, Netherlands), giving case studies of 17 commercial timber species considered to warrant CITES listing due to perceived threat from unsustainable or illegal trade. Also provides information on four CITES listed species.		
Available from	https://milieudefensie.nl/publicaties/rapporten/an-assessment-of-tree-species-which-warrant-listing-in-cites		

Annual review and assessment of the world timber situation - Appendix 3: Major tropical species traded in 2010 and 2011	International Tropical Timber Organization (ITTO)	2012	Yes – ITTO now produces biannual reviews (effective from 2013 onwards). The Biannual Review 2013-2014 is scheduled for publication in the first half of 2015.
Resource description	ITTO Annual Reviews provide statistics on global production and trade in timber, with main focus on tropical regions. They utilise data submitted by ITTO member countries. Appendix 3 of the 2012 report gives common and scientific names of the major tropical timber species in trade (2010-2011).		
Available from	http://www.itto.int/annual_review/		

Nomenclature générale des bois tropicaux (p.2-40)	L'Association Technique Internationale des Bois Tropicaux (ATIBT)	2013	Future updates possible
Resource description	Internationally-recognised nomenclature linking common name to correct scientific name for commercially traded tropical timber species. Common name given is that under which each species is traded by the main country of export or import. An English language version of this document is available on request from ATIBT.		
Available from	http://www.atibt.org/wp-content/uploads/2013/06/Nomenclature-ATIBT-26062013.pdf		

NEPCon LegalSource™ Due Diligence System	NEPCon	2013	Not updated
Resource description	NEPCon's LegalSource™ Due Diligence System provides resources for client organisations wanting to ensure legal timber sourcing. Online guidance material includes an example list of timber species in trade. Registration is required to access this resource.		
Available from	http://www.nepcon.net/5174/English/Certification/Timber_legality_services/Due_diligence_system/		

Resource name	Organisation / Author	Date / Version	Will resource be updated in future?
Commercial timbers: descriptions, illustrations, identification and information retrieval	Richter, H.G. and Dallwitz, M.J.	Dates from 2000. Version: 25th June 2009	Future updates possible
Resource description	Database of common hardwood timber species in international trade. Provides taxa descriptions and an interactive identification system for 350+ commercial timbers.		
Available from	http://delta-intkey.com		

Wood Species Database	The Timber Research and Development Association (TRADA)	Version: 2002-2014	Future updates likely
Resource description	A searchable, illustrated database of 150+ commercial timber species, including information on mechanical properties and common end uses of each wood. Registration (free) is required to access this resource. The *Wood Species Guide*, a mobile app derived from this database, is also available from iTunes and Google Play.		
Available from	http://www.trada.co.uk/techinfo/tsg		

The Wood Database	Meier, E	Version: 2014	Yes – resource continues to be updated
Resource description	Comprehensive database for woodworkers, searchable by scientific name, common name or wood appearance. Species-specific information on general distribution, average tree size, appearance and mechanical properties of wood. A regularly updated resource.		
Available from	http://www.wood-database.com/wood-identification/by-scientific-name/		

Timber species imported into the UK	Timber Trade Federation (TTF)	2009	Not updated
Resource description	Guide to UK timber species imports, divided into three categories: natural forest hardwoods, natural forest softwoods and plantation species. The guide also details which of these taxa are CITES listed. Non-TTF members will need to request access to this resource.		
Available from	http://www.ttf.co.uk/Article/Detail.aspx?ArticleUid=ee39cec8-21b6-4be4-9361-6001612c7190		

Resource name	Organisation / Author	Date / Version	Will resource be updated in future?
Precious woods: Exploitation of the finest timber (p.36-45)	TRAFFIC	2012	Not updated
Resource description	Report on high value timbers, commissioned by Chatham House as a background paper for their meeting: '*Tackling the Trade in Illegal Precious Woods*' on 23-24 April 2012.		
Available from	http://www.illegal-logging.info/sites/default/files/uploads/PreciousWoodsbackgroundpaper1ThetradeinpreciouswoodsTRAFFIC.pdf		

Wood Properties Techsheets	United States Department of Agriculture (USDA) Forest Products Laboratory	Publication date unknown	Unlikely to be updated
Resource description	Four 'Techsheets': Lesser known woods; North American hardwoods; North American softwoods; tropical hardwoods. Provide information on distribution, commercial use, wood mechanical properties and appearance of selected timber taxa.		
Available from	http://www.fpl.fs.fed.us/research/centers/woodanatomy/		

The Wood Explorer	The Wood Explorer, Inc.	Version: 2014	Yes – resource continues to be updated
Resource description	Free access to a searchable list of 1650 commercial species, including scientific, trade and common names. Species pages include common end uses and a description of both tree and wood properties. Additional data available for a fee.		
Available from	http://www.thewoodexplorer.com/species.html		

Woodworkers Source Wood Library	Woodworkers Source	2013	Future updates likely
Resource description	Database of commercial timber species, listed by scientific and common name. Species-specific information on timber end uses, geographic region, wood working properties, and appearance of tree and wood.		
Available from	http://www.woodworkerssource.com/wood_library.php		

Guide to lesser-known tropical timber species (p.4-86)	World Wildlife Fund (WWF) Global Forest & Trade Network (GFTN)	2013	Not updated
Resource description	Consumer guide to lesser-known species as alternatives for traditionally-sourced timbers. Provides information on IUCN Red List status of the traditional species, and possible end uses of the lesser-known species profiled.		
Available from	wwf_gftn_lkts_guide_final_oct_2013.pdf		

2.3 Results

A working list of 1,578 timber tree taxa, from 104 genera, was compiled. **Appendix A**, **Table A1** displays the taxa, listed alphabetically first by family, then genus and species, alongside trade/common names and the number and identifiers of sources in which each taxon was listed (see **Table 2.1** for full source list descriptions). The list was dominated by taxa belonging to the Leguminosae family (see **Figure 2.1**).

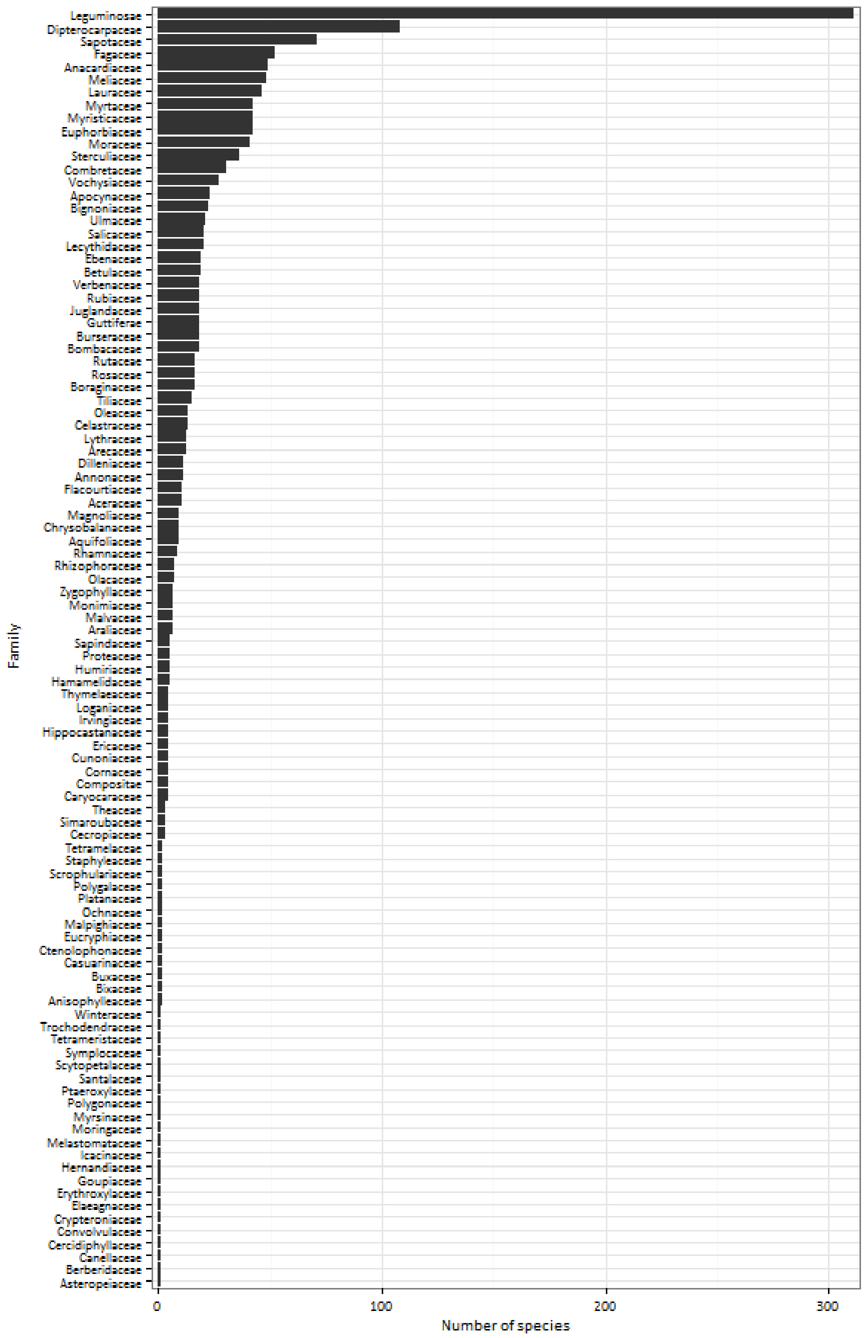


Figure 2.1 Angiosperm families represented in the working list.

2.4 Discussion

The working list of timber tree species formulated in this chapter consolidates open-access lists of taxa traded for timber, focusing on lists that identify taxa to binomial or trinomial. Consequently, 1,578 timber tree taxa, from 104 genera were identified. The list is refined in later chapters using techniques described in **Chapter 3** of this thesis, to identify timber tree species that are range-restricted and/or that have been previously placed in IUCN Red List Threatened or Near Threatened Categories; these prioritised species are assessed in **Chapter 4**. As such, the working list forms the first step towards the Red List assessments for selected timber tree species conducted in **Chapter 4**. Additionally, the published report based on this chapter provides a readily accessible summary of this information, and is provided to encourage further research and assessment, to determine with greater precision the use of different tree species for timber.

2.4.1 Dominant timber families

Figure 2.1 illustrates that the majority of angiosperm families identified in the working list were represented by fewer than ten taxa. In contrast, an exceedingly high number of timbers (311 taxa), were members of the Leguminosae family. The second best-represented family, the Dipterocarpaceae, had only approximately a third as many taxa (118). Why should the working list be so dominated by Legumes? According to the recent State of the World's Plants report (Willis, 2017), Leguminosae is the third largest angiosperm plant family in the world, with some 20,856 species. It is likely therefore that part of the reason for this family being so well-represented is simply that a large proportion of the world's angiosperm tree taxa are Legumes. However, the Rubiaceae family is reported as the world's fourth largest flowering plant family, and Rubiaceae only accounted for 18 timber taxa on the working list.

It is likely that the prominence of both Leguminosae and Dipterocarpaceae is not only due to the overall species richness of these families, but also their ecological characteristics and wood properties. Both families contain genera that can be monodominant, that is, comprise ≥60% of canopy-level trees in a forest stand. For example, the Dipterocarpaceae genus *Parashorea* is known to contain monodominant species such as *P. melaanonan* (Peh *et al.,* 2011). Both the Leguminosae and the Dipterocarpaceae are also known to contain species prized for the aesthetic quality of their timber, including the *Shorea* and *Parashorea* genera (meranti) and the genus *Dalbergia* (rosewoods) (CITES, 2013). It is therefore unsurprising that the working list is dominated by taxa from families that are characterised by a combination of canopy dominants, attractive and popular timbers, and high overall species richness.

2.4.2 How well does the working list reflect current trade?

This working list is intended to give a current overview of commercial timbers on the international market. However, trade in any timber waxes and wanes with customer demand (and thus timber price), laws concerning extraction and trade, and the availability and accessibility of harvest populations to loggers. Therefore, it is acknowledged that any list will require future updates to reflect changes in the trade.

Despite advances in certification and tracking of wood products from place of harvest to end product, there is still a flourishing illegal trade in timber species. The sources used for this working list do not explicitly focus on illegally traded species, with the possible exception of species listed in the CITES Appendices (CITES, 2013). However, consumer demand for timbers with certain desirable aesthetic and construction qualities fuels both illegal and legal trade. Therefore, it seems likely that most illegally logged taxa will be represented in the working list.

2.4.3 Limitations

Although the global timber trade is of current and historic importance, it is poorly documented and, consequently, information on which tree taxa are harvested is sparse and often difficult to access. With this in mind, it was decided that a list incorporating data from a diverse range of recent trade-related resources would provide a useful indication of current species in commercial trade. This approach enabled identification of taxa for which a high degree of consensus exists regarding their use as timber. However, the list unavoidably incorporates a degree of uncertainty.

Errors of misidentification

A broad range of sources can introduce errors of misidentification. While some of the species in the working list may have other major commercial uses, for example for essential oil, and be secondarily used for timber products, others may not be 'timbers' at all. Indeed, the working list has misidentified twelve Arecaceae (palm) taxa as timbers. Although these taxa are valued as ornamentals, they do not produce timber. Misidentified taxa were not carried forward as study species in further thesis chapters, and the published report based on this chapter continues to be updated – thus it is a 'working' list – as well as inviting comment from expert readers.

Errors of omission

Errors of omission are also a concern, and it should be noted that this list does not constitute a definitive statement on all tree species traded for timber. These results identify only those taxa for which a strong consensus exists regarding their use for timber (i.e., they have been listed in two or more sources used), in sources that have been, for the most part, produced by large conservation, timber or forestry organisations, and, crucially, that list taxa using binomial or trinomial. Many more timber lists will exist, and the need to select some sources while rejecting others reflects the fact that information relating to the use of timber tree species is poorly documented and highly fragmentary; there is a need for a consolidated, expert-reviewed, and updateable database of timber taxa.

Independence of literature sources

It is important to note that we cannot be certain of the independence of all seventeen source lists used to compile the working list. That is, older lists may have been used in the writing of newer lists, and therefore the use of 'being listed by two or more sources' as the deciding factor when deciding which taxa to include in the working list has its limitations. However, this uncertainty is an inevitable consequence of using numerous sources, rather than a single (currently non-existant) database, and may be balanced by the fact that, being online and open-access, many of the source lists continue to be updated and reviewed. The fact that the working list is nonetheless dominated by two families containing highly-prized timbers, the Leguminosae and Dipterocarpaceae, is additionally a reassuring indication that the list appears to reflect current trade.

2.5 Conclusion

The working list produced in this chapter meets an important need, by serving as a consolidated, but evolving, list of commercial timber tree taxa currently in trade. Despite some limitations of the original source lists, and the understanding that the working list as it currently stands is unlikely to contain all of the world's commercial timbers, it is nonetheless sufficient as a baseline to be reviewed and updated over time. The working list is also sufficient for the purposes of exploring extinction risk of known timber tree species using the IUCN Red List.

2.6 References

Butchart, S. H. M., Walpole, M., Collen, B., van Strien, A., Scharlemann, J. P. W., Almond, R. E. A., Baillie, J. E. M., Bomhard, B., Brown, C., Bruno, J., Carpenter, K. E., Carr, G. M., Chanson, J., Chenery, A. M., Csirke, J., Davidson, N. C., Dentener, F., Foster, M., Galli, A., Galloway, J. N., Genovesi, P., Gregory, R. D., Hockings, M., Kapos, V., Lamarque, J.-F., Leverington, F., Loh, J., McGeoch, M. A., McRae, L., Minasyan, A., Hernández Morcillo, M., Oldfield, T. E. E., Pauly, D., Quader, S., Revenga, C., Sauer, J. R., Skolnik, B., Spear, D., Stanwell-Smith, D., Stuart, S. N., Symes, A., Tierney, M., Tyrrell, T. D., Vié, J.-C. and Watson, R., 2010. Global Biodiversity: Indicators of Recent Declines. *Science*, 328 (5982), 1164-1168.

CBD, 2012. Global Strategy for Plant Conservation: 2011-2020. Richmond, United Kingdom: Botanic Gardens Conservation International.

CITES, 2013. CITES Appendices I, II and III. [Online] Available from: http://www.cites.org/eng/app/appendices.php [Accessed: February 2014]

FAO., 2012. State of the World's Forests 2012. 10th ed. Shaw, J. (ed.). Rome: Food and Agriculture Organization of the United Nations, 48.

Farjon, A., 2013. Honorary Research Associate Herbarium, Library, Arts & Archives. *The conifers database*. Royal Botanic Gardens, Kew. [Online] Available from: http://www.herbaria.plants.ox.ac.uk/bol/conifers. [Accessed: 17 January 2014].

Farjon, A. and Filer, D., 2013. *An atlas of the world's conifers: an analysis of their distribution, biogeography, diversity and conservation status*. Brill.

Farjon, A. and Page, C., 1999. Conifers status survey and conservation action plan. Gland: International Union for the Conservation of Nature.

Forest Stewardship Council A.C, 2007. FSC Species Terminology, FSC-STD-40-004b (Version 1-0). EN. Bonn, Germany. 4-25.

Friends of the Earth & Fauna and Flora International, 2013. Good Wood Guide Checklist. [Online]. Available from: http://www.foe.co.uk/campaigns/biodiversity/resource/good_wood_guide/wood_timber_types_a_to_g.html#a. [Accessed: February 2014]

Greenpeace, 2004. Good Wood Guide. [Online]. Available from: http://www.greenpeace.org.uk/MultimediaFiles/Live/FullReport/6759.pdf. [Accessed: March 2014]

Hansen, M. C., Stehman, S. V and Potapov, P. V., 2010. Quantification of global gross forest cover loss. *Proceedings of the National Academy of Sciences of the United States of America*, 107 (19), 8650-8655.

Hewitt, J., 2007. An assessment of tree species which warrant listing in CITES. Report prepared for Milieudefensie (Friends of the Earth, Netherlands).

International Tropical Timber Organization (ITTO), 2012. Annual review and assessment of the world timber situation - Appendix 3: Major tropical species traded in 2010 and 2011. Yokohama, Japan.

IUCN, 2014. IUCN Red List of Threatened Species Version 2013.2. [Online]. Available from: www.iucnredlist.org [Accessed: 3 January 2014].

L'Association Technique Internationale des Bois Tropicaux (ATIBT), 2013. Nomenclature générale des bois tropicaux, 2-40.

Mark, J., Newton, A. C., Oldfield, S. and Rivers, M., 2014. A Working List of Commercial Timber Tree Species. Botanic Gardens Conservation International. [Online]. Available from: http://www.bgci.org/news-and-events/news/1175/.

Microsoft, 2010. Microsoft Excel. Redmond, Washington: Microsoft.

Meier, E., 2014. The Wood Database. [Online]. Available from: http://www.wood-database.com/wood-identification/by-scientific-name/. [Accessed: January 2014]

Millennium Ecosystem Assessment, 2005. Ecosystems and human well-being: Synthesis (Millennium Ecosystem Assessment). Ecosystems, 5 (281), Washington, D.C.: World Resources Institute, 1-100.

NEPCon LegalSourceTM Due Diligence System, 2013. [Online] Available from: http://www.nepcon.net/5174/English/Certification/Timber_legality_services/Due_diligence_system/. [Accessed: February 2014]

Newton, A., Oldfield, S., Fragoso, G., Mathew, P., Miles, L. and Edwards, M., 2003. Towards a global tree conservation atlas. Cambridge, United Kingdom, 1-18.

Oldfield, S., Lusty, C. and MacKinven, A., 1998. The World List of Threatened Trees. Cambridge: WCMC, IUCN.

Peh, K.S.H., Lewis, S.L. and Lloyd, J., 2011. Mechanisms of monodominance in diverse tropical tree-dominated systems. *Journal of Ecology*, 99 (4), 891-898.

Richter, H.G. and Dallwitz, M.J., 2000 onwards. Commercial timbers: descriptions, illustrations, identification and information retrieval. Version: 25th June 2009. [Online]. Available from: http://delta-intkey.com. [Accessed: March 2014]

Sharrock, S., 2012. A Guide to the GSPC. Richmond, UK: Botanic Gardens Conservation International, 7-8.

The Plant List, 2013. [Online]. Available from: http://www.theplantlist.org/. [Accessed: February 2014]

The Timber Research and Development Association, 2002-14. Wood Species Database. [Online]. Available from: http://www.trada.co.uk/techinfo/tsg. [Accessed: February 2014]

The Wood Explorer, 2014. [Online]. Available from: http://www.thewoodexplorer.com/species.html. [Accessed: January 2014]

The World Bank, 2004. Sustaining Forests: A Development Strategy. Washington D.C.: The International Bank for Reconstruction and Development / The World Bank.

Timber Trade Federation, 2009. Timber species imported into the UK. [Online]. Available from: http://www.ttf.co.uk/Article/Detail.aspx?ArticleUid=ee39cec8-21b6-4be4-9361-6001612c7190. [Accessed: 12 February 2014]

TRAFFIC, 2012. Precious woods: Exploitation of the finest timber. Background Paper 1 for Chatham House 2012 workshop 'Tackling the trade in illegal precious woods', 36-45.

UNEP, 2005. Ecosystems and human well-being: a framework for assessment - Executive Summary (Millennium Ecosystem Assessment), 71-84.

UNEP, 2012. Global Environment Outlook 5: Summary for policy makers. Nairobi.

USDA Forest Products Laboratory, n.d. Wood Properties (Techsheets) - North American Hardwoods. [Online]. Available from: http://www.fpl.fs.fed.us/research/centers/woodanatomy/techsheets_display.php?geo_category_id=2&genus_commonname_criteria=c&sorting_rule=1a. [Accessed: 13 February 2014]

USDA Forest Products Laboratory, n.d. Wood Properties (Techsheets) - North American Softwoods. [Online]. Available from: http://www.fpl.fs.fed.us/research/centers/woodanatomy/techsheets_display.php?geo_category_id=3&genus_commonname_criteria=c&sorting_rule=1a. [Accessed: 13 February 2014]

USDA Forest Products Laboratory, n.d. Wood Properties (Techsheets) - Tropical Hardwoods. [Online]. Available from: http://www.fpl.fs.fed.us/research/centers/woodanatomy/techsheets_display.php?geo_category_id=4&genus_commonname_criteria=c&sorting_rule=1a. [Accessed: 13 February 2014]

USDA Forest Products Laboratory, n.d. Wood Properties (Techsheets) - Lesser Known Wood. [Online]. Available from: http://www.fpl.fs.fed.us/research/centers/woodanatomy/techsheets_display.php?geo_category_id=1&genus_commonname_criteria=c&sorting_rule=1a. [Accessed: 13 February 2014]

Willis, K.J. (ed.), 2017. State of the World's Plants 2017. Report. Royal Botanic Gardens, Kew.

Woodworkers Source, 2013. Wood Library. [Online]. Available from: http://www.woodworkerssource.com/letter1.php?common_name=no&letter=A&viewing=0. [Accessed: March 2014]

WWF/GFTN, 2013. A guide to lesser-known tropical timber species. Gland, Switzerland, 4-86.

3 Applications of GBIF data in assessing extinction risk of timber trees

3.1 Introduction

The global distribution of species yields important information about patterns and hotspots of biodiversity. A species' geographic distribution can be an indicator of extinction risk, since narrowly distributed species are more likely than widely distributed species to fall victim to single threat events (Mace *et al*., 2008; Hjarding *et al*., 2014). As such, distribution is a key indicator used to assess extinction risk under Criterion B of the IUCN Red List of Threatened Species (Red List) (Hjarding *et al*., 2014; IUCN Standards and Petitions Subcommittee, 2017).

Criterion B of the Red List uses two different estimates of species range size: extent of occurrence or 'EOO' (the area within the outer limits of all known, inferred or projected range sites of a particular species) and area of occupancy or 'AOO' (the area within the EOO that is actually occupied or suitable for occupation) (IUCN Standards and Petitions Subcommittee, 2017) to assign taxa to threat categories. Species with larger EOO and AOO estimates (measured in square kilometres) are regarded as lower risk. Although all relevant Red List Criteria (A-E) – including population structure and decline, the nature and proximity of threats, and habitat quality and fragmentation – should be applied in the course of a full Red List assessment, species EOO has been used as a valid method for prioritising species for full Red Listing attention (Miller *et al*., 2012).

EOO calculations for plant taxa commonly utilise georeferenced herbarium records (Paton *et al*., 2008; Rivers *et al*., 2011; Beck *et al.*, 2013) to map the known outer limits of ranges and draw a perimeter around these marginal occurrence points. Although Rivers *et al.* (2011) found greatest reliability when using ≥15 occurrence records, in practice, (and particularly for taxa with few published records) only three geographically distinct records are required to ensure that the connected perimeter takes the form of a convex polygon (i.e. not a straight line). This measure of EOO is known as the Minimum Convex Polygon (MCP) approach. EOO gives a metric of the risk of a threat event affecting all areas of a species' range, thus the area within an EOO polygon should include not only suitable habitat but also discontinuities between suitable patches. For this reason, the MCP approach is recommended as the most useful and consistent measure of EOO (Gaston and Fuller, 2009; Joppa *et al*., 2015; IUCN Standards and Petitions Subcommittee, 2017).

Although frequently confused with EOO in the literature (see reviews by Akçakaya *et al.,* 2000; Gaston and Fuller, 2009; Joppa *et al*., 2015), AOO is a different metric looking at actual or potential occupancy within the outer limits of range. AOO estimates are often used in red listing to assign threat categories based on the correlation of occupancy to extent and intactness of suitable habitat within range, or as a proxy for population change over time (given multiple estimates of AOO over time). AOO has typically been more difficult to estimate, as it requires detailed knowledge of occurrence within EOO limits – in essence, more and higher resolution records of presence/absence.

Historically, due to limitations of sparse or biased data, knowledge of species distribution and range has been poor (Beck *et al*., 2013) – a situation dubbed the 'Wallacean shortfall'. Now, herbarium collections are slowly becoming available online, as they are digitised by disparate holding institutions, commonly botanical gardens and universities, around the world. Furthermore, proliferation of citizen science biogeography and identification initiatives such as iNaturalist, and 'big data' biodiversity portals are seen as areas of emerging promise for conservation and taxonomy in terms of data provision (Joppa *et al*., 2012; iNaturalist, 2014; Pimm *et al*., 2014; Maes *et al*., 2015).

Increasingly, electronic web databases such as the Global Biodiversity Information Facility (GBIF) seek to address the 'Wallacean shortfall' by digitising georeferenced herbarium, museum and survey specimens (GBIF, 2014). Data aggregation by such portals makes previously disparate data collections freely and easily accessible to the research community (Beck *et al*., 2013; Ficetola *et al*., 2014). However, despite these advances, we still lack reliable range maps for many well-known and economically valuable taxa, including the majority of the world's commercial timber tree species (Oldfield *et al*., 1998; IUCN, 2014).

As the largest repository of georeferenced species presence data, GBIF is increasingly used in spatial studies (Yesson *et al*., 2007; Beck *et al*., 2013, 2014; Ficetola *et al*., 2014), including for localised conservation prioritisation (Romeiras *et al*., 2014). GBIF provides arguably the most readily accessible database of long-term species distribution data, with wide geographic coverage and taxa representation. However, scrutiny of GBIF datasets has revealed weaknesses in data quality and spatial bias (Yesson *et al*., 2007; Beck *et al*., 2014). Recent research by Hjarding *et al.* (2014) suggests that – at least for amphibians – GBIF data alone are insufficient for reliable red list assessments, and are secondary to expert knowledge. In a comparison between an expert georeferenced dataset and GBIF data for East African chameleons, Hjarding *et al.* (2014) found only 7% of raw GBIF data to be useable, and recommended expert knowledge over GBIF data for Red List assessments.

However, for many timber tree species, up to date, accessible and georeferenced (coordinate or locality) expert datasets are scarce; GBIF often represents the most widely-accessible source of georeferenced records. If we are to meet conservation targets for these species, GBIF and similar open-access databases will become of central importance, and it is vital that their use reflects their reliability. An additional concern is time, human resources and funding for Red List assessments. When compared to the alternative – time and resource-intensive expert datasets, which may necessitate ground truthing (Beck *et al*., 2013; Brummitt *et al*., 2015) –, use of GBIF data in the initial stages of tree species prioritisation for Red List assessment merits further investigation.

This study therefore addresses the research question: *Are species distribution records from the Global Biodiversity Information Facility (GBIF) sufficient for use in calculating timber tree species' IUCN Red List extent of occurrence (EOO) and area of occupancy (AOO)?*

In answering, this chapter seeks to determine the amount, reliability and coverage of timber tree occurrence data that is quickly and easily accessible from the GBIF database, compared to more laborious compilation of data from original sources. Additionally, this chapter presents a novel investigation of the application of 'big data' to the mapping and risk assessment of timber tree species.

3.2 Study species

This study focuses on tree species identified as being internationally traded for timber (Mark *et al*., 2014). The original working list (see **Chapter 2**) was refined to 1,538 species, removing intraspecific taxa. The majority of these species are located in South East Asia, South America and West Africa (see **Figure 3.1**), where deforestation remains a tangible threat to wild populations (FAO, 2010; Global Forest Watch, 2014). The analysis in this Chapter uses a subset of 304 species out of the refined 1,538, selected using random number generation in Microsoft Office Excel 2010.

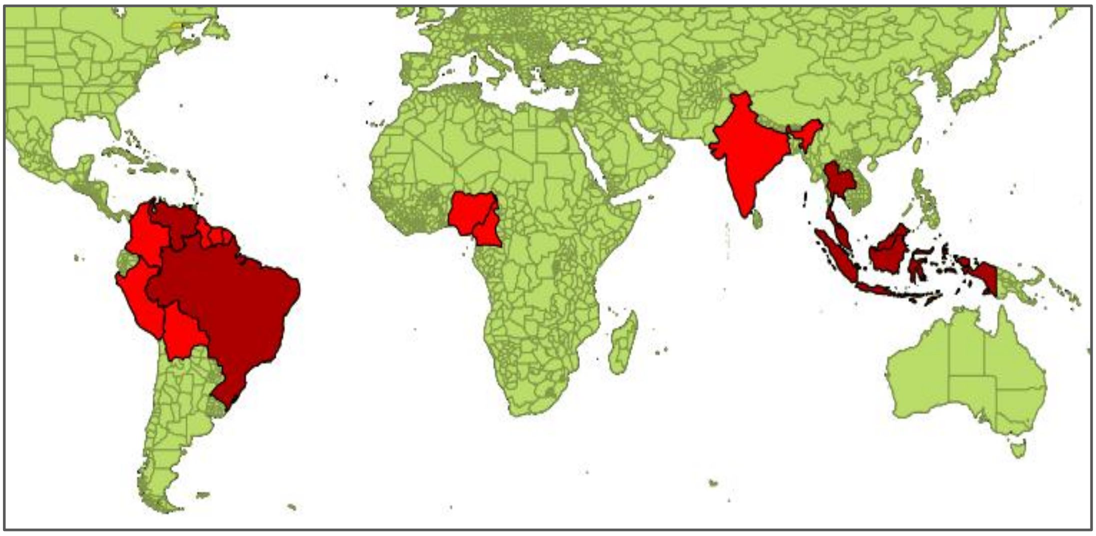


Figure 3.1 Areas of high timber tree species richness: red represents countries with 100-199 species, dark red countries with 200-400 species.

3.3 Methods

3.3.1 Study datasets

Global Biodiversity Information Facility (GBIF)

GBIF brings together occurrence records from, at present, 739 data publishers: herbarium collections, universities, museums, 'research-grade' citizen science observations, and other research institutions (GBIF, 2014). The datasets used in this paper are presence-only georeferenced (coordinate) records from numerous providers, dating from the 1900s to 2014.

National and Regional Floras ('expert' dataset 1)

National and regional floras were used as historical baselines for determining a list of native range countries for each species. A full list of reference floras and other major taxonomic sources was created and finalised after consultation with staff at Botanic Gardens Conservation International (BGCI). Volunteers at BGCI were recruited to search these sources for range information on the study timber tree species (see **Appendix B** for full source list as received by volunteers). Range state information was spot-checked by Jennifer Mark. Any range information conflicts were resolved through communication with experts at IUCN Cambridge.

Range countries were added to draft Red List assessment pages created for each species in IUCN's Species Information Service (SIS). Range country names were converted into Alpha-2 digit political codes from the International Standards Organisation (2013) for comparison with the corresponding ISO codes listed in the GBIF records for each species. ISO codes are based on political territories; as such, it was necessary to be vigilant to codes that were politically rather than geographically appropriate to the location of a record. Example: The code for France (FR) supplied for a record in French Guiana (GF). Such cases were reviewed by hand.

The World List of Threatened Trees ('expert' dataset 2)

The World List of Threatened Trees (Oldfield *et al*., 1998) – hereafter 'World List' – has generated the largest contribution of tree Red List assessments to the IUCN Red List published database to date. Some 970 species assessed in the World List were also identified as timbers in trade by Mark *et al.* (2014), 49 of which are included in the random subset under scrutiny in this study. The World List provides range countries for each species assessed, correct as of 1998. Ranges were largely sourced from individual taxonomic and regional experts, National Red Lists, and IUCN/SSC Plant Specialist Groups. They are used here as additional expert knowledge of species native range.

3.3.2 Data sourcing (raw data)

Georeferenced distribution records for 1,538 timber tree species were downloaded from the GBIF into Microsoft Excel using R package 'rgbif' in RStudio (RStudio, 2014). The Plant List (2013) was used as a taxonomic reference for accepted names. The GBIF accepted name search queries returned records for the accepted name entered, and synonyms associated with that accepted name. Resulting GBIF records for each species were saved in individual species-specific csv files. A subset of 304 species was then randomly selected using the RAND function in Microsoft Office Excel 2010.

3.3.3 Record cleaning (cleaned data)

Records for each species in the subset were cleaned by hand in Excel, following guidelines from Chapman (2005). The first stage of cleaning was to remove unneeded columns in each species spreadsheet (see **Table 3.1**). Duplicate records and records lacking coordinates were then removed. Records were considered to be duplicates if taxonomy and coordinates were identical; records such as this that had differing collection years or differing collectors were assumed to refer to the same individual that had been visited multiple times. The remaining records were sorted by scientific name, and synonyms were checked using The Plant List (2013). The number of records removed at each stage of cleaning was recorded for use in gauging GBIF data reliability. After cleaning, species with <3 coordinate records were discarded from the set.

Table 3.1 Example columns and data content of GBIF species distribution records after initial column removal.

Column name	Example row content
Name	Genus species (May attribute the same accepted name to numerous synonyms in the dataset)
DecimalLatitude	45.51105
DecimalLongitude	-73.5674
BasisOfRecord	Preserved specimen / Living specimen / Human observation
ScientificName	Genus species Auth. (Name species was identified under – column may include synonyms and unresolved names)
Elevation	10.4
ElevationAccuracy	0
Year	2011
CountryCode	CA (ISO 2-digit country code)
InstitutionCode	University name / other institution code
Locality	Locality comments
OccurrenceRemarks	Further locality / specimen comments

3.3.4 Spatial validation (flora-refined data)

Unique (non-duplicate) GBIF records were also refined by country code (ISO 2-digit code) using historic known range countries for each species sourced from national and regional floras and other reputable information sources ('country matching'). Records with a positive match between GBIF range country and a known range country from a referenced flora were considered 'valid'. A similar method, using Taxonomic Database Working Group codes in place of ISO, was used by Yesson *et al*. (2007). Again, species with <3 remaining records after matching were removed from the set. This spatial validation generated a third set of records for each species: spatially validated (flora-matched) records.

3.3.5 Spatial validation (World List-matched data)

The three sets of records for each species were mapped in ArcMap 10.1 (ESRI, 2012). 49 species from the 304 subset were previously assessed by Oldfield *et al*. (1998) in

The World List of Threatened Trees. Text range descriptions were transposed into ISO 2-digit country codes (taking into account political border shifts and nation name change since 1998). As with flora matching, all records with non-matching ISO codes were removed. This generated a fourth record set: World List-matched.

3.3.6 Cost effectiveness of different data-refining scenarios

Time taken to refine species data under each of the four scenarios – 1) raw, 2) cleaned, 3) flora-matched (unique GBIF records refined by reference flora native ranges), 4) World List-matched (unique GBIF records refined by World List native ranges) – was recorded. The average time taken to refine data for a single species under each different scenario was then compared, in order to determine which scenarios were most 'cost-effective'.

3.3.7 Applying Red List Criterion B

The GeoCAT online tool (Bachman *et al*., 2011; http://geocat.kew.org/) was used to calculate extent of occurrence and area of occupancy estimates for each of the 49 species with four data-refining scenarios. Following Hjarding *et al.* (2014) and Miller (2012), these estimates were used for partial application of Criterion B of the Red List, to examine differences in the resulting Red List categorisation under the different data-refining scenarios. Criterion B (outlined in **Table 3.2**) uses threshold values for AOO and EOO, alongside information on fragmentation, number of distinct locations occupied, continuing decline and extreme fluctuations to assign Red List Categories of threatened, near-threatened, non-threatened and data deficient (IUCN Standards and Petitions Subcommittee, 2017).

3.3.8 Statistical analysis: Impact of different data refining scenarios on EOO

EOO estimates for each species under the four different data scenarios were analysed for differences using repeated measures ANOVA and *post hoc* Bonferroni test in SPSS 22.0 (IBM Corp., 2013).

Table 3.2 IUCN Red List Criterion B: Geographic range in the form of either B1, extent of occurrence AND/OR B2, area of occupancy. Recreated from IUCN (2014a).

	Critically Endangered	**Endangered**	**Vulnerable**
B1. Extent of occurrence	<100 km^2	<5,000 km^2	<20,000 km^2
B2. Area of occupancy	<10 km^2	<500 km^2	<2,000 km^2
And at least 2 of the following 3 conditions:			
(a) Severely fragmented OR Number of locations	= 1	≤ 5	≤ 10
(b) Continuing decline observed, estimated, inferred or projected in any of: (i) extent of occurrence; (ii) area of occupancy; (iii) area, extent and/or quality of habitat; (iv) number of locations or subpopulations; (v) number of mature individuals.			
(c) Extreme fluctuations in any of: (i) extent of occurrence; (ii) area of occupancy; (iii) number of locations or subpopulations; (iv) number of mature individuals.			

3.4 Results

3.4.1 Data sourcing: Species representation

The study subset was a random sample of commercially-harvested timber species, containing species from 63 angiosperm families. The majority of species belonged to the Leguminosae, Dipterocarpaceae and Sapotaceae (see **Figure 3.2**).

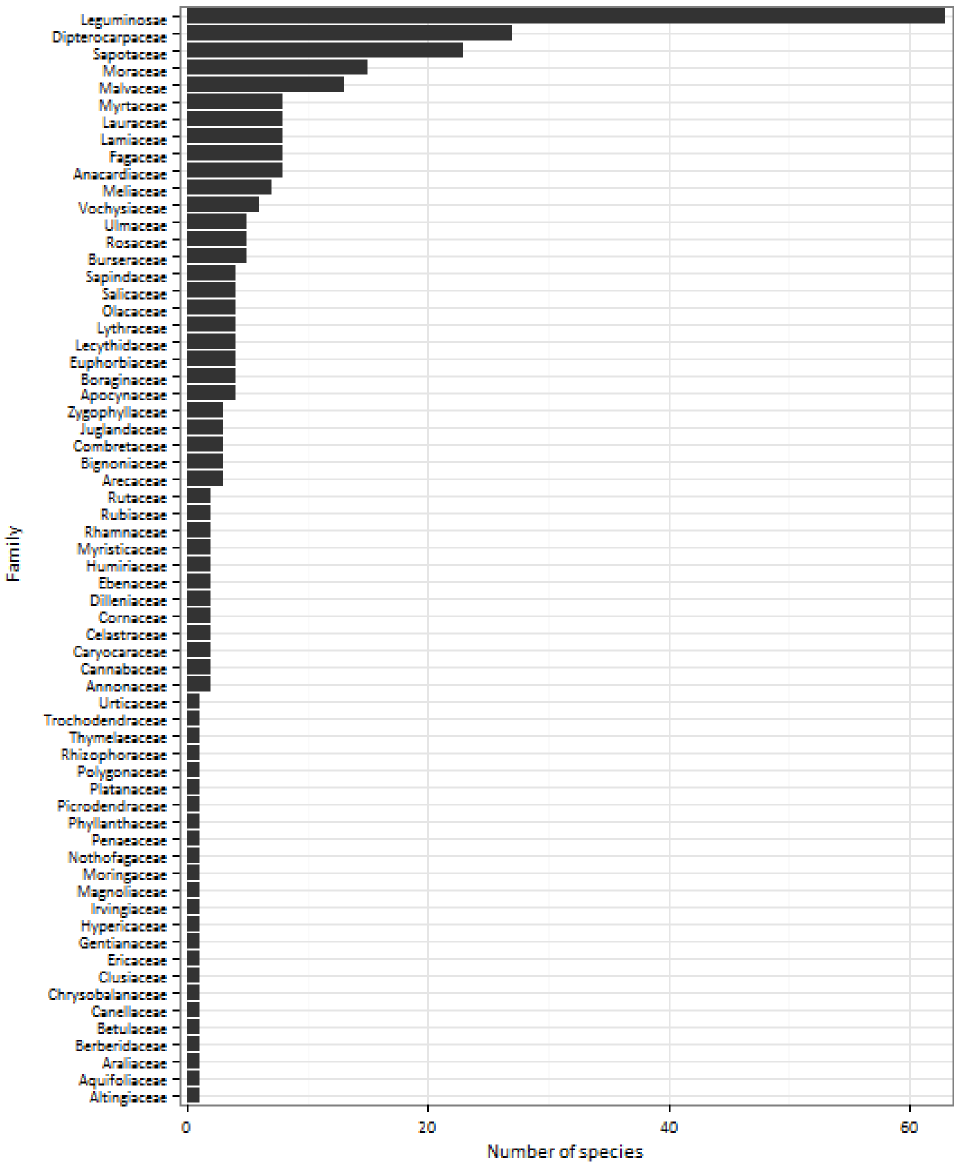


Figure 3.2 Summary of number of subset species by family.

Representation of the 304 subset species on GBIF varied widely, with number of raw, coordinate records ranging from zero to 280,505. Mean record number was 4,247. In more detail: 43.8% of species in the subset had <100 records and a further 43.8% had 100-1,000 records. 12.5% had >1,000 records. Of those species with greater numbers of records, 8.6% of the subset (26 species) had 1,001-10,000 records, and 2.3% (seven species) had 10,001-100,000 records. Lastly, 1.6% (five species) had 100,001-290,000 records. **Figures 3.3 and 3.4** illustrate the considerable variability in record number by species.

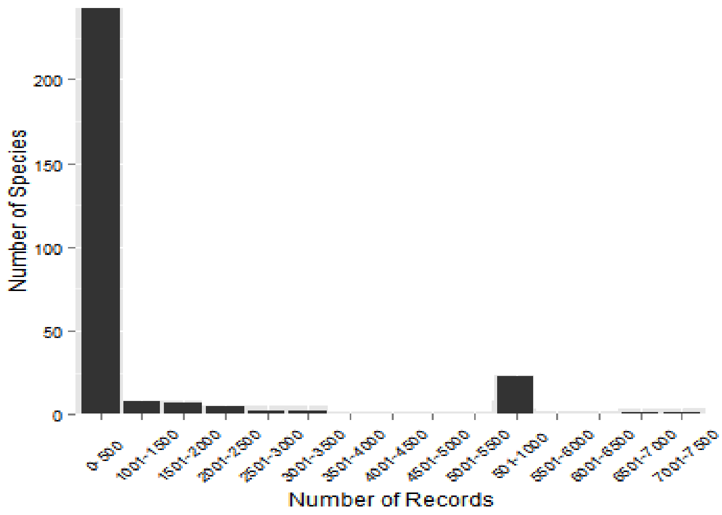


Figure 3.3 Number of subset species with <8,000 georeferenced records in GBIF database.

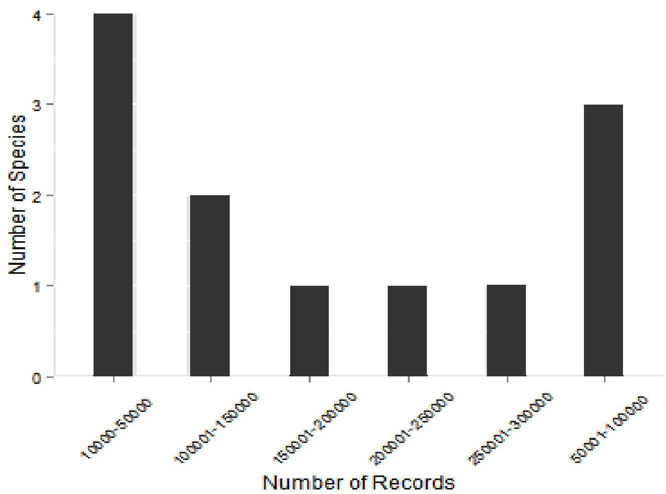


Figure 3.4 Number of subset species with >8,000 georeferenced records in GBIF database.

Notably, families with greater species representation (Leguminosae, Dipterocarpaceae, Sapotaceae) did not have correspondingly high record representation. Families with greatest mean number of records were the Rosaceae, Rhamnaceae, Sapindaceae and Salicaceae (summarised in **Figure 3.5**).

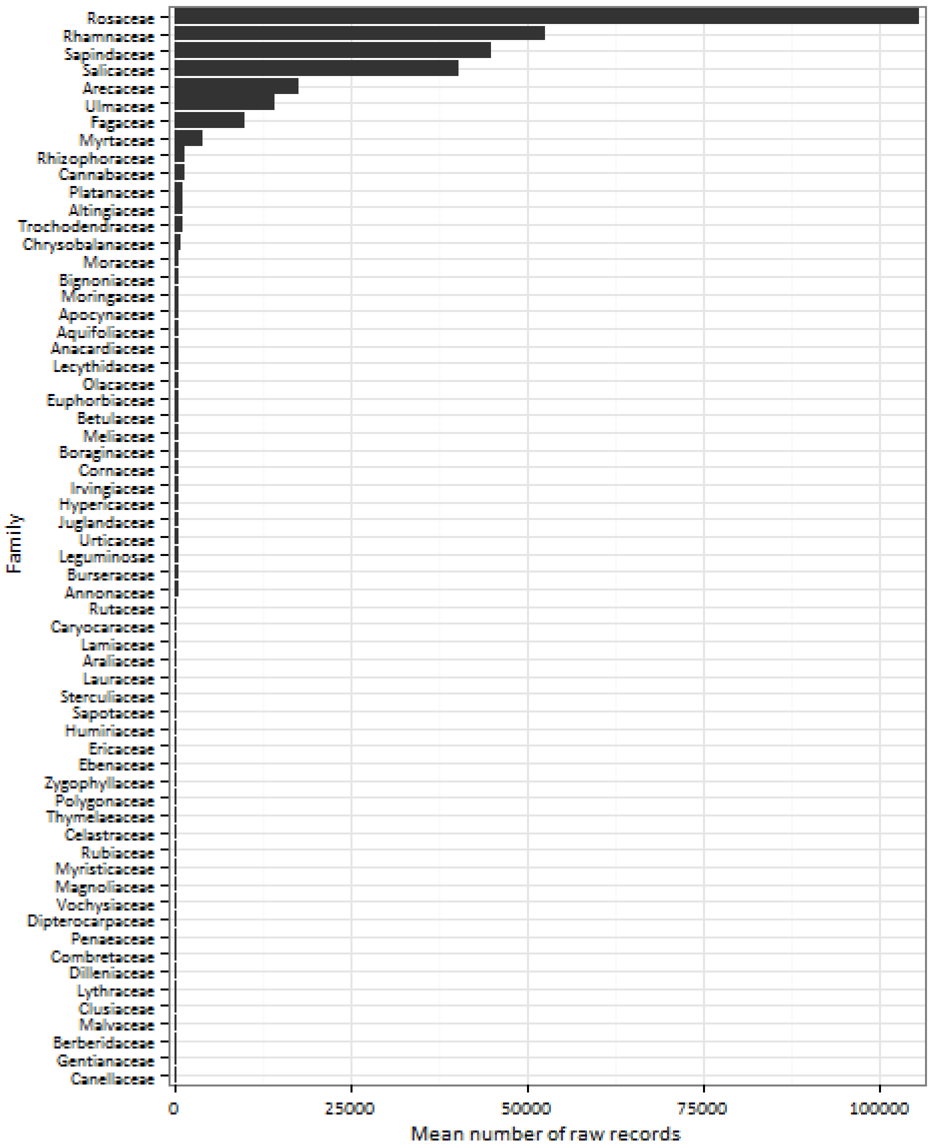


Figure 3.5 Mean number of raw GBIF records by subset family.

However, collections for tropical species are often less complete than those of species in temperate regions. Separating subset species into five latitudinal zones based on broad geographic distribution (native range country) according to our reference floras, it becomes evident that species located in temperate latitudes had greater representation (raw coordinate records) on GBIF. **Table 3.3** illustrates this pattern.

Table 3.3 Mean number of GBIF records per species before (raw) and after (usable) cleaning. Subset species have been divided into latitudinal zone of species' native range countries: tropical, (spanning both) tropical-subtropical, subtropical, (spanning both) temperate-subtropical, and temperate.

Subset representation	**Latitudinal zone (species broad distribution)**				
	Tropical	Tropical-subtropical	Subtropical	Subtropical-temperate	Temperate
Number of families	51	14	4	3	17
Number of species	240	17	5	4	38
Mean raw records	498.11	551.82	199	844	30468.39
Mean usable records (%)	166.48 (33.42)	315.88 (57.24)	113.2 (56.88)	603 (71.45)	17162.26 (56.32)

3.4.2 Record cleaning and refining

Out of a total 1,291,098 raw records (for 304 species), 590,759 (45.8%) were removed during cleaning. Of those removed, 574,122 (97.2%) were duplicates, 10,442 (1.8%) had 0,0 coordinates, and 6,195 (1%) were 'foreign' taxa/invalid synonyms. Only three species from the 49-species subset had record removals due to erroneous taxonomy: *Dalbergia maritima* (four records), *Guaiacum coulteri* (three records), and *Magnolia sororum* (four records).

Overall, removal of unusable records left 43 of 304 species datasets with fewer than the minimum number of records required for calculation of an EOO MCP (<3 coordinate records). This left 261 species with usable datasets. **Table 3.3** and **Figure 3.6** summarise record loss by latitudinal zone and record loss by family, respectively. **Figure 3.7** demonstrates the effect of cleaning and spatial validation (use of flora-refined data and World List-matched data) on range size for an example species, *Afzelia xylocarpa*.

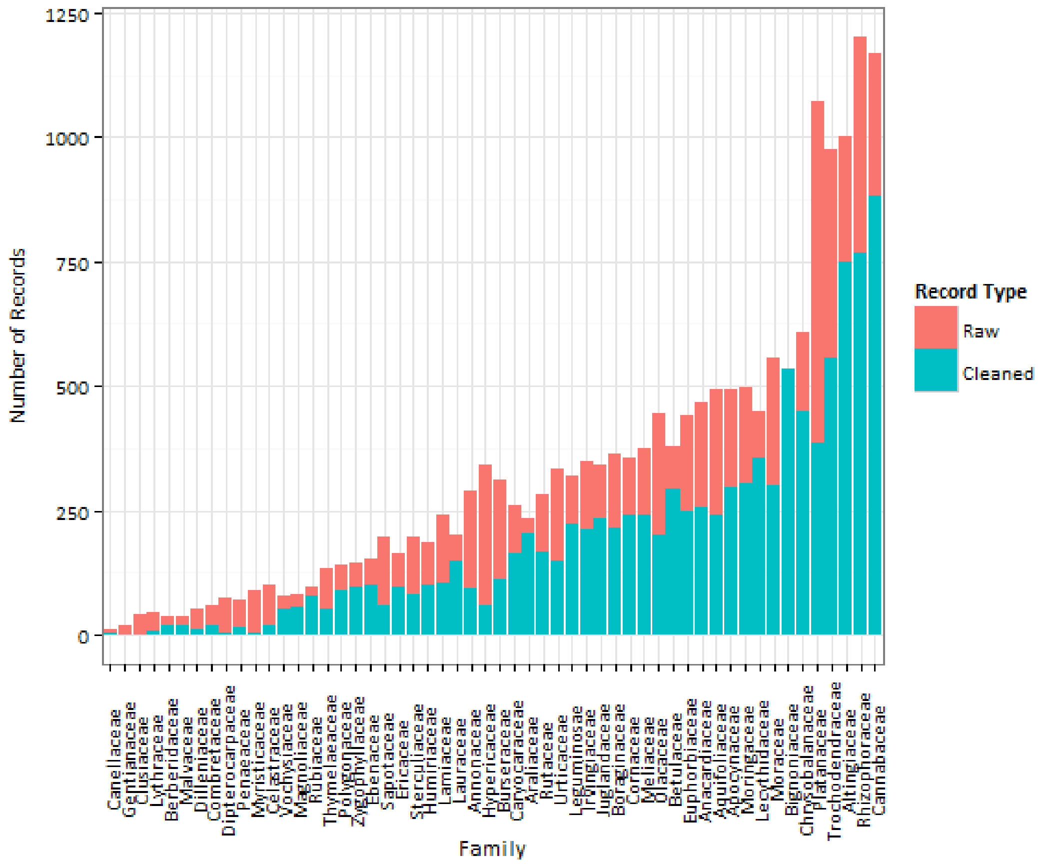


Figure 3.6 Total number of GBIF records for 54 subset families before (Raw) and after cleaning (Cleaned).

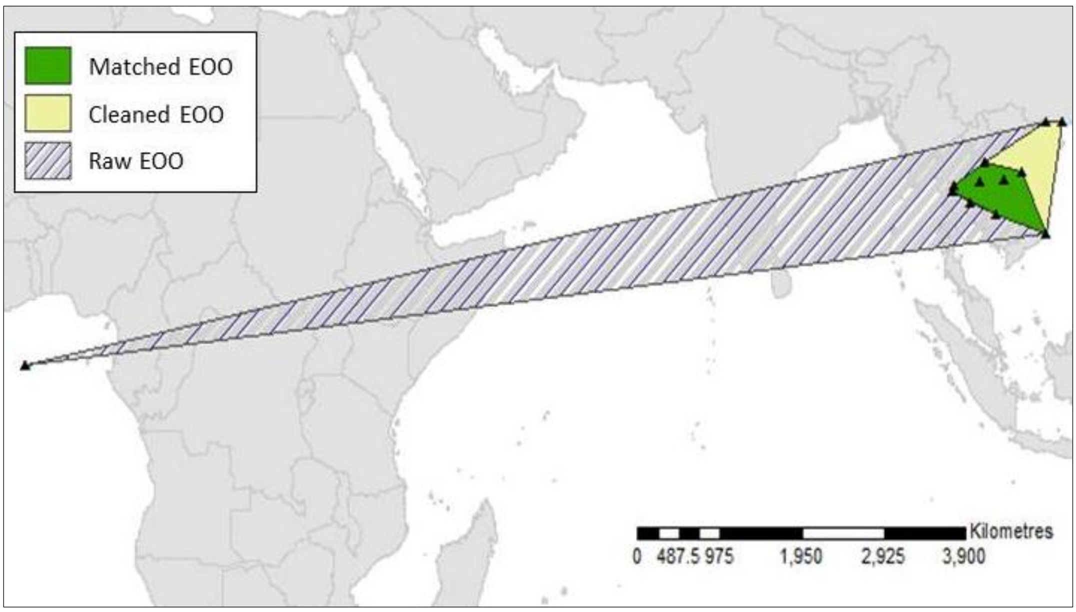


Figure 3.7 Range of <u>Afzelia xylocarpa</u> under four data-refining scenarios: Raw GBIF (striped), Cleaned GBIF (yellow), and Flora-matched (green). For <u>A. xylocarpa</u>, World List-matched range was the same as Flora-matched range (green).

3.4.3 Cost effectiveness of using GBIF data

On average, initial column removal took three to four minutes, removal of duplicate records took approximately 30 seconds, removal of records with invalid or absent coordinates took up to five minutes, and checking atypical nomenclature and synonymy took between 0-20 minutes per species. Time taken to record results is included in total time-cost, but is considered negligible. Country matching of the flora-refined and World List-refined records took, on average, approximately six minutes per species, in addition to three to four minutes for initial column removal and approximately 30 seconds for removal of duplicates.

3.4.4 Applying Red List Criterion B

Of the 304 species examined, 49 had been previously assessed as threatened by Oldfield *et al.* (1998). Each of the 49 assessments includes a written account of species range countries, according to a taxonomic or regional expert. In addition to general record cleaning and refining records using country ranges from regional floras, these expert-checked ranges constitute an important fourth data-refining scenario that may be applied to the GBIF records of previously-assessed species in order to calculate Red List Criteria B1 – extent of occurrence (EOO) – and B2 – area of occupancy (AOO).

Estimates of species EOO and AOO were calculated using GeoCAT (Bachman *et al*., 2011; http://geocat.kew.org/) for the 49 subset species with four data-refining scenarios, following Red List Guidelines (IUCN Standards and Petitions Subcommittee, 2017). EOO was calculated for each scenario. **Tables 3.4 and 3.5** below summarise the results of applying IUCN Red List assessment categories to these EOO and AOO estimates. Under partial application Red List Criteria (B1 and B2), study species qualified for the following Categories: Critically Endangered (CR), Endangered (EN), Vulnerable (VU), Near Threatened (NT), Least Concern (LC) and Data Deficient (DD).

AOO estimates were severely impacted by record scarcity under all four data-refining scenarios. With the exception of three species found to be DD under the flora- and World List-refined scenarios, all species were considered threatened (CR, EN or VU), regardless of refining technique. This was also true for AOO estimates calculated using unrefined, raw GBIF records. These results are summarised in **Table 3.4**.

For EOO, five species are listed as Threatened (VU or EN) and two as NT, under the cleaned scenario. None of the species are considered DD. The flora and World List scenarios show data deficiency for several species, reflecting species with no records inside of a known range. In these cases, data cleaning alone may result in non-range records. Importantly, species with the highest category of threat used, (no species were classed as CR), were detected as EN under all data scenarios. However, only two out of six potentially VU species were detected as such under all scenarios.

In general, The World List data-refining scenario is more conservative – that is, awards a higher threat category – than the cleaned or flora scenarios, except in the case of *Chlorocardium rodiei,* which is classed as NT under the cleaned and World List scenarios, and as VU under the flora scenario, and *Shorea rugosa,* classed as VU under the cleaned scenario, and DD under the others. The flora scenario was slightly more conservative than the cleaned scenario, and also highlighted DD species. These results are summarised in **Table 3.5.**

Table 3.4 Potential IUCN Red List Categories (using Criterion B2 only – area of occupancy), for timber tree species under three GBIF data-refining scenarios: cleaned only, refined using country ranges from regional floras, and refined using country ranges listed in The World List of Threatened Trees (Oldfield et al. 1998). Categories used: LC, Least Concern; NT, Near Threatened; VU, Vulnerable; EN, Endangered; DD, Data Deficient.

		Area of occupancy		
Category	**Raw**	**Cleaned**	**Flora-refined**	**World List-refined**
CR	0	1	4	3
EN	46	45	39	42
VU	3	3	3	3
NT	0	0	0	0
LC	0	0	0	0
DD	0	0	3	1

Table 3.5 Potential IUCN Red List Categories (using Criterion B1 only – extent of occurrence), for timber tree species under three GBIF data-refining scenarios: cleaned only, refined using country ranges from regional floras, and refined using country ranges listed in The World List of Threatened Trees (Oldfield et al. 1998). Categories used: LC, Least Concern; NT, Near Threatened; VU, Vulnerable; EN, Endangered; DD, Data Deficient.

	Extent of occurrence			
Category	**Raw**	**Cleaned**	**Flora-refined**	**World List-refined**
CR	0	0	0	0
EN	1	2	2	2
VU	0	3	3	4
NT	1	2	1	3
LC	47	42	37	37
DD	0	0	6	3

3.4.5 Statistical analysis of EOO estimates

Statistical analysis using a one-way repeated measures ANOVA was conducted to compare EOO under the four data-refining scenarios: raw, cleaned, flora-refined and World List-refined. Mauchly's test output indicated that the assumption of sphericity had been violated, X^2 (5) = 167.7, $p < 0.05$. Therefore, degrees of freedom were corrected using Greenhouse-Geisser estimates of sphericity ($\varepsilon = 0.43$). The results determined that EOO was significantly different between data-refining scenarios, F (1.29, 62.0) = 9.59, $p = 0.01$. These results are reported in **Table 3.6**.

Table 3.6 One-way repeated measures ANOVA summary.

	df	**Mean Square**	**F**	**Significance**
Greenhouse-Geisser	1.293	2.669E+15	9.585	0.001*
Error	62.043	2.784E+14		

* p < 0.05

Post hoc comparisons using Bonferroni correction revealed that, whilst there was no significant difference between species' EOO estimates under cleaned, flora and World List data-refining scenarios, EOO under the raw data scenario was significantly different from EOO under the three refined scenarios: cleaned (p = 0.01), flora (p = 0.04), World List (p = 0.03). These results are summarised in **Table 3.7**.

Table 3.7 Bonferroni comparison for four data-refining scenarios.

Data-refining method	Comparisons	Mean difference	Std. Error	Significance	95% Confidence Interval	
					Lower Bound	Upper Bound
Raw	Cleaned	5511477.05	1327661.6	0.001*	1857721.6	9165232.5
	Flora	10452002.4	2862360.7	0.004*	2574719.1	18329285.7
	World List	9899260.9	2654669.6	0.003*	2593548.4	17204973.4
Cleaned	Raw	-5511477.1	1327661.6	0.001*	-9165232.5	-1857721.6
	Flora	4940525.3	2491423	0.319	-1915928.8	11796979.5
	World List	4387783.9	2430598.8	0.464	-2301280.6	11076848.3
Flora	Raw	-10452002.4	2862360.7	0.004*	-18329285.7	-2574719.1
	Cleaned	-4940525.3	2491423	0.319	-11796979.5	1915928.8
	World List	-552741.5	510059.4	1.000	-1956436.9	850954
World List	Raw	-9899260.9	2654669.6	0.003*	-17204973.4	-2593548.4
	Cleaned	-4387783.9	2430598.8	0.464	-11076848.3	2301280.6
	Flora	552741.5	510059.4	1.000	-850954	1956436.9

* The mean difference is significant at the 0.05 level

3.4.6 Effect of data-refining on mapping

Although the differences between clean, flora and World List scenarios were not significant, there were nonetheless differences that are important on an individual species basis, when mapping distribution. These differences are illustrated in **Fig. 3.8**.

A

B

C

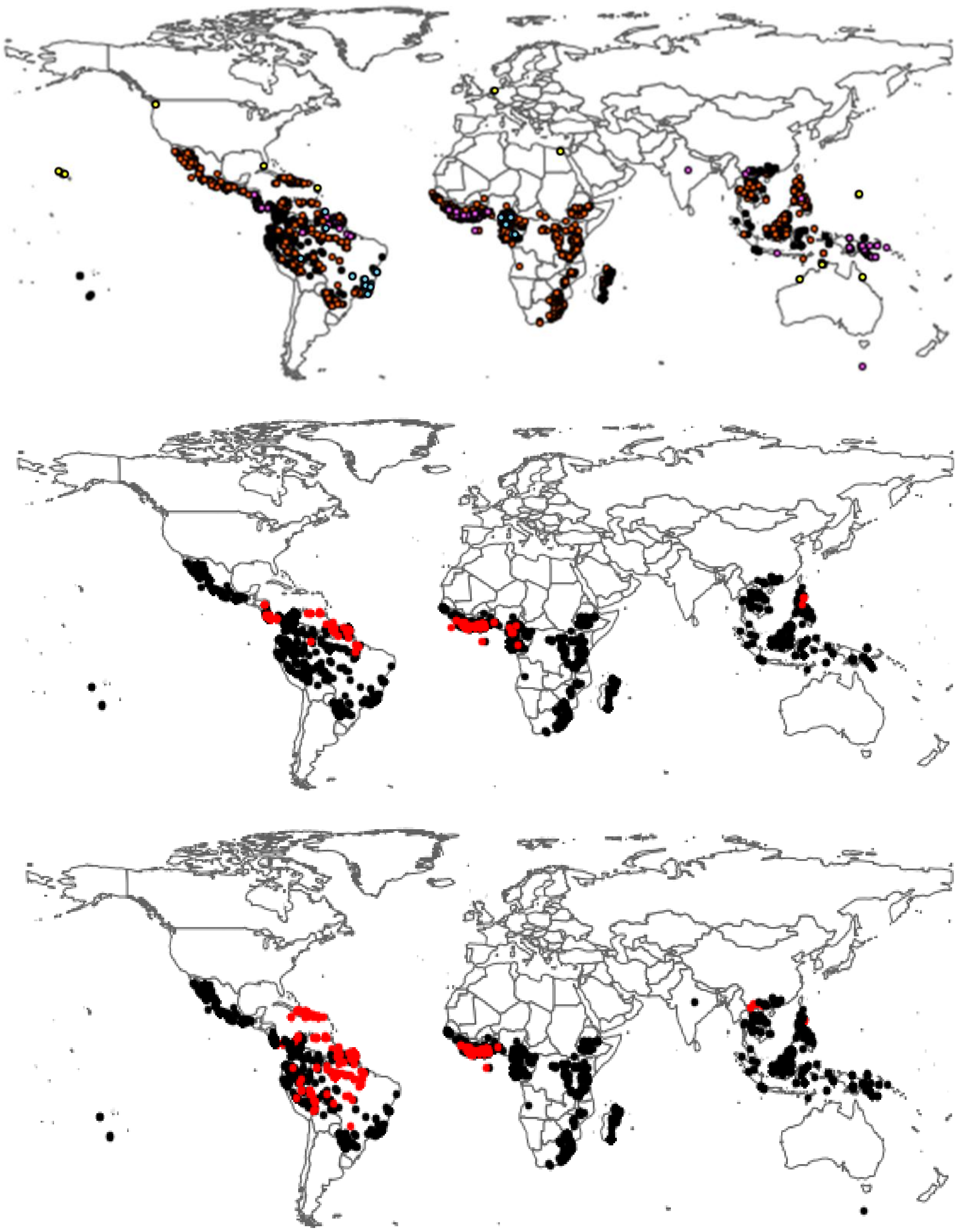


Figure 3.8 Point maps for 49 subset species under three data scenarios: A Cleaned, B Flora refined, C World List-refined. Coloured points show record removal between refining scenarios: yellow (species' records differ between A and B, C); pink (species' records differ between A and B); blue (species records differ between A and C); red (species' records differ between B and C); black (shared records).

3.5 Discussion

These results demonstrate that cleaned GBIF occurrence records are sufficient to calculate EOO for a subset of timber tree species. Notably, cleaning gives estimates that are not signficantly different from those produced using GBIF records refined by available expert knowledge of native range for these species. Furthermore, refining records using native range according to floras could present a quicker (relative to the full record cleaning process) way of editing species occurrence datasets from GBIF, for use in estimating EOO. Following from this, the flora-refining technique was used to refine GBIF records for all identified timber tree species so that they could be prioritised as (on the basis of restricted range) for full Red List assessment in thesis **Chapter 4**. For the full group of 1,538 species, the alternative – cleaning records by hand – as trialled here would represent an unfeasible time-cost.

3.5.1 Species representation

Representative of timber tree species as a group, the study subset was dominated by tropical members of the Leguminosae, Dipterocarpaceae and Sapotaceae families; however, species representation on GBIF did not correspond. Findings corroborate previous commentary on data scarcity for tropical flora (Cayuela *et al*., 2009; Joppa *et al*., 2015). Numbers of georeferenced records per species varied greatly, from <10 to hundreds of thousands (**Figures 3.1 and 3.2**), and families with the highest numbers of mean records per species were the Rosaceae, Rhamnaceae, Sapindaceae and Salicaeae – families represented by timber tree species in largely temperate latitudes. Overall, a total of >30,000 raw records for 17 families and 38 species in temperate latitudinal zones, versus <500 records for 51 families and 240 species from the tropics (**Table 3.3**) indicates a strong collection and/or digitisation bias in favour of temperate species.

These results identify a gap in accessible data for tropical timbers and, by extension, for other tropical tree taxa, as timbers are likely to be slightly better known relative to other trees due to their commercial value. Additionally, timbers may be more accessible to collectors than other tree taxa due to logging roads. Whilst on-the-ground collecting in poorly studied, inaccessible, or simply vast areas of the tropics is costly, labour intensive and time consuming, where possible the conservation and taxonomist community must make a concerted effort to mobilise digitisation and georeferencing and widen accessibility of existing records for under-represented regions.

3.5.2 Data quality

Number of GBIF records per species was significantly reduced by cleaning. 45.8% of total records for the study subset were unusable, the majority (97.2%) being duplicate records. A previous study into GBIF data quality using Chapman's cleaning guidelines (Chapman, 2005) made even greater reductions: 7.5% of records for East African chameleons were deemed useable (Hjarding *et al*., 2014). In light of this marked difference in data quality between groups, it can be argued that, for some taxa, GBIF records do represent a significant resource for biogeography and conservation research, and should not be dismissed as poor quality on the basis of previous studies of different groups. However, nor should they be used without cleaning or refining. For timbers, record removal was highest for species located in the tropics, and lowest for those in temperate zones. This geographic difference in data quality could be the result of higher rates of duplication for tropical species (i.e. the same specimen data submitted multiple times), and merits further investigation.

3.5.3 Red Listing applications

EOO estimates for 49 species under the four data-refining scenarios revealed that estimates made using cleaned or refined records were significantly different to estimates that used raw records. This suggests that cleaning or refining are necessary to increase reliability of EOO estimates using GBIF records. Refining by native range according to expert information from *The World List of Threatened Trees* (Oldfield *et al*., 1998) gave the most conservative estimates of EOO – that is, more species were assigned to higher threat categories or listed as DD under this data-refining scenario. Refining by flora gave the next most conservative estimates, followed by cleaning (**Table 3.5**). However, not all timbers are represented in the World List, whereas the reference floras gave native range for all. Therefore, in-flora native ranges will be used as spatial validation references in subsequent EOO calculations (**Chapter 4**).

The results presented here demonstrate that EOO estimates using the MCP approach for timbers using cleaned or refined GBIF records can be used to identify species likely to be at lower risk of extinction (under Criterion B1, an EOO greater than 20,000 km^2), leaving the remainder of species for full Red List assessment. It should be noted that the Category of Least Concern should not be automatically assigned to species identified as lower risk on the basis of EOO alone, as any categorisation requires a full Red List assessment; this procedure is intended to aid prioritisation of species for more urgent attention.

Results suggest that GBIF data alone give unreliable estimates of AOO for timbers, under all data-refining scenarios. AOO estimates under all scenarios were misleadingly conservative for species with few records, listing the majority of species in high threat categories (**Table 3.4**). Additionally, it is difficult to assess occupancy reliably with incomplete presence records, no absence records, and little information on sampling effort (with the exception of collection date). It is therefore recommended that, when using GBIF records to calculate species AOO, the resulting estimates be recognized as the lower end of a scale – i.e. the minimum possible occupancy – and that, in addition, maps of suitable habitat such as extent of forest cover within EOO MCP be used to estimate maximum possible occupancy, to aid in the calculation of AOO.

3.5.4 Limitations

The main study limitation is the fact that exact EOO and AOO for these species remain unknown, as a consequence of incomplete and infrequent collection. As a result, the estimates produced in this study cannot be tested against 'true' distributions (although note that this is done for select species in **Chapter 5**, when testing the uncertainty of the **Chapter 4** Red List assessments). Furthermore, both available 'expert' datasets used in this study lacked coordinates. However, these limitations are illustrative of the reality of data scarcity for many tree taxa, particularly those found in the tropics.

When comparing expert-refined (reference floras or the World List) data to cleaned data, the key procedural difference is that refined record datasets were not checked for erroneous taxonomy. Duplicates were removed in both scenarios, and refining to only native range records automatically removed 0,0 coordinate records. Of the 49 species for which EOO estimates were compared between scenarios, only three species were found to have erroneous names during cleaning, calling for removal of only three to four records each. Although we cannot be sure that these three species are typical of all timbers, erroneous taxonomy was the reason for only 1% of record removals during cleaning of the full 304 study subset, thus it the seems unlikely that a significant number of future flora-refined timber records will include taxonomic errors.

The considerable time-saving between data scenarios: six minutes per species (during flora country matching by hand) versus up to 20 minutes per species (taxonomy checks and removal of 0,0 records during cleaning) suggests that refining in place of full cleaning is a trade-off worth making in the initial stages of prioritizing species for full Red List assessment.

3.6 Conclusion

For a representative subset of 304 timber trees, over half of available GBIF records were useable after cleaning. While record cleaning by hand entailed considerable time, we demonstrate that floras can be used to more quickly and easily refine GBIF data for use in Red Listing, given that estimates of EOO were not significantly different from estimates using cleaned records. Lastly, GBIF records can represent an important addition to expert datasets that are at a broad resolution or that lack coordinates.

3.7 References

Akçakaya, H, R., Ferson, S., Burgman, M. A., Keith, D. A., Mace, G. M. and Todd, C. R., 2000. Making Consistent IUCN Classifications under Uncertainty. *Conservation Biology*, 14 (4), 1001-1013.

Bachman, S., Moat, J., Hill, A. W., de la Torre, J. & Scott, B., 2011. Supporting Red List threat assessments with GeoCAT: geospatial conservation assessment tool. In: V. Smith & L. Penev (eds), e-Infrastructures for Data Publishing in Biodiversity Science. *ZooKeys,* 150, 117-126. (Version BETA).

Beck, J., Ballesteros-Mejia, L., Nagel, P. and Kitching, I. J., 2013. Online solutions and the "Wallacean shortfall": What does GBIF contribute to our knowledge of species' ranges? *Diversity and Distributions*, 19 (8), 1043-1050.

Beck, J., Böller, M., Erhardt, A. and Schwanghart, W., 2014. Spatial bias in the GBIF database and its effect on modeling species' geographic distributions. *Ecological Informatics*, 19, 10-15.

Brummitt, N., Bachman, S. P., Aletrari, E., Chadburn, H., Griffiths-lee, J., Lutz, M., Moat, J., Rivers, M. C., Syfert, M. M. and Lughadha, E. M. N., 2015. The Sampled Red List Index for Plants , phase II: ground-truthing specimen-based conservation assessments. *Philosophical Transactions of the Royal Society of London*, *Series B, Biological Sciences*, 370 (1662). [Online] Available from: doi: 10.1098/rstb.2014.0015.

Cayuela, L., Golicher, D.J., Newton, A.C., Kolb, M., de Alburquerque, F.S., Arets, E.J.M.M., Alkemade, J.R.M. and Pérez, A.M., 2009. Species distribution modeling in the tropics: Problems, potentialities, and the role of biological data for effective species conservation. *Tropical Conservation Science*, 2 (3), 319-352.

Chapman A. D., 2005. Principles and Methods of Data Cleaning. Report for the Global Biodiversity Information Facility 2004. Copenhagen: GBIF.

ESRI (Environmental Systems Resource Institute), 2012. ArcMap 10.1. [Computer program] ESRI, Redlands, California.

FAO, 2010. Global Forest Resources Assessment 2010. Rome: Food and Agriculture Organization of the United Nations.

Ficetola, G. F., Rondinini, C., Bonardi, A., Katariya, V., Padoa-Schioppa, E. and Angulo, A., 2014. An evaluation of the robustness of global amphibian range maps. *Journal of Biogeography*, 41 (2), 211-221.

Gaston, K. J. and Fuller, R. A., 2009. The sizes of species' geographic ranges. *Journal of Applied Ecology*, 46 (1), 1-9.

Global Biodiversity Information Facility (GBIF). [Online]. Available from: http://www.gbif.org/. [Accessed: November 2013 - January 2014].

Global Forest Watch, 2014. World Resources Institute. [Online]. Available from: www.globalforestwatch.org. [Accessed 20 March 2015].

Hjarding, A., Tolley, K. A. and Burgess, N. D., 2014. Red List assessments of East African chameleons: a case study of why we need experts. *Oryx.* Available from: doi:10.1017/S0030605313001427.

IBM Corp., 2013. SPSS Statistics for Windows, Version 22.0. [Computer software]. Armonk, NY: IBM Corp.

iNaturalist, 2014. Available from: http://www.inaturalist.org. [Accessed May 2015].

International Standards Organisation, 2013. ISO Standard 3166 Country Codes [Online]. Available from: https://www.iso.org/obp/ui/#search. [Accessed: April 2015].

IUCN, 2014. IUCN Red List of Threatened Species Version 2013.2. [Online]. Available from: www.iucnredlist.org [Accessed: 3 January 2014].

IUCN Standards and Petitions Subcommittee, 2017. Guidelines for Using the IUCN Red List Categories and Criteria. Version 13. Prepared by the Standards and Petitions Subcommittee. Downloadable from: http://www.iucnredlist.org/documents/RedListGuidelines.pdf.

Joppa, L. N., Butchart, S. H. M., Hoffman, M., Bachman, S., Akçakaya, H. R., Moat, J., Bohm, M., Holland, R. A., Newton, A., Polidoro, B. and Hughes, A., 2015. Impact of alternative metrics on estimates of extent of occurrence for extinction risk assessment. *Conservation Biology*. Available from: doi: 10.1111/cobi.12591. [Accessed: 15 August 2015]

Joppa, L. N., Roberts, D. L. and Pimm, S. L., 2012. Taxonomy that matters: Response to Bacher. *Trends in Ecology and Evolution*, 27 (2), 66.

Mace, G. M., Collar, N. J., Gaston, K. J., Hilton-Taylor, C., Akçakaya, H. R., Leader-Williams, N., Milner-Gulland, E. J. and Stuart, S. N., 2008. Quantification of extinction risk: IUCN's system for classifying threatened species. *Conservation Biology*, 22 (6), 1424-1442.

Maes, D., Isaac, N. J. B., Harrower, C. A., Collen, B. E. N., Strien, A. J. V. A. N. and Roy, D. B., 2015. The use of opportunistic data for IUCN Red List assessments. *Biological Journal of the Linnean Society*. 115, 690-706.

Mark, J., Newton, A. C., Oldfield, S., Rivers, M., 2014. A Working List of Commercial Timber Tree Species. Botanic Gardens Conservation International. [Online]. Available from: http://www.bgci.org/news-and-events/news/1175/. [Accessed: 1 November 2014].

Miller, J. S., Porter-Morgan, H. A., Stevens, H., Boom, B., Krupnick, G. A., Acevedo-Rodríguez, P., Fleming, J. and Gensler, M., 2012. Addressing target two of the Global Strategy for Plant Conservation by rapidly identifying plants at risk. *Biodiversity and Conservation*, 21 (7), 1877-1887.

Oldfield, S., Lusty, C. and MacKinven, A., 1998. The World List of Threatened Trees. Cambridge: WCMC, IUCN.

Paton, A. J., Brummitt, N., Govaerts, R., Harman, K., Hinchcliffe, S., Allkin, B., Nic Lughadha, E., Species-progress, K. P., Lughadha, E. N., Taxon, S. and May, N., 2008. Towards Target 1 of the Global Strategy for Plant Conservation: a working list of all known plant species - progress and prospects. *Taxon*, 57 (2), 602-611.

Pimm, S. L., Jenkins, C. N., Abell, R., Brooks, T. M., Gittleman, J. L., Joppa, L. N., Raven, P. H., Roberts, C. M. and Sexton, J. O., 2014. The biodiversity of species and their rates of extinction, distribution, and protection. *Science*, 344 (6187), 1246752.

Rivers, M. C., Taylor, L., Brummitt, N. A., Meagher, T. R., Roberts, D. L. and Lughadha, E. N., 2011. How many herbarium specimens are needed to detect threatened species? *Biological Conservation*, 144 (10), 2541-2547.

Romeiras, M. M., Figueira, R., Duarte, M. C., Beja, P. and Darbyshire, I., 2014. Documenting biogeographical patterns of African timber species using herbarium records: A conservation perspective based on native trees from Angola. *PLoS ONE*, 9 (7), e103403.

RStudio, 2014. RStudio: Integrated Development for R. RStudio Inc., Boston, MA. [Online]. Available from: http://www.rstudio.com/.

The Plant List, 2013. Version 1.1 [online]. Available from: http://www.theplantlist.org/. [Accessed: March 2014].

Yesson, C., Brewer, P.W., Sutton, T., Caithness, N., Pahwa, J.S., Burgess, M., Gray, W.A., White, R.J., Jones, A.C., Bisby, F.A. and Culham, A., 2007. How global is the global biodiversity information facility? *PLoS One*, 2 (11), e1124.

4 IUCN Red List extinction risk assessments of timber tree species

4.1 Introduction

The world's commercial timber tree species face pressure from deforestation, fragmentation and legal and illegal logging. Additionally, the majority of hardwood timber species are long-lived, slow-growing and, particularly in the tropics, occur naturally at low population densities (Schulze *et al*., 2008). Such life-history strategies are considered high-risk, particularly in the context of current deforestation rates, and can make population recovery, from the effects of over-exploitation for example, a slow process (Purvis *et al*., 2000). Despite their economic, environmental and cultural importance, up-to-date extinction risk status of over 1,500 timber tree species remains largely unknown. Targets 2 and 12 of The Global Strategy for Plant Conservation (GSPC) call for full knowledge of the conservation status (extinction risk) of all known plant species, in addition to sustainable harvesting of all wild-sourced plant-based products, including timber, by the year 2020 (CBD, 2012).

IUCN Red List (Red List) projects involving timber trees have previously concentrated on certain regions or families. For assessments of timbers in Central Africa, Rodrigues *et al*. (n.d.) stressed the importance of making use of forest inventory data; Fauna and Flora International (2006) used logging harvest datasets in a comprehensive assessment of mahogany in Central America; and Villanueva-Almanza (2013) included an evaluation of 'harvesting likelihood' (based on access, value and size class) to assessments of seven Kenyan and Tanzanian timbers. In addition, the Global Tree Campaign (GTC) has compiled and published global Red List assessments for several groups including the Betulaceae (Shaw *et al*., 2014), Magnoliaceae (Cicuzza *et al*., 2007) and oaks (Oldfield and Eastwood, 2007).

A recent review by BGCI found that, of the 1,538 tree species identified in **Chapters 2 and 3** as commercially harvested for timber, 873 have been previously Red Listed at the global scale (M. Rivers, pers. comm., 26th February 2015). Some 80% of these previous assessments were conducted in 1998 as part of the *World List of Threatened Trees* (Oldfield *et al*., 1998). As such, the majority of existing global-scale extinction risk assessments for timber trees are almost twenty years old and were conducted using a now outdated version of the Red List Categories and Criteria (Version 2.3). Furthermore, the 1998 assessments did not include distribution maps, and often lacked quantitative evaluation of the impacts of deforestation on these taxa. Many timber tree species still lack extinction risk assessments entirely. Thus, there is an urgent need to carry out up-to-date Red List assessments for the world's timber tree species.

A further consideration is how to best apply Version 3.1 of the Red List Categories and Criteria for these up-to-date assessments. Comprehensive Red List assessment should involve application of all Red List Criteria (A-E) for which data are available (IUCN Standards and Petitions Subcommittee, 2017). Version 3.1 of the IUCN Red List was designed for maximum applicability among taxa (Mace *et al*., 2008). As a consequence, application of Criteria can involve use of proxy data, inference or estimation on the part of the assessor (Lusty *et al.,* 2007; IUCN Standards and Petitions Subcommittee, 2017). This framework allows quantitative thresholds to be applied, even under uncertainty (Akçakaya *et al.* 2000). Recent studies on the threats faced by Amazonian trees (ter Steege *et al*., 2013) and forest-dwelling vertebrates (Ocampo-Penuela *et al*., 2016; Tracewski *et al.*, 2016) have made use of a high-resolution satellite imagery dataset of forest cover, with near-global coverage, recently made open-access by researchers at the University of Maryland (Hansen *et al.,* 2013). Other open-access datasets available through the Global Forest Watch (2014) platform grant access to data on national land use, including maps of oil palm and wood fibre plantations. The growing availability of such high-quality, open-access datasets presents the Red List assessor community with valuable resources with which to tackle the challenges of meeting international conservation goals, including the approaching GSPC 2020 assessment targets.

Although studies are increasingly addressing the need for additional guidance when using limited or proxy data for Red List assessments (Syfert *et al*., 2014; Newton, 2010; Akçakaya *et al*., 2000), few studies have expressly addressed application of the Red List

Categories and Criteria to commercially harvested trees. Lusty *et al.* (2007) made general recommendations for making assessments in a forest setting, including 'rules of thumb' regarding use of proxy data when dealing with unknowns such as the generation length of certain tree species. More recently, Rivers *et al.* (2010) used spatial analysis to investigate application of Red List Criteria using herbarium specimen data. However, there remains no unified best-practice for applying the Red List Criteria to harvested trees.

This chapter aims to utilise open-access datasets and Version 3.1 of the IUCN Red List Categories and Criteria to quantitatively assess extinction risk of a study group of timber tree species, prioritised on the basis of range restriction and/or previous IUCN Red List 'Threatened' status. In doing so, it addresses the research question: *How many of the world's wild-harvested, angiosperm timber tree species are currently threatened with extinction, according to IUCN Red List Categories and Criteria Version 3.1?* The preliminary assessments produced will contribute to GSPC targets and a better understanding of the impacts of deforestation on timber tree species. The data-handling approaches used will also aid future tree species Red List assessments.

4.2 Methods

A total of 324 angiosperm timber tree species were selected for preliminary extinction risk assessment through full application of the IUCN Red List (Red List) Categories and Criteria (see **Appendix C, Table C1** for the full species list). Species were selected from the working list of timber tree species formulated in **Chapter 2** and refined in **Chapter 3**, on the basis of restricted range (that is, an extent of occurrence, or 'EOO', of <20,000 km^2), and/or previous Threatened or Near Threatened IUCN Red List categorisation. EOO (using the Minimum Convex Polygon, or 'MCP' approach) was mapped with cleaned and country-matched distribution records from the Global Biodiversity Information Facility (GBIF) records. See **Chapter 3** for full details on GBIF data cleaning and country-matching using floras.

The IUCN Red List is globally recognized as the most comprehensive and objective system for determining species extinction risk (Rodrigues *et al.*, 2006). Under the most recent revision of the Red List Categories and Criteria, Version 3.1, taxa are assigned to one of nine Categories, from Not Evaluated (NE) to Extinct (EX). **Figure 4.1** illustrates the hierarchy of Categories. Taxa assigned to the three Threatened categories: Vulnerable (VU), Endangered (EN), Critically Endangered (CR) are at the greatest risk of extinction. Taxa marked as Data Deficient (DD) should be treated as priorities for research (IUCN Standards and Petitions Subcommittee, 2017).

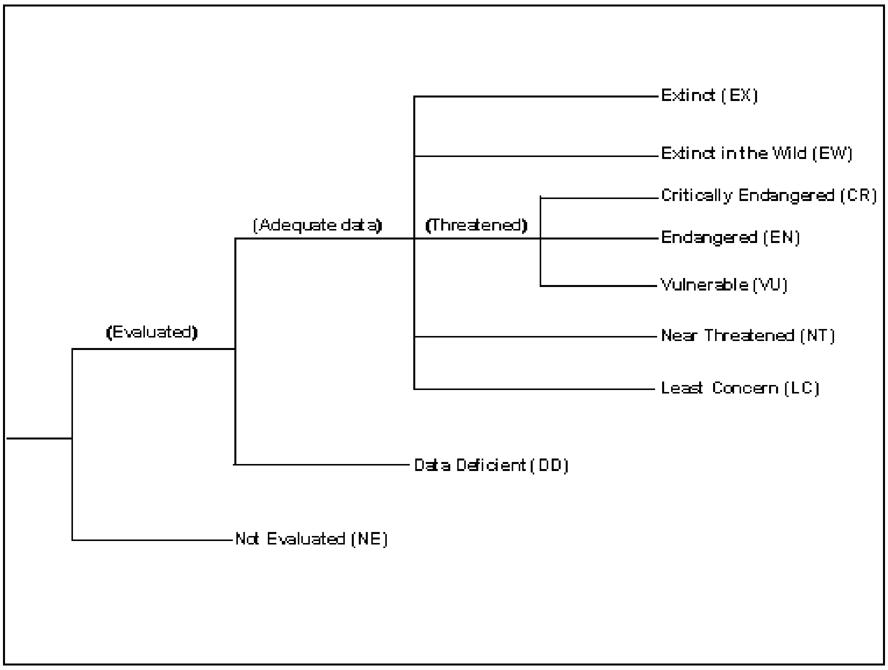


Figure 4.1 Structure of the IUCN Red List Categories, Version 3.1 (IUCN, 2001).

Categorisations are made after application of five quantitative Criteria A-E, based on past, current and future projected population reductions (A); geographic range size (B); small and declining population size (C); very small or restricted population (D); and quantitative analysis, usually in the form of a population viability analysis model (E). A taxon does not need to meet threatened thresholds for all five Criteria in order to be placed in a certain Category, but the taxon should be assessed against all Criteria for which the available data allow. In cases where multiple categories are applicable the most conservative Category (i.e. the Category signifying the greatest risk of extinction) dictates the final categorisation.

Table 4.1 outlines the thresholds and guidance for assigning Threatened and Near Threatened (NT) Categories. Importantly, the current Red List Criteria are designed to be widely applicable across a very broad range of taxonomic groups, as well as allowing assessors to make robust decisions under data uncertainty (Akçakaya *et al*., 2000). This section describes the steps taken to apply each Red List Criterion and sub-criterion, starting with Criterion A.

*Table 4.1 Summary of IUCN Criteria and Sub-criteria for applying Threatened Categories Critically Endangered (CR), Endangered (EN), and Vulnerable (VU) alongside guidance for assigning the Near Threatened (NT) category (IUCN, 2001; IUCN Standards and Petitions Subcommittee, 2017). * Where the timescale guidance "10 years/3 generations" is given, the longer of these options should be used, with reference to the taxon's life history.*

Criterion	CR	EN	VU	Guidance & Sub-criteria	NT Guidelines
A1: reduction in population size	≥90%	≥70%	≥50%	Over 10 years/3 generations in the past *, where causes are reversible, understood and have ceased.	Population has declined by 40% in the last 3 generations / 10 years, but the decline has stopped, and the causes of the decline have been understood.
A2-4: reduction in population size	≥80%	≥50%	≥30%	Over 10 years/3 generations in past, future or combination.	Population has declined by an estimated 20-25% in last 10 years / 3 generations.
B1: small range (extent of occurrence)	<100km^2	<5000km^2	<20000km^2	Plus two of (a) severe fragmentation/few localities (1, ≤5, ≤10), (b) continuing decline, (c) extreme fluctuation.	Taxon occurs at 12 locations, meets Crit. B area requirements for threatened and is declining, with no extreme fluctuations or severe fragmentation. OR taxon meets Crit. B area requirements, is severely fragmented but not declining, and occurs at >10 locations with no extreme fluctuations. The taxon is declining and occurs at 10 locations OR is severely fragmented, but has an EOO of 30,000km^2 and/or an AOO of 3,000km^2, which are uncertain estimates. OR taxon is declining and severely fragmented, but has an EOO of 22,000km^2 and/or an AOO of 3,000km^2, which are highly certain estimates.
B2: small range (area of occupancy)	<10km^2	<500km^2	<2000km^2	Plus two of (a) severe fragmentation/few localities (1, ≤5, ≤10), (b) continuing decline, (c) extreme fluctuation.	

Table 4.1 continued

Criterion	CR	EN	VU	Guidance & Sub-criteria	NT Guidelines
C: small and declining population	<250	<2500	<10 000	Mature individuals. Continuing decline either (1) over specified rates and time periods or (2) with (a) specified population structure or (b) extreme fluctuation.	Population has ~15,000 mature individuals and is declining AND has declined by estimated 10% in last 3 generations OR exists in a single subpopulation.
D1: very small population	<50	<250	<1000	Mature individuals	Population has ~1,500 mature individuals, or a best estimate of 2,000, but the estimate is very uncertain and numbers could be as low as 1,000 mature individuals.
D2: very small range locations	N/A	N/A	<20 km^2 or ≤5	Capable of becoming Critically Endangered or Extinct within a very short time.	Taxon exists at 3 sites and occupies 12 km^2; the population is harvested but is not declining and faces no current threats. Decline is plausible but unlikely to make the species EX or CR very soon.
E: quantitative analysis	50% in 10 years / 3 gens.	20% in 20 years / 5 gens.	10% in 100 years	Estimated extinction risk using quantitative models.	

4.2.1 Criterion A

Criterion A assesses past, ongoing or projected future population decine over the longer of ten years or three generations. Declines may be based on (a) direct observation, or they may be estimated, inferred or suspected based on any of: (b) an appropriate index of abundance such as habitat reduction; (c) a decline in extent of occurrence (EOO), area of occupancy (AOO), and/or habitat quality; (d) actual or potential levels of exploitation; or (e) the effects of introduced taxa (including pathogens, competitors and parasites), pollutants or hybridisation. Past reductions may have ceased and be reversible and understood (sub-criterion A1), or be ongoing, or not understood, or irreversible (sub-criterion A2). Reductions may also be projected up to a maximum of 100 years into the future (sub-criterion A3), or over a time window including both past and future, up to a maximum of 100 years into the future (sub-criterion A4).

Sub-criterion A1 was not considered applicable, as reductions were not believed to have ceased for any of the study species, as they continue to be harvested for timber (Mark *et al*., 2014). Generation length is very difficult to estimate for long-lived tree species (Lusty *et al*., 2007). Therefore, a timescale of 100 years was used to apply sub-criteria A2-A4, giving one generation length as approximately 33.3 years. This timescale was chosen to acknowledge the longevity of the majority of angiosperm timber tree species, and to utilise the maximum allowed future projection time period. Furthermore, it was assumed that 100 years would capture most of the significant major anthropogenic deforestation events that had impacted study species populations in the past. The same assumption regarding past declines was made by Tejedor Garavito *et al*. (2015) in an extinction risk assessment of Andean trees.

Where population time-series data do not exist, deforestation can be used as a proxy from which to estimate associated population reductions. In the interests of uncertainty, three forest cover change scenarios were used to apply A2-A4, using annual deforestation rates calculated using satellite images of regional gross forest loss for the years 2000-2014 downloaded from the Global Forest Change (GFC) database (Hansen *et al*., 2013).

The GFC database from Hansen *et al*. (2013) provides 30 metre resolution, global Landsat maps of baseline tree cover for the year 2000, tree cover losses 2000-2014, and gains 2000-2012. The GFC dataset is available for download from Google Earth Engine in the format of 10 by 10 degree map tiles (http://earthenginepartners.appspot.com). Tiles were downloaded in continent batches, using the ‘gfcanalysis’ package in RStudio (RStudio, 2014). All further GIS analyses were performed in ArcMap 10.1 (ESRI, 2012). For each tile, the following data layers were downloaded: baseline tree cover in the year 2000 (‘treecover2000’), total tree cover loss between the years 2000-2014 (‘loss’), and annual tree cover loss 2000-2014 (‘lossyear’). Each continent layer was re-projected into World Mollweide. Clips of baseline tree cover in the year 2000, total loss, and loss by year were batch produced to correspond to the EOO MCP of each study species. Pixels showing loss were assumed to have completely lost all their forest cover over the dataset time period, changing from a forested to non-forested state.

Originally from the Latin meaning *land that is off-limits [to commoners]*, ‘forest’ is a broad term, encompassing natural and planted trees as well as various degrees of land ownership, uses and protections. Definitions are often based on management objectives and may be regionally inconsistent (Chazdon *et al*., 2016). The GFC dataset makes no attempt to define ‘forest’, and instead provides tree cover, where ‘tree’ denotes all vegetation over five metres in height, and canopy cover is given as 0-100% per $30m^2$ pixel (Hansen *et al*., 2013). In this study, two definitions of ‘forest’ were used when calculating extent of forest; 1) canopy cover 10-100% as consistent with national Forest Resources Assessments (FAO, 2015) and 2) canopy cover 30-100%, a scale recommended for reliable detection of land cover change when using 30m resolution imagery (Hansen *et al*., 2010).

Two measures of baseline forest cover were calculated within the EOO of each species by reclassifying pixels as ‘forest’ (value of 1) or ‘non-forest’ (value of 0). Overlaying forest loss 2000-2014 over forested area in the year 2000 allowed the area of forest remaining in year 2015 to be estimated for all species. Since Red List assessments are concerned only with natural populations, plantations were not considered ‘forest’ in this study. Maps of oil palm and wood fibre plantations were available from Global Forest Watch (GFW) for the following countries: Cameroon, Gabon, Indonesia, Liberia and the Republic of Congo (Global Forest Watch, 2014). To calculate total natural forest cover within EOO MCPs, areas meeting the above definitions of ‘forest’ that were under oil palm or wood fibre plantation were removed for the 88 species for which GFW land use maps were available**.** An example of this forest versus non-forest differentiation is shown in **Fig. 4.2**.

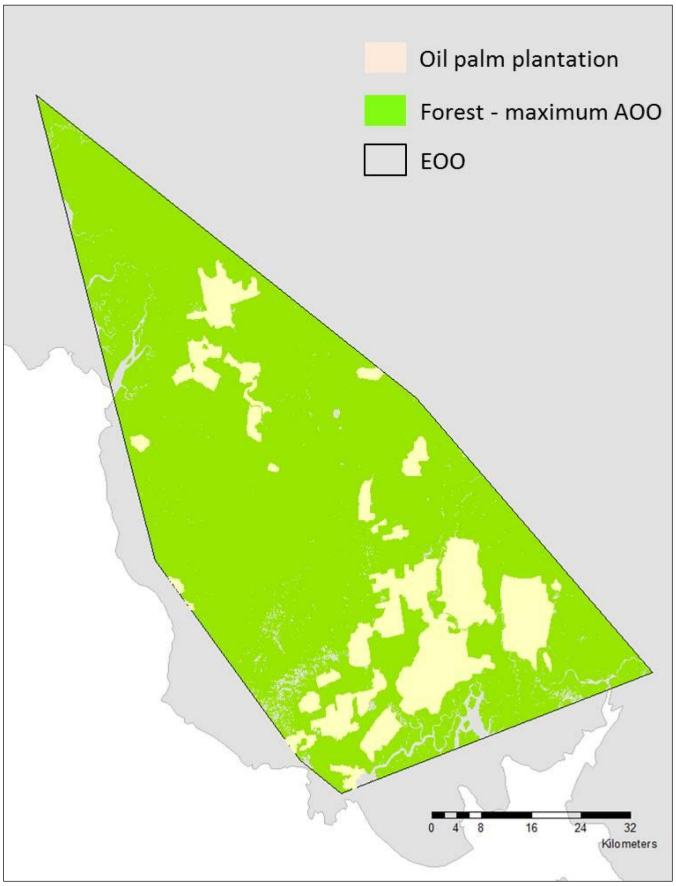


Figure 4.2 Non-native oil palm plantation (tan) contrasted with natural-growth forest (green) within the EOO of Oxystigma mannii.

To apply Criterion A, forest loss was calculated within each species' EOO MCP, or throughout the native range countries where the species occurs naturally, when EOO could not be calculated (see the 'Criterion B' section below). Deforestation estimates from the 2015 Forest Resources Assessment (FRA) – reports of national forest loss and gain 1990-2015 for species native range countries (FAO, 2015) – were used as an alternative proxy for potential population size reduction. Annual forest cover change rates for each dataset were calculated using Puyravaud's (2003) equation:

$$r = (1/ (t_2 - t_1)) \times \ln(A_2 / A_1)$$

Where r is annual rate of change of forest cover, and A_1 and A_2 are the areas of forest at the first (t_1) and second (t_2) time-points, respectively. The resulting rates were used to calculate percentage change in area of forest over 100 years past (sub-criterion A2) and future (sub-criterion A3), and 50 years into both past and future (sub-criterion A4). In all cases, area of forest in the year 2015 was taken as the baseline 'current' forest cover from which to subtract or project 100 or 50 years into past or future. This was because 2015 was the most recent year for which comprehensive forest cover data were available from GFC and FRA at the time of writing.

Forest change scenarios were as follows:

- *Scenario 1a (S1a):* GFC forest change rate 2000-2014 and GFC forested area within each species' EOO MCP, where 'forest' was defined as vegetation >5m in height with 30-100% canopy cover.
  Scenario 1b (S1b): GFC forest change rate 2000-2014 and GFC forested area within each species' total native range countries, where 'forest' was defined as vegetation >5m in height with 30-100% canopy cover.

- *Scenario 2a (S2a):* GFC forest change rate 2000-2014 and GFC forested area within each species' EOO MCP, where 'forest' was defined as vegetation >5m in height with 10-100% canopy cover.
  Scenario 2b (S2b): GFC forest change rate 2000-2014 and GFC forested area within each species' total native range countries, where 'forest' was defined as vegetation >5m in height with 10-100% canopy cover.

- *Scenario 3 (S3):* FRA forest change rate 1990-2015 (species native range country total) and FRA total native range country forested area, where 'forest' was defined as vegetation >5m in height with 10-100% canopy cover (FAO, 2015).

Scenarios 1 and 2 were each broken down into (a) and (b), based on the geographic area defined as 'species range'. S1a and S2a were used for the 240 study species with ≥3 GBIF occurrence records enabling EOO MCPs to be calculated. S1b and S2b were used for the remaining 84 species with <3 occurrence records, for which MCPs could not be calculated, but for which native range countries were known. Forest cover change and associated population size change were therefore calculated for all study species under three scenarios: S1a, S2a and S3 for species with ≥3 GBIF occurrence records; S1b, S2b and S3 for species with <3 GBIF occurrence records.

Although S1 and S2 both use the same underlying dataset, they use different definitions of forest cover. Ideally, S2 would be used alone to represent the GFC dataset, as this scenario is most consistent with the definition of 'forest' used in the FRA 2015 country reports (S3). However, a higher canopy cover value is recommended for reliable detection of land cover change when using 30 metre resolution satellite imagery (Hansen *et al*., 2010), and there is also an argument for forest change to be measured at higher canopy densities, as greater canopy cover is considered characteristic of more intact forest ecosystems, excepting some naturally sparse dry forest habitats (Rocha-Santos *et al*., 2016).

Associated percent population declines were then estimated based on the area of forest lost within each species' range (forested area within EOO MCP or range countries' total forested area) under each scenario, assuming a one-to-one relationship between percent forest loss and percent population size reduction.

Population decline estimates used to apply Criterion A were therefore based on indices of abundance appropriate to the study species – deforestation within native range, which has brought about a decline in area of EOO, area of AOO, and habitat quality. Deforestation may be the result of clearance for agriculture, extractive industry, development, or clear-cutting for timber harvest. Therefore, Criterion A sub-criteria A2-A4 were applied based on (b) index of abundance, and (c) decline in range and/or habitat quality. **Figure 4.3** illustrates GFC gross forest loss within the EOO of an example species, *Hopea beccariana* over the period 2000-2014.

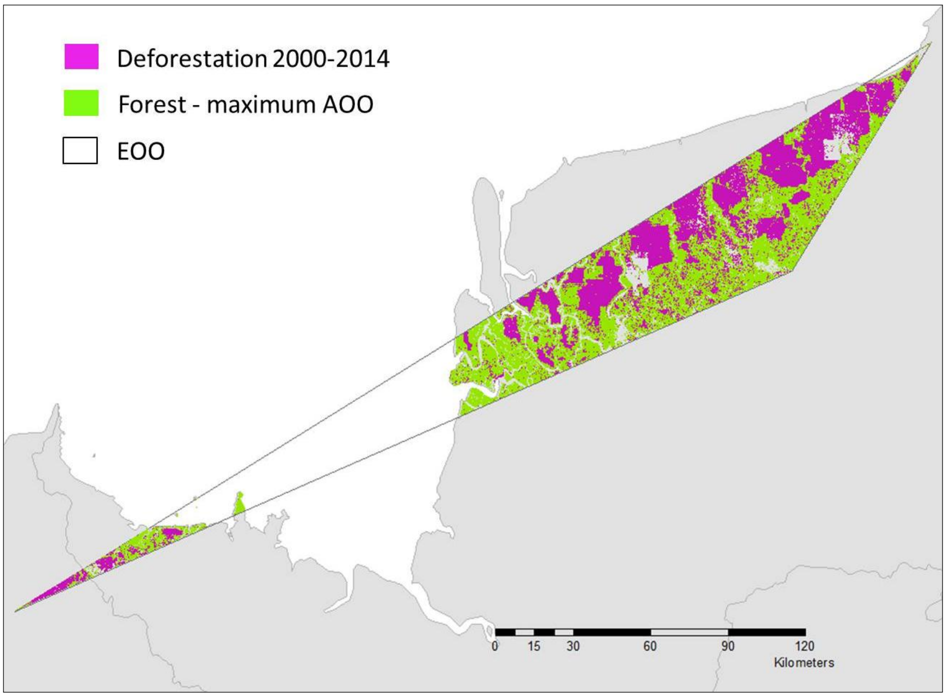


Figure 4.3 Deforestation (purple) within the EOO of Hopea beccariana over time period 2000-2014, calculated from GFC data (Hansen et al., 2013) under Scenario 1a.

4.2.2 Criterion B

Criterion B addresses species range under two metrics; extent of occurrence (EOO) and area of occupancy (AOO). EOO is usually measured as the area of a Minimum Convex Polygon (MCP) – "the smallest polygon in which no internal angle exceeds 180 degrees" (IUCN Standards and Petitions Subcommittee, 2017) – drawn around the species' outermost occurrence points. Although frequently misunderstood in the literature (Collen *et al*., 2016; Ocampo-Penuela *et al*., 2016), the EOO is used to assess the potential for a single threatening event to impact the entire population of a taxon (IUCN Standards and Petitions Subcommittee, 2017). Thus, the EOO MCP is likely to include areas of unsuitable or unoccupied habitat, if they fall within this polygon. A small EOO may increase the risk of extinction from threatening events, because the impact is more concentrated. Although various alternative 'range' metrics abound, EOO was recently demonstrated to be the most effective for Red List assessments (Joppa *et al*., 2015).

The AOO is the area of all occupied or potentially occupied habitat within the EOO, and conveys information on the area of remaining habitat. Where population size is uncertain, the AOO can also serve as a useful proxy for population size. Species with very small AOOs may be range-restricted, persisting at low population sizes, or clinging on in a diminished area of habitat that is too small to support a minimum viable population. Small populations are more likely to face increased risks from inbreeding, low genetic variation, and demographic stochasticity (Matthies *et al*., 2004).

Calculating species EOO and AOO requires knowledge of geographic occurrence. Firstly, geographical observation records for the 324 study species were extracted from the Global Biodiversity Information Facility (GBIF). The records were cleaned to remove those with absent or obviously erroneous geographic coordinates, such as non-terrestrial locations, and checked against accepted species binomials using *The Plant List* (2013) as taxonomic reference. Published floras were used to discount records falling outside of accepted historical ranges, to minimise risk of including GBIF records resulting from the recording of *ex situ* individuals situated in non-native plantations, botanical gardens or urban areas. For in-depth GBIF data processing methods, see **Chapter 3**.

The resulting cleaned and range-matched occurrence records were used to draw species-specific EOO MCPs in ArcMap 10.1. **Fig. 4.4** demonstrates EOO and GBIF occurrence records for an example species, *Copaifera salikounda*. To ensure that measurements were as consistent as possible across all latitudes, the Mollweide World equal area map projection was used for all ArcMap analyses.

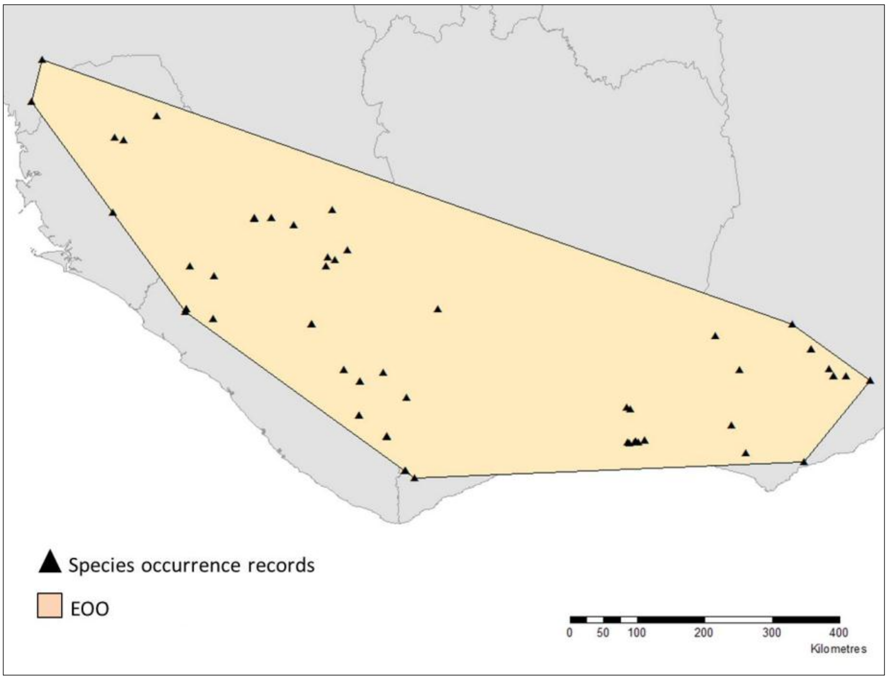


Figure 4.4 EOO and GBIF point records for Copaifera salikounda.

AOO is typically calculated by overlaying a grid onto occurrence points, and summing the maximum area of occupied cells. AOO was calculated in this way for all species, using a 4 km^2 grid. However, the grid method introduces additional bias to the AOO calculation, as it is dependent on the number of occurrence records available for each species. Thus, a 'maximum' possible occupancy was also calculated for each species using GFC satellite imagery for the year 2000, in the form of area of forest within each EOO.

In addition to EOO (sub-criterion B1) and AOO (sub-criterion B2), two out of three further sub-criteria must be met in order to apply Criterion B. Sub-criterion (a) deals with severe fragmentation or number of locations. Sub-criterion (b) deals with continuing decline in: (i) EOO; (ii) AOO; (iii) area, extent and/or quality of habitat; (iv) the number of locations or subpopulations; and (v) number of mature individuals. Sub-criterion (c) looks at extreme fluctuations in range, number of locations or subpopulations, and /or the number of mature individuals in the population.

Sub-criterion (a) *number of locations* was not assessed, as it requires knowledge of the geographic location of immediate threats to subpopulations. A 'location' in the IUCN sense refers to one part of a species' range that could be affected by a single, identified threatening factor, rather than a place where the species is found; the fewer locations there are, the fewer threatening factors are needed to impact the species across its entire range.

Instead, *severity of fragmentation* was assessed for the 52 species that met or were close to meeting threatened thresholds for B1 (EOO). A taxon qualifies as 'severely fragmented' if >50% of its total AOO (in this case, forested extent of EOO MCP is used as a proxy for maximum possible occupancy) is made up of habitat patches that are both isolated – separated from each other by a distance greater than the dispersal distance of the taxon – and smaller than would be required to support a viable population (IUCN Standards and Petitions Subcommittee, 2017). The 'Region Group' tool in ArcMap 10.1 was used to identify habitat patches within the forested EOO clips for each species (under the 30-100% canopy cover 'forest' definition). Each patch consisted of a group of 'forest' pixels connected at the sides or corners.

To identify isolated patches, the ArcMap 'Buffer' tool was used to buffer around each patch by the estimated mean maximum seed dispersal distance (MDD) of the species in question (see **Fig. 4.5** example). Seed rather than pollen dispersal was used following discussion at the 3rd Annual Meeting of the IUCN/SSC Global Tree Specialist Group (GTSG) concluding that, although pollen may travel much greater distances from the parent tree, migration of individuals (seeds) is more reliable as a measure of potentially successful dispersal than migration of gametes (pollen) (GTSG, 2015). MDD estimates for each species were calculated using the 'dispeRsal' function in RStudio (Tamme *et al*., 2014).

Linear models run in dispeRsal used the following traits as variables: seed dispersal syndrome, plant growth type, average tree height (where known) as a proxy for seed release height, and average seed mass (where known). Dispersal syndrome and seed mass data were retrieved from the Royal Botanic Gardens Kew Seed Information Database (2017) accessed 26th January 2017. Growth type in all cases was 'tree', and the remaining trait data were retrieved from a species- or genus-specific literature search. Where syndrome was unknown at the species level, the most common genus or family syndrome was assumed. The ArcMap 'Dissolve' tool was then used to merge patches with overlapping buffers, creating connected habitat patches based on dispersal distance. After this process, all unconnected patches were considered isolated by IUCN standards.

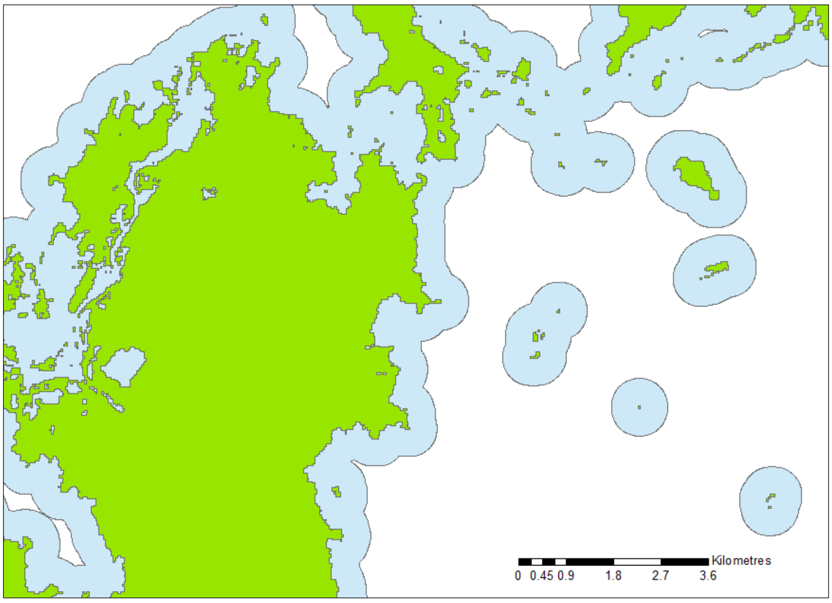


Figure 4.5 Example of maximum seed dispersal distance buffer (blue) connecting forest patches (green) within a non-forest matrix (white).

The concept of a general value for minimum viable population size (MVP) has been much-debated in the conservation literature (see Brook *et al*., 2011; Flather *et al*., 2011; Reed *et al*., 2003) but in recent years 5000 individuals has emerged as a rough 'rule of thumb' (Traill *et al*., 2007; Traill *et al*., 2010). In the absence of species-specific MVP estimates, this value was taken as the MVP for all study species. The area of each isolated patch was used in conjunction with species density estimates (see 'Criterion A' section above) extrapolated from forest plot abundance data to assess whether such patches were 'small' – i.e. too small to support the MVP. Species density of individuals per square kilometre was estimated based on mean values taken from forest plot measures of species abundance (trees ≥10cm diameter at breast height) made available by the Smithsonian Tropical Research Institute (Centre for Tropical Forest Science, 2017 – accessed 8th February 2017), and a wider species-specific literature search. Species with >50% of their forested 'maximum possible' occupancy in small and isolated patches were considered severely fragmented.

Sub-criterion (b) – continuing decline i-v – was determined by overlaying the GFC 'loss' layer over each species' forest cover clip. The ArcMap 'Combinatorial Or' tool was used to calculate the number of 'forest' pixels that had suffered tree cover loss during the time-period 2000-2014, and estimate area of forest from the year 2000 remaining at the beginning of the year 2015. Sub-criterion (b) options i, ii, and iii were thus satisfied by observation of deforestation from the GFC datasets, and option v (decline in number of mature individuals) was inferred from this deforestation. Sub-criterion (c) was not applied as knowledge of population age structure was insufficiently detailed, and deforestation data had not been recorded with sufficient regularity over a long enough timescale, to reliably distinguish extreme fluctuations in any of (c) i-iv.

4.2.3 Criteria C, D and E

Criteria C and D concern species with small, declining populations and those with very small or very restricted populations respectively. For both Criteria, population size is specified as 'number of mature individuals'. For Criterion C, threshold numbers of mature individuals are greater than for Criterion D but, for the former, the population must also be declining. Sub-criterion D2 applies only to species with very restricted populations (very small AOO). Criterion E uses quantitative analysis, usually in the form of a population viability assessment (PVA), to determine the probability of extinction in the wild within specified timeframes. With insufficient data to carry out PVAs for the study species, Criterion E could not be applied.

For Criteria C and D, number of mature individuals was inferred using species density estimates per square kilometre (see Criterion B MVP methods) to estimate densities across species' 'maximum possible occupancy' (forest extent within range) for the year 2015. Categorisation under Criterion C is dependant not only on threshold numbers of mature individuals, but on population declines also meeting thresholds under either sub-criterion C1 - ongoing, specified declines over 1-3 generations, or sub-criterion C2 - ongoing but unspecified declines as well as specified number / percentage of mature individuals in each subpopulation, or extreme fluctuations in the number of mature individuals. Due to insufficient information on subpopulation numbers or age structures, sub-criterion C2 could not be applied. However, sub-criterion C1 was applied using GFC and FRA forest cover change rates to estimate population size changes over 1-3 generations, that is approximately 33.3, 66.6, and 100 years (see Criterion A methods above for full description of calculations). Species' 'maximum possible occupancy' were used to apply sub-criterion D2 (very small AOO <20km^2).

4.2.4 Categorisation

After applying all Criteria for which the available data allowed, species were assigned to Categories following Red List Guidelines (IUCN Standards and Petitions Subcommittee, 2017). The final categorisation for each species was taken from the most conservative assessment based on all Criteria. Species that were very close to meeting VU thresholds (i.e. on the edge of Threatened Category thresholds) were assigned as NT (see **Table 4.1** for full NT guidance).

4.2.5 Calculating a Red List Index for timber tree species

A Red List Index (RLI) is a metric that monitors change in the extinction risk, assessed using IUCN Red List Categories and Criteria, of a taxonomic group over time (Butchart *et al*., 2006). RLIs have been calculated for birds, amphibians, mammals and corals (Butchart *et al*., 2004; Stuart *et al*., 2004; Carpenter *et al*., 2008; Schipper *et al*., 2008), and a Sampled Red List Index (SRLI), using a representative subset of the world's known plant species, is also underway (Brummitt *et al.,* 2015). Baseline RLI values have been calculated for reptiles, crayfish, freshwater crabs and dragonflies and damselflies (Clausnitzer *et al*., 2009; Cumberlidge *et al*., 2009; Böhm *et al*., 2013; Richman *et al*., 2015). A baseline value in this context is a single RLI value that represents the extinction risk, at a single time-point, of a taxonomic group in which all taxa have only been Red Listed once. The single time-point is thus the year in which the group was Red Listed. In addition, IUCN Red List assessments for all groups feed into the 'Barometer of Life' – an SRLI of all known species with the exception of microorganisms (Stuart *et al*., 2010), and these indexes are used to monitor progress towards the CBD 2020 global biodiversity targets and 2050 vision for biodiversity. The SRLI for plants also serves as an indicator to gauge progress towards the GSPC 2020 targets.

A RLI for harvested birds (Butchart, 2008) has been used to identify the impacts of regional and taxa-specific harvest intensity and gauge the effects of conservation actions and trade restrictions on species extinction risk over time. The impact of such positive and negative actions will have a lag time and, thus, effects on species may not be identified in a single Red List assessment Therefore a RLI represents an important monitoring tool, not only of extinction risk over time, but also of the impacts of specific events and actions. In a similar way, a RLI for angiosperm timbers could be used not only to monitor changes in extinction risk over time, but also to pinpoint regions or families suffering greatest declines and to attempt to identify and assess the effects of actions such as a range-country government imposing a trade ban, or a surge in demand for the wood of a particular genus.

A baseline RLI value for the year 2015 was calculated for the study group of 324 angiosperm timber tree species, using the preliminary species Red List assessments produced in this chapter. Calculations followed Butchart *et al.* (2007) as follows:

1) Each Red List Category, excluding Data Deficient, is weighted from zero to five, where Least Concern = zero, Near Threatened = one, Vulnerable = two, Endangered = three, Critically Endangered = four, and Extinct = five.

2) The total number of assessed study species in each Category (excluding all species assessed as Data Deficient and those species assessed as Extinct in the first assessment year) is multiplied by the corresponding weight of that Category.

3) The results of step (2) are summed across all Categories, giving a total (T).

4) The total number of species in the study group (excluding Data Deficient and Extinct) is multiplied by five (the maximum Category weight), giving a total (M).

5) The RLI value for that assessment year is then found using the formula:

$$RLI = 1 - (T/M)$$

This calculation is repeated for all years in which every study species has been Red Listed, and the calculation for each assessment year thus uses the input Red List categorisations for the study species for that year. The resulting RLI values for each year may then be examined to look at group extinction risk over time. Output values fall between zero and one, with values closer to zero indicating a higher risk of extinction, and values closer to one a lower risk of extinction.

To ensure that the RLI represents genuine change in extinction risk over time, changes in Red List Category for a study species from one year to the next may only be included if they are known to be the result of a genuine improvement or deterioration in that species' extinction risk. Therefore, if a study species has undergone a non-genuine change in Category, for example due to a change in assessor, a taxonomic revision, or improved knowledge, the original Category is kept in the RLI calculations.

4.3 Results

4.3.1 Forest areas under plantation

Under both the 10% and 30% canopy cover 'forest' definitions, total area of EOO covered by plantations ranged from 0.2 km^2 to 217,082.32 km^2. Percentage of EOO MCP area under plantation ranged from 0.01% to 22.87%, with a mean coverage of only 3.51%. With plantation areas removed, average annual area of deforestation within species EOOs over the period 2000-2014 ranged from 0.03 km^2 to 40,289.70 km^2, with a mean of 3189.95 km^2. On average, species lost 7% of their forested area per year under GFC deforestation scenarios. Plantation coverage data were only available for Cameroon, Gabon, Indonesia, Liberia and the Republic of Congo. Even assuming that all existing plantations are included in the GFW datasets for these countries, information on 'complete' coverage (i.e. for all native range countries) of oil palm and wood fibre plantations was only available for the native ranges of eight and seven endemic timber tree species respectively.

4.3.2 Criterion A

Forest cover change for species ranges based on GFC data (2000-2014) provides only gross deforestation, as the gains dataset is not comparable with the loss dataset (Hansen *et al*., 2013). In contrast, the FRA country reports (1990-2015) provide net forest cover change (losses and gains). Despite this, the majority of study species have suffered considerable deforestation over the dataset timescales under both GFC and FRA scenarios. **Figure 4.6** summarises forest cover change in square kilometres within species ranges, grouped by region. Boxplot S3 (FRA 1990-2015) shows that the majority of species suffered net loss of forested range, with the exception of some moderate gains in North America, and a few exceptionally high gains in Asia-Pacific ranges. Boxplots S1 and S2 (GFC 2000-2014 under the two different definitions of 'forest') show very similar levels of deforestation under these two scenarios. S2 shows more outliers in losses for African species, but the median and mean for this region are very similar under both GFC scenarios.

Forest cover changes for S3 are much greater than those for S1 and S2, firstly as a result of disparities in range area used for these scenario calculations – that is, S3 uses forest cover change across all native range countries of a species, for all study species, whereas S1 and S2 use forested area within EOO MCP (where known) for the majority of study species. Thus, to compare forest cover change impacts on species under GFC versus FRA scenarios, we look at the corresponding population size changes, estimated using Criterion A timescales (**Fig. 4.7**).

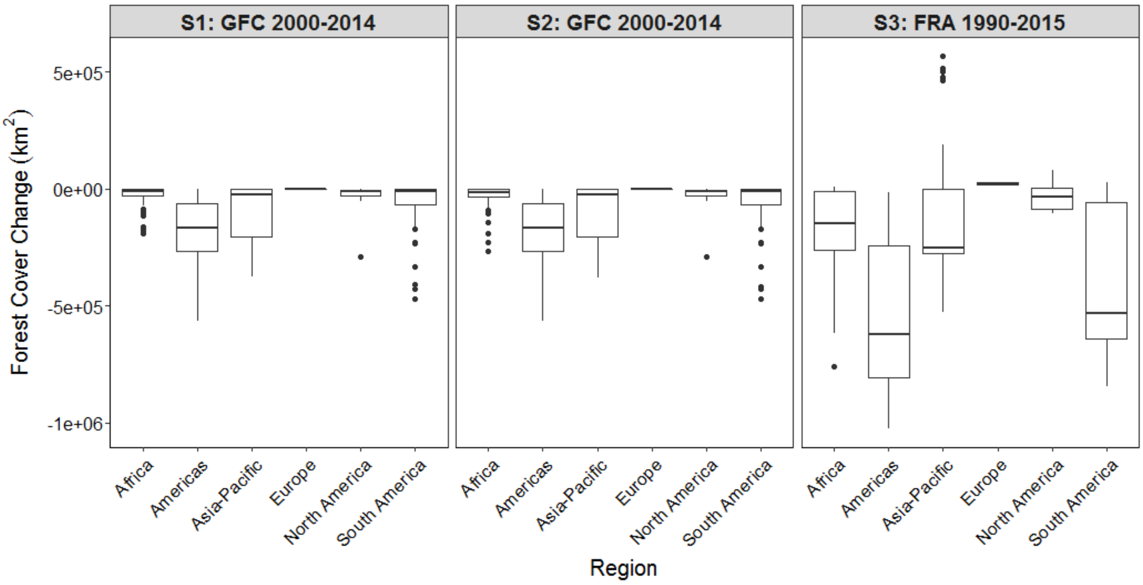


Figure 4.6 Forest cover change (km^2) within species' ranges, summarised by region, under three scenarios: GFC rates where "forest" defined as 30-100% forest cover (S1), GFC rates where "forest" defined as 10-100% forest cover (S2), and FRA country reported rates where "forest" defined as 10-100% forest cover (S3). "Asia-Pacific" refers to species with native range Asia, Oceania or both Asia and Oceania. "Americas" refers to species with native range spreading across North and South America, where "North America" includes Mesoamerica.

Fig. 4.7 shows greatest population size declines, across all three scenarios, under sub-criterion A3, with greatest projected reductions for Asia-Pacific species, followed by African and South American timbers. North American study species (of which the majority are located in Mesoamerica) also showed high median reductions under S1 and S2. Across all scenarios and time periods, the European species showed consistently low reductions and, in the case of S3, greatest net gains in population size.

This is unsurprising, as these results are based on a single European study species, *Aesculus hippocastanum,* located in Southern-Central Europe where deforestation has been low in the recent past, and is projected to continue to be low. Extreme reductions (excluding outliers), most apparent for Asia-Pacific species, appear greater under S1 and S2 than under S3. However, it is unclear whether S3 results have simply been pulled up by reported gains from some range countries. S1 and S2 results are very similar across all Criterion A time periods, as expected given the similarity of deforestation levels under the two scenarios (**Fig. 4.6**).

Because estimates of population size change under S1 and S2 are not significantly different from one another, theoretically the results for either GFC scenario could be used to apply the Red List Categories and Criteria (together with S3 - FRA results). However, although the definitions for 'forest' are closer between S2 and S3 (both using a canopy cover value of 10-100%), GFC results under S1 (30-100%) are preferentially selected in applying the full Categories and Criteria. This decision is made because it is unclear whether the GFC scenarios showed very similar deforestation and population declines because most deforestation over the study dataset time period occurred primarily in areas of species ranges with greater percentage canopy cover (≥30%), or because it is harder to detect forest change from satellite imagery when tree cover is sparse to begin with, as suggested by Hansen *et al*. (2010) when recommending use of higher percentage canopy cover in 'forest' definitions. Therefore, as S1 and S2 results show no significant differences when looking at forested range area (**Fig. 4.11**); total deforestation within species ranges (**Fig. 4.6**); or estimated population size changes over Criterion A timeframes (**Fig. 4.7**), S1 results will be used for the full Red List assessments conducted later in this chapter, because they will give the same or more conservative results as S2, but with greater confidence in genuine forest change detection.

Under GFC forest change scenarios (S1a and S1b), a total of 220 species qualified for IUCN Threatened Categories under Criterion A, of which 97 were Critically Endangered (CR), 58 Endangered (EN), and 65 Vulnerable (VU). A further 23 were classed as Near Threatened (NT) following IUCN guidance based on estimated population declines of 20-29% in the last three generations (IUCN Standards and Petitions Subcommittee, 2017). Only one species, *Serianthes myriadenia*, could not be fully assessed and was therefore classed as Data Deficient (DD) under Criterion A. This was due not only to too few (<3) GBIF records to analyse under S1a, but also to incomplete coverage of GFC satellite imagery over French Polynesia, where *S. myriadenia* is endemic. The remaining 80 species were not close to meeting VU thresholds, and were categorised as Least Concern (LC).

A higher number of species (225) met Threatened Categories under the FRA forest change scenario (S3). However, in comparison to the GFC-based assessments, these categorisations were skewed towards the lower end of the 'Threatened' scale, with only 64 CR, 49 EN, and 112 VU. Only 8 species were classed as NT based on estimated population declines of 20-29% in the last three generations, and 91 were classed as LC. FRA national reports from French Polynesia ensured that, under S3, *S. myriadenia* was classed as LC rather than DD.

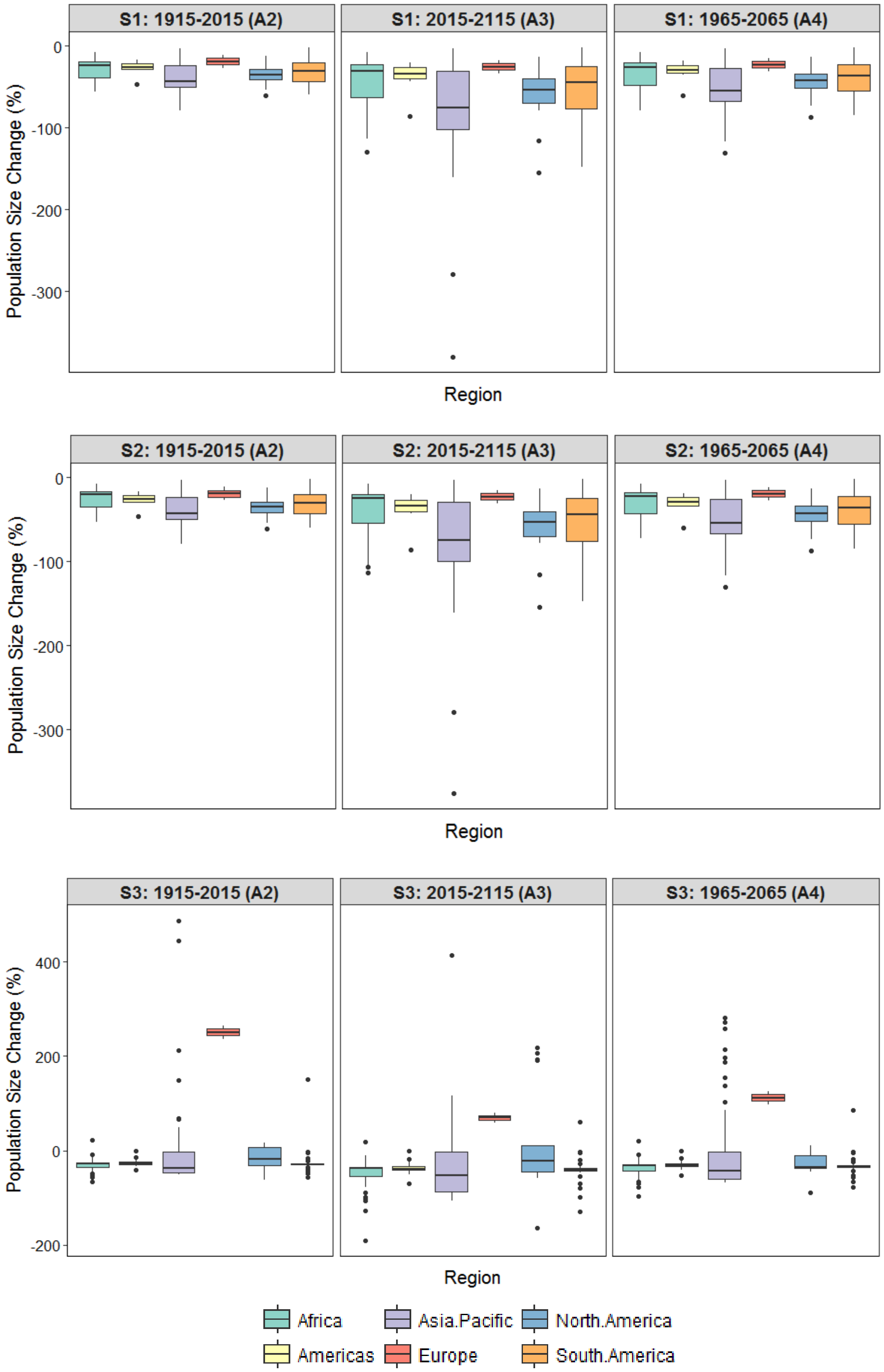


Figure 4.7 Species population size change (%) for each study region, estimated and projected using three forest cover change scenarios (S1, S2, S3, as shown in Fig. 4.6), over Criterion A timescales: 100 years past (A2), 100 years future (A3), and 50 years into both past and future (A4).

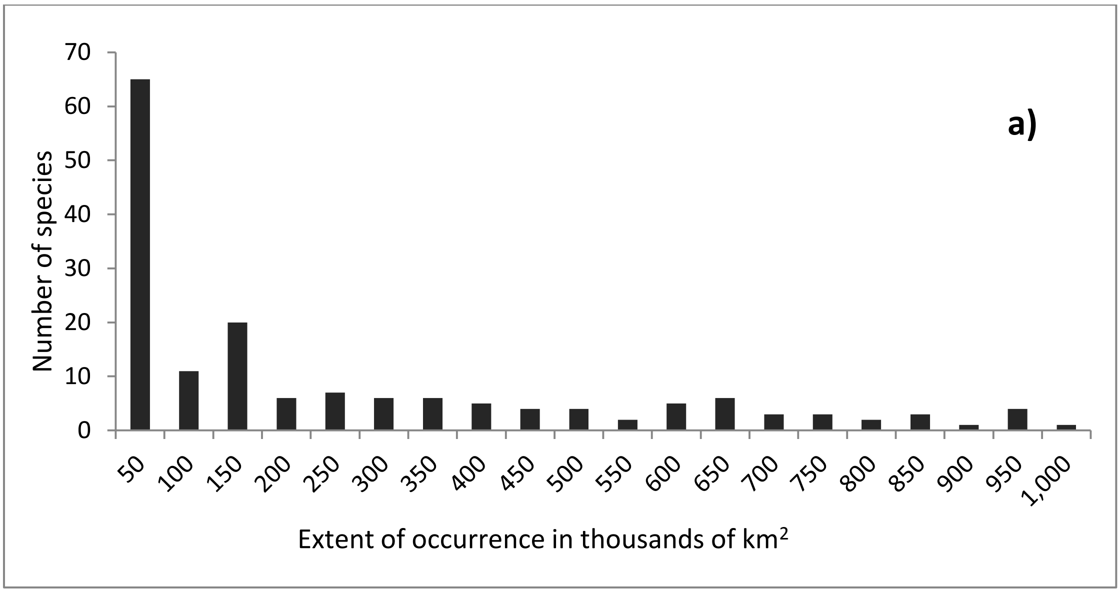
4.3.3 Criterion B

Of the 324 study species, 240 had sufficient georeferenced records (≥3) from native range countries available from GBIF to calculate an EOO MCP. The remaining 83 species had fewer than three suitable GBIF records. *Shorea acuminatissima* was an exception with three records but an EOO smaller than the 0.03 km^2 pixel resolution of the Global Forest Change (GFC) dataset (EOO = 0.0018 km^2). As such, 84 species including *S. acuminatissima* were excluded from further spatial analysis under Criterion B (all were classed as 'DD' under this criterion), and were instead assessed in full under the remaining criteria using native range country-level datasets (scenarios S1b, S2b and S3).

EOO ranged widely from 3.55 km^2 to 52,102,223.61 km^2, with a mean (± SD) area of 2,037,905.37 ± 4,706,723.52 km^2 (see **Fig. 4.8**). Under Criterion B, 52 species met the Threatened thresholds for sub-criterion B1 (EOO size). Preliminary categorisation under sub-criterion B1 was as follows: 23 species VU with EOO < 20,000 km^2; 27 EN with EOO < 5,000 km^2; and two CR with EOO < 100 km^2.

The lowest limit of AOO for each species, calculated on a 4 km^2 cell size grid, ranged from 8 km^2 to 5660 km^2**,** with a mean (± SD) of 229.86 ± 489.67km^2 (**Fig. 4.9**). All but three study species met IUCN thresholds for Threatened Categories under sub-criterion B2 (AOO size) using this grid size. Preliminary categorisation under sub-criterion B2 was as follows: 27 VU with AOO < 2,000 km^2; 212 EN with AOO < 500 km^2); and 3 CR with AOO < 10 km^2. However, such grid-calculated AOOs are heavily dependent on number of available observation records per taxon, and this number was highly variable for these study species (**Fig. 4.10**).

After cleaning and country-matching, the number of usable GBIF records per species ranged from one to 1,415, with mean (± SD) of 52.41 ± 128.22. However, this grid-based metric is heavily dependent on number of records and is thus vulnerable to recorder bias, record quality, and the Wallacean shortfall, and the fact that, of course, not all herbaria records are georeferenced or uploaded to GBIF. To avoid this issue, grid-based AOO was not used in the final Red List assessments, and a less biased ‘maximum possible occupancy' for assessing severity of fragmentation was estimated by calculating the area of suitable habitat (i.e. forest) within the species’ EOO.



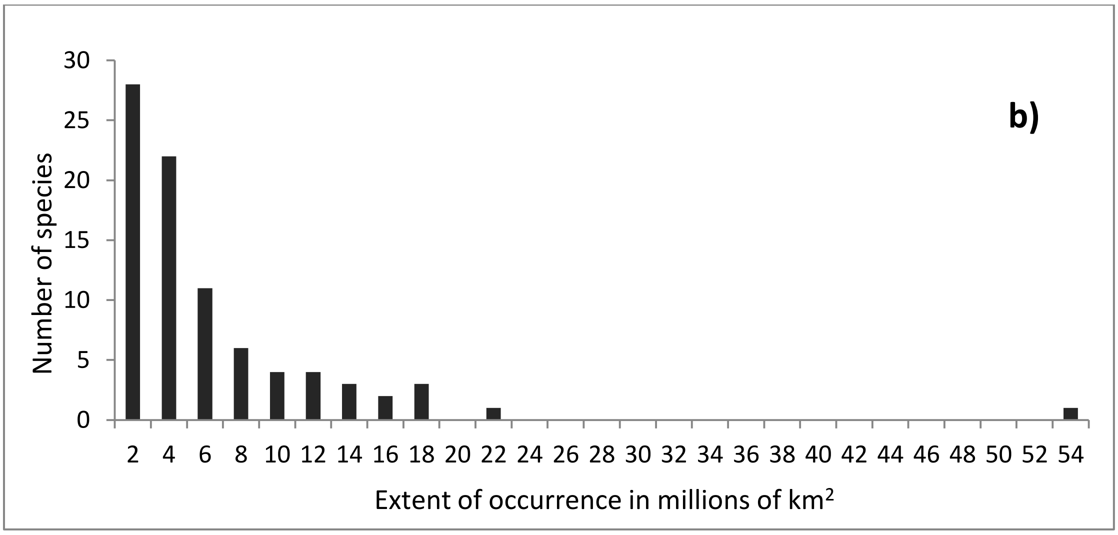


Figure 4.8 Frequency distribution of species extent of occurrence; a) EOOs smaller than 1,000,000 km^2 in area, b) EOOs larger than 1,000,000 km^2.

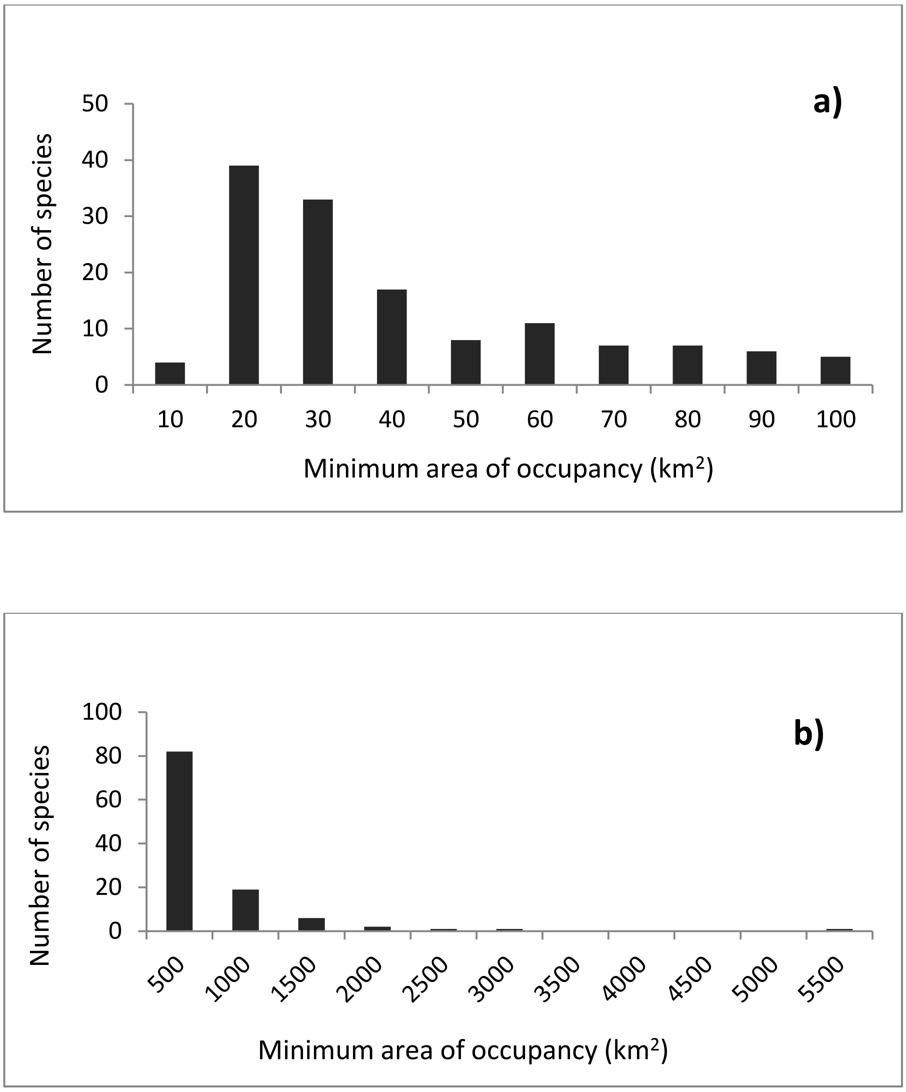
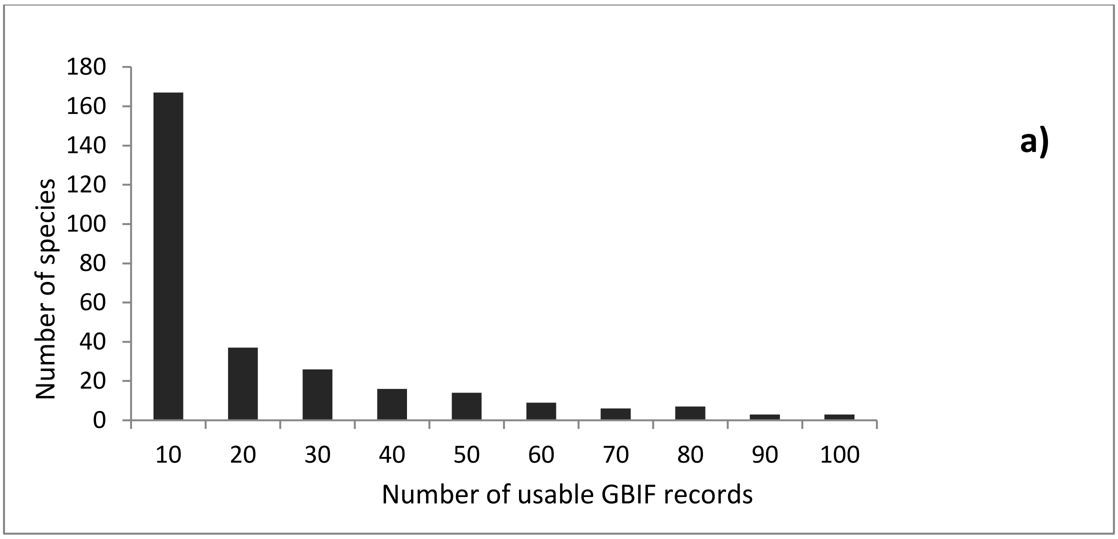


Figure 4.9 Frequency of species' minimum area of occupancy; a) <100km^2 and b) >100km^2, calculated by overlaying a 4 km^2 grid onto species occurrence records.



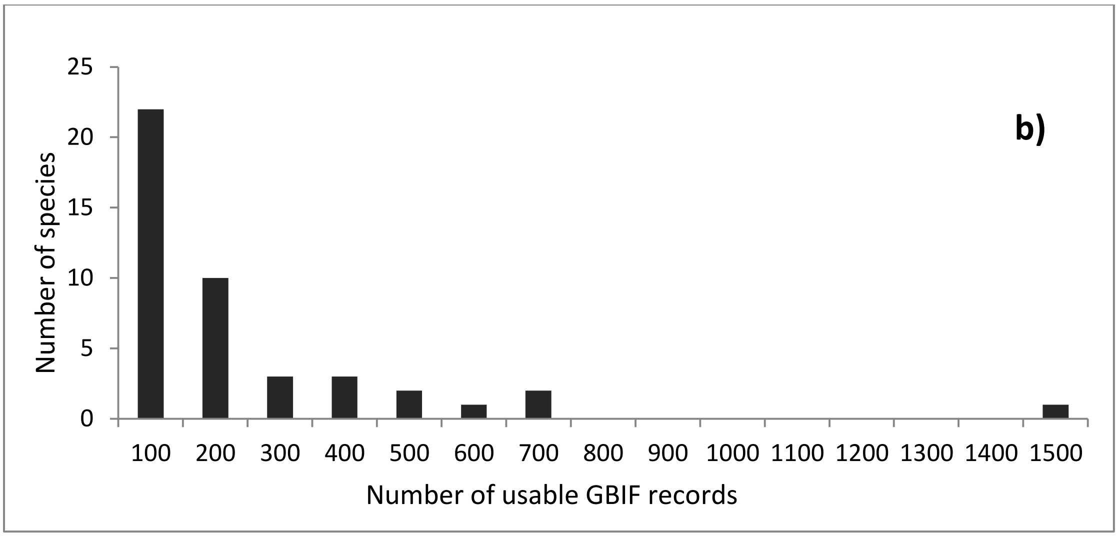


Figure 4.10 Frequency of usable GBIF records, a) <100 and b) 100-1,500

The maximum possible occupancy, calculated here as the estimated area of remaining natural forest in the year 2015 (from year 2000 baseline) within each species' EOO MCP, decreased the number of species potentially qualifying for threatened categories under B2. Where 'forest' was defined as land cover with trees over 5m in height with a canopy cover of 30-100%, maximum possible occupancy ranged from 2.85 km^2 to 8,970,451.49 km^2, with a mean (± SD) of 779,691.98 ± 1,652,384.01 km^2. Where forest was defined as land cover with trees over 5m in height with a canopy cover of 10-100%, maximum possible occupancy ranged from 2.85 km^2 to 9,339,669.23 km^2, mean

(± SD) 878,255.33 ± 1,828,569.97 km^2. Using this 'upper limit' of AOO (maximum possible occupancy), preliminary categorisation under sub-criterion B2 for study species was the same under both 'forest' definitions (30% and 10% canopy cover (**Fig. 4.11**): 28 species in total met threatened thresholds, with 14 VU; 13 EN; and 1 CR.

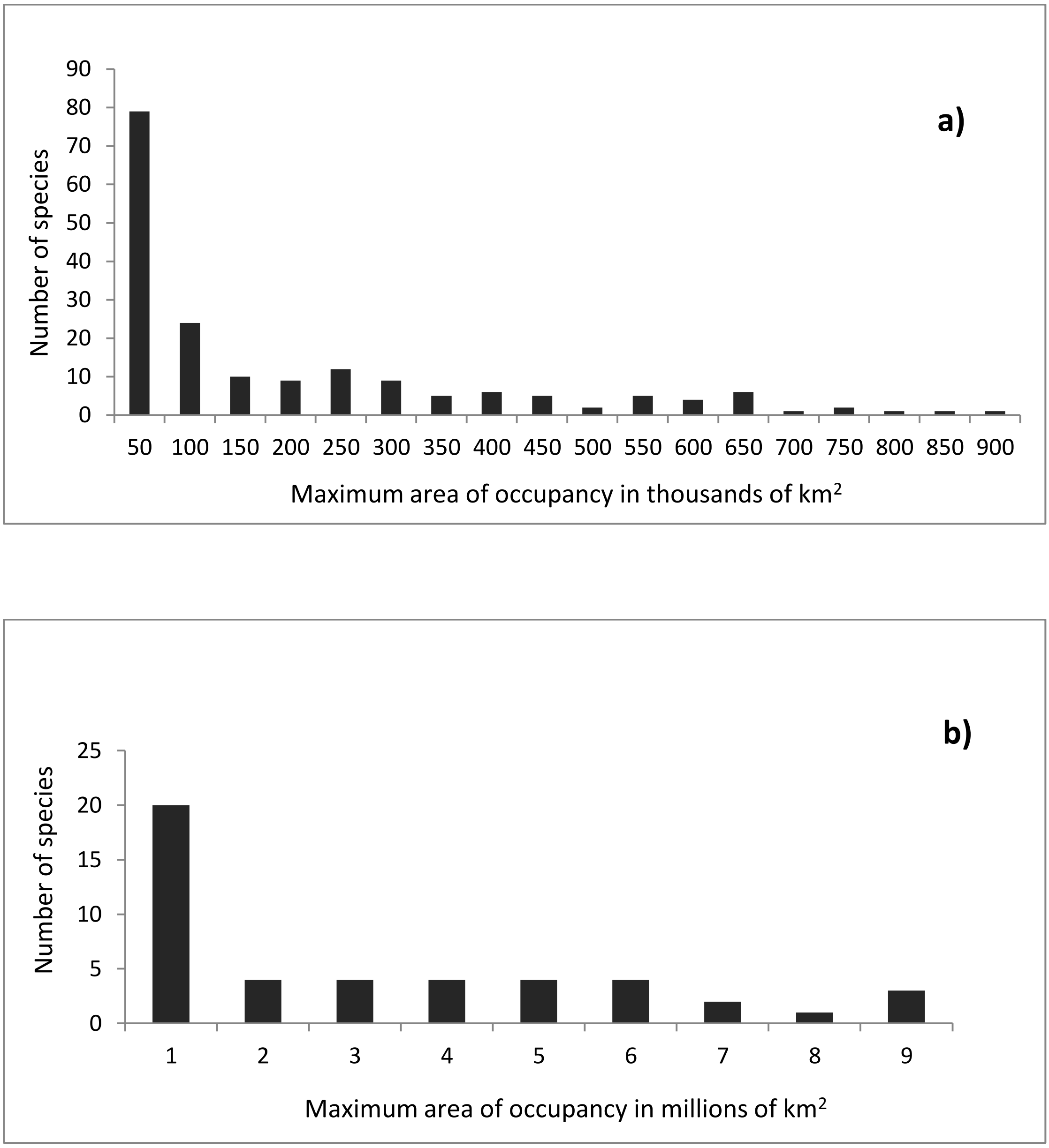


Figure 4.11 Frequency of maximum area of occupancy (forested area of EOO), where 'forest' defined as vegetation >5m in height, with 10-100% or 30-100% canopy cover. Maximum area of possible occupancy varied from the low thousands (a) to millions (a) of square kilometres.

In total, 52 species qualified or nearly qualified for Threatened categories under sub-criteria B1, as well as meeting sub-criterion (b) options i, ii and iii (continuing decline in EOO, AOO and area, extent and/or quality of habitat). In the absence of sufficiently long-term or detailed datasets, it was not possible to determine whether there had been extreme fluctuations in EOO, AOO, number of locations / subpopulations, or number of mature individuals (sub-criterion c). However, it was possible to apply sub-criterion (a) severe fragmentation.

Maximum seed dispersal distance was used to identify connected or isolated forest patches, and thus connected or isolated subpopulations, when determining whether a species qualified as 'severely fragmented' under Criterion B, sub-criterion (a). The majority (36) of the 52 species in question were found to disperse by zoochory – that is, dispersed by birds or mammals either inadvertently inside the animal vector's digestive tract or caught on fur or feathers, or deliberately carried. The dispeRsal models made no distinction between endo- (internal) and epi- (external) zoochory. Nine species had special morphological adaptations for seed dispersal by wind (anemochory), two species used ballistic dispersal, and the remaining spercies had no known specific seed adaptations and were thus assumed to disperse by gravity or wind (without morphological adaptations to maximise wind dispersal) alone (**Table 4.2** summarises species' dispersal syndromes).

Table 4.2 Summary of seed dispersal mechanisms of study species.

Total species	Seed dispersal syndrome
36	Endo-zoochory/ Epi-zoochory
9	Anemochory
5	No adaptations
2	Ballistic

The dispeRsal model results revealed that animal-dispersed seeds travelled the furthest maximum distance, with a mean (± SD) of 834.17 m ± 504.36 m. Unsurprisingly, species with seeds that displayed no special adaptation for dispersal had the shortest maximum dispersal distances, with a mean (± SD) of 10.94 m ± 7.17 m.

After buffering each species' forest patches with buffers corresponding to that species' mean maximum seed dispersal distance, habitat patches became either functionally 'connected' by seed migration, or remained isolated. Seventeen species showed full habitat connectivity after buffering. For the remaining taxa, the number of unconnected habitat patches varied widely between species, from 2 to 32,748.

Population density estimates were also variable between species, from 2 to 21,750 individuals per square kilometre. On average, population density was 458 individuals per square kilometre, though the mode and median were both 92 individuals per square kilometre, demonstrating that many large timbers grow at low population densities. In total, 6 species had populations that were classed as 'severely fragmented' under Criterion B, sub-criterion (a).

4.3.4 Criteria C, D and E

Criterion E was not applied to any of the study species, due to insufficient data to perform reliable population viability analyses. However, a small number of species met threatened category thresholds under Criterion C and D, on the basis of small and declining (C) and very small and/or highly range-restricted populations (D1 and D2).

Using GFC forest change rates (S1a and S1b), only two species (both EN) qualified for Threatened Categories under C and C1. A further three species were classed as NT based on C and C1, *"Population has ~15,000 mature individuals and is declining and has declined by an estimated 10% in the last 3 generations"* (IUCN Standards and Petitions Subcommittee, 2017). *Serianthes myriadenia* was once again considered DD due to insufficient GBIF and GFC data. The majority, 318 species, were listed as LC. For Criterion C under FRA forest change scenario S3, all species were found to be LC.

Under Criterion D, only three species qualified for Threatened Categories under GFC scenarios. Of these, two were VU under D2 (very restricted population (based on small maximum possible AOO area – that is, forested area of EOO), and the third was VU under D1. *Serianthes myriadenia* was listed as DD and the remaining 320 species as LC.

Under the FRA scenario, all species were classed as LC. No species met CR or EN thresholds under D for either scenario.

4.3.5 Categorisation

Final categorisations under GFC scenarios were slightly more conservative than under the FRA scenario, with 222 (69 %) of species placed in Threatened Categories and 101 (31 %) not threatened. Of the Threatened Category species the majority, 98, were CR, followed by 53 EN and 71 VU. Of those that were not threatened, 24 were NT and 77 LC. One species, *Serianthes myriadenia*, was classed as DD.

Under the FRA scenario, 225 (69 %) species were classed as Threatened, but these were skewed towards less conservative Threatened Categories: 64 CR, 49 EN and 112 VU. No species was considered DD under this scenario. Of the 99 (31 %) non-threatened species, eight were NT and 91 LC. **Table 4.3** summarises percentage of study species placed in each Category under the three scenarios used to conduct full assessments.

Approximately a third of the study species (111, 34%) were placed in the same final Category under both GFC and FRA scenarios. Of the 213 that did not match Categories, 138 species (65%) were assessed as either Threatened or not threatened under *both* the GFC and FRA scenarios. Where the GFC and FRA scenarios differed, FRA produced more conservative categorisations for only 55 species; for all other species, GFC scenarios produced more conservative listings.

Table 4.3 Percentage of study species assigned to preliminary IUCN Red List Categories under each forest change scenario. Scenarios as follows: S1a Area = species max. AOO; Rate = GFC 2000-2014 under forest definition of 30-100% tree cover. S1b Area = species native range countries; Rate = GFC 2000-2014 under forest definition of 30-100% tree cover. S3 Area = species native range countries; Rate = FRA 1990-2015 under forest definition of 10-100% tree cover.

Forest change scenario	Dataset	Preliminary categorisation (%)					
		DD	CR	EN	VU	NT	LC
Scenario 1a	GFC		17.08	20.83	22.92	10	29.17
Scenario 1b	GFC	1.19	67.86	3.57	19.05		8.33
Scenario 3	FRA		19.75	15.12	34.57	2.47	28.09

The most common final Criteria and sub-criteria listing was A3bc – threatened on the basis of a reduction in population size over a 100-year time period projected into the future, based on an index of abundance relevant to the taxon, and a projected decline in EOO, AOO and habitat quality. Assessments were less commonly based on Criterion B, likely because this Category was the most difficult to apply in terms of occurrence records required to calculate an EOO MCP. Given the high variability of GBIF records and the scarcity of open-source national-level land use datasets, it was not possible to reliably assess ‘number of locations’ under Criterion B. Similarly, the timescales of the GFC and FRA (2015) datasets were too short to confidently identify genuine extreme fluctuations in subpopulations, mature individuals, or even range or habitat quality under Criteria B and C. A single final listing was made on the basis of Criterion C, and none were made on the basis of Criterion D. This is likely because species range sizes, while in many cases restricted on the basis of small EOO or maximum AOO, were nonetheless large enough to support sizeable populations. This may especially appear to be the case when using forest cover as a proxy for population size – an unavoidable limitation where readily-available, up-to-date population size datasets are lacking. **Table 4.4** summarises final Criteria and sub-criteria listings.

*Table 4.4 Summary of final Criteria and sub-criteria listings used for preliminary IUCN Red List categorisation of study species. *This final species listing summary is based on the most conservative categorisations (i.e., highest threat Category) for each species, across all forest change scenarios.*

Final listing *	Preliminary categorisation						
	CR	EN	VU	NT	LC	DD	Total
A3bc	105	27	25				157
A3bc + 4bc	21	37	45				103
A2bc + 3bc + 4bc			30				30
B1ab(i,ii,iii)	1						1
B1ab(i,ii,iii) (+ 2ab(i,ii,iii))		1					1
B1ab(i,ii,iii) (+ 2ab(i,ii,iii)); C1		1					1
n/a				9	21	1	31
Total	127	66	100	9	21	1	324

4.3.6 Red List Index for timber tree species

Using these preliminary timber tree species Red List assessments (conducted using the GFC S1 scenario, where 'forest' was defined as 30-100% canopy cover), it was possible to calculate a baseline RLI value for timber tree species (for the year 2015) in comparison to other indexed groups (see **Fig. 4.12**). The baseline value for this timber tree species group was 0.56, suggesting that timbers as a group currently face a greater risk of extinction than the other taxonomic groups indexed (all with RLI values >0.75).

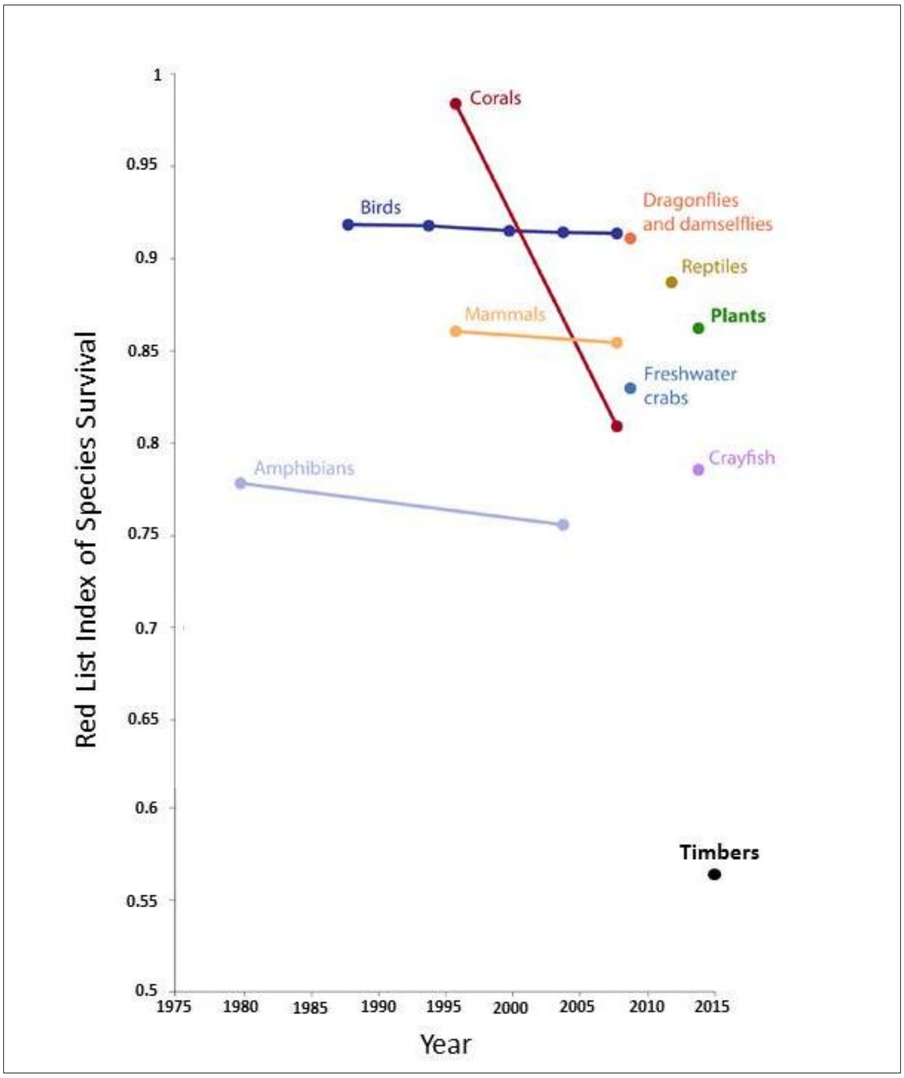


Figure 4.12 Preliminary baseline Red List Index value for assessed timber tree species, in comparison to baseline values and full indices for other groups. (Figure amended from Brummitt et al., 2015)

4.4 Discussion

This study presents the first quantitative extinction risk assessments for 30 timber tree species using IUCN Red List Categories and Criteria, and updated assessments for a further 294 species, 220 of which were last Red Listed in 1998 or earlier. Under the most conservative assessment, 222 study species were considered Threatened, 24 Near Threatened and 77 Least Concern, with one species Data Deficient. **Table 4.5** shows full application of Criteria and sub-criteria to study species. The Criterion and sub-criteria most commonly used in final 'threatened' species categorisation was Criterion A, A3bc – projected population size decline of ≥30% over a timescale of 100 years post-2015, based on forest cover change in combination with recent population density estimates as an appropriate index of abundance. The fact that many final categorisations were made on the basis of projected future losses suggests that it may be possible to prevent some population reductions if prompt action is taken.

In most cases, assessments based on GFC forest cover change (S1) conferred higher categories of threat, and it is highly likely that inclusion of forest 'gain' in FRA national reports contributed towards lower threat categorisation under S3. Under all scenarios, timbers in the Asia-Pacific region suffer the greatest estimated and projected population reductions. Hansen *et al*., (2013) identified Indonesia as a country with increasingly severe deforestation, and an Asia-Pacific hotspot of threat is echoed in recent assessments of forest-dependant vertebrates by Tracewski *et al.* (2016).

Table 4.5 Application of IUCN Red List criteria and sub-criteria to 324 species in this study Under Criterion A, species were assessed over a timeframe of 100 years into the past (A2 - 'P'), future (A3 - 'F'), and 50 years into both the past and future (A4 - 'B').[+] 'Forest change scenario' refers to the combination of geographic area assigned as 'species range', and the dataset used to calculate rate of change in forest cover over that area.*

Criteria / sub-criteria*	Forest change scenario[+]	DD	CR	EN	VU	NT	LC	n/a	Total species to which criterion / sub-criterion was applicable
A1 - population reduction P	None							324	
A2 - population reduction P	S1a			21	103	64	52		240
A2 - population reduction P	S1b	1		41	26	9	7		84
A2 - population reduction P	S3			16	145	88	75		324
A3 - population reduction F	S1a		40	49	55		96		240
A3 - population reduction F	S1b	1	57	9	10		7		84
A3 - population reduction F	S3		64	49	112		99		324
A4 - population reduction B	S1a		8	54	70		108		240
A4 - population reduction B	S1b	1	13	47	7		16		84
A4 - population reduction B	S3		2	94	116		112		324
A(a) - direct observation	None							324	
A(b) - index of abundance	All								324
A(c) - decline in AOO, EOO, habitat	All								324
A(d) - exploitation levels	None							324	
A(e) - effects of other taxa	None							324	
B1 - EOO	S1a		2	23	21	6	188		240
B2 - AOO (maximum)	S1a		1	9	10	8	212		240
B(a) - severe fragmentation	S1a							188	52
B(a) - number of locations	None							324	
B(b) - continuing decline	S1a								324
B(c) - extreme fluctuations	None							324	
C1 - small, declining pop.	S1a			2		3	235		240

Table 4.5 continued

Criteria / sub-criteria*	Forest change scenario[+]	DD	CR	EN	VU	NT	LC	n/a	Total species to which criterion / sub-criterion was applicable
C1 - small, declining population	S1b	1					83		84
C1 - small, declining population	S3						324		324
C2 - small, declining population	None							324	
D & D1 - very small population	S1a				1		239		240
D & D1 - very small population	S1b	1					83		84
D & D1 - very small population	S3						324		324
D2 - very restricted population	S1a				3		237		240
E - quantitative analysis	None							324	

4.4.1 EOO as an indicator of threat

The study results also allow us to address the question of whether estimates of species range area (e.g. number of native range countries, or size of EOO MCP where this is known) are good indicators of whether a species is likely to meet IUCN Threatened Category thresholds when fully assessed. Because population information is rarely available for large numbers of tree taxa, whereas herbarium records or native range are relatively well-known, range is often used as a first step towards prioritising tree species for Red List assessment (Nic Lughadha *et al*., 2005; Miller *et al.* , 2012; Tejedor Garavito *et al*., 2015). Indeed, this approach was used in this study, together with previous Threatened or Near Threatened categorisation. In total, 276 timber species were prioritised for this study on the basis of previous Threatened or Near Threatened categorisations, 30 on the basis of restricted range (EOO of <20,000km^2) and 18 on the basis of both range-restriction and previous threat status. Of those that were not considered range-restricted under B1 (EOO), only 72 (26 %) were found to be Least Concern under FRA scenario, and only 56 (20 %) under GFC scenarios. It is therefore important to stress that range size may not be a reliable indicator of 'Least Concern' status, and should be used with caution.

4.4.2 Timber tree species extinction risk over time

Of the 324 study species, the majority (294) have been previously assessed at the global scale using IUCN Red List Categories and Criteria. Of these, 275 were previously considered Threatened, in contrast to 222 in this study, under the most conservative assessment. **Figure 4.14** summarises previous categorisations against categorisations made in this chapter. It is important to note, however, that the majority (220) of re-assessed timbers were last Red Listed in 1998 or earlier, under a now outdated version of the IUCN Categories and Criteria; Version 2.3, in use from 1994-2001. **Figure 4.13** illustrates the great disparity in previous timber tree species assessments using Version 2.3 and (current) Version 3.1.

This study contributes a long-needed injection of up-to-date timber tree preliminary Red List assessments, and is the first step towards a RLI of threat status over time for angiosperm timbers. The baseline RLI value presented in **Fig. 4.12** appears to indicate that timber tree species as a group are currently at greater risk of extinction than the other indexed groups. However, this preliminary RLI value for timber trees should be interpreted with caution for several reasons. Firstly, the value does not represent all known timber tree taxa (only 324 species). Secondly, it was calculated using preliminary Red List categorisations only, and these preliminary categorisations themselves may be uncertain (see **Chapter 5** for analysis of assessment uncertainty). Thirdly, it is a baseline value only, and RLIs require at least two global Red List assessments for each study taxon, preferably conducted at least five years apart (Butchart *et al*., 2006), in order to look at changes in extinction risk over time. Although the previous Red List assessments existing for the majority of the 324 study species could be seen to represent a ‘first’ time-point for this RLI, the fact that most of these previous assessments were conducted using a version of the Red List Categories and Criteria that is incompatible with the current version makes this difficult. Thus, despite the apparent shift towards more conservative Threatened Categories over time (under GFC scenarios) seen in **Fig. 4.14**, our timber tree assessments will need to be made comparable by ‘back-casting’ – that is, retrospectively ‘correcting’ the previous assessments using current knowledge about the state of the species at the time of the previous assessment in question (Butchart *et al*., 2005) before long-term trends in timber extinction risk could be seen using existing timber tree Red List assessments. A RLI of two time-points could only then be calculated using ‘back-casted’ previous assessments together with current assessments, and could be periodically supplemented as future assessments are made.

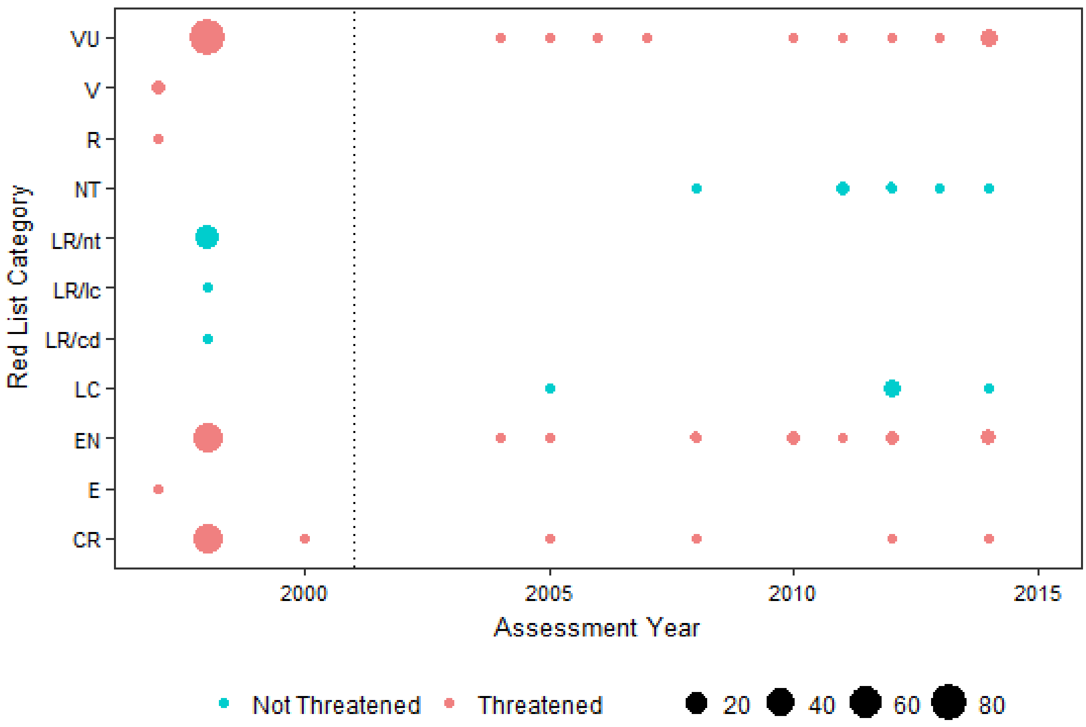
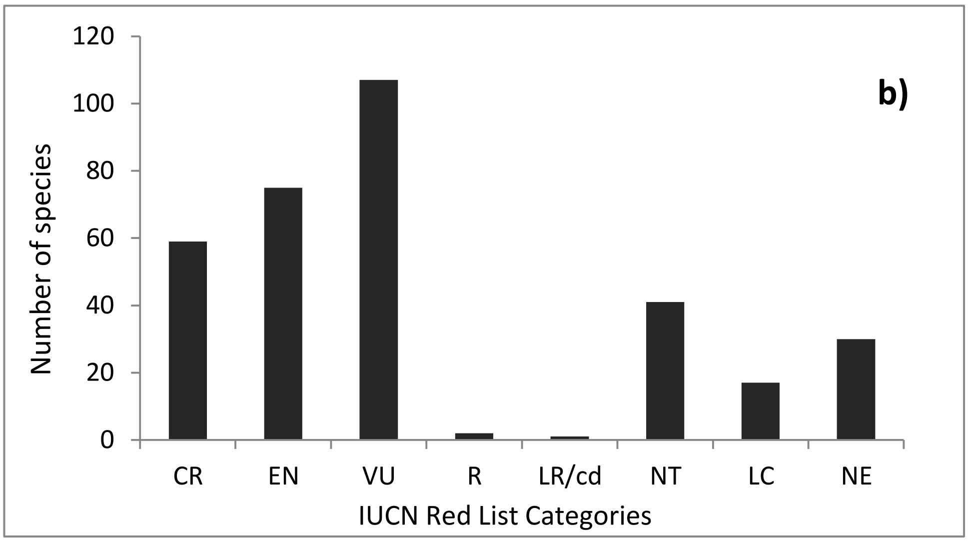


Figure 4.13 Summary of previous IUCN Red List global categorisations conducted 1997-2015 for study species that have been assessed prior to this study. For species with multiple previous assessments, the most recent previous assessment was used. Threatened (red) or not threatened (blue) outcome, and number of species under each categorisation /year (circle size) are shown. Vertical dotted line separates assessments conducted under Version 2.3 (in use 1994-2001) and Version 3.1 (in use 2001-present) of the IUCN Red List Categories and Criteria.



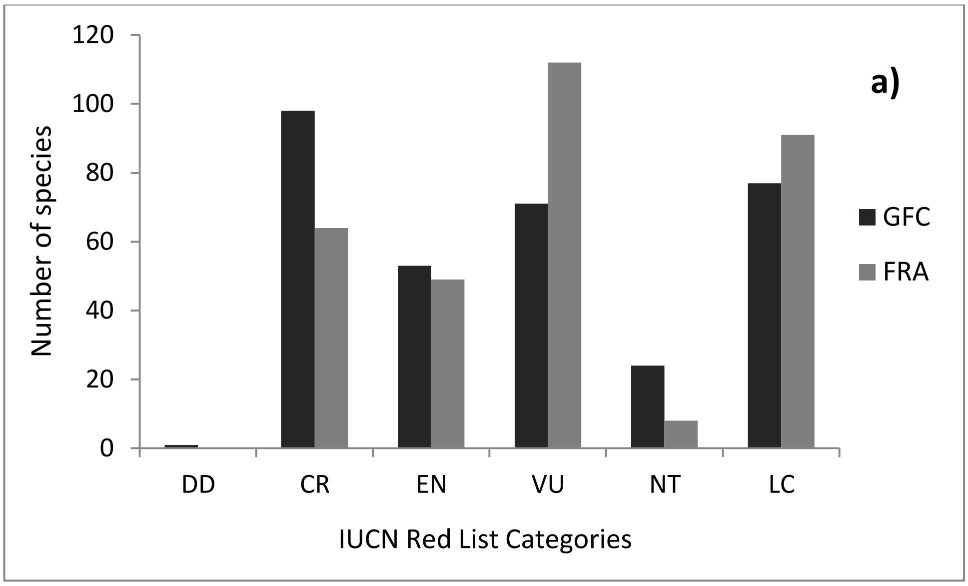


Figure 4.14 Species Red List categorisations produced in this study (a), and in previous IUCN Red List assessments (b). 4.14a uses the most conservative categorisations produced in this study under GFC (black) and FRA (grey) forest change scenarios. Where species were assessed multiple times in the past, 4.14b uses the most recent of multiple previous categorisations.

Note that categories 'R' (Rare) and 'LR/cd' (Lower Risk but Conservation Dependant) in (b) are from Version 2.3 (1994) of the IUCN Red List Categories and Criteria, and have since been amalgamated into the current categories shown in (a). 'NE' stands for Not Evaluated.

4.4.3 Assessment uncertainty

All extinction risk assessments are subject to a degree of uncertainty (Akçakaya *et al*., 2000). In this study, uncertainty stems from certain data limitations and assumptions made in order to adhere to IUCN Red List Guidelines. The major datasets: GBIF, GFC and FRA bring their own benefits and disadvantages. Forest change scenarios S1a and S2a used GBIF occurrence records to calculate EOO MCPs and forest coverage within these polygons was then considered maximum AOO area. As the largest web repository of open-access species occurrence records currently available, the GBIF database includes records from numerous herbaria across the globe. GBIF records represent an accessible option for mapping globally-dispersed study taxa, a cost-effective and rapid alternative to traditional herbaria visits and in-country species workshops.

Extinction risk studies have begun to make use of GBIF records (Miller *et al.,* 2012; Ficetola *et al*., 2014; Romeiras *et al*., 2014). However, studies have also demonstrated that GBIF records suffer from uneven collection effort and taxonomic misidentification, and geo-referencing errors (Yesson *et al*. 2007; Beck *et al*. 2013, 2014; Hjarding *et al*. 2014). **Chapter 3** explored GBIF data quality and cleaning best-practice for timber tree records, filtering by native range countries to mitigate errors of identification and faulty geo-referencing. However, uneven and incomplete recording across species range is a persistent caveat which will vey likely have resulted in underestimation of EOO limits and forested areas, and therefore may have inflated threat assessments for some species. **Chapter 5** compares GBIF records to 'complete' expert datasets for selected timbers, and explores the effect on EOO, AOO and categorisation under Criterion B.

4.4.4 Global Forest Change satellite imagery in timber tree Red List assessments

The GFC dataset (Hansen *et al*., 2013) has been used in recent extinction risk assessments of Amazonian trees (ter Steege *et al*., 2013) and forest-dependent amphibians, birds and mammals (Ocampo-Penuela *et al*., 2016; Tracewski *et al*., 2016). Due to its near-global coverage and high image resolution, the GFC dataset is currently the best option for Red List assessors looking at forest-dwelling species, particularly when study species are spread globally. GFC 'loss' data allows scrutiny of habitat loss and degradation within timber tree species ranges that would otherwise necessitate intensive, time-consuming and costly ground truthing in poorly-accessible areas. Since the first GFC maps were published, there have been updates to the dataset. Updates at regular intervals will allow Red List assessments based on GFC data to be updated in accordance with changing forests, ensuring that threat categorisations remain up-to-date. Red List Guidelines recommend that extinction risk assessments be updated every five to ten years (IUCN Standards and Petitions Subcommittee, 2017) and updates based on comparable forest cover change data will help assessors to detect genuine change in threat status over time.

The main shortcoming of the GFC is that tree cover 'gain' and 'loss' datasets are not directly comparable (Hansen *et al*., 2013), meaning that deforestation results are gross rather than net. Over the brief timescales of this study (2000-2014), use of gross rather than net deforestation is unlikely to mask species population recovery to an extent that would affect Red List categorisations because the majority of timbers are high density, slow-growing species.

However, the short timescale over which GFC data have been recorded is also a drawback to working with long-lived tree taxa, as extrapolating forest change rates for 14 years up to generation timescales of 30-100 years for Criteria A and C means assuming that deforestation in the past and future was and will be the same as current deforestation rates. Timescales for this study used a 'best guess' rule of thumb for three generations of long-lived tree species, but deforestation levels for the last 100 years have not been constant and, with the exception of North America and Europe, intensive deforestation at today's high levels dates from the 1970/80s. Categorisations under these Criteria may be overly conservative as a result of the timescales and rates used. **Chapter 5** explores extrapolation over shorter timescales.

Conversely, a further assumption may have resulted in over-estimation of population sizes in remaining forest areas. Population density was extrapolated from forest research plots at one or two locations per species, and density was assumed to be uniform across range. This is unlikely to reflect reality in all cases, as individuals may clump in areas of optimum habitat, or decline steadily in numbers from range centre to edge.

GFC coverage is also currently incomplete over parts of Oceania, and in this study this resulted in a listing of data deficient for one French Polynesia endemic, *Serianthes myriadenia*. In this case, the alternative forest change scenario, FRA national reports (FAO, 2015) was useful in closing this data gap. FRA 2015 reports also provide information on net forest change, and cover a slightly longer time-period (1990-2015) than GFC data. They are therefore a potential alternative for assessing extinction risk of forest taxa, particularly when taxa have insufficient occurrence records to calculate an EOO MCP. However, the varying quality of FRA data amongst reporting countries, and seemingly idiosyncratic inclusion of rubber plantations under the definition of 'natural forest' (Grainger, 2008; MacDicken, 2015) mean that FRA datasets should be used with caution for assessing native populations.

As Red List assessments are frequently used to prioritise taxa for conservation and policy action (Rodrigues *et al.*, 2006), it is important that assessment uncertainties be recognised and, where possible, quantified. For commercial species such as timber trees, it is doubly important that assessments be as transparent and robust as possible, as threatened status can impact livelihoods as well as national and international harvest, export and trade regulations. Therefore, thesis **Chapter 5** explores the caveats outlined above and uses a series of case studies to quantify uncertainty and inform best practice for timber tree Red List assessments. **Chapter 5** also looks at the amount of data available on timber harvest and trade for the most well-documented study species – those that are listed on the CITES Appendices – and the effect on categorisation when such exploitation data is used to apply Criterion A.

4.5 Conclusion

This study used high-resolution satellite imagery (Hansen *et al*., 2013) and recent national FRA reports (FAO, 2015) to produce up-to-date, quantitative global extinction risk assessments for 324 commercial timber tree species across seven continents. Results suggest that approximately 69% of study species may be under threat, primarily as a result of deforestation, demonstrating that study species are not protected by their commercial status. This chapter also made novel use of seed dispersal models (Tamme *et al*., 2014) to explore impacts of habitat fragmentation on sub-population connectivity; this approach is recommended for incorporation into future tree Red Listing studies. Although these IUCN Red List assessments are preliminary, they demonstrate that the use of the GFC dataset for Red Listing (Tracewski *et al*., 2016) can allow comprehensive assessment of tree taxa, and is particularly useful when study taxa are geographically widespread. Such assessments bring us closer to a global tree assessment and to GSPC 2020 targets (Newton *et al*., 2015).

4.6 References

Akçakaya, H, R., Ferson, S., Burgman, M. A., Keith, D. A., Mace, G. M. and Todd, C. R., 2000. Making Consistent IUCN Classifications under Uncertainty. *Conservation Biology*, 14 (4), 1001-1013.

Beck, J., Ballesteros-Mejia, L., Nagel, P. and Kitching, I. J., 2013. Online solutions and the "Wallacean shortfall": What does GBIF contribute to our knowledge of species' ranges? *Diversity and Distributions*, 19 (8), 1043-1050.

Beck, J., Böller, M., Erhardt, A. and Schwanghart, W., 2014. Spatial bias in the GBIF database and its effect on modeling species' geographic distributions. *Ecological Informatics*, 19, 10-15.

Böhm, M., Collen, B., Baillie, J.E., Bowles, P., Chanson, J., Cox, N., Hammerson, G., Hoffmann, M., Livingstone, S.R., Ram, M. and Rhodin, A.G., 2013. The conservation status of the world's reptiles. *Biological Conservation*, 157, 372-385.

Brook, B, W., Bradshaw, C. J. A., Traill, L. W. and Frankham, R. 2011. Minimum viable population size: Not magic, but necessary. *Trends in Ecology & Evolution,* 26, 619-620.

Brummitt, N.A., Bachman, S.P., Griffiths-Lee, J., Lutz, M., Moat, J.F., Farjon, A., Donaldson, J.S., Hilton-Taylor, C., Meagher, T.R., Albuquerque, S. and Aletrari, E., 2015. Green plants in the red: A baseline global assessment for the IUCN sampled Red List Index for plants. *PloS ONE*, 10 (8), p.e0135152.

Butchart, S.H., 2008. Red List Indices to measure the sustainability of species use and impacts of invasive alien species. *Bird Conservation International*, 18 (1), 245-262.

Butchart, S.H., Akçakaya, H.R., Chanson, J., Baillie, J.E., Collen, B., Quader, S., Turner, W.R., Amin, R., Stuart, S.N. and Hilton-Taylor, C., 2007. Improvements to the red list index. *PloS ONE*, 2 (1), e140.

Butchart, S. H. M., Akçakaya, H. R., Kennedy, E. and Hilton-Taylor, C., 2006. Biodiversity Indicators Based on Trends in Conservation Status: Strengths of the IUCN Red List Index. *Conservation Biology*, 20 (2), 579-581.

Butchart, S. H. M., Stattersfield, A. J., Baillie, J., Bennun, L. A., Stuart, S. N., Akçakaya, H. R., Hilton-Taylor, C. and Mace, G. M., 2005. Using Red List Indices to measure progress towards the 2010 target and beyond. *Philosophical transactions of the Royal Society of London. Series B, Biological Sciences*, 360 (1454), 255-268.

Butchart, S.H., Stattersfield, A.J., Bennun, L.A., Shutes, S.M., Akçakaya, H.R., Baillie, J.E., Stuart, S.N., Hilton-Taylor, C. and Mace, G.M., 2004. Measuring global trends in the status of biodiversity: Red List Indices for birds. *PLoS Biology*, 2 (12), e383.

Carpenter, K.E., Abrar, M., Aeby, G., Aronson, R.B., Banks, S., Bruckner, A., Chiriboga, A., Cortés, J., Delbeek, J.C., DeVantier, L. and Edgar, G.J., 2008. One-third of reef-building corals face elevated extinction risk from climate change and local impacts. *Science*, 321 (5888), 560-563.

CBD, 2012. *Global Strategy for Plant Conservation: 2011-2020*. Richmond, United Kingdom: Botanic Gardens Conservation International.

Chazdon, R. L., Brancalion, P. H. S., Laestadius, L., Bennett-Curry, A., Buckingham, K., Kumar, C., Moll-Rocek, J., Guimaraes Vieira, I. C. and Wilson, S. J., 2016. When is a forest a forest? Forest concepts and definitions in the era of forest and landscape restoration. *Ambio,* 45, 538-550.

Cicuzza, D., Newton, A., and Oldfield, S., 2007. The red list of Magnoliaceae. Fauna and Flora International. Cambridge, UK.

Clausnitzer, V., Kalkman, V.J., Ram, M., Collen, B., Baillie, J.E., Bedjanič, M., Darwall, W.R., Dijkstra, K.D.B., Dow, R., Hawking, J. and Karube, H., 2009. Odonata enter the biodiversity crisis debate: the first global assessment of an insect group. *Biological Conservation*, 142 (8), 1864-1869.

Collen, B., Dulvy, N. K., Gaston, K. J., Gardenfors, U., Keith, D. A., Punt, A. E., Regan, H. M., Bohm, M., Hedges, S., Seddon, M., Butchart, S. H. M., Hilton-Taylor, C., Hoffmann, M., Bachman, S. P. and Akçakaya, H. R., 2016. Biology of extinction: Clarifying misconceptions of extinction risk assessment with the IUCN Red List. *Biology Letters,* 12, e20150843.

Cumberlidge, N., Ng, P.K., Yeo, D.C., Magalhães, C., Campos, M.R., Alvarez, F., Naruse, T., Daniels, S.R., Esser, L.J., Attipoe, F.Y. and Clotilde-Ba, F.L., 2009. Freshwater crabs and the biodiversity crisis: importance, threats, status, and conservation challenges. *Biological Conservation*, 142 (8), 1665-1673.

ESRI (Environmental Systems Resource Institute), 2012. ArcMap 10.1. [Computer program] ESRI, Redlands, California.

FAO, 2015. *Global Forest Resources Assessment 2015*. Rome: Food and Agriculture Organization of the United Nations.

Fauna and Flora International., 2006. *Status and sustainable use of mahogany in Central America – Report of a Nicaraguan study and a regional coordination workshop.* Cambridge, UK: Fauna & Flora International.

Flather, C. H., Hayward, G. D., Beissinger, S. R. and Stephens, P. A., 2011. Minimum viable populations: is there a "magic number" for conservation practitioners? *Trends in Ecology & Evolution,* 26 (6), 307-316**.**

Ficetola, G. F., Rondinini, C., Bonardi, A., Katariya, V., Padoa-Schioppa, E. and Angulo, A., 2014. An evaluation of the robustness of global amphibian range maps. *Journal of Biogeography*, 41 (2), 211-221.

Global Biodiversity Information Facility (GBIF). [Online]. Available from: http://www.gbif.org/. [Accessed: November 2013 - January 2017].

Global Forest Watch, 2014. World Resources Institute. [Online]. Available from: www.globalforestwatch.org. [Accessed: 6 September 2016].

Global Tree Specialist Group, 2015. Meeting report: Third meeting of the IUCN/SSC Global Tree Specialist Group 22-24 October 2015 *Towards a global tree conservation assessment.* Morton Arboretum, Chicago.

Grainger, A., 2008. Difficulties in tracking the long-term global trend in tropical forest area. *Proceedings of the National Academy of Sciences of the United States of America,* 105 (2), 818-823.

Hansen, M. C., Stehman, S. V and Potapov, P. V., 2010. Quantification of global gross forest cover loss. *Proceedings of the National Academy of Sciences of the United States of America*, 107 (19), 8650–8655.

Hansen, M., Potapov, P., Moore, R., Hancher, M., Turubanova, S., Tyukavina, A., Thau, D., Stehman, S., Goetz, S., Loveland, T., Kommareddy, A., Egorov, A., Chini, L., Justice, C. and Townshend, J., 2013. High-resolution global maps of 21st-century forest cover change. *Science*, 342 (6160), 850-853. Data available for download from: http://earthenginepartners.appspot.com/science-2013-global-forest. [Accessed: May 2016]

Hjarding, A., Tolley, K. A. and Burgess, N. D., 2014. Red List assessments of East African chameleons: a case study of why we need experts. *Oryx*. Available from: doi:10.1017/S0030605313001427.

IUCN, 2001. IUCN Red List Categories and Criteria. Version 3.1. Gland, Switzerland and Cambridge, United Kingdom: IUCN Species Survival Commission, IUCN.

IUCN Standards and Petitions Subcommittee, 2001. The IUCN Red List Categories and Criteria: Comparison between versions 2.3 (1994) and 3.1 (2001). Downloadable from: http://www.iucnredlist.org/technical-documents/categories-and-criteria.

IUCN Standards and Petitions Subcommittee, 2017. Guidelines for Using the IUCN Red List Categories and Criteria. Version 13. Prepared by the Standards and Petitions Subcommittee. Downloadable from: http://www.iucnredlist.org/documents/RedListGuidelines.pdf.

IUCN/SSC Global Tree Specialist Group, 2015. *Meeting Report: Towards a global tree conservation assessment.* Third meeting of the IUCN/SSC Global Tree Specialist Group, Morton Arboretum, Chicago, 22-24 October, 2015.

Joppa, L. N., Butchart, S. H. M., Hoffman, M., Bachman, S., Akçakaya, H. R., Moat, J., Bohm, M., Holland, R. A., Newton, A., Polidoro, B. and Hughes, A., 2015. Impact of alternative metrics on estimates of extent of occurrence for extinction risk assessment. *Conservation Biology*. Available from: doi: 10.1111/cobi.12591. [Accessed: 15 August 2015]

Lusty, C., Amaral, W., Hawthorne, W., Hong, L. and Oldfield, S., 2007. *Applying the IUCN Red List categories in a forest setting.* From: Status of biological diversity in Malaysia and threat assessment of plant species in Malaysia. Proceedings of the Seminar and Workshop, 28-30 June, 2005, Kuala Lumpur, Malaysia: Forest Research Institute of Malaysia, 257-269.

Mace, G. M., Collar, N. J., Gaston, K. J., Hilton-Taylor, C., Akçakaya, H. R., Leader-Williams, N., Milner-Gulland, E. J. and Stuart, S. N., 2008. Quantification of extinction risk: IUCN's system for classifying threatened species. *Conservation Biology*, 22 (6), 1424-42.

MacDicken, K. G., 2015. Global Forest Resources Assessment 2015: What, why and how? *Forest Ecology and Management,* 352, 3-8.

Mark, J., Newton, A. C., Oldfield, S., Rivers, M., 2014. *A Working List of Commercial Timber Tree Species*. Botanic Gardens Conservation International. [Online]. Available from: http://www.bgci.org/news-and-events/news/1175/. [Accessed: 1 November 2015].

Matthies, D., Brauer, I., Maibom, W. and Tscharntke, T., 2004. Population size and the risk of local extinction: Empirical evidence from rare plants. *Oikos,* 105, 481-488.

Miller, J. S., Porter-Morgan, H. A., Stevens, H., Boom, B., Krupnick, G. A., Acevedo-Rodríguez, P., Fleming, J. and Gensler, M., 2012. Addressing target two of the Global Strategy for Plant Conservation by rapidly identifying plants at risk. *Biodiversity and Conservation*, 21 (7), 1877-1887.

Newton, A. C., 2010. Use of a Bayesian network for Red Listing under uncertainty. *Environmental Modelling & Software*, 25 (1), 15-23.

Newton, A., Oldfield, S., Rivers, M., Mark, J., Schatz, G., Garavito, N. T., Cantarello, E., Golicher, D., Cayuela, L. and Miles, L., 2015. Towards a global tree assessment. *Oryx*, 49 (3), 410-415.

Nic Lughadha, E., Baillie, J., Barthlott, W., Brummitt, N. A., Cheek, M. R., Farjon, A., Govaerts, R., Hardwick, K. A., Hilton-Taylor, C., Meagher, T. R., Moat, J., Mutke, J., Paton, A. J., Pleasants, L. J., Savolainen, V., Schatz, G. E., Smith, P., Turner, I., Wyse-Jackson, P. and Crane, P. R., 2005. Measuring the fate of plant diversity: towards a foundation for future monitoring and opportunities for urgent action. *Philosophical Transactions of the Royal Society of London, Series B: Biological Sciences,* 360 (1454), 359-372.

Ocampo-Penuela, N., Jenkins, C. N., Vijay, V., Binbin, V. L. and Pimm, S. L., 2016. Incorporating explicit geospatial data shows more species at risk of extinction than the current Red List. *Scientific Advances,* 2, e1601367.

Oldfield, S., Lusty, C. and MacKinven, A., 1998. *The World List of Threatened Trees*. Cambridge: WCMC, IUCN.

Oldfield, S. and Eastwood, A., 2007. The red list of oaks. Fauna and Flora International. Cambridge, UK.

Purvis, A., Gittleman, J. L., Cowlishaw, G. and Mace, G. M., 2000. Predicting extinction risk in declining species. *Proceedings of the Royal Society of London, Series B*, 267, 1947-1952.

Puyravaud, J-P., 2003. Standardizing the calculation of the annual rate of deforestation. *Forest Ecology and Management,* 177, 593-596.

Reed, D. H., O'Grady, J. J., Brook, B. W., Ballou, J. D. and Frankham, R., 2003. Estimates of minimum viable population sizes for vertebrates and the factors influencing those estimates. *Biological Conservation,* 113, 23-34.

Richman, N.I., Böhm, M., Adams, S.B., Alvarez, F., Bergey, E.A., Bunn, J.J., Burnham, Q., Cordeiro, J., Coughran, J., Crandall, K.A. and Dawkins, K.L., 2015. Multiple drivers of decline in the global status of freshwater crayfish (Decapoda: Astacidea). *Philosophical Transactions of the Royal Society of London, Series B: Biological Sciences*, 370 (1662), 20140060.

Rivers, M. C., Bachman, S. P., Meagher, T. R., Lughadha, E. N., Brummitt, N. A., 2010. Subpopulations, locations and fragmentation: Applying IUCN red list criteria to herbarium specimen data. *Biodiversity and Conservation,* 19 (7), 2071-2085.

Rocha-Santos, L., Pessoa, M. S., Cassano, C. R., Talora, D. C., Orihuela, R. L. L., Mariana-Neto, E., Morante-Filho, J. C., Faria, D. and Cazetta, E. 2016. The shrinkage of a forest: Landscape-scale deforestation leading to overall changes in local forest structure. *Biological Conservation,* 196, 1-9.

Rodrigues, A. N., Jourget, J-G., Kiyulu, J. and Walters, G, n.d. Assessing the conservation status of commercially exploited trees in Central Africa using the IUCN Red List Categories and Criteria. [Unpublished draft].

Rodrigues, A. S. L., Pilgrim, J. D., Lamoreux, J. F., Hoffmann, M. and Brooks, T. M., 2006. The value of the IUCN Red List for conservation. *Trends in Ecology & Evolution*, 21 (2), 71-76.

Romeiras, M. M., Figueira, R., Duarte, M. C., Beja, P. and Darbyshire, I., 2014. Documenting biogeographical patterns of African timber species using herbarium records: A conservation perspective based on native trees from Angola. *PLoS ONE*, 9 (7), e103403.

Royal Botanic Gardens Kew, 2017. Seed Information Database (SID). Version 7.1. [Online]. Available from: http://data.kew.org/sid/ [Accessed: 26 January 2017].

RStudio, 2014. RStudio: Integrated Development for R. RStudio Inc., Boston, MA. [Online]. Available from: http://www.rstudio.com/.

Schipper, J., Chanson, J.S., Chiozza, F., Cox, N.A., Hoffmann, M., Katariya, V., Lamoreux, J., Rodrigues, A.S., Stuart, S.N., Temple, H.J. and Baillie, J., 2008. The status of the world's land and marine mammals: diversity, threat, and knowledge. *Science*, 322 (5899), 225-230.

Schulze, M., Grogan, J., Landis, R. M. and Vidal, E., 2008. How rare is too rare to harvest? Management challenges posed by timber species occurring at low densities in the Brazilian Amazon. *Forest Ecology and Management,* 256, 1443-1457.

Shaw, K., Stritch, L., Rivers, M., Roy, S., Wilson, B. and Govaerts, R., 2014. The red list of Betulaceae. Botanic Gardens Conservation International. Richmond, UK.

Smithsonian Tropical Research Institute, Centre for Tropical Forest Science, 2017. Plot Summary Data [Online]. Available from: http://www.ctfs.si.edu/plots/summary/ [Accessed: 8 February 2017].

Stuart, S.N., Chanson, J.S., Cox, N.A., Young, B.E., Rodrigues, A.S., Fischman, D.L. and Waller, R.W., 2004. Status and trends of amphibian declines and extinctions worldwide. *Science*, 306 (5702), 1783-1786.

Stuart, S.N., Wilson, E.O., McNeely, J.A., Mittermeier, R.A. and Rodríguez, J.P., 2010. The barometer of life. *Science*, 328 (5975), 177-177.

Syfert, M., Joppa, L., Smith, M. J., Coomes, D. A., Bachman, S. and Brummitt, N., 2014. Using species distribution models to inform IUCN Red List assessments. *Biological Conservation,* 177, 174-184.

Ter Steege, H., Pitman, N. C .A., Sabatier, D., Baraloto, C., Salomao, R. P., Guevara, J. E., Phillips, O. L., Castilho, C. V., Magnusson, W. E., Molino, J-F., Monteagudo, A., Nunez Vargas, P., Carlos Montero, J., Feldpausch, T. R., Coronado, E. N. H., Killeen, T. J., Mostacedo, B., Vasquez, R., Assis, R. L., Terborgh, J., Wittmann, F., Andrade, A., Laurance, W. F., Laurance, S. G. W., Marimon, B. S., Marimon, B-H., Guimaraes Vieira, I. C., Amaral, I. L., Brienen, R., Castellanos, H., Cardenas Lopez, D., Duivenvoorden, J. F., Mogollon, H. F., de Almeida Matos, F. D., Davila, N., Garcia-Villacorta, R., Stevenson Diaz, P. R., Costa, F., Emilio, T., Levis, C., Schietti, J., Souza, P., Alonso, A., Dallmeier, F., Duque Montoya, A. J., Fernandez Piedade, M. T., Araujo-Murakami, A., Arroyo, L., Gribel, R., Fine, P. V. A., Peres, C. A., Toledo, M., Gerardo, A. A. C., Baker, T. R., Ceron, C., Engel, J., Henkel, T. W., Maas, P., Petronelli, P., Stropp, J., Eugene Zartman, C., Daly, D., Neill, D., Silveira, M., Rios Paredes, M., Chave, J., de Andrade Lima, D., Jorgensen, P. M., Fuentes, A., Schoengart, J., Cornejo Valverde, F., Di Fiore, A., Jimenez, E. M., Penuela Mora, M. C., Fernando Phillips, J., Rivas, G., van Andel, T. R., von Hildebrand, P., Hoffman, B., Zent, E. L., Malhi, Y., Prieto, A., Rudas, A., Ruschell, A. R., Silva, N., Vos, V., Zent, S., Oliveira, A. A., Cano Schutz, A., Gonzales, T., Nascimento, M. T., Ramirez-Angulo, H., Sierra, R., Tirado, M., Umana Medina, M. N., van der Heijden, G., Vela, C. I. A., Vilanova Torre, E., Vriesendorp, C., Wang, O., Young, K. R., Baider, C., Balslev, H., Ferreira, C., Mesones, I., Torres-Lezama, A., Urrego Giraldo, L. E., Zagt, R., Alexiades, M. N., Hernandez, L., Huamantupa-Chuquimaco, I., Milliken, W., Palacios Cuenca, W., Pauletto, D., Valderrama Sandoval, E., Valenzuela Gamarra, L., Dexter, K. G., Feeley, K., Lopez-Gonzalez, G. and Silman, M. R., 2013. Hyperdominance in the Amazonian Tree Flora. *Science*, 342 (6156), 325.

Tamme, R., Gotzenberger, L., Zobel, M., Bullock, J., Hooftman, D. A. P., Kaasik, A. and Partel, M., 2014. Predicting species' maximum dispersal distances from simple plant traits. *Ecology,* 95, 505-513.

Tejedor Garavito, N., Newton, A. C. and Oldfield, S. 2015. Regional Red List assessment of tree species in upper montane forests of the Tropical Andes. *Oryx*, *49* (3), 397-409.

The Plant List, Version 1.1. 2013. [Online]. Available from: http://www.theplantlist.org/. [Accessed: March 2014].

Tracewski, L., Butchart, S. H. M., Di Marco, M., Ficetola, G. F., Rondinini, C., Symes, A., Wheatley, H., Beresford, A. E. and Buchanan, G. M., 2016. Toward quantification of the impact of 21st-century deforestation on the extinction risk of terrestrial vertebrates. *Conservation Biology,* 30, 1070-1079.

Traill, L. W., Bradshaw, C. J. A. and Brook, B. W., 2007. Minimum viable population size: A meta-analysis of 30 years of published estimates. *Biological Conservation,* 139, 159-166.

Traill, L. W., Brook, B. W., Frankham, R. R. and Bradshaw, C. J. A., 2010. Pragmatic population viability targets in a rapidly changing world. *Biological Conservation,* 143, 28-34.

Villanueva-Almanza, L., 2013. Risk assessment of seven timber species in the Eastern Arc Mountains and Coastal Forests of Tanzania and Kenya [online]. Thesis (MSc). University of Edinburgh.

Yesson, C., Brewer, P. W., Sutton, T., Caithness, N., Pahwa, J. S., Burgess, M., Gray, W. A., White, R. J., Jones, A. C., Bisby, F. A. and Culham, A., 2007. How global is the global biodiversity information facility? *PLoS ONE*, 2 (11), e1124.

5 Assessing the uncertainty of IUCN Red List categorisations for timber tree species using open-source and expert datasets

5.1 Introduction

Version 3.1 of the IUCN Red List was designed for maximum applicability across a broad range of taxa (IUCN Standards and Petitions Subcommittee, 2017). As a consequence, application of Red List Criteria can involve use of proxy data, inference or estimation on the part of the assessor. For example, a decline in population size may be *observed* (directly measured), *estimated* (allowing assumptions to be drawn from observed evidence, such as projecting future decline based on current or past rates), *inferred* (based on indirect evidence that uses the same units of measurement) or *suspected* (based on indirect evidence that uses different units of measurement) (IUCN Standards and Petitions Subcommittee, 2017). This framework allows quantitative thresholds to be applied, even under uncertainty (Akcakaya *et al*., 2000). However, a large amount of uncertainty can affect the final Red List Category applied to an assessed taxon, making assessments unreliable. An important follow-up to any Red List assessment should therefore be to evaluate assessment uncertainty.

Akcakaya *et al.* (2000) identify three main types of uncertainty affecting extinction risk assessments. Under their definitions, uncertainty may be semantic – that is, arising from unclear definition of terms – or it may arise from measurement error or natural variability. Measurement error arises from a shortage of precise information. For many tree species, data on generation length, population size and trends, area of occupancy (AOO) and extent of occurrence (EOO) are highly uncertain and often must be estimated or inferred using proxy data or modelling approaches (e.g. Tejedor Garavito *et al*., 2015) or general rules of thumb (e.g. Lusty *et al*., 2007). For the timber tree Red List assessments conducted in Chapter 4, further uncertainty has been introduced by using species distribution records from the Global Biodiversity Information Facility (GBIF) to calculate range metrics, and by inferring population declines based on deforestation data for the years 2000-2014, from the Global Forest Change repository

(Hansen *et al*., 2013), extrapolated over timescales assumed to correspond to three generations of a long-lived timber tree species.

Although use of such databases for Red List assessments is likely to be of growing importance as we work towards CBD and GSPC 2020 Targets (CBD, 2012), due to constraints of time and money, use of ‘big data’ comes with issues of data reliability (Yesson *et al*., 2007) that are of concern, especially if research outputs may be used to inform conservation actions (Romeiras *et al*., 2014). This chapter therefore addresses the research question: *How uncertain are the IUCN Red List categorisations that were made in thesis Chapter 4 using open-source distribution record and deforestation datasets?* To do so, this chapter compares Chapter 4 Red List categorisations under selected Criteria and sub-criteria to categorisations made using alternative datasets sourced from taxonomic and regional experts as well as other published studies.

5.2 Methods

To assess uncertainty of IUCN Red List categorisations carried out in Chapter 4, four case studies were conducted, each comparing outcomes under Chapter 4 datasets versus ‘expert’ datasets – that is, data supplied by taxonomic or regional experts or data obtained from published studies. The number of species assessed in each case study was dependent on availability of expert data for each study species. Therefore, only one case study used the full group of 324 timber tree species assessed in Chapter 4. Case study datasets were not combined together to produce Red List assessments using all available data because the case studies were designed to assess impact of each alternative dataset or methodology in isolation to gauge the effects of each on Category thresholds. The following sections describe methods and datasets used for each case study in detail. It should be noted that when referring to Chapter 4 Red List assessments, the assessments in question are those conducted under deforestation scenarios 1a and 1b, where forest cover and deforestation rates were calculated using Global Forest Change (GFC) 30 metre resolution satellite imagery of global forest cover for the years 2000 to 2014 (Hansen *et al.,* 2013), and where 'forest' was defined as pixels containing a trees >5 metres in height with canopy cover of 30-100%. These scenarios are used because they gave the most conservative Red List categorisations.

5.2.1 Case study 1 - Assessing population declines under different time-periods of deforestation

Chapter 4 preliminary Red List assessments inferred and projected population size change under Criterion A by calculating percent deforestation occurring within species' EOO Minimum Convex Polygons (MCPs) over time periods of 100 years into the past (sub-criterion A2) and future (sub-criterion A3), and over a window of 50 years in the past and 50 years into the future (sub-criterion A4). These time periods were chosen on the assumption that the majority of study species are long-lived, slow growing hardwoods for which IUCN timescales of three generations could be estimated as spanning 100 years. Slightly shorter time periods (to constitute one and two generations), but using the same underlying data and methods, were used to apply Criterion C.

Deforestation was extrapolated over these time periods based on rates calculated using Global Forest Change satellite imagery of global forest cover for the years 2000 to 2014 (Hansen *et al.,* 2013). A major source of uncertainty in these assessments is that deforestation rates from only 14 years of data were used to estimate forest cover and deforestation in the relatively distant past and future (100 years both ways). This technique assumes that the deforestation rates were the same a century ago as they are today. However, this is not the case. Industrial deforestation in the world's tropical forests only began in earnest in the 1920s and 1930s, climbing in the 1950s as post-war demand for raw materials boomed. Deforestation accelerated in the 1980s, and has remained at very high levels ever since (Williams, 2003).

To bring Red List assessment time periods in line with these historical trends, deforestation was therefore re-calculated for all 324 timber tree species assessed in

Chapter 4, using the same methodology as that chapter, but over the following updated timescales:

- Sub-criterion A2 – 1980-2015 (35 years in the past).
- Sub-criterion A3 – time periods remained the same, 2015-2115 (100 years into the future).
- Sub-criterion A4 – two new time periods: 1980-2080 (a window of 100 years) and 1980-2065 (window of 85 years up to the same future time point as A4 in Chapter 4).
- Criterion C timescales were estimated based on Criterion A timescales, but reduced as appropriate to assess declines over one and two generations as necessary.

Criteria A and C were re-applied to all 324 study species using percentage deforestation calculated over these updated timescales. Sub-criteria categorisation outcomes were compared to Chapter 4 categorisations.

5.2.2 Case study 2 - Use of timber exploitation datasets in timber tree Red List assessments

The assessments conducted in Chapter 4 looked at the threat of deforestation facing angiosperm timber tree species. However, they did not include data on timber tree species harvest and trade. This is an important area of uncertainty to address, as many timbers may be at risk of or suffering from over-exploitation.

This also represents a challenge – as discussed in Chapter 2, timber tree taxa are typically traded under common or trade names, or at best by genus. Therefore, from the 324 timber species assessed in Chapter 4, only 30 species were selected for analysis in this case study (see **Table 5.4**), based on their listing on the Appendices of the Convention on International Trade in Endangered Species of Wild Flora and Fauna (CITES) (CITES, 2013a). Species are listed on the CITES Appendices on the understanding that they are at risk or may soon become at risk of over-exploitation.

‘CITES listing’ aims to protect listed species from over-harvest by imposing trade restrictions.

A literature search was conducted to obtain exploitation information, including harvest/trade volumes over time, for these 30 species. The search primarily focused on species proposals submitted at various Conferences of the Parties to CITES. Such proposals may be submitted by countries to which a species is native, and should provide as much relevant evidence as possible in support of the species being listed on CITES. Ideally, quantitative information will be included on species declines, population size, remaining distribution and threats. As proposals are made for each CITES listed species, it was assumed that these 30 species, out of the total 324 study timber tree species, would have the most available open-access data on exploitation. In addition, relevant journal papers and reports were used to supplement CITES proposals where available.

Once information on harvest and/or trade of wood over time was obtained for as many case study species as possible, all yields reported by weight (e.g. metric tonnes sawn logs) were converted into volumes of wood in cubic metres, using UNECE Forest Products Statistics 2005-2009 conversion factors for tropical roundwood and processed wood. In a very few cases, yield was reported in metric tonnes of wood chips – to convert these weights into cubic metres, FAO/UNECE guidelines for volumetric measurement of non-coniferous wood particles were used: 2.74 cubic metres of wood chips to every cubic metre of solid wood (FAO/UNECE, 2010).

The next step was to convert wood harvest volumes into numbers of individual harvested trees for each case study species. Conversion factors are highly important for conservation and forestry alike, to determine the number of logged trees represented by a certain timber yield or, conversely, to estimate the timber yield represented by a stand of living trees. However, determining what this conversion factor should be is very difficult. Simply using tree trunk length and diameter to calculate cylindrical volume is very unreliable, as trunks taper and furthermore often contain hollows and wood of differing quality. In addition, individuals are not of uniform size or shape (FAO/UNECE, 2010). With this in mind, it is unsurprising that conversion factors have been calculated for very few timber tree species. Grogan and Schultze (2008) have calculated a factor for *Swietenia macrophylla* (big-leaf mahogany), which was used to convert volumes for all case study species that lacked species- or genus-level factors in the literature.

Once yields were converted into individuals, Red List Categories and Criteria were applied to all species for which there was sufficient exploitation information.

5.2.3 Case study 3 - Calculating species range and habitat extent under GBIF versus 'expert' records datasets

Chapter 4 used species occurrence records from the Global Biodiversity Information Facility (GBIF) to calculate species EOO, AOO and forested area of EOO MCP. These calculations formed the basis of the entire Red List assessment for 240 timber tree species (those with >3 occurrence records). GBIF data are increasingly used in Red Listing, but have often been branded too unreliable for this purpose (e.g. Hjarding *et al.*, 2014). It is therefore of great importance that GBIF datasets be tested against other records datasets.

This case study utilised expert records collections and published range maps for 85 study species, to compare number of useable records, records 'completeness' (i.e. how many records are present across native range countries for each study species), EOO, AOO and forested area within EOO MCP.

The following expert datasets were used:

- *Biodiversity of West African Forests: An ecological atlas of woody plant species* (Poorter, 2004) provided range maps for 17 species of West African timber tree.
- *Malaysia Plant Red List: Peninsular Malaysian Dipterocarpaceae* (Chua *et al.*, 2010) provided species range maps for 32 Dipterocarpaceae species.
- Mark Newman provided expert distribution records for a further 26 Dipterocarpaceae species (Newman, M., May 2017, pers. comm.).

- Peter Wilkie provided expert records for eight Sapotaceae species (Wilkie, P., April 2017, pers. comm.).
- Martinez *et al*. (2008) provided a range map for *Swietenia macrophylla.*
- George Schatz provided expert records for *Diospyros crassiflora* (Schatz, G., May 2017, pers. comm.).

Additionally, availability of GBIF records for species synonyms was checked for all study species. For those with synonym records, new values for EOO, AOO and forested area of EOO were calculated, using combined accepted name (original GBIF) and synonym records, and were then compared to these range metrics from Chapter 4 (which used accepted name only).

5.2.4 Case study 4 - Exploration of uncertainty in estimates of maximum seed dispersal distance when determining if a species is 'severely fragmented'

In Chapter 4, Maximum Seed Dispersal Distance (MDD) was used in assessing habitat and, consequently, population fragmentation under Criterion B, sub-criterion (a) 'severe fragmentation'. Mean MDD estimates were calculated using the dispeRsal function for RStudio created by Tamme *et al*. (2014). However, the model also calculates estimates of minimum and maximum MDD, which were not used in Chapter 4 assessments. This case study used these minimum and maximum MDD values to re-assess fragmentation severity for the 52 timber tree species assessed under sub-criterion (a) in Chapter 4. 'Severe fragmentation' yes/no outputs and final Criterion B categorisation, resulting from the use of minimum, mean and maximum MDD, were then compared.

5.2.5 Bayesian Belief Network

A Bayesian Belief Network (BBN) is a probabilistic graphical model, usually presented in the form of a network diagram showing linked conditional dependencies of a set of variables. BBNs are increasingly being used in environmental modelling and, in recent years, for examining Red List assessment uncertainty (Newton, 2010).

In a Red Listing BBN, each Red List Criterion and sub-criterion is a variable. However, since each Criterion can only be applied if certain sub-criterion thresholds are met (conditional dependency), only the sub-criteria, which form the terminal nodes of the BBN network diagram, can be manipulated to input different threshold values. Use of different input datasets, as in cases where Red Listing data are uncertain, may alter which terminal node thresholds are met, and thus may produce different Red List categorisation outcomes for a study species.

For case studies 2, 3 and 4, a BBN developed specifically for this purpose by Newton (2010) was used to quantify likelihood of a species being listed under one Category rather than another, when different input datasets were used.

5.3 Results

5.3.1 Case study 1 - Assessing population declines under different time-periods of deforestation

This case study addressed species population declines inferred from percent deforestation within species' EOO, by applying Criterion A sub-criteria A2-A4, and Criterion C sub-criterion C1. Sub-criteria categorisations made using Chapter 4 timescales (based on broad estimates of 'three generations' for angiosperm timbers) were compared to categorisations made under new timescales that more accurately captured time-periods in the past over which 'current' rates of deforestation – that is, rates calculated using Global Forest Change satellite imagery for the years 2000-2014 (Hansen *et al*., 2013) – have been in operation.

Under Chapter 4 timescales, 220 of the324 species assessed were categorised as Threatened using sub-criteria A2-A4 only: 65 Vulnerable (VU), 58 Endangered (EN), and 97 Critically Endangered (CR) (see **Table 5.2** for tally totals of species in each Red List Category under the different timescales). Under Chapter 5 timescales, there was no change in the number of species placed in each Threatened Category, or between non-threatened and Threatened Categories. However, there were 23 changes between non-threatened Categories Near Threatened (NT) to Least Concern (LC). **Table 5.1** illustrates changes of full IUCN listing for these Criteria, within Threatened Categories and within non-threatened Categories.

Table 5.1 Criterion A sub-criterion under which 'Threatened' species were listed for this case study.
** Where sub-criterion A4 uses the timescale 1980-2065*
*** Where sub-criterion A4 uses the timescale 1965-2065 or 1980-2080 (100 years)*
****Where species qualified for listing under sub-criterion A4 under both the 1980-2080 and 1980-2065 timescales (100 and 85 years).*

Criterion A sub-criteria combinations used in each species categorisation	Total study species in Threatened Categories	
	Chapter 4 timescales	Chapter 5 timescales
A2 + 3 + 4bc*	15	0
A3bc	123	106
A3 + 4bc**	82	47
A3 + 4bc***	0	67

Table 5.2 Tally totals of study species in each Category for Criterion A when applied using different deforestation timescales.

Sub-criteria A2-A4 categorisation	Total study species	
	Chapter 4 timescales	Chapter 5 timescales
CR	97	97
EN	58	58
VU	65	65
NT	23	0
LC	80	103
DD	1	1

Under Criterion C, all categorisations were made under sub-criterion C1. Only two species were considered Threatened, (both EN) under Chapter 4 timescales, and these remained EN under Chapter 5 timescales. There was no movement in preliminary Criterion C categorisation between Threatened and non-threatened Categories, although three species considered NT under Chapter 4 timescales were categorised as LC under Chapter 5 timescales (see **Table 5.3**).

Table 5.3 Tally totals of study species in each Category for Criterion C when applied using different deforestation timescales.

Sub-criteria C1 categorisation	Total study species	
	Chapter 4 timescales	Chapter 5 timescales
CR	0	0
EN	2	2
VU	0	0
NT	3	0
LC	318	321
DD	1	1

Categorisation likelihood was not analysed using a Bayesian Belief Network (BBN) for this case study, because all the changes in overall A and C categorisations were between non-threatened Categories (LC and NT), and the BBN created by Newton (2010) supplies 'LC/NT' as a combined categorisation option only. This is likely because, although the IUCN Red List Guidelines offer guidance and examples for assigning 'NT' (for examples, see **Table 4.1**), this Category does not have a set of quantitative thresholds in the same way as VU, EN and CR.

5.3.2 Case study 2 - Use of timber exploitation datasets in timber tree Red List assessments

This case study assessed availability and quality of open-source exploitation data that are readily available for CITES listed species from the list of 324 timber tree species prioritised in Chapter 4. Thirty study species are listed in CITES Appendices, the majority being from the genus *Dalbergia* (rosewood).

Of the 30 case study species, all but two (*Swietenia humilis* and *S. mahagoni*) had time-series information on timber yield (that is, information on logging harvest and/or trade in wood products for certain years). However, these two mahogany species were documented as being "commercially extinct", so it is unsurprising that no quantitative yield data were forthcoming. Of the 38 species that did have yield information, 14 had species-specific data and the remainder had data documented at the genus level.

Only four species, *Aniba rosaeodora*, *Dalbergia cochinchinensis*, *Prunus africana* and *Swietenia macrophylla* had species-specific conversion factors for estimating the number of harvested individuals represented by volume of traded product. Additionally, *Aquilaria malaccensis* has a genus-specific conversion factor documented. As a result, the conversion factor for *Dalbergia cochinchinensis* was used to estimate number of harvested individuals, based on reported trade volumes over time, for all *Dalbergia spp*., and the conversion factor for *Swietenia macrophylla* was used to estimate number of harvested individuals for all other case study species for which no species- or genus-specific conversion factor was available. This may have resulted in underestimation of the number of logged individuals for some species, as *Swietenia macrophylla* grows to a large allowable cutting size, and conversions were based on trees 60-80 cm in diameter (Grogan and Schultz, 2008). Conversion factors for *Aquilaria malaccensis, Aniba rosaeodora* and *Prunus africana* were not applied to other species, as, though secondarily used for timber, they are primarily harvested for agarwood (infected bark), essential oil, and bark respectively (all unsustainable harvest of these products typically involves felling). Few species had information relating to regeneration time and/or growth rate, regional cutting cycles and/or permitted harvestable tree size classes, or population size and/or a measure of percentage decline. **Table 5.4** below summarises availability of exploitation data useful for Red List assessment for the thirty case study species.

In total, only five case study species (highlighted in grey in **Table 5.4**) had sufficient quantitative information on harvest intensity over time, population size or percentage decline, cutting cycles / allowable harvest by size class, and regeneration time / tree growth rate to allow Red List categorisation (see **Table 5.5** for data summary). The most important information for applying Red List Criteria was population size or estimate of decline, and time-series yield data that could be converted into an estimate of harvested individuals.

Table 5.4 Summary of Red List-relevant information available for each CITES timber species, obtained from exploitation documentation. Data marked with "y" are species-specific; data marked "y+" are genus-specific; "n" denotes no available species- or genus-specific dataset for the timber tree species in question.*

Species	CITES Appendix	Data available on:				
		Yield volume time series	Conversion factor	Regeneration time / growth rate	Cutting cycles / allowable harvest size class	Population size / measure of % decline
Aniba rosaeodora	2	y*	y*	n	n	n
Aquilaria malaccensis	2	y*	y+	y+	y+	y+
Bulnesia sarmientoi	2	y*	n	n	y*	y*
Caesalpinia echinata	2	y*	n	n	n	y*
Cedrela fissilis	3	n	n	n	n	n
Cedrela odorata	3	y*	n	n	n	n
Dalbergia bariensis	2	y+	y+	n	n	n
Dalbergia baronii	2	y+	y+	n	n	n
Dalbergia cambodiana	2	y+	y+	n	n	n
Dalbergia cearensis	2	y+	y+	n	n	n
Dalbergia cochinchinensis	2	y*	y*	y*	n	y*
Dalbergia cultrata	2	y+	y+	n	n	n
Dalbergia decipularis	2	y+	y+	n	n	n
Dalbergia greveana	2	y+	y+	n	n	n
Dalbergia latifolia	2	y+	y+	n	n	n
Dalbergia louvelii	2	y+	y+	n	n	n
Dalbergia madagascariensis	2	y+	y+	n	n	n
Dalbergia maritima	2	y+	y+	n	n	n
Dalbergia melanoxylon	2	y*	y+	y*	y*	n
Dalbergia monticola	2	y+	y+	n	n	n
Dalbergia nigra	1	y*	y+	n	n	n

Table 5.4 continued

Species	CITES Appendix	Data available on:				
		Yield volume time series	Conversion factor	Regeneration time / growth rate	Cutting cycles / allowable harvest size class	Population size / measure of % decline
Dalbergia oliveri	2	y+	y+	n	n	n
Dalbergia pervillei	2	y+	y+	n	n	n
Dalbergia retusa	2	y*	y+	y*	n	n
Dalbergia stevensonii	2	y*	y+	y*	n	n
Gonystylus bancanus	2	y+	n	y+	n	y+
Gonystylus forbesii	2	y+	n	y+	n	y+
Gonystylus macrophyllus	2	y+	n	y+	n	y+
Guaiacum coulteri	2	y+	n	n	n	n
Guaiacum officinale	2	y+	n	n	n	n
Guaiacum sanctum	2	y*	n	n	n	n
Pericopsis elata	2	y*	n	n	n	n
Prunus africana	2	y*	y*	y*	y*	n
Pterocarpus santalinus	2	y*	n	y*	y*	n
Swietenia humilis	2	n	y+	n	n	n
Swietenia macrophylla	2	y*	y*	y*	y*	y*
Swietenia mahagoni	2	n	y+	n	n	n

Table 5.5 Summary of preliminary IUCN Red List Categories and supporting information for the five case study species with sufficient exploitation data.
** "Non-harvest exports" in this case refers to exports from timber stockpiles that were created prior to harvest restrictions coming into force.*

Species	Range state	Years of available data	Total harvested individuals	Supporting information	Preliminary Red List Category	References
Aquilaria malaccensis *Aquilaria spp.*	India legal exports Indonesia official legal exports	1989-1993 1991-1996 2001	9,008,643 (high grade) - 1,087,249 (low grade) 360,000 <30,000 - >100,000	Estimated population size of *Aquilaria* genus in Indonesia is 2.6 million individuals >10cm DBH (year 2001).	CR A2 or CR A4, depending on harvest volume	Soehartono and Newton, 2001; CITES, 1994
Bulnesia sarmientoi	Argentina legal exports Argentina customs seizure Argentina & Paraguay exports	2006-2008 2008 2000 2010-2012	37,826 1,963 373 78,288	Slow growing. Most size classes harvested. Range in Argentina (major exporting country) estimated at 8.3 million ha. Volume extracted equal to / higher than stands remaining.	VU A2	CITES, 2010; Medicinal Plant Specialist Group, 2012
Caesalpinia echinata	Estimated annual global demand. Brazilian non-harvest legal exports *	2007 2006-2007	104 10,630	Slow growth rate, maximum stem diameter typically 70cm. In 2005, the Pau-Brazil Program recorded 1,754 trees, of which 1,669 natural and 85 planted.	EN C1	Mejía and Buitrón, 2008
Dalbergia cochinchinensis	Thailand illegal trade	2007-2013	600,000	EOO 557.76 km^2; fragmented. In Thailand, estimated 80,000-100,000 trees in 2011, reduced from 300,000 in 2005. Population size in Vietnam unknown but rosewood population has declined 50-60% in last 5-10 yrs.	VU A2 & EN B1ab	CITES, 2013b
Swietenia macrophylla	Total exports Bolivia, Brazil, Guatemala, Nicaragua & Peru Peru reported exports. International exports	2000-2005 1996-2008 2002	64,777 154,000 - 203,000 20,542	30 year cutting cycle in Brazil. Modelling indicates current harvest regulations will lead to commercial depletion after 2-3 cutting cycles (60-90 years future from 2014).	VU A4 or VU A2	Hewitt, 2007; Grogan and Schulze, 2008; CITES, 2002

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In comparison to their Chapter 4 final categorisations, under Chapter 5 – information from exploitation sources only – the five species listed in **Table 5.5** mostly saw a shift towards slightly less conservative Categories (see **Table 5.6**).

Table 5.6 Tally totals of study species in each Category, using Chapter 4 and Chapter 5 datasets.

Final categorisation	Total study subset species	
	Chapter 4 spatial and deforestation datasets	Chapter 5 exploitation datasets
CR	2	1
EN	2	1
VU	0	2
NT	0	0
LC	1	0
DD	0	1

Table 5.7 summarises Bayesian Belief Network (Newton, 2010) final categorisation outcomes for the five study species when threshold values were entered under varying degrees of uncertainty for relevant sub-criteria (i.e., all sub-criteria that could be applied using the available exploitation data). Final categorisation outcomes under maximum certainty scenarios differed typically by one Category 'level' (i.e. EN versus CR) between the two datasets. When more thresholds were entered with more uncertainty, Category outcomes were typically more conservative, illustrating the conservative nature of the Red List.

Table 5.7 Bayesian Belief Network Category outcomes under Chapter 4 and Chapter 5 datasets and varying degrees of assessment uncertainty.

Species	Sub-criteria thresholds under maximum certainty		Sub-criteria thresholds under total uncertainty	Sub-criteria thresholds under intermediate uncertainty
	Exploitation outcome	Chapter 4 outcome		
Aquilaria malaccensis 1	100% CR	100% EN	78.23% CR; 20.48% EN; 1.28% VU; 0.01% LC	50% CR; 25% EN; 25% VU
Aquilaria malaccensis 2	100% CR	100% EN	78.23% CR; 20.48% EN; 1.28% VU; 0.01% LC	50% CR; 25% EN; 25% VU
Bulnesia sarmentoi	100% VU	100% CR	78.23% CR; 20.48% EN; 1.28% VU; 0.01% LC	50% CR; 25% EN; 25% VU
Caesalpinia echinata	100% EN	100% EN	34.38% VU; 34.38% LC; 20.31% EN; 10.94% CR	62.50% LC; 31.25% EN; 6.25% VU
Dalbergia cochinchinensis	100% EN	100% CR	58.98% CR; 28.71% EN; 11.04% VU; 1.27% LC	50% CR; 33.06% EN; 16.94% VU
Swietenia macrophylla 1	100% VU	100% LC	78.23% CR; 20.48% EN; 1.28% VU; 0.01% LC	50% VU; 50% LC
Swietenia macrophylla 2	100% VU	100% LC	78.23% CR; 20.48% EN; 1.28% VU; 0.01% LC	50% VU; 50% LC

5.3.3 Case study 3 - Calculating species range and habitat extent under GBIF versus 'expert' records datasets

This case study addressed number, coverage and completeness of species distribution records from GBIF (Chapter 4 datasets) in comparison to that of expert records collections and published range maps ('expert' datasets). EOO (sub-criterion B1), AOO (sub-criterion B2) and forested area within EOO, calculated using GBIF and expert datasets were also compared.

Addition of GBIF records for species synonyms

A search of The Plant List (2013) and Kew World Checklist of Selected Plant Families yielded 159 synonyms, corresponding to accepted names of 43 out of 85 case study species. The remaining 42 case study species had no synonyms. Of these 159 synonyms, GBIF only returned records for 77. Raw records per synonym ranged from one to 133, with a mean average of 28 raw records per species, a mode of four and a median of seven. However, the majority of synonym records lacked coordinates. After cleaning and native range country matching it was found that, of the 77 synonyms with GBIF records, only 11 (corresponding to 11 different accepted names) had ‘useable’ (cleaned and matched) records. Of the 11 synonyms with useable records, only four names had three or more useable records and the remainder had only one useable record each. The greatest number of useable records per synonym was 17, and synonyms had a mean average of five records, and a mode and median of one record.

The useable synonym records were added to the existing GBIF accepted-name point maps (used in Chapter 4 assessments) for these 11 case study species, and EOO was recalculated for these ‘accepted + synonym’ point maps. The addition of synonym records altered the overall GBIF EOO for only two species, *Milicia regia* and *Guarea cedrata*. For the other nine species, synonym records were distributed within the current EOO and therefore did not alter the area of the EOO MCP. Both *Milicia regia* and *Guarea cedrata* are West African timbers, with 13 and one useable synonym records, respectively.

The original GBIF EOO for *Milicia regia* was 911,838.9 km^2. With the addition of synonym records, overall EOO was 951,480.3 km^2 – an increase of the original area by 4%. For *Guarea cedrata*, original GBIF EOO was 2,837,598.9 km^2. With the addition of the single useable synonym record, EOO increased by 3.7% to 2,942,229.96 km^2. Since original EOO for both species was already large (B1 LC), the addition of synonym records did not cause a Category change. However, **Figures 5.1a and b, and Figures 5.2a and b** illustrate the changes in records coverage and EOO MCPs when three different records datasets: original GBIF, original GBIF with synonyms added, and expert records only. EOO MCP and records coverage for *Guarea cedrata* (**Fig. 5.1a and Fig. 5.1b**) are visibly very different under expert versus original GBIF, whereas *Milicia regia* (**Fig. 5.2a and Fig. 5.2b**) shows a very similar EOO MCP under all three scenarios.

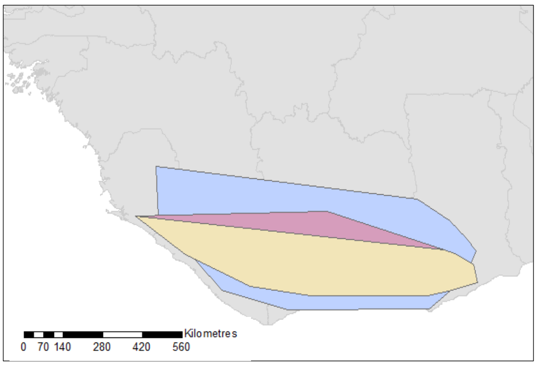

Figure 5.1a EOO for <u>Guarea cedrata</u> using expert (blue), original GBIF (yellow), and original GBIF plus synonyms (red) records datasets.

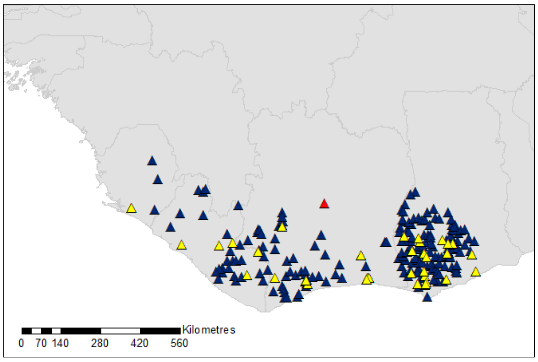

Figure 5.1b Records coverage for <u>Guarea cedrata</u> using expert (blue), original GBIF (yellow), and original GBIF plus synonyms (red) datasets.

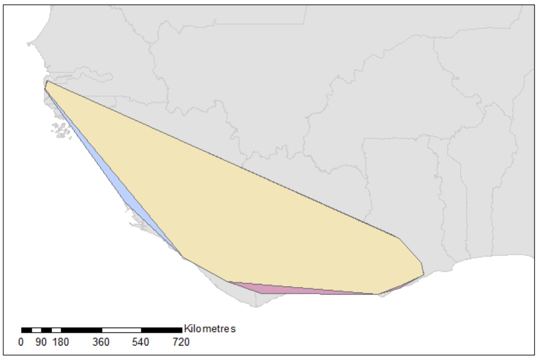

Figure 5.2a EOO for <u>Milicia regia</u> using expert (blue), original GBIF (yellow), and original GBIF plus synonyms (red) records datasets.

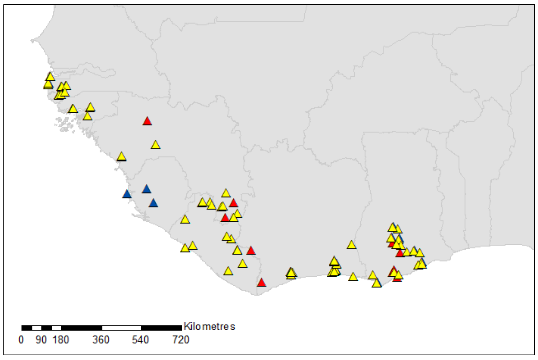

Figure 5.2b Records coverage for <u>Milicia regia</u> using expert (blue), original GBIF (yellow), and original GBIF plus synonyms (red) datasets.

Expert species maps

Out of the 324 timber tree species Red Listed in Chapter 4, expert distribution records collections or peer-reviewed published range maps were obtained for 85 species. *Biodiversity of West African Forests: An ecological atlas of woody plant species* (Poorter, 2004) provided expert point maps for 17 species (20% of case study species). The 17 species were West African timbers from nine families. Species maps were available for 32 Dipterocarpaceae species (38% of case study species) from *Malaysia Plant Red List: Peninsular Malaysian Dipterocarpaceae* (Chua *et al*., 2010). Mark Newman provided expert distribution records for a further 26 (31%) Dipterocarpaceae, and Peter Wilkie provided expert records for eight species of Sapotaceae (9% of case study records). Additionally, one range map, for *Swietenia macrophylla*, was obtained from Martinez *et al*. (2008), and one set of records, for *Diospyros crassiflora*, was supplied by George Schatz.

Expert records cleaning

Twenty-four out of the 26 species records sets supplied by Mark Newman had duplicates and/or some coordinate error (for example, ocean records). Of these, number of duplicate records ranged from one to 67 per species, with a mean of 23, and number of ocean records ranged from one to five per species, with a mean of two. All eight species records sets supplied by Peter Wilkie had duplicate records and/or some records with coordinate errors (for example, records far outside native range), ranging from four to 846 records per species, with a mean of 142. The record set for *Diospyros crassiflora* had 42 records that were either duplicates or erroneous (for example, records far outside native range). The relatively large number of erroneous records in these datasets may reflect inclusion of botanical collections or specimens in cultivation outside of species native range countries. All other expert maps were obtained in the form of published images rather than raw records, and were georeferenced in ArcMap 10.1 (ESRI, 2012) to produce digital point maps.

Determining 'native range'

Twenty-eight species had discrepancies, under expert versus Chapter 3 SIS datasets (see **Chapter 3** for more information on the process of determining native range), in the countries that were thought to be part of their native range. For species with deliberate partial-range expert maps, countries were only counted as being in dispute if they were represented by the expert map but not the SIS dataset.

The maximum number of disputed countries per species was four, and minimum one. Mean average number of disputed countries was two, mode one and median two.

In total, 23 range countries were in dispute. Brunei was the most disputed (eight times), Singapore and Laos were the second-most disputed (five times each), followed by Thailand, Sierra Leone and Liberia (three times each). Viet Nam, the Republic of the Congo, the Democratic Republic of the Congo, Central African Republic, Cameroon and Bangladesh were each disputed twice, and Sri Lanka, the Philippines, Nigeria, Nicaragua, Myanmar, Indonesia (Sumatra), Honduras, Guinea-Bissau, Guatemala, Equatorial Guinea and Cambodia were each disputed once. It is likely that Brunei and Singapore were so highly disputed because they are both geographically very small countries relative to their closest neighbour, Malaysia, and records may be noted as 'Malaysia' in error. The GlobalTreeSearch (Beech *et al*., 2017) database of tree taxa distributions was used as an 'independent adjudicator' for disputed countries – it supported SIS country listing in 53.6% of species, and did not support 46.4% of SIS country listings.

Number and completeness of records

Fifty species had partial-range expert maps, and for these species, the corresponding GBIF point maps were edited to cover only those range countries included in the expert map. In the process of being made comparable, 44 species lost enough records to be left with <3 less than the required amount of records needed to draw an EOO MCP. These 44 species were therefore excluded from further analysis in this case study, leaving 41 species to be carried forward (note that for this analysis, *Swietenia macrophylla* was excluded because its expert map was composed of polygons rather than individual point records).

For the remaining 41 case study species, the total number of expert records per species ranged from three to 194, with a mean of 89 and a median of 68. Total number of useable GBIF records per species was significantly lower, ranging from three to 62 with a mean of 22 records per species and a median of 14. In terms of dataset 'completeness', the number of species with at least one record in each of its native range countries also varied considerably between GBIF and expert datasets. Using expert datasets, 33 of the 40 species had at least one record in each range country, whilst for GBIF datasets this number was only ten of the 40. Under expert datasets, the total number of records per native range country was ranged from zero to 119. Under GBIF, it ranged from zero to only 38. The mean number of expert records per range country was 16, with a median of four and a mode of one. The mean number of GBIF records per range country was four, with a median of one and a mode of zero. **Figure 5.3** illustrates the difference in number of records under GBIF and expert datasets.

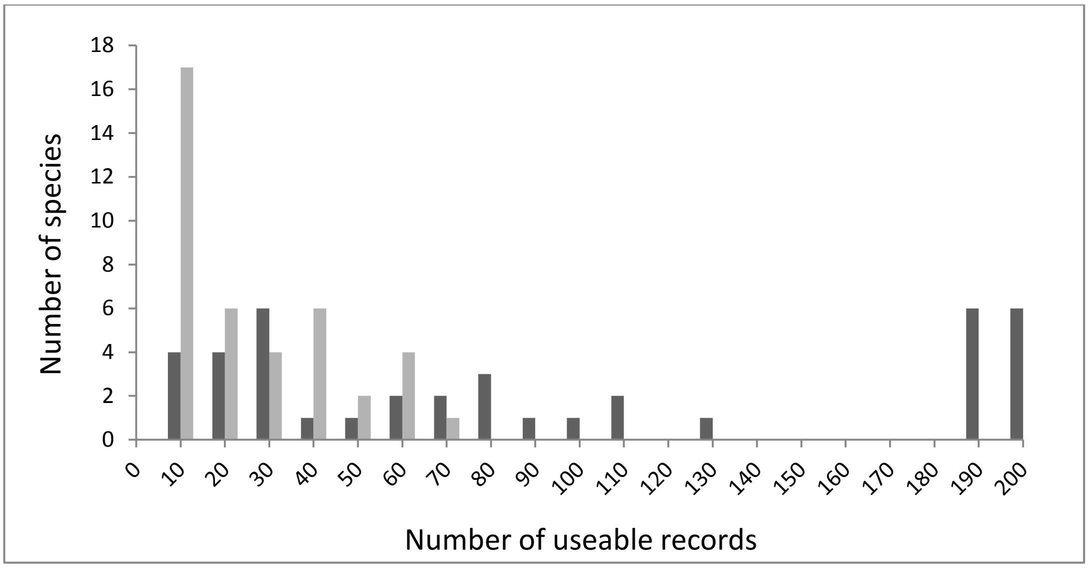

Figure 5.3 Frequency distribution of number of useable records per study species under GBIF (grey) and expert (black) datasets.

EOO, AOO and area of forest

EOO calculated using expert records ranged from 16,506 km^2 to 6,670,637 km^2, with a mean of 1,343,678 km^2. In contrast, GBIF-calculated EOO ranged from 3,743 km^2 to 4,531,303 km^2, with a mean of 659,009 km^2. AOO – calculated in GeoCAT (Bachman *et al*., 2011; http://geocat.kew.org/) using a 4km^2 grid – was similarly different for expert and GBIF datasets; expert AOO ranged from 4 km^2 to 776 km2, with a mean of 352.8 km^2, while GBIF AOO ranged from 12 km^2 to 240 km^2, with a mean of 83.9 km^2. Forested area of EOO was slightly less disparate under expert versus GBIF datasets. Expert forested area ranged from 3,493 km^2 to 1,467,209 km^2, with a mean of 474,479 km^2. GBIF forested area ranged from 3,524 km^2 to 3,944,609 km^2, with a mean of 323,833 km^2.

In total, six species had different categorisations under sub-criterion B1 (EOO): *Madhuca betis* was VU under expert but LC under GBIF, *Pericopsis elata* was LC under expert but VU under GBIF, *Dryobalanops beccarii* was LC under expert but EN under GBIF, *Payena maingayi* was LC under expert but VU under GBIF, *Hopea beccariana* was LC under expert but VU under GBIF, and *Cotylelobium lanceolatum* was LC under expert but EN under GBIF. It appears that in general, more conservative categorisations were applied on the basis of EOO when using GBIF rather than expert datasets, likely as a result of fewer GBIF records and lower record 'completeness' giving the illusion of a smaller range for some species. **Table 5.8** summarises total case study species B1 categorisations for these datasets, and **Figures 5.4, 5.5, and 5.6** illustrate the differences in EOO, AOO and forested area respectively.

Sub-criterion B1 categorisation	Total study species	
	Expert	GBIF
LC	40	35
VU	1	4
EN	0	2

Table 5.8 Tally totals for case study species B1 categorisations using expert and GBIF datasets.

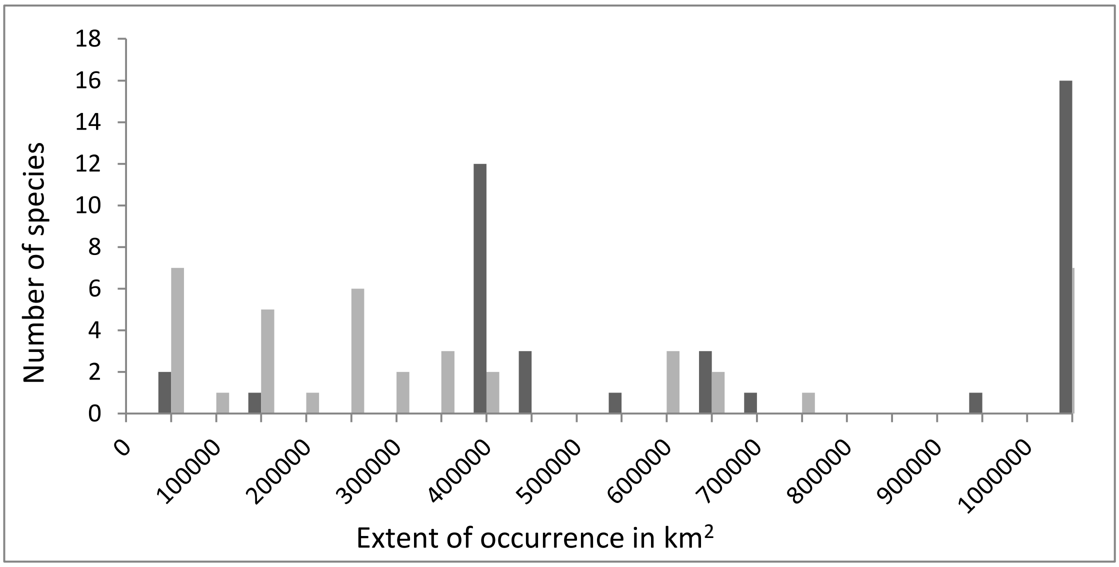

Figure 5.4 Frequency of species' extent of occurrence calculated using GBIF (grey) and expert (black) datasets.

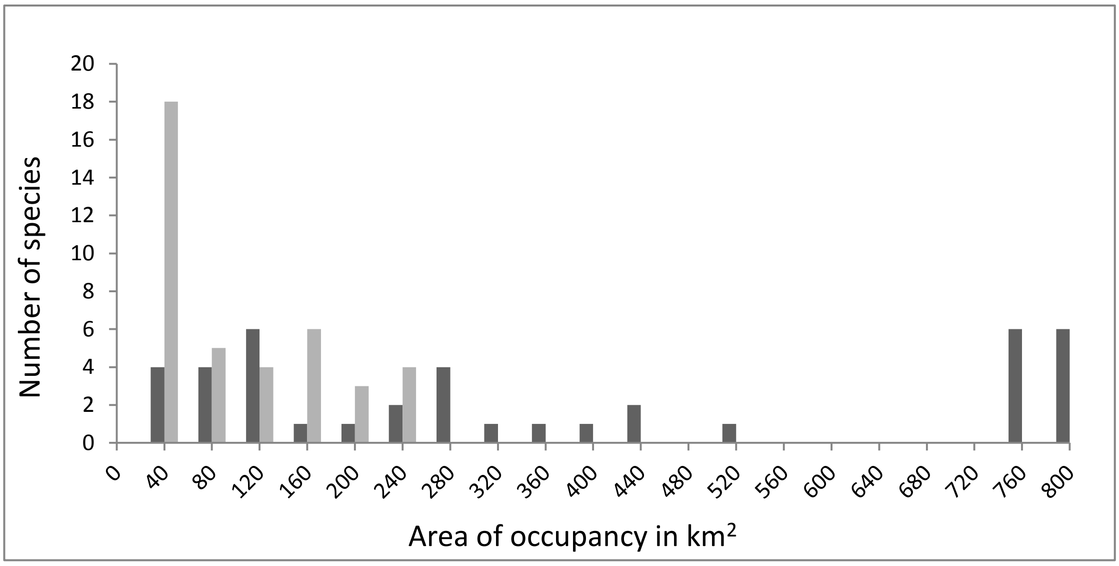

Figure 5.5 Frequency of species' area of occupancy calculated using GBIF (grey) and expert (black) datasets.

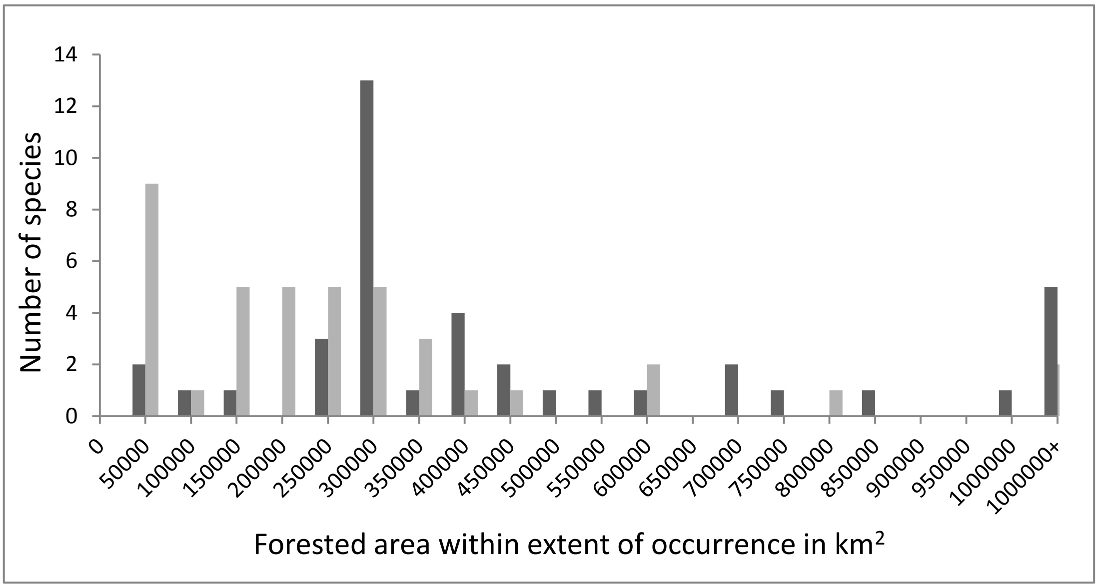

Figure 5.6 Frequency of forested area within species' EOO calculated using GBIF (grey) and expert (black) datasets.

Table 5.9 summarises Bayesian Belief Network final Red List Category outcomes for the six case study species that had a different sub-criterion B1 Category under GBIF versus expert datasets. In most cases, most likely final categorisation was the same across all uncertainty scenarios for sub-criterion B1 thresholds, with the exception of outcomes for *Dryobalanops beccarii,* which remained EN under maximum GBIF input certainty, but was VU under all other input scenarios.

Table 5.9 Bayesian Belief Network final outcomes for species' final Red List Category under different uncertainty scenarios for sub-criterion B1 (EOO).

Binomial	Maximum certainty		Total uncertainty	Intermediate uncertainty		
	Expert outcome	GBIF outcome		Most likely to be Expert or GBIF	Expert outcome most likely, followed by GBIF	GBIF outcome most likely, followed by Expert
Dryobalanops beccarii	100% VU	50% EN 50% VU	75% VU 12.5% EN 12.5% CR	75% VU 25% EN	80% VU 15% EN 5% CR	70% VU 25% EN 5% CR
Cotylelobium lanceolatum	100% CR	100% CR	100% CR	100% CR	100% CR	100% CR
Payena maingayi	100% CR	100% CR	100% CR	100% CR	100% CR	100% CR
Hopea beccariana	100% CR	100% CR	100% CR	100% CR	100% CR	100% CR
Pericopsis elata	100% LC	50% LC 50% VU	62.5% LC 12.5% CR 12.5% EN 12.5% VU	75% LC 25% VU	75% LC 15% VU 5% CR 5% EN	65% LC 25% VU 5% CR 5% LC
Madhuca betis	100% EN	100% EN	87.5% EN 12.5% CR	100% EN	95% EN 5% CR	95% EN 5% CR

5.3.4 Case study 4 - Exploration of uncertainty in estimates of maximum seed dispersal distance when determining if a species is 'severely fragmented'

This case study addressed Criterion B sub-criterion (a) severe fragmentation assessed using estimates of maximum seed dispersal distance (MDD) calculated with the dispeRsal function (Tamme *et al*., 2014) in RStudio (RStudio, 2014). Minimum and maximum MDD estimates were used to assess whether case study species qualified as 'severely fragmented', and the outcomes were compared to outcomes generated in Chapter 4 using mean MDD.

Only three study species showed differences in connectivity under the different MDD buffers that were sufficient to change the categorisation under Criterion B based on the sub-criterion (a) threshold for 'severe fragmentation'. *Coelostegia griffithii*, *Phyllostylon rhamnoides*, and *Gonystylus bancanus* met 'severely fragmented' thresholds using the minimum MDD buffer, but not using mean or maximum MDD buffers. **Table 5.10** summarises severe fragmentation outcomes for all case study species using the three different buffer distances.

Bayesian Belief Network final Category outcomes for these three species were mixed (see **Table 5.11**). *Coelostegia griffithii* final categorisations were the same, CR, under all uncertainty scenarios – the result of the species being listed as 'CR' under a Criterion other than Criterion B (i.e., the species was already at the highest level of extinction risk in the wild on the basis of other Criteria and sub-criteria, thus the 'severe fragmentation' input matters little in this case. The other two species had variable final categorisation output under the different uncertainty scenarios, indicating that for these species, Criterion B sub-criterion (a) had a significant effect on final listing.

Table 5.10 Criterion B, sub-criterion (a) (severe fragmentation) outcomes under minimum, mean and maximum seed dispersal buffer distances

Binomial	Minimum buffer distance /m	Mean buffer distance /m	Maximum buffer distance /m	Severely fragmented?		
				Minimum buffer	Mean buffer	Maximum buffer
Allantoma integrifolia	6.68	12.90	24.91	No	No	No
Archidendropsis xanthoxylon	220.38	813.37	3001.92	No	No	No
Carapa grandiflora	30.38	214.37	1512.60	No	No	No
Coelostegia griffithii	**508.82**	**1896.09**	**7065.68**	**Yes**	**No**	**No**
Cotylelobium lanceolatum	124.49	206.86	343.74	No	No	No
Cynometra inaequifolia	184.90	683.11	2523.64	No	No	No
Desmodium oojeinense	162.69	611.19	2296.06	No	No	No
Dillenia philippinensis	356.67	1049.32	3087.08	No	No	No
Gossweilerodendron joveri	308.00	544.16	961.39	No	No	No
Hopea beccariana	47.21	146.04	451.76	No	No	No
Hopea foxworthyi	45.00	130.65	379.35	No	No	No
Horsfieldia ralunensis	363.57	642.33	1134.84	No	No	No
Isoberlinia scheffleri	4.17	23.35	130.78	No	No	No
Mezzettia parviflora	101.62	340.86	1143.40	No	No	No
Ocotea comoriensis	228.86	404.33	714.35	No	No	No
Phyllostylon rhamnoides	**34.91**	**106.09**	**322.37**	**Yes**	**No**	**No**
Pterocymbium beccarii	52.32	163.04	508.06	No	No	No
Shorea lamellata	49.71	156.35	491.77	No	No	No
Sindora supa	166.93	624.48	2336.18	No	No	No
Artocarpus chama	403.37	1495.21	5542.44	No	No	No
Shorea bracteolata	420.26	1546.68	5692.19	No	No	No
Andira coriacea	308.00	544.16	961.39	No	No	No
Aniba rosaeodora	466.36	1353.93	3930.65	No	No	No
Anisoptera laevis	420.26	1546.68	5692.19	No	No	No

Table 5.10 continued						
Aspidostemon perrieri	228.86	404.33	714.35	No	No	No
Bastardiopsis densiflora	14.14	27.31	52.73	Yes	Yes	Yes
Breonia madagascariensis	877.84	1550.92	2740.07	No	No	No
Bulnesia carrapo	324.72	519.31	830.51	No	No	No
Dacryodes excelsa	433.18	1593.73	5863.58	No	No	No
Diospyros korthalsiana	294.62	1088.43	4021.06	No	No	No
Gonystylus bancanus	**13.90**	**133.35**	**1279.42**	**Yes**	**No**	**No**
Gonystylus forbesii	410.51	1515.06	5591.65	No	No	No
Horsfieldia superba	412.90	1519.60	5592.53	No	No	No
Huertea cubensis	386.57	1128.70	3295.58	No	No	No
Ilex amplifolia	324.72	519.31	830.51	No	No	No
Juglans jamaicensis	178.40	656.35	2414.81	No	No	No
Lonchocarpus leucanthus	5.92	11.43	22.08	No	No	No
Mangifera mucronulata	395.07	697.98	1233.15	No	No	No
Mora gonggrijpii	0.05	1.03	20.67	No	No	No
Oxystigma mannii	233.26	867.31	3224.87	No	No	No
Paratecoma peroba	11.00	10.59	41.03	Yes	Yes	Yes
Payena maingayi	375.28	663.02	1171.38	No	No	No
Pericopsis mooniana	28.39	171.83	1040.17	No	No	No
Quercus phillyreoides	0.02	0.27	2.84	Yes	Yes	Yes
Sapium laurocerasus	601.14	1062.07	1876.39	No	No	No
Swartzia leiocalycina	95.10	350.56	1292.22	No	No	No
Tarrietia densiflora	484.36	1791.28	6624.51	No	No	No
Vitex turczaninowii	331.64	585.92	1035.17	No	No	No
Vochysia duquei	124.49	206.86	343.74	No	No	No
Vochysia obidensis	124.49	206.86	343.74	No	No	No
Vouacapoua macropetala	7.49	70.96	672.22	No	No	No

Table 5.11 Bayesian Belief Network outcomes for species' final categorisation under different uncertainty scenarios for Criterion B, sub-criterion B (a) (severe fragmentation)

Binomial	Maximum certainty		Total uncertainty	Intermediate uncertainty	
	Minimum buffer outcome	Mean buffer outcome		Minimum buffer outcome most likely	Mean buffer outcome most likely
Coelostegia griffithii	100% CR	100% CR	100% CR	100% CR	100% CR
Phyllostylon rhamnoides	100% EN	100% LC	50% EN 25% VU 25% LC	75% EN 18.75% VU 6.25% LC	56.25% LC 25% EN 18.75% VU
Gonystylus bancanus	100% CR	100% VU	75% CR 25% VU	93.75% CR 6.25% VU	43.75% CR 56.25% VU

5.4 Discussion

5.4.1 Key findings

Expert datasets were scarce in comparison to Chapter 4 datasets. This was particularly apparent for case study 2 (use of timber exploitation datasets), where out of 30 CITES listed timber species, only five had sufficient information on study taxa to allow application of IUCN Red List Categories and Criteria. This indicates that, despite uncertainties, 'big data' such as GBIF records and GFC deforestation data will still need to play an important role in tree Red List assessments if we are to meet GSPC 2020 Targets 2 and 12 (CBD, 2012).

In general, Chapter 4 data were shown to give uncertain categorisations. However, in case study 3, the large disparity in number of GBIF records compared to expert records (**Figure 5.3**) rather surprisingly did not appear to have much of an impact on either B1 (EOO) categorisation – only six of the 41 species showed Category changes between datasets – or on final species categorisation. Bayesian Belief Network outcomes gave the same most-likely Category across all uncertainty scenarios for the majority of species. These findings appear to indicate that GBIF records were as useful as expert records in applying sub-criterion B1.

5.4.2 General limitations

Due to limited availability of expert datasets, only a small number of study species were assessed in each case study, relative to the entire timber list of 324 priority species. Therefore, it is more difficult to make broad statements about likely Category movement under different data scenarios for the entire timber group.

Expert review is a key step in getting a Red List assessment published on the IUCN Red List of Threatened Species. The role of taxonomic and regional experts has been touched upon indirectly in this chapter through use of expert-compiled species distribution records in comparison to GBIF data, and in the use of CITES proposals and other peer-reviewed literature when looking at exploitation of timbers, but contact with regional experts in particular, to provide another source of comparison to the Chapter 4, 'big data' assessments would be valuable in further investigating reliability of these assessments.

The Bayesian Belief Network (Newton, 2010) was only used to compare likelihood of different categorisation outcomes for species that exhibited a change in Category when the sub-criteria under scrutiny were applied using different datasets. It would be interesting to find out the contribution of each sub-criterion, under data uncertainty, to the overall categorisation likelihood for all 324 timber species, and all sub-criteria separately.

5.5 Recommendations for Red Listing

Case study 1 - Assessing population declines under different time-periods of deforestation

A source of uncertainty that was not addressed due to lack of information is the relationship between % deforestation and % population size reduction – Chapter 4 assessments assumed a 1:1 relationship but this is highly unlikely. Additionally, looking at deforestation over species-specific timescales versus Chapter 4 generation length estimates would be an interesting comparison to the analyses conducted in the chapter, assuming that species-specific generation length estimates were reliable and available for a substantial number of study species. **Table 5.1** suggests that for the majority of species listed under A4, the longer future projection is needed in order to maintain Threatened Category from Chapter 4, thus, under more precise future deforestation scenarios, categorisations are likely to change. Hence, if we are to Red List timbers (and other long-lived forest tree species) under A4 or A3, the stipulation of "up to a maximum of 100 years into the future" may allow many species to slip into threat categories that may not be reliable, as we do not yet have good models projecting global forest trends in the far future. It is therefore recommended that assessments made under sub-criteria A3 and A4 for timber and other long-lived tree taxa, especially when using current deforestation rates as a proxy with which to project future population decline, should be treated as highly uncertain and, where possible, Criterion A assessments should preferentially be made under sub-criterion A2 (or A1 were applicable).

Case study 2 - Use of timber exploitation datasets in timber tree Red List assessments

The literature search conducted for exploitation information in this chapter was not exhaustive and there may be more data available for other, non-CITES listed timber tree species. Additionally, exploitation datasets were not combined with Chapter 4 datasets to make assessments using all available data, for the same reason that datasets for the other three case studies were not pooled into unified assessments. This was because the aim of this chapter was to assess how well Chapter 4 'big data' stood up in comparison to expert datasets and data from other published sources. However, final Red List assessments for timbers, to be published in the IUCN Red List database, should incorporate all available data.

Case study 3 - Calculating species range and habitat extent under GBIF versus 'expert' records datasets

B1 (EOO) Category results and Bayesian Belief Network outcomes for this case study indicate that GBIF data *are* in fact suitable for calculating timber species EOO, and provide similar results to 'expert' data. However, these analyses were carried out on small sets of study species (41 and six, respectively) and will need to be repeated for larger study groups to be confident in recommending use of GBIF records for Red Listing other tree taxa.

Case study 4 - Exploration of uncertainty in estimates of maximum seed dispersal distance when determining if a species is 'severely fragmented'

It is important to note that the dispeRsal buffer values used are all variations on maximum dispersal distance and do not give the entire dispersal kernel (seed shadow) from minimum to maximum dispersal distance (see Bullock *et al*., 2017). Thus it is possible that patch connectivity is overestimated by using dispeRsal estimates, as not all seeds will travel the maximum distance from their parent tree. Of course, the presence of parent trees at the margins of all forest patches within a species' EOO is itself uncertain. So although dispeRsal appears to be a very useful tool for exploring severity of fragmentation for tree Red Listing, particularly in the absence of expert knowledge on study species habitat and population structure, it should be used with caution.

5.6 References

Akçakaya, H.R., Ferson, S., Burgman, M.A., Keith, D.A., Mace, G.M. and Todd, C.R., 2000. Making consistent IUCN classifications under uncertainty. *Conservation Biology*, 14 (4), 1001-1013.

Bachman, S., Moat, J., Hill, A. W., de la Torre, J. & Scott, B. (2011). Supporting Red List threat assessments with GeoCAT: geospatial conservation assessment tool. In: V. Smith & L. Penev (eds), e-Infrastructures for Data Publishing in Biodiversity Science. *ZooKeys,* 150, 117-126. (Version BETA).

Beech, E., Rivers, M., Oldfield, S. and Smith, P.P., 2017. GlobalTreeSearch: the first complete global database of tree species and country distributions. *Journal of Sustainable Forestry*, 36, 1-36.

Bullock, J.M., Mallada González, L., Tamme, R., Götzenberger, L., White, S.M., Pärtel, M. and Hooftman, D.A., 2017. A synthesis of empirical plant dispersal kernels. *Journal of Ecology*, 105 (1), 6-19.

CBD, 2012. Global Strategy for Plant Conservation: 2011-2020. Richmond, United Kingdom: Botanic Gardens Conservation International.

Chua, L.S.L., Suhaida, M., Hamidah, M. and Saw, L.G., 2010. Malaysia plant Red List: Peninsular Malaysian Dipterocarpaceae. Research Pamphlet. Forest Research Institute Malaysia.

CITES, 1994. *Amendments to Appendices I and II of the Convention: Other proposals*. From: Proposal 114, Ninth Meeting of the Conference of the Parties, 7-18 November 1994, Fort Lauderdale (United States of America), 223-226.

CITES, 2002. *Consideration of proposals for amendment of Appendices I and II*. From: Proposal 50, Twelfth Meeting of the Conference of the Parties, 3-15 November, Santiago (Chile), 1-20.

CITES, 2010. *Consideration of proposals for amendment of Appendices I and II.* From: Proposal 42, Fifteenth Meeting of the Conference of the Parties, 13-25 March 2010, Doha (Qatar), 1-13.

CITES, 2013a. CITES Appendices I, II and III. [Online] Available from: http://www.cites.org/eng/app/appendices.php. [Accessed: May 2017]

CITES, 2013b. *Consideration of proposals for amendment of Appendices I and II.* From: Proposal 60, Sixteenth Meeting of the Conference of the Parties, 3-14 March 2013, Bangkok (Thailand), 1-10.

ESRI (Environmental Systems Resource Institute), 2012. ArcMap 10.1. [Computer program] ESRI, Redlands, California.

FAO/UNECE, 2010. Geneva timber and forest discussion paper 49: Forest product conversion factors for the UNECE region. United Nations, Geneva.

Grogan, J. and Schulze, M., 2008. Estimating the number of trees and forest area necessary to supply internationally traded volumes of big-leaf mahogany (*Swietenia macrophylla*) in Amazonia. *Environmental Conservation*, 35 (1), 26-35.

Hansen, M.C., Potapov, P.V., Moore, R., Hancher, M., Turubanova, S., Tyukavina, A., Thau, D., Stehman, S.V., Goetz, S.J., Loveland, T.R. and Kommareddy, A., 2013. High-resolution global maps of 21st-century forest cover change. *Science*, 342 (6160), 850-853.

Hewitt, J. 2007. An assessment of tree species which warrant listing in CITES. Report for Millieudefensie (Friends of the Earth, Netherlands).

IUCN Standards and Petitions Subcommittee, 2017. Guidelines for Using the IUCN Red List Categories and Criteria. Version 13. Prepared by the Standards and Petitions Subcommittee. Downloadable from: http://www.iucnredlist.org/documents/RedListGuidelines.pdf.

Hjarding, A., Tolley, K. A. and Burgess, N. D., 2014. Red List assessments of East African chameleons: a case study of why we need experts. *Oryx*. Available from: doi:10.1017/S0030605313001427.

Lusty, C., Amaral, W., Hawthorne, W., Hong, L. and Oldfield, S., 2007. *Applying the IUCN Red List categories in a forest setting.* From: Status of biological diversity in Malaysia and threat assessment of plant species in Malaysia. Proceedings of the Seminar and Workshop, 28-30 June, 2005, Kuala Lumpur, Malaysia: Forest Research Institute of Malaysia, 257-269.

Martinez, M., Blundell, A.G., Gullison, R.E. and Grogan, J., 2008. Historic range and current status of big-leaf mahogany, *Swietenia macrophylla*, in South America. Report for the Center for Applied Biodiversity Science, Washington DC, USA.

Medicinal Plant Specialist Group of the IUCN Species Survival Commission Newsletter, Volume 15, 2012.

Mejía, E. and Buitrón, X., 2008. Brazilwood (*Caesalpinia echinata*) in Brazil. In *Non-Detriment Findings Workshop Case Studies, WG 1 - Trees, Case Study 5*.

Newton, A.C., 2010. Use of a Bayesian network for Red Listing under uncertainty. *Environmental Modelling & Software*, 25 (1), 15-23.

Poorter, L. ed., 2004. *Biodiversity of West African forests: an ecological atlas of woody plant species*. CABI.

Romeiras, M. M., Figueira, R., Duarte, M. C., Beja, P. and Darbyshire, I., 2014. Documenting biogeographical patterns of African timber species using herbarium records: A conservation perspective based on native trees from Angola. *PLoS ONE*, 9 (7), e103403.

RStudio, 2014. RStudio. [Computer software]. Boston, MA: RStudio.

Soehartono, T. and Newton, A.C., 2001. Conservation and sustainable use of tropical trees in the genus *Aquilaria* II. The impact of gaharu harvesting in Indonesia. *Biological Conservation*, 97 (1), 29-41.

Tamme, R., Götzenberger, L., Zobel, M., Bullock, J.M., Hooftman, D.A., Kaasik, A. and Pärtel, M., 2014. Predicting species' maximum dispersal distances from simple plant traits. *Ecology*, *95*(2), 505-513.Tejedor Garavito, N., Newton, A.C. and Oldfield, S., 2015. Regional Red List assessment of tree species in upper montane forests of the Tropical Andes. *Oryx*, 49 (3), 397-409.

The Plant List, Version 1.1. 2013. [Online]. Available from: http://www.theplantlist.org/. [Accessed: May 2017].

UNECE Forest Products Statistics 2005-2009. [Online] Available from: http://www.unece.org/fileadmin/DAM/timber/statsdata/fps05-09.pdf. [Accessed: August 2017].

Williams, M., 2003. *Deforesting the earth: from prehistory to global crisis*. University of Chicago Press.

World Checklist of Selected Plant Families. Facilitated by the Royal Botanic Gardens, Kew. Published on the Internet; http://wcsp.science.kew.org. [Accessed: May 2017].

Yesson, C., Brewer, P.W., Sutton, T., Caithness, N., Pahwa, J.S., Burgess, M., Gray, W.A., White, R.J., Jones, A.C., Bisby, F.A. and Culham, A., 2007. How global is the global biodiversity information facility? *PLoS ONE*, 2 (11), e1124.

6 Discussion

6.1 Original contribution to knowledge

This thesis made original contributions to knowledge by addressing the knowledge gaps identified in Chapter 1 in the manner discussed below.

6.1.1 Chapter 2: Identifying timber tree taxa in trade: A working list of commercial timber trees

Knowledge gap:

The number of angiosperm tree species currently exploited and traded commercially for their timber is unknown.

Findings:

Chapter 2 identified 1,578 tree taxa that were traded for timber under Latin binomials or trinomials, and consolidated these taxa into a working list of angiosperm timbers. Of these, 12 taxa in the Arecaceae (palm) family were pinpointed as being misidentified, bringing the working list down to 1,566 tree taxa identified as being traded commercially for timber. These findings therefore go some way towards answering Research Question 1: '*How many angiosperm tree taxa are currently harvested and traded for timber?*', and fulfil Objectives 1a and 1b.

Implications:

It is possible that more of these 1,566 tree taxa have been misidentified and are not in fact timber trees, and it is highly likely that many timber tree taxa were not added to the working list due to search specifications (i.e. many will be documented under common, trade or genus name) and the need to limit the search due to project time-constraints. However, we can use the Chapter 2 working list to estimate that at least 1,500 timber tree taxa may be at risk from over-exploitation.

6.1.2 Chapter 3: Applications of GBIF data in assessing extinction risk of timber trees

Knowledge gap:

Use of 'big data' such as large, open-access repositories of species distribution records in species range mapping represents an important time-saving resource for conservation if we are to meet CBD and GSPC 2020 Targets. Record datasets from the Global Biodiversity Information Facility (GBIF) are increasingly being used to this end. However, it is not known whether species distribution records from GBIF are adequate for calculating reliable extent of occurrence (EOO) and area of occupancy (AOO) for timber tree species.

Findings:

Chapter 3 assessed volume, coverage, and reliability of GBIF records for a random subset of 304 timber tree species. It found that, although mean record number was over 4,000 per species, discards after cleaning and range-matching were high, with only 54.2 % of records useable. Record coverage was also higher for species in temperate latitudes and lowest in the tropics. However, results demonstrated that range-matched records from GBIF gave native ranges (at the country level) that were not significantly different to native ranges derived from regional floras or *The World List of Threatened Trees* (Oldfield *et al*., 1998).

Implications:

Although the analysis in Chapter 3 confirmed that there are coverage gaps in tropical regions (Cayuela *et al*., 2009) and that GBIF data have a high discard rate after cleaning, the number of usable records was far higher than that found by Hjarding *et al*. (2014) for East African amphibians, and that record reliability was sufficient to calculate EOO, though not AOO. Thus, GBIF records were shown to be useful in prioritising timber tree species for full Red List assessment on the basis of range-restriction (EOO <20,000 km^2). This Chapter successfully met Objectives 2a, 2b and 2c, thus answering Research Question 2: '*Are species distribution records from the Global*

Biodiversity Information Facility (GBIF) sufficient for use in calculating timber tree species' IUCN Red List extent of occurrence (EOO) and area of occupancy (AOO)?'.

6.1.3 Chapter 4: IUCN Red List extinction risk assessments of timber tree species

Knowledge gap:

Up-to-date extinction risk status of over 1,500 commercially and ecologically valuable angiosperm timber tree taxa remains unknown, despite ongoing threats of deforestation and over-exploitation.

Findings:

Chapter 4 prioritised 324 timber tree species on the basis of small EOO (<20,000 km^2) and/or previous Threatened or Near Threatened IUCN Red List categorisation. Red List Criteria were then applied to these priority species, under three deforestation scenarios. Full preliminary extinction risk assessments were produced for all study species, thirty of which had never before been Red Listed at the global scale. The most conservative assessments used Global Forest Change (GFC) deforestation data (Hansen *et al*., 2013) as a proxy for population reduction. Under this scenario, 222 of the 324 study species (69 %) were considered Threatened, 24 Near Threatened (7 %) and 77 Least Concern (24 %), with one species Data Deficient. Species were predominately assigned final Categories on the basis of Criterion A sub-criterion A3 – future projections of population reduction.

Implications:

The assessments produced in Chapter 4 indicate that if deforestation continues at current rates, within an approximation of three generations (100 years) into the future, the majority of tropical and subtropical angiosperm timbers may qualify for IUCN Red List Threatened Categories. However, Red List assessments typically contain a degree of uncertainty, and use of GBIF and GFC datasets is likely to compound this uncertainty. Thus, Chapter 4 met Objectives 3a and 3b, and laid the groundwork for answering Research Question 3: '*How many of the world's wild-harvested, angiosperm* *timber tree species are currently threatened with extinction, according to IUCN Red List Categories and Criteria Version 3.1?'*

6.1.4 Chapter 5: Assessing the uncertainty of IUCN Red List categorisations for timber tree species using open-source and expert datasets

Knowledge gap:

Chapter 4 assessed extinction risk of 324 angiosperm timbers by applying IUCN Red List Categories and Criteria. However, the extent of uncertainty around these preliminary assessments is not known.

Findings:

Some changes in species categorisations using expert/alternative datasets versus Chapter 4 datasets indicate that some aspects of Chapter 4 Red List assessments had a high degree of uncertainty – AOO, severe fragmentation, and population declines in the past. However, Bayesian Belief Network outcomes for case study 3 suggested that GBIF data may provide EOO categorisations that are as reliable as EOO categorisations produced using expert records collections and peer-reviewed, published species distribution maps. Criterion A categorisations were shown to be strongly influenced by future projections under both sub-criterion A3 and sub-criterion A2. Additionally, exploitation information on CITES listed timber tree species was found to be insufficient to apply IUCN Red List Categories and Criteria, except in a few cases.

Implications:

The case study results indicate that, although categorisations made with Chapter 4 datasets had varying degrees of uncertainty, EOO values calculated using cleaned and matched GBIF records may be more reliable than other studies suggest (Hjarding *et al*., 2014). Overall, despite some categorisation uncertainties, Chapter 4 datasets were much more readily-available for many more taxa than expert – and particularly exploitation – datasets for timber trees. Thus, Chapter 5 findings suggest that open-access ‘big data’, as used in Chapter 4, still represents a valuable source of readily-accessible information for Red List assessments, though it should be used with caution. Chapter 5 addressed Objectives 4a-4e and Research Question 4: ‘*How uncertain are the IUCN Red List categorisations that were made in Chapter 4 using open-source distribution record and deforestation datasets?*’

6.2 Research limitations

6.2.1 Study species selection

The working list of timber tree taxa produced in Chapter 2 is likely to have missed some timber tree taxa that are identified only to family or genus level or by a common/trade name in the literature. Additionally, intraspecific taxa and gymnosperms were excluded. Lastly, some traded tree species that are not timbers were misidentified as such in the original working list (i.e. some Arecaceae), despite expert input from TRAFFIC and IUCN in the early stages (Oldfield, T., and Osborn, T., January 2014, pers. comm.). Although this error was not carried over into the species subsets analysed in Chapter 3 and assessed in Chapter 4, it demonstrates that the original identification method will need to be refined in future when carrying out assessments of all known timbers and that expert input must be sought throughout the identification process.

6.2.2 IUCN Red List assessments

The preliminary IUCN Red List assessments made in Chapter 4 were shown to be uncertain in Chapter 5, particularly in terms of the species distribution records used to calculate extent of occurrence and area of occupancy. Thus, these preliminary assessments will require expert input before they can be published on the IUCN Red List of Threatened Species, or included in the calculation of a Red List Index (RLI) for timber trees. Although expert review is standard Red Listing procedure before assessments can be published (IUCN Standards and Petitions Subcommittee, 2017) the uncertainty analyses conducted in Chapter 5 allows for *targeted* review.

6.2.3 Uncertainty assessments

In Chapter 5, uncertainty analysis was carried out on small subsets of timber tree species due to scarcity of readily-available expert / peer reviewed datasets (e.g. distribution records and CITES proposals). Ideally this uncertainty analysis would be carried out for all 324 preliminary assessments, and followed by a Bayesian Belief Network (BBN) assessment (Newton, 2010) to quantify the likelihood of each possible Red List categorisation outcome, based on degree of certainty in each sub-criterion threshold. This would allow a complete evaluation of 'how far off' each preliminary categorisation is, and would feed into the expert review process. Further uncertainty analysis using RAMAS Red List software (Akçakaya and Ferson*,* 1999) could additionally be explored, to compare categorisation likelihoods generated by BBN versus the fuzzy logic sets used by RAMAS Red List.

6.3 Recommendations for future research

It is recommended that the following avenues of further research be explored, in light of the findings of this thesis:

1. Expert review for Chapter 4 preliminary Red List assessments, to determine how 'far off' these categorisations are, when compared to expert-reviewed Red List assessments. This will be an important step towards an up-to-date and in-depth understanding of angiosperm timber tree extinction risk, as well as contributing to a set of guidelines for use of 'big data' repositories in tree Red List assessments. In particular, this would be useful for datasets from the Global Biodiversity Information Facility (GBIF) and Global Forest Change repository (Hansen *et al*., 2013), as these are increasingly being used in Red List assessments (ter Steege *et al*., 2013; Ocampo-Penuela *et al*., 2016; Tracewski *et al.*, 2016).

2. Further timber tree Red List assessments – especially for the species rejected in Chapter 4 on the basis of large range and no previous IUCN Red List 'Threatened' or

Near Threatened categorisation – will ensure that angiosperm timbers as a whole have been assessed at least once under Version 3.1 of the IUCN Red List. This will provide a platform from which to re-assess this group at regular intervals of 5-10 years, as recommended by IUCN (IUCN Standards and Petitions Subcommittee, 2017). Additionally, once all members of a group have been assessed at least twice, a RLI of their extinction risk over time can be calculated (Butchart *et al*., 2005).

3. A RLI for angiosperm timbers should be calculated using the expert-reviewed Red List assessments discussed in steps (1) and (2) above, along with 'back-casted' previous timber tree Red List assessments (see **Chapter 4** discussion). Such a RLI would enable us to look at trends in extinction risk for timber trees as a group, but would also allow for more targeted examination of trends at the regional or taxonomic family / genus level (see Brummitt *et al*., 2015). The RLI should be updated as future Red List assessments are conducted and, in the long-term, could potentially enable the impacts of particular trade sanctions, conservation actions, and changes in market demand on timber tree extinction risk to be analysed.

4. An evaluation of how the 1998 *World List of Threatened Trees* (Oldfield *et al*., 1998) impacted timber conservation action and harvest sanctions and policies would give an important indication of possible conservation, government and timber industry stakeholder reactions to published, up-to-date extinction risk assessments for these valuable species.

6.4 Conclusion: Wider reflections on tree Red Listing

At a time when the world's forest species face multiple anthropogenic threats, we are also at an exciting stage for tree conservation. The GlobalTreeSearch database, recently launched by Beech *et al.* (2017) has for the first time pinpointed the total number of known tree species in the world. Vast online repositories of species occurrence records, land cover satellite imagery, and maps of plantations, forest concessions and road networks are all available at the click of a mouse. It is increasingly evident that such pooled digital resources are the answer to bridging the gaps in our knowledge of species distributions, population trends, habitat quality, connectivity and extent, and spread of threats. In short, they are the answer to the problem of data scarcity in species extinction risk assessments.

This thesis explored utility and reliability of several open-access datasets for conducting Red List assessments of angiosperm timber tree species. In doing so, it became clear that despite assumptions and uncertainties introduced by use of such data, the benefit of readily-accessible information on otherwise data-scarce species, which could be utilised by thousands of Red List assessors around the world, cannot be ignored. 'Big data' such as GBIF occurrence records can and should be used in tandem with traditional expert review, and we must additionally work to mobilise existing but undigitised datasets (in the case of timber tree species, particularly harvest and trade data) to this end.

6.5 References

Akçakaya, H.R. and Ferson, S., 1999. Ramas Red List: Threatened Species Classifications under Uncertainty: User Manual for Version 1.0. *Applied Biomathematics*.

Beech, E., Rivers, M., Oldfield, S. and Smith, P.P., 2017. GlobalTreeSearch: the first complete global database of tree species and country distributions. *Journal of Sustainable Forestry*, 36, 1-36.

Brummitt, N.A., Bachman, S.P., Griffiths-Lee, J., Lutz, M., Moat, J.F., Farjon, A., Donaldson, J.S., Hilton-Taylor, C., Meagher, T.R., Albuquerque, S. and Aletrari, E., 2015. Green plants in the red: A baseline global assessment for the IUCN sampled Red List Index for plants. *PloS ONE*, 10 (8), p.e0135152.

Butchart, S. H. M., Akçakaya, H. R., Kennedy, E. and Hilton-Taylor, C., 2006. Biodiversity Indicators Based on Trends in Conservation Status: Strengths of the IUCN Red List Index. *Conservation Biology*, 20 (2), 579-581.

Cayuela, L., Golicher, D.J., Newton, A.C., Kolb, M., de Alburquerque, F.S., Arets, E.J.M.M., Alkemade, J.R.M. and Pérez, A.M., 2009. Species distribution modeling in the tropics: Problems, potentialities, and the role of biological data for effective species conservation. *Tropical Conservation Science*, 2 (3), 319-352.

Hansen, M., Potapov, P., Moore, R., Hancher, M., Turubanova, S., Tyukavina, A., Thau, D., Stehman, S., Goetz, S., Loveland, T., Kommareddy, A., Egorov, A., Chini, L., Justice, C. and Townshend, J., 2013. High-resolution global maps of 21st-century forest cover change. *Science*, 342 (6160), 850-853. Data available for download from: http://earthenginepartners.appspot.com/science-2013-global-forest. [Accessed May 2016]

Hjarding, A., Tolley, K. A. and Burgess, N. D., 2014. Red List assessments of East African chameleons: a case study of why we need experts. *Oryx*. Available from: doi:10.1017/S0030605313001427.

IUCN Standards and Petitions Subcommittee. 2017. Guidelines for Using the IUCN Red List Categories and Criteria. Version 13. Prepared by the Standards and Petitions Subcommittee. Downloadable from: http://www.iucnredlist.org/documents/RedListGuidelines.pdf.

Newton, A. C., 2010. Use of a Bayesian network for Red Listing under uncertainty. *Environmental Modelling & Software*, 25 (1), 15-23.

Ocampo-Penuela, N., Jenkins, C. N., Vijay, V., Binbin, V. L. and Pimm, S. L., 2016. Incorporating explicit geospatial data shows more species at risk of extinction than the current Red List. *Scientific Advances*, 2, e1601367.

Oldfield, S., Lusty, C. and MacKinven, A., 1998. The World List of Threatened Trees. Cambridge: WCMC, IUCN.

Ter Steege, H., Pitman, N. C .A., Sabatier, D., Baraloto, C., Salomao, R. P., Guevara, J. E., Phillips, O. L., Castilho, C. V., Magnusson, W. E., Molino, J-F., Monteagudo, A., Nunez Vargas, P., Carlos Montero, J., Feldpausch, T. R., Coronado, E. N. H., Killeen, T. J., Mostacedo, B., Vasquez, R., Assis, R. L., Terborgh, J., Wittmann, F., Andrade, A., Laurance, W. F., Laurance, S. G. W., Marimon, B. S., Marimon, B-H., Guimaraes Vieira, I. C., Amaral, I. L., Brienen, R., Castellanos, H., Cardenas Lopez, D., Duivenvoorden, J. F., Mogollon, H. F., de Almeida Matos, F. D., Davila, N., Garcia-Villacorta, R., Stevenson Diaz, P. R., Costa, F., Emilio, T., Levis, C., Schietti, J., Souza, P., Alonso, A., Dallmeier, F., Duque Montoya, A. J., Fernandez Piedade, M. T., Araujo-Murakami, A., Arroyo, L., Gribel, R., Fine, P. V. A., Peres, C. A., Toledo, M., Gerardo, A. A. C., Baker, T. R., Ceron, C., Engel, J., Henkel, T. W., Maas, P., Petronelli, P., Stropp, J., Eugene Zartman, C., Daly, D., Neill, D., Silveira, M., Rios Paredes, M., Chave, J., de Andrade Lima, D., Jorgensen, P. M., Fuentes, A., Schoengart, J., Cornejo Valverde, F., Di Fiore, A., Jimenez, E. M., Penuela Mora, M. C., Fernando Phillips, J., Rivas, G., van Andel, T. R., von Hildebrand, P., Hoffman, B., Zent, E. L., Malhi, Y., Prieto, A., Rudas, A., Ruschell, A. R., Silva, N., Vos, V., Zent, S., Oliveira, A. A., Cano Schutz, A., Gonzales, T., Nascimento, M. T., Ramirez-Angulo, H., Sierra, R., Tirado, M., Umana Medina, M. N., van der Heijden, G., Vela, C. I. A., Vilanova Torre, E., Vriesendorp, C., Wang, O., Young, K. R., Baider, C., Balslev, H., Ferreira, C., Mesones, I., Torres-Lezama, A., Urrego Giraldo, L. E., Zagt, R., Alexiades, M. N., Hernandez, L., Huamantupa-Chuquimaco, I., Milliken, W., Palacios Cuenca, W., Pauletto, D., Valderrama Sandoval, E., Valenzuela Gamarra, L., Dexter, K. G., Feeley, K., Lopez-Gonzalez, G. and Silman, M. R., 2013. Hyperdominance in the Amazonian Tree Flora. *Science*, 342, (6156), 325.

Tracewski, L., Butchart, S. H. M., Di Marco, M., Ficetola, G. F., Rondinini, C., Symes, A., Wheatley, H., Beresford, A. E. and Buchanan, G. M., 2016. Toward quantification of the impact of 21st-century deforestation on the extinction risk of terrestrial vertebrates. *Conservation Biology*, 30, 1070-1079.

7 Appendices

Appendix A – Working list of commercial timber tree taxa identified in Chapter 2

* Sources in the fifth column of **Table A1** below are identified by letter as follows:

A - Commercial timbers: descriptions, illustrations, identification and information retrieval (Delta-Intkey)

B - Nomenclature générale des bois tropicaux (ATIBT)

C - Wood Species Database (TRADA)

D - Woodworkers Source Wood Library

E - Annual review and assessment of the world timber situation - Appendix 3: Major tropical species traded in 2010 and 2011 (ITTO)

F - Good Wood Guide (Greenpeace)

G - Good Wood Guide Checklist (Friends of the Earth; Fauna and Flora International)

H - FSC Species Terminology (Forest Stewardship Council)

I - Wood Properties Techsheets (USDA - US Department of Agriculture)

J - The Wood Database (Meier, E)

K - Guide to lesser-known tropical timber species (WWF - World Wildlife Fund)

L - Timber species imported into the UK, 2009 (UK Timber Trade Federation)

M - Report: Precious woods: Exploitation of the finest timber (TRAFFIC)

N - Report: An assessment of tree species which warrant listing in CITES (Hewitt, J)

O - CITES Appendices I, II, III

P - The Wood Explorer, Inc.

Q - NEPCon LegalSourceTM Due Diligence System

Refer to **Table 2.1** for full descriptions of each source.

Table A1 - Working list of commercial timber tree taxa

Family *(total taxa)*	**Scientific name**	**Common/Trade name**	**Total sources**	*** Sources**
Achariaceae (2)	*Scottellia coriacea*	Akossika	4	DGIP
	Scottellia kamerunensis	Akossika	2	DP
Altingiaceae (3)	*Altingia excelsa*	Rasamala	3	ABH
	Liquidambar formosana	Thâu	3	BHQ
	Liquidambar styraciflua	Sweet Gum	6	ADHIJL
Anacardiaceae (49)	*Anacardium excelsum*	Caracoli	5	ABDIP
	Anacardium giganteum	Caracoli	4	ABHQ
	Anacardium occidentale	Cashew	3	AHP
	Anacardium spruceanum	Caracoli	3	ABH
	Antrocaryon klaineanum	Onzabili	3	BDP
	Antrocaryon micraster	Onzabili	3	BDP
	Astronium fraxinifolium	Gonçalo Alvez	6	ABDHKM
	Astronium graveolens	Urunday	6	ABDHIJ
	Astronium lecointei	Gonçalo Alvez	4	BDKP
	Astronium urundeuva	Urunday	4	ABHQ
	Buchanania arborescens	Little Gooseberry Tree	2	DP
	Buchanania latifolia	Chirauli	2	DP
	Campnosperma auriculatum	Terentang	6	ABDEHP
	Campnosperma brevipetiolatum	Terentang	6	ABDGHP
	Campnosperma coriaceum	Terentang	3	ABH
	Campnosperma montanum	Hotong Otan; Kaauwe; Campnosperma	2	AH
	Campnosperma panamense	Orey	6	ABDHIP
	Campnosperma squamatum	Terentang	3	ABH
	Dracontomelon costatum	Cây Snto2	AH	
	Dracontomelon dao	Sengkuang	6	ABDHPQ
	Dracontomelon lenticulatum	Cây Snto2	AH	
	Euroschinus vieillardii		2	DP
	Gluta curtisii		2	AH
	Gluta papuana	Rengas	2	AH
	Gluta renghas	Rengas	4	ABHQ
	Gluta tourtour	Rengas	2	DP
	Gluta wallichii	Rengas	2	AH
	Koordersiodendron pinnatum	Ranggu	5	BDEIP
	Lannea coromandelica	Indian Ash	2	DP
	Lannea welwitschii	Kumbi	3	BDP
	Loxopterygium sagotii	Hububalli	3	DJP
	Mangifera altissima	Machang	3	ADH
	Mangifera caloneura	Machang	2	AH
	Mangifera foetida	Machang	3	ABH

	Mangifera indica	Machang	7	ABDHJPQ
	Mangifera mucronulata	Machang	2	AH
	Mangifera salomonensis	Machang	2	AH
	Metopium brownei	Chechen	4	DJMP
	Parishia insignis	Lelayang	2	BP
	Rhus typhina	Staghorn Sumach	3	DJP
	Schinopsis balansae	Quebracho Colorado	2	BP
	Schinopsis lorentzii	Quebracho Colorado	2	BP
	Schinopsis quebracho-colorado	Quebracho Colorado	3	AHQ
	Schinus molle	False Pepper	2	EQ
	Spondias mombin	Yellow Mombin	4	ADHI
	Swintonia floribunda	Merpauh	3	ABH
	Swintonia schwenckii	Merpauh	4	ABHP
	Swintonia spicifera	Merpauh	2	BP
	Tapirira guianensis		2	AH
Anisophylleaceae (2)	*Combretocarpus rotundatus*	Keruntum	3	BEQ
	Poga oleosa	Ovoga	4	BDIP
Annonaceae (11)	*Annickia chlorantha*		2	BP
	Anonidium mannii	Junglesop	2	DP
	Cananga odorata	Cananga; Perfume Tree	4	DIPQ
	Cleistopholis glauca	Sobu	2	BP
	Cleistopholis patens	Sobu	2	BP
	Duguetia confinis		2	DP
	Duguetia staudtii	Ntom; Aniouketi	2	DP
	Mezzettia parviflora	Mempisang	3	KPQ
	Oxandra lanceolata	Lancewood	3	DJP
	Polyalthia fragrans	Mempisang	2	DP
	Polyalthia oblongifolia	Mempisang	2	DP
Apocynaceae (23)	*Alstonia actinophylla*	Milkwood	2	DP
	Alstonia angustifolia		2	DP
	Alstonia angustiloba	Pulai	3	AEH
	Alstonia boonei	Emien	2	BI
	Alstonia congensis	Emien	4	BDIP
	Alstonia macrophylla	Hard Alstonia	2	BQ
	Alstonia scholaris	Pulai	4	ABDH
	Alstonia spatulata	Pulai	4	BDHP
	Aspidosperma album	Araracanga	4	BDPQ
	Aspidosperma desmanthum	Araracanga	4	BDPQ
	Aspidosperma megalocarpon	Carreto	5	BDJMP
	Aspidosperma polyneuron	Peroba Rosa	6	ABDHJQ
	Aspidosperma quebracho-blanco	Quebracho Blanco	5	ABHPQ
	Aspidosperma tomentosum	Pau Marfim	2	BQ

	Aspidosperma vargasii	Pau Marfim	3	BKQ
	Cerbera odollam	Suicide Tree; Pong-pong; Othalanga	2	DP
	Couma macrocarpa	Leche Huayo	3	DIP
	Dyera costulata	Jelutong	10	ABCDEGHIJL
	Dyera polyphylla	Jelutong	4	ABHQ
	Funtumia africana	Mutondo	3	BDP
	Gonioma kamassi	Boxwood	5	ABDHI
	Wrightia arborea	Lanete	3	ABP
	Wrightia pubescens	Lanete	2	BQ
Aquifoliaceae (9)	*Ilex aggregata*		2	AH
	Ilex amplifolia		2	AH
	Ilex anomala	Hawaiian Holly	2	AHQ
	Ilex aquifolium	Common Holly	3	GPQ
	Ilex boliviana		2	AH
	Ilex laurina		2	AH
	Ilex mitis		2	JP
	Ilex opaca		3	DJP
	Ilex petiolaris		2	AH
Araliaceae (6)	*Dendropanax arboreus*		3	AIP
	Dendropanax cuneatus	Pau de Tamanco	2	AH
	Kalopanax septemlobus	Sen Acajou; Castor Aralia	3	BHQ
	Polyscias ornifolia		2	DP
	Schefflera decaphylla	Morototo	2	BQ
	Schefflera morototoni	Morototo	7	ABDHIPQ
Arecaceae (12)	*Beccariophoenix madagascariensis*	Giant Windowpane Palm	2	OQ
	Borassus flabellifer	Doub Palm; Palmyra Palm	2	JQ
	Caryota urens	Fishtail Palm	2	MQ
	Cocos nucifera	Coconut	2	JQ
	Dypsis decaryi	Triangle Palm	2	OQ
	Dypsis decipiens	Manambe Palm	2	OQ
	Lemurophoenix halleuxii		2	OQ
	Marojejya darianii	Darian Palm	2	OQ
	Oenocarpus bataua	Batawa	2	BQ
	Ravenea louvelii		2	OQ
	Ravenea rivularis	Majestic Palm	2	OQ
	Satranala decussilvae		2	OQ
Asteropeiaceae (1)	*Asteropeia rhopaloides*		2	DP
Atherospermataceae (5)	*Atherosperma moschatum*	Southern Sassafras	3	DJP
	Doryphora sassafras	Sassafras; Yellow/Golden Sassafras	2	DP
	Laurelia novae-zelandiae	Pukatea	2	DP
	Laurelia sempervirens	Laurelia	2	BP

	Laureliopsis philippiana	Tepa	2	BQ
Berberidaceae (1)	*Sinopodophyllum hexandrum*	Himalayan May Apple	2	OQ
Betulaceae (19)	*Alnus glutinosa*	Common Alder	8	CDGHJLPQ
	Alnus incana	Grey Alder	2	HQ
	Alnus nepalensis	Nepal Black Cedar; Nepalese Alder	3	DJ
	Alnus rubra	Red Alder	6	CDHIJP
	Betula alleghaniensis	Yellow Birch	7	ACDHJPQ
	Betula alnoides	Himalayan Birch; Indian Birch	3	AHJ
	Betula lenta	Sweet Birch	5	CDHJP
	Betula maximowicziana	Monarch Birch	3	AHQ
	Betula nigra	River Birch	2	JQ
	Betula papyrifera	Paper Birch	5	CDHJP
	Betula pendula	Silver Birch	7	ACDHJPQ
	Betula populifolia	Grey Birch	3	HJQ
	Betula pubescens	Downy Birch	5	ACHJL
	Betula schmidtii	Schmidt's Birch	3	AHQ
	Carpinus betulus	Hornbeam	5	ADGHJ
	Carpinus caroliniana	American Hornbeam	4	DIJP
	Corylus avellana	Hazel	2	AH
	Corylus colurna	Turkish Hazel	3	AHQ
	Ostrya virginiana	Ironwood	3	DJP
Bignoniaceae (25)	*Catalpa bignonioides*	Indian Bean Tree	3	AHJ
	Catalpa speciosa	Northern Catalpa; Hardy Catalpa	3	DJP
	Daniella thurifera	Copal Tree	3	BHI
	Daniellia klainei	Faro	3	BHP
	Handroanthus capitatus	Ipé	2	EQ
	Handroanthus guayacan	Ipé	3	EJP
	Handroanthus heptaphyllus	Ipé	3	BHQ
	Handroanthus serratifolius	Ipé	11	ABCDEHJKMPQ
	Jacaranda acutifolia	Blue Jacaranda	2	HQ
	Jacaranda caroba	Coroba Tree	2	HQ
	Jacaranda copaia	Parapara	8	ABDHIKPQ
	Jacaranda cuspidifolia	Jacaranda	2	HQ
	Jacaranda micrantha	Jacaranda	2	AH
	Jacaranda mimosifolia	Blue Jacaranda	3	AHQ
	Jacaranda obtusifolia subsp. *rhombifolia*	Jacaranda	2	HP
	Jacaranda obtusifolia	Jacaranda	3	AHQ
	Jacaranda puberula	Jacaranda	3	AHQ
	Kigelia africana	Sausage Tree	2	PQ
	Paratecoma peroba	Pavala de Campos	5	BDGIP
	Phyllarthron madagascariense		2	DP
	Roseodendron donnell-	Primavera	6	BDIJPQ

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	Spathodea campanulata	African Tulip Tree	2	DP
	Tabebuia insignis	Apamate	3	BDP
	Tabebuia pallida	Apamate	2	BQ
	Tabebuia rosea	Apamate	4	ABDH
Bixaceae (2)	*Bixa arborea*	Urucu da Mata	2	AH
	Bixa orellana	Urucum; Annatto; Achiote; Lipstick Tree	2	HP
Boraginaceae (16)	*Cordia africana*	African Cordia	2	BP
	Cordia alliodora	Pardillo	4	ABDH
	Cordia americana	Guayaibi Blanco	5	BDHPQ
	Cordia collococca	Clammy Cherry	2	DP
	Cordia dichotoma	Salimuli	3	BPQ
	Cordia dodecandra	Canalete	5	BDJMP
	Cordia elaeagnoides		2	DQ
	Cordia fragrantissima	Salimuli	2	BQ
	Cordia gerascanthus	Canalete	4	BDMQ
	Cordia glabrata	Louro Preto	3	ABH
	Cordia goeldiana	Freijo	5	ABDGH
	Cordia millenii	African Cordia	4	BGIP
	Cordia platythyrsa	African Cordia	4	BDIP
	Cordia sebestena	Canalete	2	BQ
	Cordia subcordata	Salimuli	2	BQ
	Cordia trichotoma	Freijo	3	ABH
Burseraceae (18)	*Aucoumea klaineana*	Okoumé	14	ABCDEGHIJKLNPQ
	Bursera simaruba	Gumbo-limbo; Copperwood	3	DIP
	Canarium euphyllum	Kedondong	3	BHP
	Canarium hirsutum		3	DHP
	Canarium indicum	Galip Nut	2	AH
	Canarium littorale	Kedondong	2	AH
	Canarium luzonicum	Elemi	3	ADH
	Canarium schweinfurtii	Aielé	9	ABDEGHIKP
	Dacryodes buettneri	Ozigo	3	BDP
	Dacryodes excelsa	Candlewood	2	IP
	Dacryodes igaganga	Igaganga	2	BP
	Garuga pinnata		2	DP
	Protium altsonii		2	DP
	Protium decandrum		2	DP
	Protium sagotianum		2	DP
	Santiria laevigata	Kedondong	2	DP
	Tetragastris altissima	Sali	3	BDP
	Tetragastris panamensis	Sali	2	BQ
Buxaceae (2)	*Buxus macowanii*	Boxwood	2	BH
	Buxus sempervirens	Common Box; Boxwood	5	DGHJP
Calophyllaceae (3)	*Mammea africana*	Oboto	6	ABDHIK

	Mammea americana	Mammee; South American Apricot	2	DP
	Mesua ferrea	Penaga	7	ABDEHIP
Canellaceae (1)	*Warburgia ugandensis*	Muziga	2	BP
Cannabaceae (10)	*Aphananthe philippinensis*	Grey Handlewood	2	PQ
	Celtis adolfi-friderici	Diania	3	BDP
	Celtis laevigata	Sugarberry	3	AHQ
	Celtis laevigata var. *reticulata*	Netleaf Hackberry; Netleaf Sugar Hackberry	2	HQ
	Celtis mildbraedii	Ohia	4	BDKP
	Celtis occidentalis	Common Hackberry	4	ADHJ
	Celtis philippensis	Hard Celtis	2	BP
	Celtis rigescens	Celtis	2	DP
	Celtis zenkeri	Ohia	4	BDKP
	Trema orientalis	Charcoal Tree	3	DPQ
Caryocaraceae (4)	*Caryocar costaricense*	Ajillo; Ajo; Manú; Plomillo	3	OPQ
	Caryocar glabrum	Piquirana	4	BDKP
	Caryocar nuciferum	Piquia	2	BQ
	Caryocar villosum	Piquia	5	BCDKP
Casuarinaceae (2)	*Casuarina cunninghamiana*	Agoho	2	BQ
	Casuarina equisetifolia	Agoho	3	BDP
Celastraceae (13)	*Kokoona littoralis*	Mata Ulat	3	ABH
	Kokoona reflexa	Mata Ulat	2	BQ
	Lophopetalum beccarianum	Perupok	2	HQ
	Lophopetalum duperreanum	Perupok	2	DP
	Lophopetalum floribundum	Perupok	2	AH
	Lophopetalum javanum	Perupok	3	BDP
	Lophopetalum multinervium	Perupok	3	BHQ
	Lophopetalum pachyphyllum	Perupok	2	AH
	Lophopetalum pallidum	Perupok	2	AH
	Lophopetalum rigidum	Perupok	2	AH
	Lophopetalum subobovatum	Perupok	2	HQ
	Lophopetalum wightianum	Perupok	2	AB
	Siphonodon australis	Ivorywood	2	PQ
Cercidiphyllaceae (1)	*Cercidiphyllum japonicum*	Katsura	3	AHP
Chrysobalanaceae (10)	*Licania divaricata*		2	AQ
	Licania heteromorpha		2	AP
	Licania hypoleuca		2	AP
	Licania macrophylla		2	DP
	Licania platypus	Licania	2	AP
	Licania sparsipilis		2	DP

	Licaria capitata	Laurel; Canela	2	AH
	Parinari campestris	Sougué	2	EP
	Parinari curatellifolia	Sougué	2	AQ
	Parinari excelsa	Sougué	4	ADIP
Clusiaceae (12)	*Calophyllum brasiliense*	Jacareuba	7	ABDHIKQ
	Calophyllum ferrugineum	Bintangor	2	BQ
	Calophyllum inophyllum	Bintangor	5	ABDHP
	Calophyllum papuanum	Bintangor	5	ABDHP
	Calophyllum peekelii	Calophyllum; Baula	3	DPQ
	Calophyllum tetrapterum	Bintangor; Tanghon	2	AH
	Calophyllum tomentosum	Bintangor	2	DP
	Calophyllum vitiense	Bintangor	3	BHP
	Garcinia cowa	Cowa	2	DP
	Pentadesma butyracea	Kiasose	2	BP
	Platonia insignis	Parcouri	2	BP
	Symphonia globulifera	Manil	5	ABDHI
Combretaceae (30)	*Anogeissus acuminata*	Yon	2	BP
	Anogeissus latifolia	Axlewood	2	DP
	Buchenavia tetraphylla	Tanimbuca	4	BDIP
	Bucida buceras	Black Olive; Bullet Tree; Gregorywood	3	DIP
	Combretum imberbe	Leadwood	2	JQ
	Conocarpus erectus	Silver-leaved Buttonwood	2	IP
	Pteleopsis hylodendron	Osanga	3	BKP
	Pteleopsis myrtifolia	Osanga	2	BP
	Terminalia alata	Indian Laurel	2	BQ
	Terminalia amazonia	Nargusta	7	ABDHIKP
	Terminalia arjuna		2	AD
	Terminalia bellirica		2	AQ
	Terminalia bialata		3	AIP
	Terminalia brassii	Brown Terminalia	4	BDGP
	Terminalia calamansanay	Yellow Terminalia	2	AB
	Terminalia catappa	Brown Terminalia	4	ABIP
	Terminalia celebica		2	DP
	Terminalia chebula	Indian Laurel	3	ABP
	Terminalia complanata	Yellow Terminalia	2	AB
	Terminalia guyanensis	Nargusta	5	ABDEP
	Terminalia ivorensis	Framiré	12	ABCDEGHIJLMP
	Terminalia macroptera		2	DP
	Terminalia microcarpa	Yellow Terminalia	2	AB
	Terminalia nitens	Terminalia	2	AM
	Terminalia oblonga	Nargusta	2	BQ
	Terminalia paniculata		2	DQ
	Terminalia procera		3	DIP

	Terminalia solomonensis	Brown Terminalia	2	AB
	Terminalia superba	Limba	12	ABCDEGHIJLPQ
	Terminalia tomentosa	Indian Laurel	4	BIKP
Compositae (3)	*Brachylaena huillensis*	Mühühü	8	ABDGHIPQ
	Brachylaena merana		2	AH
	Brachylaena ramiflora	Merana	4	ABDH
Convolvulaceae (1)	*Humbertia madagascariensis*	Endra Endra	2	DP
Cornaceae (5)	*Alangium meyeri*		2	DP
	Cornus florida	Flowering Dogwood	4	DIJP
	Nyssa aquatica	Water Tupelo	4	DHJP
	Nyssa ogeche	Ogeechee Tupelo	2	AH
	Nyssa sylvatica	Black Tupelo	5	ADHJP
Ctenolophonaceae (2)	*Ctenolophon englerianus*	Okip	2	DP
	Ctenolophon parvifolius	Mertas	6	ABDEHP
Cunoniaceae (6)	*Ceratopetalum succirubrum*	North Queensland Coachwood	2	DP
	Eucryphia cordifolia	Ulmo	3	BIP
	Eucryphia lucida	Leatherwood	2	DP
	Geissois benthamiana	Red Carabeen; Brush Mahogany	2	PQ
	Geissois biagiana	Northern Brush Mahogany	2	DP
	Weinmannia trichosperma	Tineo	3	BJP
Dilleniaceae (11)	*Dillenia excelsa*	Simpoh	4	ABHQ
	Dillenia indica	Simpoh	4	ABHQ
	Dillenia luzoniensis	Katmon; Malakatmon; Simpoh	2	DP
	Dillenia ovata	Simpoh	4	ABHQ
	Dillenia papuana	Simpoh	2	AH
	Dillenia pentagyna	Karmal	3	ADH
	Dillenia philippinensis	Katmon	2	AH
	Dillenia pulchella		2	AH
	Dillenia reticulata	Simpoh; Beringin	2	AH
	Dillenia salomonensis		2	AH
	Dillenia schlechteri		2	AH
Dipterocarpaceae (118)	*Anisoptera costata*	Mersawa	3	ADHP
	Anisoptera curtisii	Mersawa	2	DP
	Anisoptera laevis	Mersawa	2	DP
	Anisoptera marginata	Mersawa	3	AHQ
	Anisoptera scaphula	Mersawa	3	AHQ
	Anisoptera thurifera	Mersawa	4	ADHP
	Balanocarpus heimii	Chengal	5	DEHLP
	Cotylelobium burckii	Resak	3	ABH
	Cotylelobium lanceolatum	Resak	3	ABH
	Cotylelobium melanoxylon	Resak	3	ABH
	Dipterocarpus acutangulus		2	DQ

Dipterocarpus alatus	Apitong	2	AH
Dipterocarpus basilanicus		2	DP
Dipterocarpus baudii	Keruing	2	AH
Dipterocarpus borneensis	Keruing	3	BDP
Dipterocarpus caudiferus	Keruing	2	DP
Dipterocarpus costulatus	Keruing	2	CH
Dipterocarpus grandiflorus	Keruing	6	ABCDHP
Dipterocarpus kerrii	Keruing	2	AH
Dipterocarpus lowii	Keruing	2	CQ
Dipterocarpus retusus	Keruing	2	DP
Dipterocarpus validus	Keruing	3	CDP
Dipterocarpus verrucosus	Keruing	5	ABCHQ
Dryobalanops beccarii	Kapur	2	CQ
Dryobalanops lanceolata	Kapur	6	ABCDHP
Dryobalanops oblongifolia	Kapur	2	BC
Dryobalanops sumatrensis	Kapur	6	ABCDHP
Hopea acuminata	Merawan	3	AHQ
Hopea beccariana	Heavy Merawan	2	AH
Hopea dryobalanoides		4	ABHQ
Hopea ferrea	Giam	3	ABH
Hopea forbesii	Giam	3	ABH
Hopea foxworthyi		2	D
Hopea helferi	Giam	3	ABH
Hopea iriana		2	DP
Hopea mengarawan	Merawan	4	ABHQ
Hopea nervosa	Merawan	2	AH
Hopea nutans	Merawan	2	AH
Hopea odorata	Merawan	4	ABDH
Hopea sangal	Merawan	4	ABHQ
Hopea scaphula		2	AH
Hopea semicuneata	Jangkang Putih; Kerangan	2	AH
Neobalanocarpus heimii	Chengal	4	ABHQ
Parashorea aptera		2	AH
Parashorea densiflora	Gerutu	3	ABH
Parashorea lucida	Gerutu	4	ABDH
Parashorea macrophylla		3	AHQ
Parashorea malaanonan	White Seraya	4	ABDH
Parashorea parvifolia		2	HQ
Parashorea plicata		2	DQ
Parashorea smythiesii	Gerutu	4	ABHQ
Parashorea tomentella	White Seraya	3	ABHQ
Pentacme contorta	White Seraya	2	IP
Shorea acuminata	Light Red Meranti	5	CDHPQ
Shorea acuminatissima	Yellow Meranti	7	ABCDHJQ
Shorea albida	Light Red Meranti	2	CE

Shorea assamica	White Meranti	6	ABDHJQ
Shorea atrinervosa	Selangan Batu	3	ACQ
Shorea balangeran	Red Balau	3	BHQ
Shorea balanocarpoides	Yellow Meranti	2	CP
Shorea bracteolata	White Meranti	3	ABQ
Shorea brunnescens		3	AHQ
Shorea collina	Red Balau	3	ACH
Shorea contorta	White Seraya	4	BDJP
Shorea crassa		2	HQ
Shorea curtisii	Dark Red Meranti	4	BCHQ
Shorea dasyphylla	Light Red Meranti	3	ACH
Shorea dealbata	White Meranti	3	AHQ
Shorea exelliptica		2	HQ
Shorea faguetiana	Yellow Balau	6	ABCDJQ
Shorea foxworthyi		3	CHQ
Shorea gibbosa	Yellow Meranti	4	ACHQ
Shorea glauca	Yellow Balau	5	ABCHQ
Shorea guiso	Red Balau	7	ABCDHPQ
Shorea havilandii	Selangan Pinang	2	HQ
Shorea hemsleyana	Meranti Daun Besar; Red Meranti	2	HQ
Shorea hopeifolia	Yellow Meranti	4	ACHQ
Shorea hypochra	White Meranti	5	ADHJQ
Shorea javanica	White Meranti	4	ABHQ
Shorea johorensis	Light Red Meranti	4	ABHQ
Shorea kalunti	Kalunti	3	DJP
Shorea kunstleri	Red Balau	5	BCHPQ
Shorea laevifolia	Bangkirai	3	HLQ
Shorea laevis	Yellow Balau	4	BCHQ
Shorea lamellata	White Meranti	3	AHQ
Shorea lepidota	Light Red Meranti	4	ACHQ
Shorea leprosula	Light Red Meranti	7	ABCDHJQ
Shorea leptoclados	Light Red Meranti	4	DJPQ
Shorea leptoderma		2	HQ
Shorea longipetala	Red Balau	2	HQ
Shorea macrantha	Meranti Kepong Hantu	2	HQ
Shorea macroptera	Light Red Meranti	4	CEHQ
Shorea materialis		2	HQ
Shorea maxwelliana	Yellow Balau	4	BCHQ
Shorea multiflora	Yellow Meranti	4	ACHQ
Shorea negrosensis	Red Lauan	4	DEJP
Shorea ochrophloia	Red Balau	4	ACHQ
Shorea ovalis	Light Red Meranti	2	CQ
Shorea ovata	Dark Red Meranti	2	AH
Shorea parvifolia	Light Red Meranti	4	ABCH

	Shorea pauciflora	Dark Red Meranti	6	ABCHLQ
	Shorea plagata		2	DP
	Shorea platyclados	Dark Red Meranti	5	ABCHQ
	Shorea quadrinervis	Light Red Meranti	2	CQ
	Shorea resina-nigra	Yellow Meranti	2	CQ
	Shorea roxburghii	White Meranti	4	DJPQ
	Shorea rugosa	Dark Red Meranti	4	AEHQ
	Shorea seminis		2	HQ
	Shorea singkawang	Dark Red Meranti	3	AHQ
	Shorea smithiana	Light Red Meranti	4	CDJP
	Shorea stellata	White Seraya	2	HP
	Shorea submontana	Red Balau	4	ACHQ
	Shorea sumatrana	Kayu Meranti	2	AH
	Shorea superba	Yellow Balau	3	ABQ
	Upuna borneensis	Upun Batu; Resak	5	ADEHI
	Vatica rassak	Resak	3	BDP
	Vatica scaphula	Mersawa	2	AH
	Vatica tonkinensis		2	DP
Ebenaceae (21)	*Diospyros celebica*	Macassar Ebony; Indonesia Ebony	7	ABDHJMP
	Diospyros crassiflora	Gabon Ebony	6	ABCHJM
	Diospyros discolor	Mabolo	4	AHMQ
	Diospyros ebenum	Ceylon Ebony	8	ABDEHJMP
	Diospyros gracilipes	Madagascar Ebony	2	BM
	Diospyros greveana		2	MO
	Diospyros insularis	Papua Ebony; Black Ebony	2	AH
	Diospyros korthalsiana		2	DP
	Diospyros kurzii	Marblewood; Andaman Ebony	2	AH
	Diospyros lanceolata	Ebony	2	MO
	Diospyros lotus	Persimmon	2	MQ
	Diospyros marmorata	Andaman Ebony; Zebrawood; Marblewood	3	BHP
	Diospyros melanoxylon	East Indian Ebony; Coromandel	4	ABDH
	Diospyros mespiliformis	African Ebony	3	BPQ
	Diospyros mindanaensis	Ata Ata; Camagon; Ebony Persimmon	2	DP
	Diospyros mollis	Maklua	2	BQ
	Diospyros perrieri	Madagascar Ebony	4	ABHM
	Diospyros pyrrhocarpa		3	DMP
	Diospyros toxicaria	Ebony	2	BM
	Diospyros vera	Narrow-leaved Ebony	3	BMP
	Diospyros virginiana	Common Persimmon	5	ADGHJ

Elaeagnaceae (1)	*Elaeagnus angustifolia*	Oleaster; Russian Olive	2	JQ
Ericaceae (4)	*Arbutus menziesii*	Pacific Madrone; Madrona	3	ADJ
	Arbutus unedo	Strawberry Tree	2	AQ
	Kalmia latifolia	Mountain Laurel	2	IQ
	Oxydendrum arboreum	Sorrel	2	IQ
Erythroxylaceae (1)	*Erythroxylum mannii*	Landa	4	BDIP
Euphorbiaceae (32)	*Alchornea triplinervia*	Tapia	3	AHQ
	Aleurites moluccanus	Candlenut Tree	2	DP
	Balakata baccata		2	HP
	Balakata luzonica		2	AH
	Croton megalocarpus	Musine	4	BDIP
	Elateriospermum tapos	Tapus; Perah	2	EP
	Endospermum diadenum	Sesendok	7	ABCEHPQ
	Endospermum macrophyllum	Ekor Belangkas; Gubas; Kauvulu	3	DHP
	Endospermum medullosum	Sesendok	4	BGHQ
	Endospermum moluccanum		2	AH
	Endospermum peltatum	Sesendok	3	ABH
	Excoecaria agallocha	Blind-your-eye; Buta-buta	2	DP
	Falconeria insignis	Tiger's Milk Spruce	2	DP
	Glycydendron amazonicum	Glícia	3	AHQ
	Gymnanthes lucida	Oysterwood	2	AP
	Hevea brasiliensis	Rubber; Pará Rubber	11	ABCDEGHIJPQ
	Hura crepitans	Assacù; Sandbox Tree; Possumwood	7	ABDHIKP
	Hura polyandra	Jabilla	2	AH
	Ricinodendron heudelotii	Essessang; Groundnut Tree; African Oil-nut	4	ABHI
	Sapium glandulosum	Leiteiro	4	AHPQ
	Sapium haematospermum		2	AH
	Sapium jenmannii		2	DP
	Sapium laurifolium		2	AH
	Sapium laurocerasus	Milktree; Lechecillo	2	AH
	Sapium marmieri		2	AH
	Sapium stylare		2	AH
	Schinziophyton rautanenii	Mongongo	2	BP
	Sclerocroton integerrimus	Duiker Berry	2	AH
	Shirakiopsis elliptica	Jumping-seed Tree	3	AHP
	Shirakiopsis indica		2	AH
	Spirostachys africana	Tamboti	3	BJP
	Triadica cochinchinensis		2	AH
Fagaceae (47)	*Castanea crenata*	Japanese Chestnut	2	AQ

Castanea dentata	American Chestnut	5	ADIJP
Castanea sativa	Sweet Chestnut	9	ACDGHJLPQ
Castanopsis acuminatissima	Berangan	5	ABDHK
Castanopsis argentea	Berangan	3	ABH
Castanopsis cuspidata	Chinquapin	2	DP
Castanopsis javanica	Berangan	3	ABH
Castanopsis tungurrut	Malayan Chestnut	2	AH
Chrysolepis chrysophylla	Golden Chinquapin	4	DIJP
Fagus grandifolia	American Beech	5	DIJLP
Fagus sylvatica	European Beech	8	ACDFHJLP
Lithocarpus amygdalifolius	Mempening	2	AH
Lithocarpus cyrtorhyncha	Mempening	2	AH
Lithocarpus daphnoideus	Mempening	2	AH
Lithocarpus henryi	Mempening	2	AH
Lithocarpus solerianus	Mempening	2	AH
Lithocarpus vinkii	Mempening	2	AH
Notholithocarpus densiflorus	Tanoak	5	DIJPQ
Quercus acuta	Japanese Evergreen Oak	2	CQ
Quercus alba	White Oak	7	ACDHLPQ
Quercus arkansana	Arkansas Oak	2	DP
Quercus bicolor	Swamp White Oak	2	DP
Quercus cerris	Turkey Oak	2	AH
Quercus chrysolepis	Canyon Oak	2	DP
Quercus coccinea	Scarlet Oak	2	DP
Quercus dentata	Korean Oak	2	CQ
Quercus falcata	Southern Red Oak	4	CHLQ
Quercus garryana	Oregon White Oak	2	DP
Quercus kelloggii	California Black Oak	2	DP
Quercus lobata	Valley Oak	2	DP
Quercus lyrata	Overcup Oak	2	CQ
Quercus macrocarpa	Bur Oak	2	DP
Quercus michauxii	Swamp Chestnut Oak	6	CDJLPQ
Quercus mongolica	Mongolian Oak	5	CDHLP
Quercus mongolica subsp. *crispula*	Mizu-nara	3	AHQ
Quercus montana	Chestnut Oak	2	CQ
Quercus muehlenbergii	Chinkapin Oak	3	AHQ
Quercus myrsinifolia	Bamboo-leaved Oak; Chinese Evergreen Oak	2	CQ
Quercus palustris	Pin Oak	2	DP
Quercus petraea	Sessile Oak	7	ACDHLPQ
Quercus phillyreoides	Ubame Oak	2	CQ

	Quercus robur	European Oak	8	ACDHJLPQ
	Quercus rubra	Northern Red Oak	8	ACDHJLPQ
	Quercus shumardii	Shumard Oak	2	CJ
	Quercus stellata	Post Oak	3	DJP
	Quercus velutina	Black Oak	3	DJP
	Quercus virginiana	Southern Live Oak	3	DJP
Gentianaceae (4)	*Fagraea crenulata*	Tembusu	2	BH
	Fagraea elliptica	Tembusu	2	BH
	Fagraea fragrans	Tembusu	3	ABH
	Fagraea gracilipes		3	DHP
Goupiaceae (1)	*Goupia glabra*	Cupiuba	9	ABDEHIKLP
Hamamelidaceae (2)	*Exbucklandia populnea*	Malayan Aspen	3	DIP
	Hamamelis virginiana	American Witchhazel	2	IQ
Hernandiaceae (1)	*Hazomalania voyronii*		2	DP
Humiriaceae (5)	*Endopleura uchi*	Uxi	3	AHQ
	Humiria balsamifera	Tauroniro; Umiri	4	BDIP
	Sacoglottis cydonioides	Bitterbark Tree	2	AH
	Sacoglottis gabonensis	Ozouga	5	BDHKP
	Sacoglottis guianensis		3	AHQ
Hypericaceae (3)	*Cratoxylum arborescens*	Geronggang	8	ABCDHIKP
	Cratoxylum formosum	Derum	3	BDP
	Harungana madagascariensis		2	PQ
Irvingiaceae (4)	*Irvingia gabonensis*	African Mango	5	ADHIP
	Irvingia grandifolia	African Mango; Udika	3	ADH
	Irvingia malayana	Wild Almond; Krabok	6	ABEHKQ
	Klainedoxa gabonensis	Eveuss	5	BDIKP
Juglandaceae (18)	*Carya alba*	Mockernut Hickory	7	ACDHJPQ
	Carya aquatica	Water Hickory	3	DJP
	Carya cordiformis	Bitternut Hickory	3	DJP
	Carya glabra	Pignut Hickory	5	ACHJQ
	Carya illinoinensis	Pecan	4	DJP
	Carya laciniosa	Shellbark Hickory	5	CDHJP
	Carya myristiciformis	Nutmeg Hickory	3	DJP
	Carya ovata	Shagbark Hickory	5	CDHJP
	Engelhardtia roxburghiana	Kayu Hujan	3	BDP
	Juglans australis	Nogal	4	ABHQ
	Juglans boliviana	Nogal	2	AB
	Juglans cinerea	Butternut; White Walnut	4	DIJP
	Juglans hindsii	Northern California Walnut	2	JQ
	Juglans jamaicensis	West Indian Walnut	2	AQ
	Juglans neotropica	Nogal	6	ABDJMQ
	Juglans nigra	Black Walnut	9	ACDHIJLPQ

	Juglans olanchana	Cedro Negro	3	AJQ
	Juglans regia	Common Walnut	8	ACDHJLPQ
Lamiaceae (18)	*Gmelina arborea*	Yemane	7	ABDGHIQ
	Gmelina fasciculiflora	White Beech; Grey Teak	2	DP
	Gmelina leichardtii	White Beech; Grey Teak	2	DP
	Gmelina moluccana	White Beech; Grey Teak	4	ABDH
	Peronema canescens	Sungkai	4	ABHK
	Tectona grandis	Teak	15	ABCDEFGHIJKLMPQ
	Vitex cofassus	Leban	5	BDGHP
	Vitex doniana	Evino	3	BIP
	Vitex gaumeri	Fiddlewood	2	DP
	Vitex glabrata	Leban	4	ABHQ
	Vitex micrantha	Evino	3	BDP
	Vitex parviflora	Vitex; Sagat	3	ADH
	Vitex phaeotricha		2	AH
	Vitex pinnata	Leban	4	ABHQ
	Vitex quinata		3	AHP
	Vitex triflora		2	AH
	Vitex turczaninowii		2	DP
	Vitex vestita		2	AH
Lauraceae (44)	*Alseodaphne archboldiana*		2	AH
	Alseodaphne malabonga		2	AH
	Aniba canellila		2	MQ
	Aniba parviflora	Bois Rose Femelle; Rosewood	2	BQ
	Aniba rosaeodora	Bois Rose Femelle; Rosewood	5	BDOPQ
	Aspidostemon perrieri	Longotra	2	AH
	Beilschmiedia letouzeyi	Kanda Brun	3	BDP
	Beilschmiedia mannii	Kanda Rose	4	BDKP
	Beilschmiedia tawa	Tawa	2	IP
	Beilschmiedia velutina	Voankoromanga	2	DP
	Chlorocardium rodiei	Greenheart	13	ABCDEFGHIJLPQ
	Cinnamomum camphora	Camphorwood	4	BDJP
	Cinnamomum iners	Camphorwood	3	BDP
	Cinnamomum porrectum	Camphorwood	4	BDPQ
	Endiandra laxiflora	Medang	2	DP
	Endiandra palmerstonii	Queensland Walnut; Black Walnut	5	DGIJP
	Eusideroxylon melagangai	Malagangai	2	AEQ
	Eusideroxylon zwageri	Bornean Ironwood; Billian; Ulin	9	ABDEHINPQ
	Licaria canella	Kaneelhart	5	ABHPQ
	Licaria subbullata	Louro	3	AHQ
	Litsea ferruginea	Medang	2	DP

	Litsea reticulata	Medang	2	DP
	Mezilaurus ita-uba	Itaùba	4	BHLP
	Mezilaurus lindaviana	Itaùba	2	AH
	Mezilaurus navalium	Itaùba	3	BDP
	Nectandra lanceolata	Laurel Moroti	3	AHQ
	Nectandra megapotamica		2	AH
	Nothaphoebe elata	Medang	2	AH
	Nothaphoebe kingiana	Medang	2	AH
	Nothaphoebe panduriformis	Medang	2	AH
	Nothaphoebe spathulata	Medang	2	AH
	Nothaphoebe umbelliflora	Medang	2	AH
	Ocotea comoriensis		2	DP
	Ocotea porosa	Imbua	10	BCDEGIJMPQ
	Ocotea puberula	Laurel Guaika	4	AHPQ
	Ocotea thouvenotii	Varongy	3	BDP
	Ocotea usambarensis	Kikenzi	4	BDIP
	Persea lingue	Lingue	2	DP
	Persea odoratissima	Fragrant Bay	3	DPQ
	Phoebe elongata		2	DP
	Phoebe hainesiana		2	DP
	Sassafras albidum	Sassafras	4	DIJP
	Sextonia rubra	Louro Vermelho	7	ABCDHIP
	Umbellularia californica	California Laurel	5	DIJPQ
Lecythidaceae (21)	*Allantoma integrifolia*		2	DP
	Allantoma pluriflora		2	AH
	Barringtonia acutangula	Freshwater Mangrove; Indian Oak	2	PQ
	Bertholletia excelsa	Castanhiero Para	5	ABDHI
	Cariniana domestica	Cachimbo	2	AH
	Cariniana estrellensis	Jequitiba	3	ABH
	Cariniana legalis	Jequitiba	3	BHP
	Cariniana pyriformis	Abarco	5	ABHIP
	Couratari guianensis	Tauari	5	ABDHP
	Couratari macrosperma	Tauari	3	ABH
	Couratari multiflora	Tauari	4	ABHQ
	Couratari oblongifolia	Tauari	2	BH
	Couratari stellata	Tauari	2	AH
	Couroupita guianensis	Couroupita	3	BHQ
	Couroupita nicaraguarensis	Cannonball Tree	3	AHP
	Eschweilera sagotiana	Mata-mata	2	DP
	Lecythis lurida	Mata-mata	3	IPQ
	Petersianthus macrocarpus	Essia	4	BDIP
	Planchonia papuana	Putat	3	BDP
	Planchonia valida	Putat	2	BQ

	Scytopetalum tieghemii		2	DP
Leguminosae (311)	*Acacia auriculiformis*	Acacia	2	BP
	Acacia crassicarpa	Northern Wattle	2	DP
	Acacia decurrens	Green Wattle	2	DP
	Acacia koa	Koa	3	DJP
	Acacia mangium	Acacia	5	ABEHQ
	Acacia mearnsii	Black Wattle	3	DIQ
	Acacia melanoxylon	Australian Blackwood	3	DJP
	Acacia nilotica	Gum Arabic Tree	3	DPQ
	Acacia pubescens	Downy Wattle	3	DIP
	Acosmium panamense	Balsamo Amarillo	3	DIP
	Acrocarpus fraxinifolius	Kuranjan	2	BP
	Adenanthera pavonina	Coralwood	2	BP
	Afzelia africana	Doussié	7	ABDHLMP
	Afzelia bella	Doussié	3	ABH
	Afzelia bipindensis	Doussié	7	ABDHMPQ
	Afzelia pachyloba	Doussié	6	ABDHMP
	Afzelia quanzensis	Doussié	4	ABDH
	Afzelia rhomboidea	Merbau	2	BM
	Afzelia xylocarpa	Merbau	3	BMQ
	Albizia adianthifolia	Mepepe	2	BP
	Albizia antunesiana	Iatandza	2	BP
	Albizia ferruginea	Iatandza	3	BGP
	Albizia guachapele	Guachapele	4	BDIP
	Albizia gummifera	Mepepe	4	BDPQ
	Albizia lebbeck	Kungkur	4	BDIP
	Albizia lebbekoides	Kungkur	2	BQ
	Albizia pedicellaris	Guachapele	3	BDP
	Albizia procera	Kungkur	4	ABDH
	Albizia saman	Kungkur	7	ABHIJPQ
	Albizia versicolor	Iatandza	2	BP
	Albizia zygia	Mepepe	3	BDP
	Alexa grandiflora	Haiari	3	ABH
	Alexa imperatricis	Haiari	4	BDIP
	Alexa wachenheimii	Haiari	2	BQ
	Amblygonocarpus andongensis	Banga-wanga	2	BP
	Amburana cearensis	Cerejeira	6	ABDEHIP
	Amphimas ferrugineus	Lati	3	ABH
	Amphimas pterocarpoides	Lati	6	ABHJKP
	Andira coriacea	Andira	2	BP
	Andira inermis	Andira	5	BDIMP
	Aphanocalyx heitzii	Andoung	4	BDIP
	Apuleia leiocarpa	Grapia	7	ABCHJKP
	Archidendropsis xanthoxylon	Kungkur	2	BQ
	Baikiaea insignis	Nkobakoba;	2	IP

	Nkoba		
Baikiaea plurijuga	Umgusi	8	ABDGHIJP
Baphia nitida	Okoué	2	BP
Batesia floribunda	Acupu Rana	2	BQ
Berlinia auriculata	Ebiara	2	PQ
Berlinia bracteosa	Ebiara	3	ABH
Berlinia confusa	Ebiara	7	ABDHPQ
Berlinia grandiflora	Ebiara	4	ABDH
Bobgunnia fistuloides	Pau Rosa	8	ABDHJMPQ
Bobgunnia madagascariensis	Snake Bean	5	AHJPQ
Bowdichia nitida	Sucupira	5	ABCDH
Bowdichia virgilioides	Sucupira	3	ABH
Brachystegia cynometroides	Naga	3	BHP
Brachystegia eurycoma	Naga	3	BHP
Brachystegia laurentii	Bomanga	3	BDP
Brachystegia leonensis	Naga	3	BEH
Brachystegia mildbraedii	Bomanga	2	BP
Brachystegia nigerica	Naga	3	ABH
Brachystegia spiciformis	Messassa	4	BDIP
Brachystegia zenkeri	Bomanga	3	BDP
Burkea africana	Mukarati	5	BDGIP
Caesalpinia echinata	Pernambuco; Brazilwood	8	ABHJMOPQ
Caesalpinia ferrea	Pau Ferro; Brazilian Ironwood	2	BQ
Caesalpinia granadillo	Bridalveil Tree; Partridge Wood	2	BP
Caesalpinia paraguariensis	Guayacán; Partridge Wood	5	ABJMQ
Caesalpinia platyloba	Palo Colorado	3	DJQ
Calpocalyx heitzii	Miama	3	BDP
Cassia javanica	Java Cassia; Pink Shower	3	DKP
Castanospermum australe	Blackbean	5	ABDGH
Cedrelinga cateniformis	Tornillo	6	ABHIPQ
Centrolobium ochroxylon	Araribà	2	BQ
Centrolobium paraense	Araribà	3	BD
Centrolobium paraense var. *orenocense*	Araribà	3	BPQ
Chamaecrista apoucouita	Muira Pixuna	2	BQ
Clathrotropis brachypetala	Aromata	3	BPQ
Clathrotropis macrocarpa	Aromata	3	BPQ
Cojoba arborea	Aguacillo; Wild Tamarind	3	DPQ
Colophospermum mopane	Mopaani	3	BJP
Copaifera langsdorffii	Copaiba; Diesel Tree	2	HQ
Copaifera mildbraedii	Etimoé	3	BJP

Copaifera multijuga	Copaiba	3	BDP
Copaifera officinalis	Copaiba	3	BHQ
Copaifera religiosa	Nténé	3	BDP
Copaifera salikounda	Etimoé	5	BDGJQ
Cordyla africana	Metondo	4	BDIP
Cylicodiscus gabunensis	Okan	9	ABCDEHIKP
Cynometra alexandri	Muhimbi	6	BDGIPQ
Cynometra ananta	Nganga	2	BK
Cynometra elmeri		2	AH
Cynometra inaequifolia	Kekatong	2	AHQ
Cynometra malaccensis	Kekatong	3	ABH
Cynometra mirabilis		3	AHQ
Cynometra ramiflora	Kekatong	6	ABDHPQ
Dalbergia bariensis	Rosewood; Bois de Rose	3	BMQ
Dalbergia baronii	Madagascar Rosewood; Palisandar	4	DJMP
Dalbergia brownei	Rosewood; Bois de Rose	2	MQ
Dalbergia cambodiana	Rosewood; Bois de Rose	2	BM
Dalbergia cearensis	Kingwood; Violetwood; Tulipwood	5	BDJMP
Dalbergia cochinchinensis	Thialand Rosewood; Siamese Rosewood	4	BMOQ
Dalbergia congestiflora	Rosewood; Bois de Rose	2	MQ
Dalbergia cubilquitzensis	Guatemalan Rosewood	3	BMQ
Dalbergia cultrata	Rosewood; Bois de Rose	4	BJMQ
Dalbergia cuscatlanica		2	MQ
Dalbergia decipularis	Tulipwood	7	ABDEHJM
Dalbergia ecastaphyllum	Coinvine	2	MQ
Dalbergia frutescens	Rosewood; Bois de Rose	5	BJMPQ
Dalbergia glabra	Chacté	2	MQ
Dalbergia granadillo	Cocobolo	6	ABHMOQ
Dalbergia greveana	Madagascar Rosewood	3	BMQ
Dalbergia latifolia	Asian Rosewood	10	ABCDHIJMPQ
Dalbergia louvelii	Violet Rosewood	2	MQ
Dalbergia madagascariensis	Madagascar Rosewood	3	AHM
Dalbergia maritima	Rosewood; Bois de Rose	4	AHJM
Dalbergia melanoxylon	African Blackwood	10	ABDGHIJMPQ
Dalbergia monticola	Madagascar Rosewood	2	BM

Dalbergia nigra	Bahia Rosewood; Brazilian Rosewood	12	ABCDHIJKMOPQ
Dalbergia oliveri	Asian Rosewood	4	BJMP
Dalbergia pervillei		2	MQ
Dalbergia retusa	Cocobolo	11	ABDEHIJMOPQ
Dalbergia rimosa		2	MQ
Dalbergia sissoides		2	MQ
Dalbergia sissoo	Indian Rosewood	4	BJMP
Dalbergia spruceana	Amazon Rosewood	5	ABHMQ
Dalbergia stevensonii	Honduran Rosewood	5	BDJMP
Dalbergia tucurensis	Yucatan Rosewood	4	BDMQ
Daniellia ogea	Faro	7	ABHIKPQ
Daniellia thurifera	Faro	4	ABHI
Desmodium oojeinense	Sandan	2	MP
Detarium macrocarpum	Manbodé	3	ABH
Detarium senegalense	Manbodé	5	ABHPQ
Dialium cochinchinense	Keranji	2	BP
Dialium dinklagei	Eyoum	3	BIP
Dialium guianense	Jutai	6	ABDIKP
Dialium indum	Keranji	3	ABH
Dialium kunstleri		2	AH
Dialium patens	Velvet Tamarind	2	DP
Dialium platysepalum	Keranji	3	ABH
Dialium procerum	Merbau Merah	2	AH
Dicorynia guianensis	Basralocus	7	ABDGHIP
Dicorynia paraensis	Basralocus	3	ABH
Didelotia africana	Gombé	3	BDP
Didelotia brevipaniculata	Gombé	6	ABDHIP
Didelotia idae	Gombé	3	ABEH
Didelotia letouzeyi	Gombé	3	ABH
Dimorphandra polyandra	Aiéouéko	2	BQ
Dinizia excelsa	Angelim Vermelho	8	ABCDHKLP
Diplotropis martiusii	Sucupira	5	BCDGP
Diplotropis purpurea	Sucupira	10	ABCDEHIKPQ
Dipteryx odorata	Cumaru	11	ABCDHIJMNPQ
Dipteryx oleifera		2	OQ
Distemonanthus benthamianus	Movingui	11	ABCDGHIJKPQ
Enterolobium contortisiliquum	Timbo	4	ABHQ
Enterolobium cyclocarpum	Timbo	4	BDIP
Enterolobium schomburgkii	Batibatra	5	BDIKP
Enterolobium timbouva	Caro-caro	2	HQ
Eperua falcata	Walaba	8	BDEGHKPQ
Eperua grandiflora		4	CDPQ

Eperua jenmanii		4	CHPQ
Eperua rubiginosa	Walaba	2	BQ
Erythrophleum ivorense	Tali	5	ABEHIP
Erythrophleum suaveolens	Tali	6	BDHIKP
Falcataria moluccana	Batai	8	ABDEHIPQ
Fillaeopsis discophora	Nieuk	2	BP
Gilbertiodendron brachystegioides		2	AH
Gilbertiodendron dewevrei	Limbali	6	ABHKPQ
Gilbertiodendron mayombense		2	DP
Gilbertiodendron preussii	Limbali	3	ABH
Gleditsia triacanthos	Espina de Corona; Honey Locust	4	DJ
Gossweilerodendron balsamiferum	Tola; Agba	10	ABCDEGHILP
Gossweilerodendron joveri	Oduma	2	BH
Guibourtia arnoldiana	Mutenyé	8	ABDGHIPQ
Guibourtia coleosperma	Mussibi	4	ABDH
Guibourtia conjugata	Black Chacate	3	AHQ
Guibourtia demeusei	Bubinga	8	ABDHJMPQ
Guibourtia ehie	Ovangkol; Black Hyedua	10	ABDGHIJMPQ
Guibourtia pellegriniana	Bubinga	6	ABDHJP
Guibourtia schliebenii		2	MQ
Guibourtia tessmannii	Bubinga	7	ABDHJPQ
Gymnocladus dioica	Kentucky Coffee Tree	4	DIJP
Haematoxylum campechianum	Campeché	2	BP
Haplormosia monophylla	Idewa	2	BP
Hardwickia binata	Anjan	2	JP
Hymenaea courbaril	Jatoba	12	ABCDFHIJMNPQ
Hymenaea intermedia	Jatoba	2	BQ
Hymenolobium elatum	Angelim	2	BH
Hymenolobium excelsum	Angelim	6	ABDHIP
Hymenolobium flavum	Angelim	2	HQ
Hymenolobium petraeum	Angelim	4	ABHQ
Inga alba	Inga	2	BP
Inga pezizifera	Inga	2	BQ
Intsia bijuga	Merbau	12	ABCDGHIJLMPQ
Intsia palembanica	Merbau	10	ABCDHIJLPQ
Isoberlinia doka	Kobo; Abogo	2	DP
Isoberlinia scheffleri		2	IP
Julbernardia globiflora	Mnondo	2	IP
Julbernardia pellegriniana	Awoura	4	BDJP
Koompassia excelsa	Tualang	4	ABDH
Koompassia malaccensis	Kempas	12	ABCDEGHIJLPQ
Leucaena pulverulenta	Great Leadtree	2	AQ

Leucaena trichodes		2	AP
Lonchocarpus castilloi	Machiche; Balche; Cabbage-bark	3	DKP
Lonchocarpus leucanthus	Yvyra Ita	2	AH
Lysiloma latisiliquum	False Tamarind	3	JPQ
Machaerium scleroxylon	Santos Palisander; Pau Ferro; Morado	6	ABDHKM
Machaerium villosum	Jacaranda-do-cerrado	2	DP
Macrolobium acaciifolium	Arapari	2	KP
Macrolobium bifolium	Arapari	2	BQ
Marmaroxylon racemosum	Bois Serpent; Marblewood	4	DIKP
Martiodendron excelsum	Groçai-rosa	2	BQ
Martiodendron parviflorum	Groçai-rosa	3	BEQ
Melanoxylon brauna	Braùna	2	BP
Microberlinia bisulcata	Zingana	3	ABH
Microberlinia brazzavillensis	Zingana	7	ABDHIJP
Mildbraediodendron excelsum	Muyati	2	AH
Millettia laurentii	Wengé	13	ABCDFGHJKMNPQ
Millettia leucantha		5	BDMPQ
Millettia stuhlmannii	Wengé	11	ABCDGJLMNPQ
Mora excelsa	Mora	8	BCDEIJPQ
Mora gonggrijpii	Mora	4	DIJP
Myrocarpus fastigiatus	Cabreùva	2	BP
Myrocarpus frondosus	Cabreùva	4	ABHQ
Myroxylon balsamum	Balsamo	9	ABDHIJMPQ
Myroxylon peruiferum	Balsamo	5	ABHJQ
Newtonia buchananii	Mafumati	3	BDP
Olneya tesota	Desert Ironwood	3	DJQ
Ormosia coccinea	Tento	3	BKQ
Ormosia coutinhoi	Tento	2	BQ
Ormosia monosperma	Necklace Tree	2	DP
Ormosia nobilis		2	DQ
Ormosia paraensis	Tento	2	BQ
Oxystigma buchholzii	Tchitola	2	AH
Oxystigma gilbertii	Tchitola	2	AH
Oxystigma mannii	Tchitola	2	AH
Oxystigma oxyphyllum	Tchitola	8	ABDGHIKP
Parapiptadenia rigida	Curupay-ra	5	ABHPQ
Parkia bicolor	Esseng	2	DP
Parkia pendula		2	DP
Peltogyne maranhensis	Pau Roxo	2	AB
Peltogyne paniculata	Pau Roxo	4	BDEP
Peltogyne paniculata subsp. *pubescens*		2	CQ

Peltogyne porphyrocardia	Amarante	2	DP
Peltogyne venosa	Pau Roxo	5	ABDEP
Peltophorum dasyrhachis	Peltophorum; Soga	2	KP
Peltophorum dubium	Ibirà Pytâ	5	ABEHQ
Pentaclethra macroloba	Kroebara	2	BP
Pentaclethra macrophylla	African Oil Bean	3	BDP
Pericopsis elata	Afrormosia	12	ABCDGHIJKLOQ
Pericopsis mooniana	Kayu Kuku	4	BDJP
Piptadeniastrum africanum	Dabéma	8	ABCDEGHI
Plathymenia reticulata	Vinhatico	3	BDP
Platymiscium pinnatum	Trebol	6	ABDHPQ
Platymiscium trinitatis	Trebol	2	BP
Platymiscium ulei	Trebol	3	BDP
Platymiscium yucatanum	Granadillo	2	DP
Prioria copaifera	Cativo	4	BDIP
Prosopis africana	Ironwood; African Mesquite	2	DP
Prosopis juliflora	Mesquite	2	DP
Prosopis nigra	Algarroba Negro	3	AHQ
Pseudopiptadenia pittieri		3	DIP
Pseudopiptadenia psilostachya		2	BQ
Pseudosindora palustris	Sepetir	7	BCDGIPQ
Pterocarpus acapulcensis	Padauk; Mukwa	2	DP
Pterocarpus angolensis	Bleedwood Tree; Kiaat; Mukwa	8	ABDGHIMP
Pterocarpus dalbergioides	Andaman Rosewood; East Indian Mahogany	5	BDIMQ
Pterocarpus erinaceus	African Kino; Senegal Rosewood	4	BELM
Pterocarpus indicus	Amboyna Padauk; Red Sandalwood	8	ABDHILMP
Pterocarpus macrocarpus	Burma Padauk	6	BDIMPQ
Pterocarpus marsupium	East Indian Kino; Malabar Kino	4	BDMP
Pterocarpus officinalis	Dragonsblood Tree	3	ABH
Pterocarpus rohrii	Bloodwood; Sangre de Gallo	2	HQ
Pterocarpus santalinus	Red Sanders; Red Sandalwood	5	AHMOQ
Pterocarpus soyauxii	African Padouk; African Coralwood	9	ABCDEHIMP
Pterocarpus tinctorius	African Padouk	2	BQ
Pterogyne nitens	Cocal; Guiraró; Tipa Colorado	5	ABDHI
Robinia pseudoacacia	Black Locust; False Acacia	7	ACDGHIJ
Schizolobium amazonicum	Gavilan	2	BL
Schizolobium parahyba	Gavilan	2	BP

	Senna siamea	Djohar	4	BJMP
	Serianthes myriadenia	Vaivai	2	DP
	Sindora bruggemanii	Tapak Tapak	2	AH
	Sindora coriacea	Sepetir	3	ACH
	Sindora javanica	Sepetir	2	DP
	Sindora leiocarpa	Sepetir	2	BQ
	Sindora siamensis	Sepetir	3	BCQ
	Sindora supa	Sepetir	2	AH
	Sindora velutina	Sepetir	5	ABCHQ
	Sindora wallichii	Sepetir	2	CQ
	Swartzia benthamiana	Saboarana	6	BDEJPQ
	Swartzia cubensis	Katalox	3	DJP
	Swartzia leiocalycina	Panacoco	4	BDMP
	Swartzia panacoco	Panacoco	3	BMQ
	Sweetia fruticosa	Lapachin	4	ABHQ
	Sympetalandra densiflora	Merbau Lalat	2	DP
	Tachigali myrmecophila	Tachi	2	AQ
	Tachigali paniculata	Tachi	3	ABQ
	Tamarindus indica	Tamarind	3	DJP
	Tessmannia africana	Wamba	2	BP
	Tetraberlinia bifoliolata	Ekaba	5	ABDHP
	Tetraberlinia tubmaniana	Ekaba	7	ABDEHIP
	Tetrapleura tetraptera	Prekese; Uhio	2	DP
	Tipuana tipu	Tipa; Rosewood; Tipuana	2	AQ
	Vatairea guianensis	Faveira Amargosa	2	EQ
	Vouacapoua americana	Wacapou	5	BDIJP
	Vouacapoua macropetala	Wacapou	2	BQ
	Wallaceodendron celebicum	Banuyo	3	DIP
	Xylia xylocarpa	Pyinkado	5	BDEIP
	Zollernia paraensis	Pau Santo	3	BPQ
	Zygia racemosa	Angelim Rajado	2	BJ
Lythraceae (13)	*Duabanga grandiflora*	Duabanga	5	ABHKP
	Duabanga moluccana	Duabanga	6	ABHKLQ
	Lagerstroemia angustifolia	Crepe Myrtle	2	AH
	Lagerstroemia balansae	Crepe Myrtle	2	AH
	Lagerstroemia calyculata	Guava Crepe Myrtle	2	AP
	Lagerstroemia cochinchinensis	Crepe Myrtle	2	AH
	Lagerstroemia duppereana	White Crepe Myrtle	2	AH
	Lagerstroemia floribunda	Thai Crepe Myrtle	2	AH
	Lagerstroemia hypoleuca	Crepe Myrtle	2	AP
	Lagerstroemia ovalifolia	Crepe Myrtle	2	AH
	Lagerstroemia piriformis	Batitinan	2	DP
	Lagerstroemia speciosa	Crepe Myrtle	3	AHQ
	Lagerstroemia tomentosa	White Crepe	2	KP

		Myrtle		
Magnoliaceae (10)	*Liriodendron tulipifera*	Tulip Tree	8	ACDGHIJL
	Magnolia acuminata	Cucumbertree	3	DJP
	Magnolia grandiflora	Bullbay	3	DJP
	Magnolia pubescens		2	AH
	Magnolia sororum		2	DP
	Magnolia tsiampacca subsp. *mollis*		3	AHQ
	Magnolia tsiampacca		2	AH
	Magnolia virginiana	Sweetbay Magnolia	4	DIJP
	Magnolia vrieseana		2	AH
	Magnolia yoroconte	Yoroconte Magnolia	2	DP
Malpighiaceae (2)	*Byrsonima crassifolia*	Changunga; Nance; Wild Cherry	2	DP
	Byrsonima spicata	Locustberry	2	DP
Malvaceae (78)	*Apeiba glabra*		2	DP
	Bastardiopsis densiflora	Loro Blanco	3	AHP
	Bombax brevicuspe	Buma	3	DHP
	Bombax ceiba	Kapok	3	BDP
	Catostemma commune	Baromalli	2	BP
	Catostemma fragrans	Baromalli	3	BDP
	Cavanillesia platanifolia	Quipo	3	ABH
	Ceiba pentandra	Fuma	10	ABDEGHILPQ
	Ceiba samauma	Sumauma	3	BKP
	Ceiba speciosa	Palo Borracho; Silk Floss Tree	2	HP
	Coelostegia griffithii	Durian	2	BP
	Diplodiscus paniculatus	Balobo	2	DP
	Durio griffithii	Durian Tupai	3	AHQ
	Durio lowianus	Durian Duan	2	AH
	Durio oxleyanus	Durian	2	AH
	Durio wyatt-smithii	Durian	2	AH
	Durio zibethinus	Durian	4	ABHQ
	Eriotheca globosa	Imburana	2	BQ
	Grewia eriocarpa		2	DP
	Guazuma ulmifolia	West Indian Elm; Bay Cedar	2	AH
	Heliocarpus americanus	White Moho	2	AH
	Heliocarpus popayanensis		2	HP
	Heritiera borneensis	Mengkulang	3	ACH
	Heritiera densiflora	Niangon	2	BC
	Heritiera elata	Dungun Bukit; Mengkulang	2	AH
	Heritiera javanica	Mengkulang	5	ABCHP
	Heritiera littoralis	Dungun	2	BP
	Heritiera ornithocephala		2	DP

Heritiera simplicifolia	Mengkulang	4	ABCH
Hibiscus elatus	Blue Mahoe	2	IP
Hibiscus lasiococcus	Alampona	2	DP
Hibiscus tilliaceus	Coast Cottonwood	3	DIP
Luehea divaricata	Açoita-cavalo	2	AH
Mansonia altissima	Bété	8	ABDGHIJP
Nesogordonia papaverifera	Kotibé	7	ABCDGHI
Ochroma pyramidale	Balsa	12	ABCDEGHIJLPQ
Pachira quinata	Saqui-saqui	7	BDEHIPQ
Pentace adenophora	Burmog	2	AH
Pentace burmanica	Melanuk	3	BDP
Pentace curtisii		2	HQ
Pentace laxiflora		2	HQ
Pentace triptera	Melanuk	3	ABH
Pseudobombax ellipticum	Shaving Brush Tree	2	DP
Pterocymbium beccarii	Amberoi	4	BDHP
Pterocymbium tinctorium	Amberoi	4	BDHP
Pterospermum acerifolium	Bayur	3	BH
Pterospermum canescens	Sembolavu	2	AH
Pterospermum elongatum	Bayur	2	HQ
Pterospermum javanicum	Bayur	3	ABH
Pterygota alata	Mabin	2	BQ
Pterygota bequaertii	Koto	8	ABCDHLPQ
Pterygota horsfieldii	Mabin	3	BDP
Pterygota macrocarpa	Koto	8	BCDEHLPQ
Rhodognaphalon brevicuspe	Kondroti	6	ABDEHP
Scaphium linearicarpum	Kembang Semangkok	3	ABH
Scaphium longiflorum	Kembang Semangkok	2	AH
Scaphium longipetiolatum	Kembang Semangkok	2	AH
Scaphium macropodum	Kembang Semangkok	4	ABHQ
Scaphium scaphigerum	Kembang Semangkok	4	ABHQ
Scleronema micranthum	Cardeiro	2	BQ
Sterculia apetala	Panama Tree	4	ADHI
Sterculia ceramica	Sterculia	2	DP
Sterculia conwentzii		2	DP
Sterculia oblonga	Yellow Sterculia	6	ABDEIP
Sterculia pruriens	Xixa	5	BDILP
Sterculia rhinopetala	Lotofa	6	BDEGKP
Sterculia rugosa	Xixa	2	BP
Sterculia vitiensis		2	DP
Tarrietia densiflora	Niangon	2	IQ
Tarrietia sylvatica	Niangon	2	DP

	Tarrietia utilis	Niangon	11	ABCDEGHILPQ
	Thespesia populnea	Milo	2	BP
	Tilia americana	American Linden; American Basswood	8	ACDHIJLP
	Tilia cordata	Small-leaved Lime	4	ACHQ
	Tilia glabra		2	AH
	Tilia platyphyllos	Large-leaved Lime	3	ACHQ
	Tilia x europaea	Common Lime	5	CHJPQ
	Triplochiton scleroxylon	Ayous	11	ABCDEGHIJLP
Melastomataceae (1)	*Mouriri huberi*		2	HQ
Meliaceae (49)	*Aglaia cucullata*	Pacific Maple	2	DP
	Aglaia spectabilis		2	DP
	Azadirachta excelsa	Sentang	5	ABEHQ
	Azadirachta indica	Neem	5	ABDPQ
	Cabralea cangerana	Cangerana	4	BDIP
	Cabralea canjerana		3	AHP
	Carapa grandiflora	Crab Nut; Uganda Crabwood	2	IP
	Carapa guianensis	Andiroba	11	ABCDGHIJKLP
	Carapa procera	Andiroba; Crabwood	5	BDIKP
	Cedrela angustifolia	Cedro	3	BOQ
	Cedrela fissilis	Cedro	6	ABCHOP
	Cedrela odorata	Cedro	11	ABCDHJLMOPQ
	Cedrela serrata	Chinese Toona; Surian	2	DP
	Chisocheton pentandrus		2	DP
	Chukrasia tabularis	Chickrassy	7	ABDHIPQ
	Dysoxylum alliaceum	Kayu Bawang	2	DP
	Dysoxylum fraserianum	Australian Rosewood; Australian Mahogany	2	PQ
	Dysoxylum malabaricum	White Cedar	2	DP
	Ekebergia capensis	Cape Ash	3	DIP
	Entandrophragma angolense	Tiama	10	ABCDEGHILQ
	Entandrophragma candollei	Kosipo; Cedar Kokoti	9	ABDEGHIPQ
	Entandrophragma congolense	Tiama	2	BQ
	Entandrophragma cylindricum	Sapele	13	ABCDEFHIJKLPQ
	Entandrophragma utile	Sipo	13	ABCDEFHIJKLPQ
	Guarea cedrata	Light Bossé; Scented Guarea	10	BCDEGHIJLP
	Guarea glabra	Alligatorwood	2	DP
	Guarea guidonia	Jito	4	BDPQ
	Guarea laurentii	Light Bossé	2	BH
	Guarea thompsonii	Black Guarea; Dark Bossé	10	ABCDGHIJLP

	Khaya anthotheca	African Mahogany	10	ABCDEHIJPQ
	Khaya grandifoliola	African Mahogany; Benin Mahogany	8	ABCDHIJQ
	Khaya ivorensis	African Mahogany; Lagos Mahogany	13	ABCDEFGHIJKPQ
	Khaya nyasica	African Mahogany	3	CDP
	Khaya senegalensis	African Mahogany; Dry Zone Mahogany	7	BCDIJPQ
	Lovoa brownii	Dibétou	2	BQ
	Lovoa swynnertonii	Dibétou	2	BP
	Lovoa trichilioides	Dibétou	12	ABCDFGHIJKLP
	Melia azedarach	Xoan	6	ABDHIJ
	Sandoricum koetjape	Santol; Sentul	2	BQ
	Sandoricum vidalii	Santol; Sentul	2	DP
	Swietenia humilis	Pacific Coast Mahogany	3	HOQ
	Swietenia macrophylla	Big Leaf Mahogany	16	ABCDEFGHIJKLMOPQ
	Swietenia mahagoni	Small-leaved Mahogany	8	BDHJKOPQ
	Toona calantas	Suren	3	ABQ
	Toona ciliata	Suren	8	ABDEIJPQ
	Toona sureni	Suren	3	ABE
	Turraeanthus africana	Avodiré	8	ABDHIJPQ
	Xylocarpus granatum	Nyirih	4	ABHQ
	Xylocarpus moluccensis	Nyirih	5	ABDHQ
Monimiaceae (1)	*Tambourissa thouvenotii*		2	DP
Moraceae (43)	*Antiaris toxicaria* subsp. *welwitschii*	Ako	2	BH
	Antiaris toxicaria var. *africana*	Ako	8	ABDEHKLP
	Antiaris toxicaria	Ako	4	BDHP
	Artocarpus altilis	Terap	2	BP
	Artocarpus chama	Chaplash	2	AQ
	Artocarpus elasticus	Terap	3	ABQ
	Artocarpus hirsutus	Aini; Wild Jackfruit	2	DP
	Artocarpus integer	Keledang	2	BQ
	Artocarpus lanceifolius	Keledang	3	ABQ
	Artocarpus ovatus	Anubing; Kubi; Kili-kili	3	ADP
	Artocarpus rigidus	Terap	2	AB
	Artocarpus scortechinii	Terap	2	AB
	Bagassa guianensis	Tatajuba	12	ABCDGHIJKLPQ
	Brosimum alicastrum	Capomo	5	ABDHP
	Brosimum costaricanum		3	AHP
	Brosimum guianense	Amourette	8	ABHIJMPQ
	Brosimum parinarioides		2	AH
	Brosimum potabile	Sandé	2	BH

	Brosimum rubescens	Muira-piranga	8	ABDHJMPQ
	Brosimum utile	Sandé	4	ABDH
	Clarisia racemosa	Guariuba	8	ABCDGHIK
	Ficus coerulescens		2	AH
	Ficus crassiuscula		2	AH
	Ficus hartwegii		2	AH
	Ficus insipida		4	AHPQ
	Ficus mathewsii		2	AH
	Ficus nymphaeifolia		2	AH
	Ficus obliqua		2	DP
	Ficus pertusa		2	AH
	Ficus subandina		2	AH
	Ficus trigona		3	AHQ
	Ficus watkinsiana	Watkins' Fig	2	DP
	Helicostylis tomentosa	Letterwood	3	DIP
	Maclura pomifera	Osage Orange	3	DJP
	Maclura tinctoria	Fustic	8	ABDHIJPQ
	Maquira sclerophylla	Muiratinga	3	ABH
	Milicia excelsa	Iroko	12	ABCDFGHJKMPQ
	Milicia regia	Iroko	8	BCDFIJPQ
	Morus alba	White Mulberry	3	DJP
	Morus mesozygia	Difou	4	BDIP
	Morus nigra	Black Mulberry	2	JQ
	Morus rubra	Red Mulberry	3	DJP
	Poulsenia armata		3	DIP
Moringaceae (1)	*Moringa oleifera*	Moringa	2	PQ
Myristicaceae (44)	*Cephalosphaera usambarensis*	Mtambara	4	BDIP
	Coelocaryon preussii	Ekoune	2	BP
	Endocomia macrocoma		2	AH
	Horsfieldia amygdalina	Penarahan	2	AH
	Horsfieldia brachiata	Penarahan	2	AH
	Horsfieldia bracteosa	Penarahan	2	AH
	Horsfieldia flocculosa	Penarahan	2	AH
	Horsfieldia glabra	Penarahan	2	AH
	Horsfieldia irya	Penarahan	3	ADH
	Horsfieldia lauterbachii	Penarahan	2	AH
	Horsfieldia pilifera	Penarahan	2	AH
	Horsfieldia punctatifolia	Penarahan	2	AH
	Horsfieldia ralunensis	Penarahan	2	AH
	Horsfieldia spicata	Penarahan	2	AH
	Horsfieldia sucosa	Penarahan	2	AH
	Horsfieldia superba	Penarahan	2	AH
	Horsfieldia trifida	Penarahan	2	AH
	Horsfieldia wallichii	Penarahan	2	AH
	Knema conferta	Penarahan	2	BQ
	Myristica buchneriana	Penarahan	3	DHP

	Myristica chartacea		2	DP
	Myristica elliptica	Penarahan	2	HQ
	Myristica gigantea		2	AH
	Myristica hypargyraea		2	DP
	Myristica iners		2	AH
	Myristica lowiana		2	AH
	Myristica maingayi		2	BH
	Myristica maxima	Darah-darah; Kumpang	2	AH
	Myristica simiarum		2	AH
	Pycnanthus angolensis	Ilomba	8	ABDEGHIP
	Scyphocephalium mannii	Ossoko	2	BP
	Staudtia kamerunensis	Niové	2	BP
	Staudtia kamerunensis var. *gabonensis*	Niové	5	DGIPQ
	Virola albidiflora	Virola	2	AH
	Virola carinata	Virola	2	AH
	Virola elongata	Virola	2	AH
	Virola flexuosa	Virola	2	AH
	Virola gardneri	Virola	2	AH
	Virola koschnyi	Virola	4	CDEP
	Virola michelii	Virola	6	ABCHPQ
	Virola multicostata	Virola	3	ABH
	Virola pavonis	Virola	2	AH
	Virola sebifera	Virola	3	ACH
	Virola surinamensis	Virola	5	ABCDH
Myrtaceae (43)	*Corymbia citriodora*	Lemon-scented Gum	4	DJPQ
	Corymbia maculata	Spotted Gum	2	JQ
	Eucalyptus alba	White Gum; Khaki Gum	2	DP
	Eucalyptus astringens	Brown Mallet	2	DP
	Eucalyptus bridgesiana	Apple Box	2	DP
	Eucalyptus camaldulensis	Red Gum	3	DJQ
	Eucalyptus cloeziana	Gympie Messmate	2	DP
	Eucalyptus coolabah	Coolabah	2	JQ
	Eucalyptus deglupta	Rainbow Gum	6	ADHIJP
	Eucalyptus delegatensis	Tasmanian Oak; Alpine Ash	5	BCGLP
	Eucalyptus diversicolor	Karri	10	ABCDGHIJLP
	Eucalyptus dives	Peppermint Eucalyptus	2	DP
	Eucalyptus eugenioides	Thin-leaved Stringybark	3	DPQ
	Eucalyptus globoidea	White Stringybark	2	DP
	Eucalyptus globulus	Tasmanian Bluegum	4	ADHI
	Eucalyptus globulus subsp. *maidenii*	Maiden's Gum	2	DP
	Eucalyptus grandis	Rose Gum	4	CJPQ

	Eucalyptus longifolia	Woollybutt	2	DP
	Eucalyptus marginata	Jarrah	8	BCDGIJLP
	Eucalyptus melliodora	Yellow Box	2	JP
	Eucalyptus moluccana	Grey Box; Gum-topped Box	4	DJPQ
	Eucalyptus nitens	Shining Gum	2	DP
	Eucalyptus obliqua	Tasmanian Oak; Australian Oak	6	BCDJLP
	Eucalyptus paniculata	Grey Ironbark	2	BP
	Eucalyptus papuana	Ghost Gum	2	DP
	Eucalyptus pilularis	Blackbutt	2	GP
	Eucalyptus regnans	Tasmanian Oak; Mountain Ash	5	BCJLP
	Eucalyptus resinifera	Red Mahogany	3	BDP
	Eucalyptus robusta	Swamp Mahogany	4	BJPQ
	Eucalyptus socialis	Pointed Mallee	2	JQ
	Eucalyptus tereticornis	Forest Red Gum	3	BDP
	Melaleuca leucadendra	Niaouli	5	BDIPQ
	Melaleuca quinquenervia	Paperbark Tree	3	DIQ
	Myrcianthes pungens	Guabiju	2	AH
	Psidium guajava	Guava	2	DP
	Syncarpia glomulifera	Turpentine Tree	4	DIJP
	Syzygium buettnerianum	Kelat	2	DP
	Syzygium cumini	Kelat	2	KQ
	Syzygium dyerianum	Kelat	2	DP
	Syzygium eugenioides	Kelat	2	DP
	Syzygium kuranda	Kelat	2	DP
	Syzygium suborbiculare	Kelat	3	DPQ
	Tristaniopsis decorticata	Pelawan	2	DP
Nothofagaceae (6)	*Nothofagus alpina*	Rauli	6	ABGHIP
	Nothofagus cunninghamii	Myrtle Beech	2	DP
	Nothofagus dombeyi	Coigue	5	ABGHI
	Nothofagus menziesii	Silver Beech	2	AH
	Nothofagus obliqua	Pellin	2	BH
	Nothofagus pumilio	Lenga	3	ABH
Ochnaceae (2)	*Lophira alata*	Azobé	15	ABCDEFGHIJKLNPQ
	Testulea gabonensis	Izombé	5	BDGIP
Olacaceae (7)	*Coula edulis*	Coula	2	BP
	Minquartia guianensis	Manwood	5	ABDHP
	Ochanostachys amentacea	Petaling	3	ABH
	Ongokea gore	Angueuk	5	BDIKP
	Scorodocarpus borneensis	Kulim	6	BDEIKP
	Strombosia glaucescens	Afina	3	DIP
	Strombosia pustulata	Afina	3	BDP
Oleaceae (13)	*Fraxinus americana*	White Ash	7	ACDHJKP
	Fraxinus excelsior	Common Ash	8	ACDHJLPQ
	Fraxinus latifolia	Oregon Ash	3	DJP

	Fraxinus mandshurica	Manchurian Ash; Tamo Ash	2	AD
	Fraxinus nigra	Black Ash	6	ACDHJP
	Fraxinus ornus	Manna Ash	2	HQ
	Fraxinus pennsylvanica	Green Ash	6	ACDHJP
	Fraxinus profunda	Pumpkin Ash	2	JQ
	Fraxinus quadrangulata	Blue Ash	2	JQ
	Olea capensis	Musharagi	2	BQ
	Olea europaea	European Olive	4	DHJP
	Olea welwitschii	Loliondo	2	BP
	Syringa vulgaris	Lilac	2	JQ
Paulowniaceae (1)	*Paulownia tomentosa*	Foxglove Tree	4	ADHJ
Penaeaceae (1)	*Dactylocladus stenostachys*	Jongkong	7	ABEHIPQ
Peraceae (1)	*Pera glabrata*	Pilon Rosado	3	AHQ
Phyllanthaceae (7)	*Bischofia javanica*	Bishop Wood	6	ABDHIK
	Bridelia grandis	Assas	3	BDP
	Bridelia micrantha	Bridelia; Coast Goldleaf	2	DP
	Hieronyma alchorneoides	Pilon	6	ABDHPQ
	Hieronyma oblonga	Pilon	3	ABH
	Uapaca guineensis	Rikio	2	BP
	Uapaca heudelotii	Rikio	3	BDP
Picrodendraceae (2)	*Androstachys johnsonii*	Mecrussé	4	BDIP
	Oldfieldia africana	Vésàmbata	2	BP
Platanaceae (4)	*Platanus acerifolia*	Plane	2	CH
	Platanus occidentalis	American Sycamore	4	DHIP
	Platanus orientalis	Oriental Plane	3	ACH
	Platanus x hispanica	London Plane	6	CDGLPQ
Podocarpaceae (1)	*Retrophyllum vitiense*		2	DP
Polygalaceae (2)	*Xanthophyllum excelsum*	Lilin	3	CDP
	Xanthophyllum papuanum	Lilin	3	CDP
Polygonaceae (1)	*Triplaris weigeltiana*	Ant Tree	3	DPQ
Primulaceae (1)	*Rapanea melanophloeos*	Cape Beech	2	DP
Proteaceae (6)	*Cardwellia sublimis*	Northern Silky Oak	3	DJP
	Grevillea robusta	Silky Oak	6	ABDHIJ
	Grevillea striata	Beefwood	2	JQ
	Roupala cordifolia	Louro Faia	2	AH
	Roupala montana	Faieira; Louro Faia	3	AHQ
	Roupala montana var. *paraensis*	Louro Faia	4	BDMQ
Putranjivaceae (1)	*Drypetes gossweileri*	Yungu	3	BDP
Rhamnaceae (8)	*Alphitonia philippinensis*		2	DP
	Alphitonia zizyphoides	Doi Selawa; Toi	2	DP
	Berchemia zeyheri	Red Ivorywood; Pink Ivory	5	DJMPQ
	Frangula alnus	Alder Buckthorn	2	HQ
	Frangula purshiana	Cascara Buckthorn	2	JQ

	Krugiodendron ferreum	Black Ironwood	2	JP
	Maesopsis eminii	Musizi	5	BDIPQ
	Rhamnus cathartica	Buckthorn	3	AHQ
Rhizophoraceae (6)	*Anopyxis klaineana*	Bodioa	7	ABDEGHP
	Carallia brachiata	Maniawga	2	BQ
	Cassipourea gummiflua	Large-leaved Onionwood	2	DP
	Cassipourea malosana	Pillarwood	3	BI
	Ceriops tagal	Yellow Mangrove	2	HP
	Rhizophora mangle	Red Mangrove	5	ABDHI
Rosaceae (17)	*Crataegus azarolus*	Azarole	2	AH
	Crataegus coccinea	Scarlet Hawthorn	2	AH
	Crataegus laevigata	Midland Hawthorn	2	HQ
	Crataegus monogyna	Common Hawthorn	2	HQ
	Crataegus pinnatifida	Mountain Hawthorn	3	AHQ
	Malus domestica	Apple	2	JQ
	Malus pumila	Apple	2	DP
	Malus sylvestris	European Crab Apple	4	GIJQ
	Prunus africana	African Cherry	5	DIOPQ
	Prunus avium	Wild Cherry	5	ADHLP
	Prunus serotina	Black Cherry	6	CDHILP
	Prunus turneriana	Wild Almond	2	DP
	Pyrus communis	Wild Pear	4	ADGH
	Sorbus aria	Whitebeam	2	HQ
	Sorbus aucuparia	Rowan	3	AHQ
	Sorbus intermedia	Swedish Whitebeam	3	AHQ
	Sorbus torminalis	Wild Service Tree	3	AHQ
Rubiaceae (18)	*Balmea stormiae*		2	OQ
	Breonadia salicina	Mugonha	2	BQ
	Breonia madagascariensis		2	DP
	Calycophyllum candidissimum	Madroño; Alazano; Harino; Lemonwood	4	DIJP
	Calycophyllum multiflorum	Castelo	4	AHMQ
	Calycophyllum spruceanum	Pau Mulato	3	BKP
	Exostema caribaeum	Caribbean Princewood	2	PQ
	Fleroya ledermannii	Abura	10	ABCDEGHIJP
	Fleroya stipulosa	Abura	7	ABCDHPQ
	Genipa americana	Jagua	7	ABDHIKP
	Haldina cordifolia	Haldu	4	BDIP
	Mitragyna parvifolia	Kaim	2	DP
	Nauclea diderrichii	Bilinga	10	ABCDEGHILP
	Nauclea orientalis	Bangkal	2	BQ
	Neolamarckia cadamba	Kadam	8	ABDEHIPQ

	Neonauclea calycina	Bangkal	3	BDP
	Pertusadina eurhyncha	Haldu	2	BQ
	Simira salvadorensis	Colorado	4	BDPQ
Rutaceae (17)	*Balfourodendron riedelianum*	Guatambu	6	ABDEGI
	Chloroxylon swietenia	Ceylon Satinwood	6	BDIJM
	Euxylophora paraensis	Yellowheart; Pau Amarelo	8	BCDEIJMP
	Fagaropsis angolensis	Mafu	4	BDIP
	Flindersia australis	Crow's Ash; Australian Teak; Silkwood Maple	2	DP
	Flindersia brayleyana	Queensland Maple; Silkwood Maple	3	JPQ
	Flindersia ifflaiana	Cairn's Hickory; Hickory Ash	2	AQ
	Flindersia pimenteliana	Silkwood Maple	2	DP
	Flindersia schottiana	Silver Ash	4	ADPQ
	Phellodendron amurense	Amur Cork	2	AQ
	Ptaeroxylon obliquum	Paco	2	BP
	Zanthoxylum caribaeum		3	AHQ
	Zanthoxylum flavum	West Indian Satinwood	4	BDJP
	Zanthoxylum gilletii	Olonvogo	2	BP
	Zanthoxylum heitzii	Olon	4	BGKP
	Zanthoxylum rhetsa		3	CDP
	Zanthoxylum riedelianum		3	AHQ
Salicaceae (30)	*Casearia battiscombei*	Casearia; Muirungi; White Matua	2	IP
	Casearia dallachyi		2	DP
	Casearia gossypiosperma	Zapatero	3	ABH
	Casearia praecox	Zapatero	6	ABDHPQ
	Homalium bhamoense		4	ABHP
	Homalium foetidum	Malas	4	BDHP
	Homalium le-testui		2	DP
	Homalium longifolium		2	HP
	Populus alba	White Poplar	3	CHQ
	Populus balsamifera	Balsam Poplar	2	DP
	Populus canescens	Grey Poplar	2	CH
	Populus ciliata	Himalayan Poplar	2	DP
	Populus deltoides	Eastern Cottonwood	3	DHP
	Populus grandidentata	Bigtooth Aspen	2	HQ
	Populus heterophylla	Swamp Cottonwood	2	HQ
	Populus nigra	Black Poplar	3	CHQ
	Populus tremula	Aspen	7	ACDHLPQ
	Populus tremuloides	Quaking Aspen	5	ACDHL
	Populus trichocarpa	Western Balsam Poplar	2	DP

	Salix alba	White Willow	5	ACDJP
	Salix babylonica	Weeping Willow	2	HQ
	Salix caprea	Goat Willow	3	AHQ
	Salix cinerea	Grey Willow	2	AH
	Salix eleagnos	Bitter Willow	2	AQ
	Salix humboldtiana	Humboldt's Willow	2	AH
	Salix nigra	Black Willow	5	ADHIJ
	Salix purpurea	Purple Willow	4	ACHQ
	Salix triandra	Almond Willow	2	AH
	Salix viminalis	Osier Willow	3	ACQ
	Salix x fragilis	Crack Willow	4	CDJP
Santalaceae (1)	*Santalum album*	Sandalwood	4	BDIP
Sapindaceae (21)	*Acer campestre*	Field Maple	4	ADHJ
	Acer macrophyllum	Bigleaf Maple	3	DJP
	Acer negundo	Box Elder; Manitoba Maple	4	DIJP
	Acer palmatum	Japanese Maple	2	DP
	Acer pensylvanicum	Moosewood	2	JQ
	Acer pictum	Painted Maple	3	HPQ
	Acer platanus		2	DP
	Acer pseudoplatanus	Sycamore	9	ACDGHIJLP
	Acer rubrum	Red Maple	4	CDJP
	Acer saccharinum	Silver Maple	6	CDJLPQ
	Acer saccharum	Sugar Maple; Rock Maple	6	ACDHJL
	Acer saccharum subsp. *nigrum*	Black Maple	4	CDJP
	Aesculus flava	Yellow Buckeye	7	ADHIJPQ
	Aesculus glabra	Ohio Buckeye	5	ADHJP
	Aesculus hippocastanum	Horse Chestnut	8	ACDGHJLP
	Aesculus turbinata	Japanese Horse Chestnut	3	AHP
	Allophylus cobbe	Titberry	6	ACDGHP
	Dimocarpus longan	Longan	2	PQ
	Harpullia arborea	Tulipwood Tree	2	DP
	Hypelate trifoliata	White Ironwood	2	PQ
	Nephelium lappaceum	Rambutan	2	DQ
Sapotaceae (74)	*Autranella congolensis*	Mukulungu	5	ABDHI
	Baillonella toxisperma	Moabi	9	ABCDHINPQ
	Breviea sericea	Apobaeou	2	AH
	Chrysophyllum africanum	Longhi	6	BDGHIP
	Chrysophyllum albidum	White Star Apple; Mululu	3	AHP
	Chrysophyllum beguei		2	AH
	Chrysophyllum boivinianum		2	DP
	Chrysophyllum giganteum	Aningré	3	ABH
	Chrysophyllum gonocarpum		2	AH

Chrysophyllum lacourtianum	Longhi	2	BP
Chrysophyllum lucentifolium	Goiabao	2	BP
Chrysophyllum perpulchrum	Longhi	3	BDP
Chrysophyllum pomiferum		3	DPQ
Chrysophyllum sanguinolentum	Apple Balata	3	BPQ
Chrysophyllum subnudum	Longhi	3	BDP
Ecclinusa guianensis	Chicle; Coquirana	3	AHQ
Ecclinusa lanceolata	Chicle; Coquirana	2	AH
Letestua durissima	Congotali	2	BQ
Madhuca aspera		2	AH
Madhuca bejaudii		2	AH
Madhuca betis	Bitis	4	ABHQ
Madhuca lanceolata		3	BCH
Madhuca longifolia var. *latifolia*		4	ADHP
Madhuca longifolia	Honey Tree	2	AH
Madhuca malaccensis	Nyatoh	2	BP
Madhuca motleyana	Nyatoh	4	BCPQ
Madhuca neriifolia		2	AH
Madhuca pasquieri		2	AH
Madhuca philippinensis		2	AH
Madhuca pierrei		2	AH
Madhuca sericera	Bitis	2	AH
Madhuca utilis	Bitis	4	ABHP
Manilkara bidentata	Maçaranduba	10	ABCDEHILPQ
Manilkara celebica	Manilkara; Sawo	2	AH
Manilkara fasciculata	Manilkara	3	ABH
Manilkara hexandra	Ceylon Wood; Khirni	2	AH
Manilkara huberi	Maçaranduba	4	ABHQ
Manilkara kanosiensis	Manilkara	3	AHQ
Manilkara kauki	Manilkara	4	ABHQ
Manilkara zapota	Sapodilla	3	DPQ
Micropholis gardneriana	Curupixa	2	BQ
Micropholis guyanensis	Wild Balata	2	DP
Micropholis melinoniana	Curupixa	3	BDP
Micropholis venulosa	Curupixa	2	BQ
Mimusops elengi	Bitis	2	AB
Palaquium ellipticum	Pali	2	DP
Palaquium fidjiense		2	PQ
Palaquium gutta	Gutta Percha	2	CQ
Palaquium hexandrum	Nyatoh	4	ABHQ
Palaquium hispidum	Nyatoh	4	ACHQ
Palaquium hornei		2	PQ
Palaquium impressionervium		2	HQ

	Palaquium maingayi	Nyatoh	4	ACHQ
	Palaquium obovatum	Nyatoh	5	ABCHQ
	Palaquium philippense	Malak-malak	2	DP
	Palaquium regina-montium	Nyatoh Gugong	3	AHQ
	Palaquium rostratum	Nyatoh	2	CQ
	Palaquium semaram	Nyatoh	4	ACHQ
	Palaquium sumatranum		3	AHQ
	Palaquium walsurifolium	Nyatoh	4	ACHQ
	Payena acuminata	Nyatoh	3	ABH
	Payena leerii	Bitis	3	BHQ
	Payena lucida		2	AH
	Payena maingayi	Nyatoh	3	ABH
	Payena obscura	Bitis	4	ABCH
	Planchonella euphlebia	Nyatoh	2	DP
	Pouteria alnifolia		2	HP
	Pouteria altissima	Aningré	6	ABDEHP
	Pouteria izabalensis		2	DP
	Pouteria pierrei	Aningré	6	ABDEHP
	Pradosia schomburgkiana	Casca	2	BQ
	Sideroxylon obtusifolium	Guaraniná	3	AHP
	Tieghemella africana	Douka	8	ABCHIJPQ
	Tieghemella heckelii	Makoré	13	ABCDEGHIJLMPQ
Simaroubaceae (3)	*Ailanthus altissima*	Tree of Heaven	3	IJP
	Ailanthus triphysa	White Siris	2	BQ
	Simarouba amara	Marupa	9	ABCDIKLPQ
Staphyleaceae (1)	*Turpinia ovalifolia*		2	DP
Stemonuraceae (1)	*Cantleya corniculata*	Bedaru	4	ABHQ
Symplocaceae (1)	*Symplocos martinicensis*	Cacarat; Martinique Sweetleaf	2	DP
Tapisciaceae (1)	*Huertea cubensis*		2	DP
Tetramelaceae (2)	*Octomeles sumatrana*	Benuang	9	ABDEGHILP
	Tetrameles nudiflora	Binung	4	BDIP
Tetrameristaceae (1)	*Tetramerista glabra*	Punah	5	ABDHI
Theaceae (3)	*Schima crenata*		2	HK
	Schima noronhae	Samak	3	HKP
	Schima wallichii	Samak	4	ABDH
Thymelaeaceae (4)	*Aquilaria malaccensis*	Agarwood; Aloewood; Eaglewood	3	MPQ
	Gonystylus bancanus	Ramin	5	ABDGH
	Gonystylus forbesii	Ramin	4	ADHP
	Gonystylus macrophyllus	Ramin	6	BCDHPQ
Trochodendraceae (1)	*Trochodendron aralioides*	Japanese Wheel Tree	3	AHP
Ulmaceae (14)	*Holoptelea grandis*	Kekele	2	BP
	Phyllostylon rhamnoides		6	ABDHPQ
	Ulmus alata	Winged Elm	3	DJP

	Ulmus americana	American Elm	6	ACDHJL
	Ulmus campestris	Common Elm	3	ADH
	Ulmus crassifolia	Cedar Elm	3	DJP
	Ulmus glabra	Wych Elm	7	ACDHJPQ
	Ulmus hollandica	Dutch Elm	3	CDP
	Ulmus laevis	European White Elm	2	CQ
	Ulmus minor	Field Elm	6	CDHJPQ
	Ulmus pumila	Siberian Elm	3	DPQ
	Ulmus rubra	Slippery Elm	5	CDJPQ
	Ulmus thomasii	Rock Elm	5	CDJPQ
	Zelkova serrata	Keaki	3	CDP
Urticaceae (3)	*Cecropia peltata*	Imbauba	4	BDIP
	Cecropia sciadophylla		2	PQ
	Musanga cecropioides	Parasolier	4	BDIP
Vochysiaceae (27)	*Erisma calcaratum*		2	AH
	Erisma lanceolatum		2	AH
	Erisma nitidum	Cambara	2	BQ
	Erisma uncinatum	Cambara	8	ABCDHKLP
	Qualea albiflora	Mandioqueira	3	CDP
	Qualea coerulea	Mandioqueira	2	BC
	Qualea dinizii	Mandioqueira	2	AB
	Qualea paraensis	Mandioqueira	6	ABCDHK
	Qualea parviflora	Mandioqueira	2	AH
	Qualea rosea	Mandioqueira	6	ABCDHP
	Vochysia citrifolia	Quaruba	2	AH
	Vochysia densiflora	Quaruba	3	AHQ
	Vochysia divergens	Quaruba	2	AH
	Vochysia diversa	Quaruba	2	AH
	Vochysia duquei	Quaruba	2	AH
	Vochysia ferruginea	Botarrama; Quaruba	3	ADH
	Vochysia guatemalensis	Quaruba	4	ADHP
	Vochysia guianensis	Quaruba	3	ADH
	Vochysia lanceolata	Quaruba	3	AHQ
	Vochysia leguiana	Quaruba	2	AH
	Vochysia lehmannii	Quaruba	4	ADHP
	Vochysia maxima	Quaruba	4	ABHQ
	Vochysia obidensis	Quaruba	3	AHQ
	Vochysia obscura	Quaruba	2	AH
	Vochysia schomburgkii	Quaruba	2	EQ
	Vochysia tetraphylla	Quaruba	4	AHPQ
	Vochysia tomentosa	Quaruba	4	ABDH
Winteraceae (1)	*Drimys winteri*	Canelo	2	BQ
Zygophyllaceae (6)	*Bulnesia arborea*	Vera	7	ABDHIJP
	Bulnesia carrapo		2	MQ
	Bulnesia sarmientoi	Lignum Vitae	5	AHJMQ

Guaiacum coulteri	Gaïac; Guayacan	2	BM
Guaiacum officinale	Lignum Vitae; Guayacan; Palo Santo	8	ABCJLMPQ
Guaiacum sanctum	Holywood Lignum Vitae; Guayacan	7	ABCJLMQ

Appendix B – List of reference sources for native range countries for each subset species, used in Chapter 3

Guidelines produced by J Mark for BGCI volunteers assisting with range country lookup:

<u>Guide to floras used as references for species country ranges</u>

Sources in look-up order:
1. SIS – previous draft / published assessments

Anything without an assessment in SIS:

2. Kew World Checklist of Selected Plant Families

3. For Leguminosae family, use ILDIS World Database

4. National and regional floras – use most recent edition.

    Some key floras by geographical region:
    - Flora Neotropica
    - Flora Malesiana
    - Flora of Sabah & Sarawak
    - Flora of West Tropical Africa
    - Flora Europaea

    Where to find floras (and type-specimen monographs)?
    - JSTOR Global Plants Resource
    - Biodiversity Heritage Library
    - Google "Flora of ….."
    - Hard copies at BGCI

5. Tropicos

6. GRIN Taxonomy for Plants

7a. PROTA (tropical Africa) http://www.prota4u.info/

7b. PROSEA (Southeast Asia) http://proseanet.org

8. Herbarium records online

9. Peer-reviewed journal articles on certain taxa (Google Scholar for keywords)

10. In the unlikely event that there is no species-level distribution information, we may find genus / family distribution in Mabberley's *The Plant Book* (genus-level) or Heywood's

Flowering Plants of the World (family-level), and can then look up the species-level distribution in a regional/national flora.

Other sources:
(These are less reliable, as they give unreferenced info or have dubious sources for their data. However, use these if there is nothing to be found for a taxon in the previous 1-10)

11. Encyclopedia of Life

12. USDA Plants http://plants.usda.gov/core/profile?symbol=RHTY

13. World Agroforestry Centre - articles/reports on specific taxa (or articles from similar organisations e.g. CIFOR, FAO…)

14. Delta-Intkey

15. Independent websites on national/regional flora, or biodiversity search engines with few references (i.e. websites that don't give references for their information, or reference unreliable sources), e.g. http://www.asianplant.net/Anacardiaceae/Parishia_insignis.htm or http://www.gwannon.com/

AND

Independent websites on timbers / fruit trees / other forest products, with unreliable / no references for taxa information, e.g. http://www.tradewindsfruit.com/ ; http://www.woodworkerssource.com/wood_library.php

16. Wikipedia – some of the references at the end of an article may be more useful

Please do <u>not</u> use GBIF, as we are using these country distributions to check GBIF maps.

In the case of conflicting distribution information, please go with the distribution from the more reliable source (i.e. the source higher up the preference list).

Thank you for your help!
Any urgent queries / you find a good source not mentioned: jennifer.mark@bournemouth.ac.uk

Appendix C – Timber tree species prioritised for IUCN Red List assessment in Chapter 4

Table C1 - List of timber tree species prioritised for IUCN Red List assessment in Chapter 4, on the basis of range restriction and/or previous 'Threatened' categorisation

Family	Binomial	Taxonomic authority	Previous IUCN Red List Categorisations (Categories and Criteria Versions 2.3 and 3.1)	Preliminary Categorisation 2015 (Categories and Criteria Version 3.1)
ANACARDIACEAE	*Antrocaryon micraster*	A. Chev. & Guillaum.	VU (A1cd) - 1998	VU A3bc+4bc
ANACARDIACEAE	*Gluta papuana*	Ding Hou	VU (A1cd+2cd) - 1998	LC
ANACARDIACEAE	*Mangifera altissima*	Blanco	VU (A1d) - 1998	LC
ANACARDIACEAE	*Mangifera mucronulata*	Blume		LC
ANACARDIACEAE	*Schinopsis balansae*	Engl.	LR/lc - 1998; EN - 2014	EN A3bc+4bc
ANISOPHYLLEACEAE	*Combretocarpus rotundatus*	(Miq.) Danser	VU (A1cd) - 1998	VU A2bc+3bc+4bc
ANNONACEAE	*Mezzettia parviflora*	Becc.		CR A3bc+4bc
APOCYNACEAE	*Aspidosperma megalocarpon*	Muell. Arg	LR/nt - 1998	VU A3bc+4bc
APOCYNACEAE	*Aspidosperma polyneuron*	Muell. Arg	R - 1997; EN (A1acd+2cd) - 1998	VU A3bc+4bc
APOCYNACEAE	*Dyera polyphylla*	(Miq.) Steenis	VU (A1cd) - 1998	CR A3b
AQUIFOLIACEAE	*Ilex amplifolia*	Rusby		LC
ASTERACEAE	*Brachylaena huillensis*	O. Hoffm.	LR/nt - 1998; LC - 2012	VU A3bc+4bc
ASTEROPEIACEAE	*Asteropeia rhopaloides*	(Baker) Baill.	EN (A3cd) - 2004	CR A3bc
BETULACEAE	*Ostrya virginiana*	(Mill.) K.Koch	NT - 2011; LC - 2014	EN A3bc
BIGNONIACEAE	*Jacaranda acutifolia*	Bonpl.	V - 1997	EN A3bc
BIGNONIACEAE	*Jacaranda mimosifolia*	D. Don	R - 1997; VU (B1+2ac) - 1998	CR A3bc
BIGNONIACEAE	*Paratecoma peroba*	(Record) Kuhlm.	E - 1997; EN - 2014	EN B1ab(i,ii,iii) (+ 2ab(i,ii,iii))
BORAGINACEAE	*Cordia platythyrsa*	Bak.	VU (A1d) - 1998	VU A2bc+3bc+4bc
BURSERACEAE	*Aucoumea klaineana*	Pierre	VU (A1cd) - 1998	LC
BURSERACEAE	*Bursera simaruba*	(L.) Sarg.	LC - 2005; VU - 2014	VU A3bc
BURSERACEAE	*Canarium luzonicum*	(Blume) A.Gray	VU (A1cd) - 1998	VU A3b
BURSERACEAE	*Dacryodes excelsa*	Vahl		LC
BURSERACEAE	*Dacryodes igaganga*	Aubrev. & Pellegrin	VU (A1cd+2cd) - 1998	LC
CARYOCARACEAE	*Caryocar costaricense*	J.D. Sm.	VU (A1acd) - 1998	VU A3bc+4bc
CERCIDIPHYLLACEAE	*Cercidiphyllum japonicum*	Sieb. & Zucc.	LR/nt - 1998	LC
CLUSIACEAE	*Calophyllum tomentosum*	Wight	VU (A1c, B1+2c) - 1998	LC
COMBRETACEAE	*Terminalia ivorensis*	A. Chev.	VU (A1cd) - 1998	EN A3bc
COMBRETACEAE	*Terminalia nitens*	Presl.	VU (A1d) - 1998	LC

CUNONIACEAE	*Ceratopetalum succirubrum*	C.T.White	VU (A2cd) - 1998	LC
CUNONIACEAE	*Eucryphia cordifolia*	Cav.	LR/nt - 1998	VU A3bc+4bc
DILLENIACEAE	*Dillenia luzoniensis*	(Vid.) Martelli	VU (A1cd) - 1998	VU A3b
DILLENIACEAE	*Dillenia philippinensis*	Rolfe	V - 1997; VU (A1d) - 1998	NT
DIPTEROCARPACEAE	*Anisoptera costata*	Korth.	EN (A1cd+2cd) - 1998	EN A3bc+4bc
DIPTEROCARPACEAE	*Anisoptera curtisii*	Dyer ex King	CR (A1cd+2cd) - 1999	CR A3b
DIPTEROCARPACEAE	*Anisoptera laevis*	Ridl.	EN (A1cd+2cd) - 1998	LC
DIPTEROCARPACEAE	*Anisoptera marginata*	Korth.	EN (A1cd+2cd) - 1998	CR A3b
DIPTEROCARPACEAE	*Anisoptera scaphula*	(Roxb.) Kurz	CR (A1cd+2cd) - 1998	CR A3b
DIPTEROCARPACEAE	*Cotylelobium burckii*	(F.Heim) F.Heim	EN (A1cd+2cd) - 1998	CR A3b+4b
DIPTEROCARPACEAE	*Cotylelobium lanceolatum*	Craib	VU (A1cd, B1+2c) - 1998	CR A3bc
DIPTEROCARPACEAE	*Cotylelobium melanoxylon*	(Hook.f.) Pierre	EN (A1cd+2cd) - 1998	CR A3b
DIPTEROCARPACEAE	*Dipterocarpus alatus*	Roxb.	EN (A1cd+2cd, B1+2c) - 1998	VU A2bc+3bc+4bc
DIPTEROCARPACEAE	*Dipterocarpus baudii*	Korth.	V - 1997; CR (A1cd+2cd) - 1998	CR A3b
DIPTEROCARPACEAE	*Dipterocarpus costulatus*	Sloot.	CR (A1cd+2cd, B1+2c) - 1998	CR A3b
DIPTEROCARPACEAE	*Dipterocarpus eurynchus*	Miq.	V - 1997; CR (A1cd+2cd, B1+2c) - 1998	CR A3b
DIPTEROCARPACEAE	*Dipterocarpus grandiflorus*	Blanco	CR (A1cd+2cd) - 1998	EN A3bc+4bc
DIPTEROCARPACEAE	*Dipterocarpus kerrii*	King	V - 1997; CR (A1cd+2cd, B1+2c) - 1998	EN A3b+4b
DIPTEROCARPACEAE	*Dipterocarpus lowii*	Hook. f.	CR (A1cd+2cd, B1+2c) - 1998	CR A3b
DIPTEROCARPACEAE	*Dipterocarpus retusus*	Blume	VU (A1cd+2cd, B1+2c) - 1998	EN A3b+4b
DIPTEROCARPACEAE	*Dipterocarpus validus*	Blume	CR (A1cd+2cd) - 1998	CR A3b
DIPTEROCARPACEAE	*Dryobalanops beccarii*	Dyer	EN (A1cd+2cd) - 1998	VU A2bc+3bc+4bc
DIPTEROCARPACEAE	*Dryobalanops lanceolata*	Burck	EN (A1cd) - 1998	VU A3bc+4bc
DIPTEROCARPACEAE	*Hopea acuminata*	Merr.	CR (A1cd, B1+2c) - 1998; CR (A1cd;B1+2c) - 2008	VU A3b
DIPTEROCARPACEAE	*Hopea beccariana*	Burck	CR (A1cd+2cd) - 1998	CR A3bc+4bc
DIPTEROCARPACEAE	*Hopea ferrea*	Lanessan	EN (A1cd+2cd, B1+2c) - 1998	CR A3bc
DIPTEROCARPACEAE	*Hopea foxworthyi*	Elmer	EX/E - 1997; VU (D2) - 1998; CR (A1cd;B1+2bc) - 2008	EN A3bc
DIPTEROCARPACEAE	*Hopea helferi*	(Dyer) Brandis	CR (A1cd+2cd, B1+2c) - 1998	VU A2b+3b+4b
DIPTEROCARPACEAE	*Hopea mengerawan*	Miq.	CR (A1cd, B1+2c) - 1998	CR A3b
DIPTEROCARPACEAE	*Hopea nervosa*	King	CR (A1c, B1+2c) -	CR A3bc

			1998	
DIPTEROCARPACEAE	*Hopea nutans*	Ridl.	V - 1997; CR (A1cd+2cd, B1+2c) - 1998	CR A3b
DIPTEROCARPACEAE	*Hopea odorata*	Roxb.	VU (A1cd+2cd) - 1998	VU A2bc+3bc+4bc
DIPTEROCARPACEAE	*Hopea plagata*	(Blanco) S.Vidal	CR (A1cd, B1+2c) - 1998	CR A3b
DIPTEROCARPACEAE	*Hopea sangal*	Korth.	CR (A1cd, B1+2c, C1, D) - 1998	VU A3bc
DIPTEROCARPACEAE	*Hopea semicuneata*	Symington	CR (A1cd, B1+2c) - 1998	CR A3b
DIPTEROCARPACEAE	*Neobalanocarpus heimii*	(King) P.S.Ashton	VU (A1cd) - 1998	CR A3b
DIPTEROCARPACEAE	*Parashorea aptera*	Slooten	V - 1997; CR (A1cd) - 1998	CR A3b
DIPTEROCARPACEAE	*Parashorea densiflora*	Slooten & Symington	V - 1997; EN (A1cd, B1+2c) - 1998	CR A3b+4b
DIPTEROCARPACEAE	*Parashorea lucida*	(Miq.) Kurz	V - 1997; CR (A1cd, B1+2c, C2a) - 1998	CR A3bc+4bc
DIPTEROCARPACEAE	*Parashorea macrophylla*	Wyatt-Sm. ex P.S.Ashton	V - 1997; CR (A1cd, B1+2c, C2a) - 1998	CR A3b+4b
DIPTEROCARPACEAE	*Parashorea malaanonan*	(Blanco) Merr.	CR (A1cd) - 1998	CR A3b
DIPTEROCARPACEAE	*Parashorea stellata*	Kurz	CR (A1cd, B1+2c) - 1998	VU A3bc+4bc
DIPTEROCARPACEAE	*Shorea acuminata*	Dyer	CR (A1cd) - 1998	CR A3b+4b
DIPTEROCARPACEAE	*Shorea acuminatissima*	Sym.	V - 1997; CR (A1cd) - 1998	CR A3b
DIPTEROCARPACEAE	*Shorea albida*	Sym.	EN (A1cd+2cd) - 1998	CR A3b
DIPTEROCARPACEAE	*Shorea balangeran*	(Korth.) Burck	CR (A1cd) - 1998	EN A3bc
DIPTEROCARPACEAE	*Shorea balanocarpoides*	Sym.	EN (A1cd) - 1998	CR A3b
DIPTEROCARPACEAE	*Shorea bracteolata*	Dyer	EN (A1cd+2cd) - 1998	LC
DIPTEROCARPACEAE	*Shorea brunnescens*	Ashton	EN (A1cd+2cd, C2a) - 1998	CR A3b+4b
DIPTEROCARPACEAE	*Shorea collina*	Ridley	V - 1997; CR (A1cd+2cd, C2a) - 1998	CR A3b+4b
DIPTEROCARPACEAE	*Shorea contorta*	Vidal	CR (A1cd) - 1998	LC
DIPTEROCARPACEAE	*Shorea dasyphylla*	Foxw.	EN (A1cd) - 1998	CR A3b
DIPTEROCARPACEAE	*Shorea dealbata*	Foxw.	V - 1997; CR (A1cd+2cd, C2a) - 1998	CR A3b
DIPTEROCARPACEAE	*Shorea faguetiana*	Heim.	EN (A1cd) - 1998	VU A3bc
DIPTEROCARPACEAE	*Shorea foxworthyi*	Symington	CR (A1cd) - 1998	CR A3b
DIPTEROCARPACEAE	*Shorea gibbosa*	Brandis.	CR (A1cd) - 1998	VU A2b+3b+4b
DIPTEROCARPACEAE	*Shorea glauca*	King	V - 1997; EN (A1cd) - 1998	CR A3b
DIPTEROCARPACEAE	*Shorea guiso*	(Blanco) Blume	CR (A1cd) - 1998	EN A3bc+4bc
DIPTEROCARPACEAE	*Shorea hopeifolia*	(F.Heim) Symington	CR (A1cd) - 1998	LC
DIPTEROCARPACEAE	*Shorea hypochra*	Hance	V - 1997; CR (A1cd) - 1998	CR A3b
DIPTEROCARPACEAE	*Shorea johorensis*	Foxw.	CR (A1cd) - 1998	VU A3bc+4bc
DIPTEROCARPACEAE	*Shorea kunstleri*	King	CR (A1cd) - 1998	CR A3b

DIPTEROCARPACEAE	*Shorea lamellata*	Foxw.	CR (A1cd) - 1998	EN A3bc
DIPTEROCARPACEAE	*Shorea lepidota*	(Korth.) Blume	CR (A1cd) - 1998	CR A3b
DIPTEROCARPACEAE	*Shorea leprosula*	Miq.	EN (A1cd) - 1998	EN A3bc+4bc
DIPTEROCARPACEAE	*Shorea leptoderma*	Meijer	E - 1997; CR (A1cd) - 1998	CR A3b+4b
DIPTEROCARPACEAE	*Shorea longisperma*	Roxb.	CR (A1cd, C2a) - 1998	CR A3bc
DIPTEROCARPACEAE	*Shorea macrantha*	Brandis	V - 1997; CR (A1cd, C2a) - 1998	CR A3b
DIPTEROCARPACEAE	*Shorea materialis*	Ridley	V - 1997; CR (A1cd, C2a) - 1998	CR A3b
DIPTEROCARPACEAE	*Shorea maxwelliana*	King	EN (A1c) - 1998	CR A3b
DIPTEROCARPACEAE	*Shorea negrosensis*	Foxw.	CR (A1cd) - 1998	VU A3b
DIPTEROCARPACEAE	*Shorea ochrophloia*	Strugn. ex Sym.	V - 1997; CR (A1cd) - 1998	CR A3b
DIPTEROCARPACEAE	*Shorea ovata*	Dyer ex Brandis	EN (A1cd) - 1998	CR A3b
DIPTEROCARPACEAE	*Shorea pauciflora*	King	EN (A1cd) - 1998	EN A3bc+4bc
DIPTEROCARPACEAE	*Shorea platyclados*	Sloot. ex Foxw.	EN (A1cd) - 1998	CR A3b
DIPTEROCARPACEAE	*Shorea quadrinervis*	Sloot.	EN (A1cd) - 1998	CR A3b+4b
DIPTEROCARPACEAE	*Shorea roxburghii*	G.Don	EN (A1cd) - 1998	EN A3bc
DIPTEROCARPACEAE	*Shorea rugosa*	Heim	CR (A1cd, C2a) - 1998	CR A3b
DIPTEROCARPACEAE	*Shorea seminis*	(De Vriese) Sloot.	CR (A1cd) - 1998	CR A3b
DIPTEROCARPACEAE	*Shorea singkawang*	(Miq.) Burck	CR (A1cd) - 1998	CR A3b
DIPTEROCARPACEAE	*Shorea smithiana*	Sym.	CR (A1cd) - 1998	EN A3bc
DIPTEROCARPACEAE	*Shorea submontana*	Sym.	EN (A1cd) - 1998	CR A3b+4b
DIPTEROCARPACEAE	*Shorea sumatrana*	(Slooten) Desch	CR (A1cd) - 1998	CR A3b
DIPTEROCARPACEAE	*Shorea superba*	Sym.	R - 1997; CR (A1cd) - 1998	CR A3b+4b
DIPTEROCARPACEAE	*Upuna borneensis*	Symington	EN (A1cd, C2a) - 1998	CR A3b
EBENACEAE	*Diospyros celebica*	Bakh.	R - 1997; VU (A1cd) - 1998	VU A3bc
EBENACEAE	*Diospyros crassiflora*	Hiern	EN (A1d) - 1998	LC
EBENACEAE	*Diospyros insularis*	Bakh.	EN (A1cd+2cd, B1+2c) - 1998	VU A3bc
EBENACEAE	*Diospyros korthalsiana*	Bakh.		NT
EUPHORBIACEAE	*Sapium laurocerasus*	Desf.	V - 1997	LC
FAGACEAE	*Nothofagus alpina*	(Popp. & Endl.) Oerst.	LR/nt - 1998	EN A3bc+4bc
FAGACEAE	*Quercus arkansana*	Sarg.	R - 1997; VU (D2) - 1998; VU (B1ab(iii)) - 2007	CR A3bc+4bc
FAGACEAE	*Quercus phillyreoides*	A.Gray		CR B1ab(i,ii,iii)
GENTIANACEAE	*Fagraea gracilipes*	A.Gray	LR/nt - 1998	LC
HIPPOCASTANACEAE	*Aesculus hippocastanum*	L.	NT - 2013	LC
IRVINGIACEAE	*Irvingia gabonensis*	Baill. ex Lanen.	LR/nt - 1998; LC - 2012	NT
JUGLANDACEAE	*Juglans australis*	Griseb.	LR/nt - 1998	NT
JUGLANDACEAE	*Juglans hindsii*	Jeps. ex R.E.Sm.	E - 1997	EN A3bc+4bc
JUGLANDACEAE	*Juglans jamaicensis*	C.DC.	R - 1997; VU (A1c, B1+2c) - 1998	VU A3bc+4bc
JUGLANDACEAE	*Juglans neotropica*	Diels	EN (A1acd+2cd) -	LC

			1998	
JUGLANDACEAE	*Juglans olanchana*	Standl. & L.O.Williams	VU (A4c) - 2011	VU A2bc+3bc+4bc
JUGLANDACEAE	*Juglans regia*	L.	NT - 2007; NT - 2008	LC
LAMIACEAE	*Vitex gaumeri*	Greenm.	EN (C2a) - 1998; LC - 2005	EN A3bc
LAMIACEAE	*Vitex parviflora*	Juss.	VU (A1cd) 1998	VU A2bc+3bc+4bc
LAMIACEAE	*Vitex turczaninowii*	Merr.		LC
LAURACEAE	*Aniba rosaeodora*	Ducke	EN (A1d + 2d) - 1998	LC
LAURACEAE	*Aspidostemon perrieri*	(Danguy) Rohwer		CR A3bc
LAURACEAE	*Eusideroxylon zwageri*	Teysm. & Binnend.	VU (A1cd+2cd) - 1998	CR A3bc
LAURACEAE	*Licaria capitata*	(Cham. & Schltdl.) Kosterm.	EN (B1ab(iii)) - 2011	EN A3bc
LAURACEAE	*Mezilaurus ita-uba*	(Meisn.) Taub. ex Mez	VU (A1a) - 1998; VU - 2014	VU A3bc
LAURACEAE	*Mezilaurus navalium*	(Fr. Allem.) Taub.	VU (A1ac) - 1998; EN - 2014	VU A2b+3b+4b
LAURACEAE	*Ocotea comoriensis*	Kosterm.		VU A3bc
LAURACEAE	*Ocotea porosa*	(Nees & Mart.) Barroso	V - 1997; VU (A1cd) - 1998; EN - 2014	CR A3bc
LAURACEAE	*Ocotea puberula*	(Rich.) Nees	LR/lc - 1998; NT - 2011	VU A3bc+4bc
LAURACEAE	*Persea lingue*	(R. & P.) Nees ex Kopp	R - 1997; LR/nt - 1998	CR A3bc+4bc
LECYTHIDACEAE	*Allantoma integrifolia*	(Ducke) S.A.Mori, Ya Y.Huang & Prance		LC
LECYTHIDACEAE	*Bertholletia excelsa*	Bonpl.	VU (A1acd+2cd) - 1998; VU - 2014	NT
LECYTHIDACEAE	*Cariniana legalis*	(Martius) Kuntze	VU (A1ac) - 1998; EN - 2014	EN A3bc
LECYTHIDACEAE	*Cariniana pyriformis*	Miers	LR/nt - 1998	VU A2bc+3bc+4bc
LECYTHIDACEAE	*Couratari guianensis*	Aublet	VU (A2bcde) - 1998	NT
LEGUMINOSAE	*Acacia crassicarpa*	A.Cunn ex Benth.	VU (A1cd+2cd, B1+2abcd) - 1998	LC
LEGUMINOSAE	*Acacia pubescens*	(Vent.) R.Br.	V - 1997; EN - 2010	NT
LEGUMINOSAE	*Afzelia africana*	Sm.	VU (A1d) - 1998	LC
LEGUMINOSAE	*Afzelia bipindensis*	Harms	VU (A1cd) - 1998	CR A3bc
LEGUMINOSAE	*Afzelia pachyloba*	Harms	VU (A1d) - 1998	LC
LEGUMINOSAE	*Afzelia rhomboidea*	(Blanco) Vidar	VU (A1cd) - 1998	CR A3bc+4bc
LEGUMINOSAE	*Afzelia xylocarpa*	(Kurz) Craib	EN (A1cd) - 1998	EN A3bc+4bc
LEGUMINOSAE	*Albizia ferruginea*	(Guill. & Perr.) Benth.	VU (A1cd) - 1998	LC
LEGUMINOSAE	*Amburana cearensis*	(Fr. Allem.) A.C. Smith	EN (A1acd+2cd) - 1998	EN A3bc
LEGUMINOSAE	*Andira coriacea*	Pulle		LC
LEGUMINOSAE	*Apuleia leiocarpa*	(Vogel) J.F.Macbr.	VU - 2014	VU A3bc+4bc
LEGUMINOSAE	*Archidendropsis xanthoxylon*	(C.T.White & W.D.Francis) I.C.N	R - 1997	LC
LEGUMINOSAE	*Baikiaea plurijuga*	Harms	LR/nt - 1998	LC
LEGUMINOSAE	*Berlinia auriculata*	Benth.	NT - 2011	LC
LEGUMINOSAE	*Berlinia confusa*	Hoyle	NT - 2011	VU A3bc+4bc

LEGUMINOSAE	*Brachystegia nigerica*	Hoyle & A. Jones	VU (B1+2c) - 1998	LC
LEGUMINOSAE	*Caesalpinia echinata*	Lam.	V - 1997; EN (A1acd) - 1998; EN - 2014	EN A3bc+4bc
LEGUMINOSAE	*Caesalpinia paraguariensis*	(Parodi) Burkart	VU (A1acd) - 1998	CR A3bc
LEGUMINOSAE	*Calpocalyx heitzii*	Pellegr.	VU (A1c, B1+2c) - 1998	LC
LEGUMINOSAE	*Cojoba arborea*	(L.) Britton & Rose	NT - 2011	NT
LEGUMINOSAE	*Copaifera salikounda*	Heckel	VU (A1d) - 1998	EN A3bc
LEGUMINOSAE	*Cynometra inaequifolia*	A.Gray	VU (A1d) - 1998	LC
LEGUMINOSAE	*Dalbergia bariensis*	Pierre	EN (A1cd) - 1998	VU A2b+3b+4b
LEGUMINOSAE	*Dalbergia baronii*	Baker.	VU (A1cd+2cd) - 1998	CR A3bc
LEGUMINOSAE	*Dalbergia cambodiana*	Pierre	EN (A1cd) - 1998	CR A3b
LEGUMINOSAE	*Dalbergia cearensis*	Ducke	V - 1997	VU A3bc+4bc
LEGUMINOSAE	*Dalbergia cochinchinensis*	Pierre	VU (A1cd) - 1998	CR A3bc
LEGUMINOSAE	*Dalbergia cultrata*	Graham ex Benth.	NT - 2012	VU A3bc
LEGUMINOSAE	*Dalbergia decipularis*	Rizzini & A.Mattos	V - 1997	EN A3bc+4bc
LEGUMINOSAE	*Dalbergia greveana*	Baillon	LR/nt - 1998	CR A3bc
LEGUMINOSAE	*Dalbergia latifolia*	Roxb.	VU (A1cd) - 1998	LC
LEGUMINOSAE	*Dalbergia louvelii*	R.Vig.	EN (A1cd+2cd) - 1998; EN - 2010	CR A3bc
LEGUMINOSAE	*Dalbergia madagascariensis*	Vatke.	VU (A1cd+2cd) - 1998	CR A3bc
LEGUMINOSAE	*Dalbergia maritima*	R. Vig.	EN (A1cd+2cd) - 1998; EN - 2010	CR A3bc
LEGUMINOSAE	*Dalbergia melanoxylon*	Guill. & Perr.	LR/nt - 1998; NT - 2012	LC
LEGUMINOSAE	*Dalbergia monticola*	Bosser & Rabevohitra	VU (A1cd+2cd) - 1998	CR A3bc
LEGUMINOSAE	*Dalbergia nigra*	Allem. ex Benth.	VU (A1cd) - 1998; EN - 2010; VU - 2014	CR A3bc
LEGUMINOSAE	*Dalbergia oliveri*	Gamble ex Prain	EN (A1cd) - 1998	EN A3bc+4bc
LEGUMINOSAE	*Dalbergia pervillei*	Vatke.	LR/nt - 1998	EN A3bc+4bc
LEGUMINOSAE	*Dalbergia retusa*	Hemsl.	VU (A1acd) - 1998	VU A3bc+4bc
LEGUMINOSAE	*Dalbergia stevensonii*	Standl.	VU (A2cd) - 2006	CR A3bc
LEGUMINOSAE	*Daniellia klainei*	A. Chev.	LR/nt - 1998	CR A3bc
LEGUMINOSAE	*Desmodium oojeinense*	(Roxb.) H.Ohashi		LC
LEGUMINOSAE	*Dialium cochinchinense*	Pierre	LR/nt - 1998	CR A3bc
LEGUMINOSAE	*Didelotia idae*	Oldem., De Wit. & Leon.	LR/nt - 1998	EN A3bc+4bc
LEGUMINOSAE	*Gossweilerodendron balsamiferum*	(Verm.) Harms	EN (A1cd) - 1998	LC
LEGUMINOSAE	*Gossweilerodendron joveri*	Aubrev.	VU (B2ab(iii)) - 2004	LC
LEGUMINOSAE	*Guibourtia schliebenii*	(Harms) J.Leonard	VU (B2ab(iii)) - 2013	EN A3bc
LEGUMINOSAE	*Haplormosia monophylla*	(Harms) Harms	VU (A1d+2d) - 1998	EN A3bc
LEGUMINOSAE	*Hymenolobium excelsum*	Ducke	VU - 2014	VU A3bc+4bc

LEGUMINOSAE	*Intsia bijuga*	(Colebr.) Kuntze	VU (A1cd) - 1998; EN - 2010	EN A3bc
LEGUMINOSAE	*Isoberlinia scheffleri*	(Harms) Greenway	VU (B1+2b) - 1998	VU A2bc+3bc+4bc
LEGUMINOSAE	*Lonchocarpus leucanthus*	Burkart		CR A3bc
LEGUMINOSAE	*Machaerium scleroxylon*	Tul.	R - 1997; LC - 2012	EN A3bc+4bc
LEGUMINOSAE	*Machaerium villosum*	Vogel	E - 1997; VU (A1cd) - 1998	CR A3bc
LEGUMINOSAE	*Melanoxylon brauna*	Schott	VU - 2014	EN A3bc+4bc
LEGUMINOSAE	*Microberlinia bisulcata*	A.Chev.	CR (A1c+2c) - 2000	LC
LEGUMINOSAE	*Microberlinia brazzavillensis*	A.Chev.	VU (A1c) - 1998	LC
LEGUMINOSAE	*Millettia laurentii*	Wildem.	EN (A1cd) - 1998	LC
LEGUMINOSAE	*Mora gonggrijpii*	(Kleinhoonte) Sandwith		LC
LEGUMINOSAE	*Oxystigma mannii*	(Baill.) Harms		VU A3bc+4bc
LEGUMINOSAE	*Peltogyne maranhensis*	Ducke	VU - 2014	VU A2b+3b+4b
LEGUMINOSAE	*Pericopsis elata*	(Harms) van Meeuwen	EN (A1cd) - 1998	LC
LEGUMINOSAE	*Pericopsis mooniana*	(Thw.) Thw.	VU (A1cd) - 1998	LC
LEGUMINOSAE	*Platymiscium yucatanum*	Standl.	VU - 2005	EN A3bc+4bc
LEGUMINOSAE	*Pterocarpus angolensis*	DC.	LR/nt - 1998	NT
LEGUMINOSAE	*Pterocarpus indicus*	Willd.	VU (A1d) - 1998	VU A2bc+3bc+4bc
LEGUMINOSAE	*Pterocarpus marsupium*	Roxb.	VU (A1cd) - 1998	LC
LEGUMINOSAE	*Pterocarpus santalinus*	Linn.f.	E - 1997; EN (B1+2de) - 1998	LC
LEGUMINOSAE	*Pterogyne nitens*	Tul.	LR/nt - 1998	EN A3bc+4bc
LEGUMINOSAE	*Serianthes myriadenia*	J.Planchon ex Bentham	R - 1997; LR/nt - 1998	DD
LEGUMINOSAE	*Sindora javanica*	(K. & V.) Back.	VU (B1+2c) - 1998	CR A3b
LEGUMINOSAE	*Sindora supa*	Merr.	VU (A1d) - 1998; EN (A1cd;B2c) - 2008	NT
LEGUMINOSAE	*Swartzia leiocalycina*	Benth.		LC
LEGUMINOSAE	*Sympetalandra densiflora*	(Elmer) Steenis	EN (A1c;B2c) - 2008	VU A3b
LEGUMINOSAE	*Tetraberlinia tubmaniana*	J. Léonard	VU (A1c, B1+2c) - 1998	EN A3bc
LEGUMINOSAE	*Vouacapoua americana*	Aubl.	CR (A1cd+2cd) - 1998; EN - 2014	LC
LEGUMINOSAE	*Vouacapoua macropetala*	Sandwith		LC
LEGUMINOSAE	*Wallaceodendron celebicum*	Koord.	EN (A1cd;B2c) - 2008	VU A3bc+4bc
MAGNOLIACEAE	*Magnolia sororum*	Seibert	NT - 2014	EN A3bc
MAGNOLIACEAE	*Magnolia yoroconte*	Dandy	VU (A1c) - 1998; VU - 2007; VU - 2011	EN A3bc+4bc
MALVACEAE	*Bastardiopsis densiflora*	(Hook. & Arn.) Hassl.		EN B1ab(i,ii,iii) (+ 2ab(i,ii,iii)); C1
MALVACEAE	*Cavanillesia platanifolia*	(Humb. & Bonpl.) Kunth	LR/nt - 1998	VU A3bc

MALVACEAE	*Coelostegia griffithii*	Benth.		CR A3bc
MALVACEAE	*Diplodiscus paniculatus*	Turcz.	V - 1997; VU (A1cd) - 1998	VU A3b
MALVACEAE	*Rhodognaphalon brevicuspe*	(Sprague) Roberty	VU (A1cd) - 1998	VU A3bc+4bc
MALVACEAE	*Tarrietia densiflora*	(Pellegr.) Aubrév. & Normand		LC
MELIACEAE	*Carapa grandiflora*	Sprague		LC
MELIACEAE	*Cedrela angustifolia*	DC.	VU - 2010	LC
MELIACEAE	*Cedrela fissilis*	Vell.	EN (A1acd+2cd) - 1998; VU - 2010; VU - 2014	VU A3bc+4bc
MELIACEAE	*Cedrela odorata*	L.	VU (A1cd+2cd) - 1998; LC - 2010; VU - 2014	VU A3bc+4bc
MELIACEAE	*Entandrophragma angolense*	(Welw.) C. DC.	VU (A1cd) - 1998; LC - 2012	NT
MELIACEAE	*Entandrophragma candollei*	Harms	VU (A1cd) - 1998	LC
MELIACEAE	*Entandrophragma cylindricum*	(Sprague) Sprague	VU (A1cd) - 1998; LC - 2012	LC
MELIACEAE	*Entandrophragma utile*	(Dawe & Sprague) Sprague	VU (A1cd) - 1998; LC - 2012	LC
MELIACEAE	*Guarea cedrata*	(A. Chev.) Pellegrin	VU (A1c) - 1998; LC - 2012	LC
MELIACEAE	*Guarea glabra*	Vahl	LC - 2005; NT - 2011	LC
MELIACEAE	*Guarea thompsonii*	Sprague & Hutch.	VU (A1c) - 1998	LC
MELIACEAE	*Khaya anthotheca*	(Welw.) C.DC.	VU (A1cd) - 1998; LC - 2012	NT
MELIACEAE	*Khaya grandifoliola*	C. DC.	VU (A1cd) - 1998; LC - 2012	VU A2bc+3bc+4bc
MELIACEAE	*Khaya ivorensis*	A. Chev.	VU (A1cd) - 1998	LC
MELIACEAE	*Khaya senegalensis*	(Desr.) A. Juss.	VU (A1cd) - 1998; LC - 2012	NT
MELIACEAE	*Lovoa swynnertonii*	E.G.Baker	LC - 2012; NT - 2013	VU A3bc+4bc
MELIACEAE	*Lovoa trichilioides*	Harms	VU (A1cd) - 1998; LC - 2012	NT
MELIACEAE	*Sandoricum vidalii*	Merr.	V - 1997; VU (A1cd) - 1998	VU A3b
MELIACEAE	*Swietenia humilis*	Zuccarini	VU (A1cd) - 1998	VU A3bc+4bc
MELIACEAE	*Swietenia macrophylla*	King	VU (A1cd+2cd) - 1998; VU - 2014	NT
MELIACEAE	*Swietenia mahagoni*	(L.) Jacq.	EN (A1cd) - 1998	VU A3bc
MONIMIACEAE	*Laurelia sempervirens*	(R. & P.) Tul.	LR/nt - 1998	CR A3bc
MORACEAE	*Artocarpus chama*	Buch.-Ham.		VU A3bc+4bc
MORACEAE	*Milicia excelsa*	(Welw.) C.C. Berg	LR/nt - 1998; LC - 2012	NT
MORACEAE	*Milicia regia*	(A. Chev.) C.C. Berg	VU (A1cd) - 1998	EN A3bc
MYRISTICACEAE	*Cephalosphaera usambarensis*	Warb.	VU - 1998	EN A3bc
MYRISTICACEAE	*Horsfieldia flocculosa*	(King) Warb.	VU (B1+2c) - 1998	CR A3b+4b
MYRISTICACEAE	*Horsfieldia ralunensis*	Warb.		CR A3bc
MYRISTICACEAE	*Horsfieldia superba*	(Hk. f. & Th.) Warb.	LR/nt - 1998	CR A3bc+4bc
MYRISTICACEAE	*Myristica buchneriana*	Warb.	VU (A1d) - 1998	LC
MYRISTICACEAE	*Myristica gigantea*	King	LR/nt - 1998	CR A3b
MYRISTICACEAE	*Myristica lowiana*	King	LR/nt - 1998	CR A3b

MYRISTICACEAE	*Myristica maingayi*	Hk. f.	LR/nt - 1998	CR A3b+4b
MYRISTICACEAE	*Virola surinamensis*	(Rol.) Warb.	EN (A1ad+2cd) - 1998; VU - 2014	NT
MYRTACEAE	*Myrcianthes pungens*	(Berg) Legr.	EN (B1+2c) - 1998	CR A3bc
MYRTACEAE	*Tristaniopsis decorticata*	(Merr.) Peter G.Wilson & J.T.Waterh.	CR (A1cd;B2c) - 2008	VU A3b
OCHNACEAE	*Lophira alata*	Banks ex Gaertn.	VU (A1cd) - 1998	NT
OCHNACEAE	*Testulea gabonensis*	Pellegr.	EN (A1cd) - 1998	LC
OLACACEAE	*Minquartia guianensis*	Aublet	LR/nt - 1998	NT
PROTEACEAE	*Roupala montana*	Aubl.	LC - 2005; NT - 2011	VU A3bc+4bc
RHIZOPHORACEAE	*Anopyxis klaineana*	(Pierre) Engl.	VU (A1cd) - 1998	EN A3bc
ROSACEAE	*Prunus africana*	(Hook.f.) Kalkman	VU (A1cd) - 1998; NT - 2012	NT
RUBIACEAE	*Balmea stormae*	Martínez	VU (B1ab(iii)) - 2006; EN (A4c) - 2011	LC
RUBIACEAE	*Breonia madagascariensis*	A.Rich. ex DC.		CR A3bc
RUBIACEAE	*Nauclea diderrichii*	(De Wild. & T.Durand) Merrill	VU (A1cd) - 1998; LC - 2012	NT
RUTACEAE	*Balfourodendron riedelianum*	Engl.	EN (A1acd+2cd) - 1998	CR A3bc
RUTACEAE	*Chloroxylon swietenia*	DC.	VU (A1c) - 1998	LC
RUTACEAE	*Euxylophora paraensis*	Huber	CR - 2014	VU A2b+3b+4b
RUTACEAE	*Flindersia pimenteliana*	F. Muell	EN (C2a) - 1998	LC
RUTACEAE	*Flindersia schottiana*	F. Muell	LR/nt - 1998	LC
RUTACEAE	*Zanthoxylum flavum*	Vahl.	VU (A1c) - 1998; CR (B2ab(ii,iii)) - 2005	VU A3bc+4bc
SANTALACEAE	*Santalum album*	Linn.	VU (A1d) - 1998	CR A3bc
SAPINDACEAE	*Dimocarpus longan*	Lour.	V - 1997; LR/nt - 1998	VU A2bc+3bc+4bc
SAPOTACEAE	*Autranella congolensis*	(De Wild.) A.Chev.	CR (A1cd) - 1998	LC
SAPOTACEAE	*Baillonella toxisperma*	Pierre	VU (A1cd) - 1998	LC
SAPOTACEAE	*Breviea sericea*	Aubrev. & Pellegr.	LR/nt - 1998	VU A3bc
SAPOTACEAE	*Madhuca betis*	(Blanco) J.F.Macbr.	VU (A1cd) - 1998	EN A3bc
SAPOTACEAE	*Madhuca neriifolia*	(Moon) H.J.Lam	EN (B1+2c) - 1998	LC
SAPOTACEAE	*Madhuca pasquieri*	(Dubard) H.J.Lam	R - 1997; VU (A1cd) - 1998	EN A3bc+4bc
SAPOTACEAE	*Manilkara kanosiensis*	H.J.Lan & B.Meeuse	EN (A1cd+2cd, C2a) - 1998	EN A3b+4b
SAPOTACEAE	*Micropholis grandiflora*	Aubrév.	E - 1997; CR (B1+2c) - 1998	VU A2b+3b+4b
SAPOTACEAE	*Palaquium impressionervium*	Ng	VU (B1+2a) - 1998	CR A3b
SAPOTACEAE	*Palaquium philippense*	(Perr.) C.B.Rob.	V - 1997; VU (A1d) - 1998	VU A3b
SAPOTACEAE	*Payena maingayi*	C.B.Clarke in J.D.Hooker	LR/lc - 1998	CR A3bc+4bc
SAPOTACEAE	*Pouteria izabalensis*	(Standl.) Baehni	R - 1997; LR/nt - 1998	EN A3bc+4bc
SAPOTACEAE	*Tieghemella africana*	Pierre	EN (A1cd) - 1998	LC

SAPOTACEAE	*Tieghemella heckelii*	(A.Chev) Pierre ex Dubard	EN (A1cd) - 1998	EN A3bc+4bc
STEMONURACEAE	*Cantleya corniculata*	(Bacc.) Howard	VU (A1cd) - 1998	CR A3b
STERCULIACEAE	*Nesogordonia papaverifera*	(A. Chev.) Capuron	VU (A1cd) - 1998	NT
STERCULIACEAE	*Pterocymbium beccarii*	K. Schum.		LC
STERCULIACEAE	*Pterygota bequaertii*	De Wild.	VU (A1cd) - 1998	LC
STERCULIACEAE	*Pterygota macrocarpa*	K. Schum.	VU (A1cd) - 1998	VU A2bc+3bc+4bc
STERCULIACEAE	*Scaphium longiflorum*	Ridl.	VU (B1+2c) - 1998	CR A3b+4b
TAPISCIACEAE	*Huertea cubensis*	Griseb.	VU (B1+2c) - 1998; CR (B2ab(ii,iii,iv); D) - 2005	VU A3bc
THYMELAEACEAE	*Aquilaria malaccensis*	Lam.	VU (A1cd) - 1998	EN A3bc
THYMELAEACEAE	*Gonystylus bancanus*	(Miq.) Kurz	VU (A1cd) - 1998	VU D2
THYMELAEACEAE	*Gonystylus forbesii*	Gilg		EN A3bc+4bc
THYMELAEACEAE	*Gonystylus macrophyllus*	(Miq.) Airy Shaw	VU (A1cd) - 1998	VU A3bc+4bc
ULMACEAE	*Phyllostylon rhamnoides*	(J.Poiss.) Taub.		NT
VOCHYSIACEAE	*Erisma nitidum*	DC.		LC
VOCHYSIACEAE	*Qualea coerulea*	Aubl.	VU - 2014	LC
VOCHYSIACEAE	*Vochysia duquei*	Pilg.		VU A3bc+4bc
VOCHYSIACEAE	*Vochysia obidensis*	(Huber ex Ducke) Ducke		NT
ZYGOPHYLLACEAE	*Bulnesia arborea*	(Jacq.) Engl.	R - 1997	VU A3bc+4bc
ZYGOPHYLLACEAE	*Bulnesia carrapo*	Killip & Dugand	EN (B1+2c) - 1998	LC
ZYGOPHYLLACEAE	*Bulnesia sarmientoi*	Lorentz & Griseb.	LR/cd - 1998	CR A3bc
ZYGOPHYLLACEAE	*Guaiacum coulteri*	Gray	LR/cd - 1998; EN (A2cd) - 2005	LC
ZYGOPHYLLACEAE	*Guaiacum officinale*	L.	EN (C2a) - 1998	EN A3bc
ZYGOPHYLLACEAE	*Guaiacum sanctum*	L.	EN (C2a) - 1998; EN (B2ab(ii,iii,iv)) - 2005	EN A3bc