Completing the global inventory of plants – Species discovery and diversity

Zoë Africa Goodwin

Wolfson College

Department of Plant Sciences

Thesis submitted for the degree of

Doctor of Philosophy

Hilary Term, 2017

ABSTRACT

To complete an online world Flora by 2020 rapid progress is required towards understanding the taxonomy and distributions of the world's plants. This ambitious target set by the Global Strategy for Plant Conservation is hampered by two facts; first, many species of seed plant remain poorly known and second, the process of improving taxonomy and discovering species is not well understood. Here I investigate in detail the taxonomy and process of species discovery in a genus of tropical plants, *Aframomum* by examining specimens, taxonomic literature and authors of specimen determinations. I demonstrate that >50% of *Aframomum* specimens did not have the correct name prior to a recent comprehensive revision, that the number of specimens in herbaria doubled between 1970 and 2000, and that these results are also found in other taxa. I deconstruct the process of 'species discovery' by identifying four key events: Initial collection, publication, conservation assessment, and distribution mapping. The time lags between the initial collection and completion of a) an accurate conservation assessment (101 years) and b) a comprehensive distribution map (115 years) demonstrate that many seed plant species published in the last 100 years are not fully understood. This is partly due to the fact that most species protologues (>90%) cite too few specimens at publication to produce an accurate conservation assessment. Furthermore, I explore variation in species' distribution patterns over time, taking account of specimen misidentification. Taken together the thesis identifies the lack of taxonomic capacity to efficiently deal with the tremendous influx of specimens since 1970, the poor current state of taxonomic knowledge of many taxa, and three significant time lags in the process of species discovery. Focused taxonomic effort is required for the successful completion of a world online Flora with conservation assessments to meet the 2020 GSPC target.

ACKNOWLEDGEMENTS

Thank you to my supervisors Robert and David for their knowledge, patience and support.
A big thank you to my family; my parents Alan, Rose and Jane, my siblings Alexis and Josh y mi sobrinito Ivor. The many Brownes of London and the Lake District; Frankie, Tom, Rose, Luke, George, and of course Aggie, who looked after me in dire times. Thank you to all of the EES Plant Science DPhil students, especially Lizzie, Kirsty, Louise, Cicely, Pablo, Tom, Sean, Claudia, Gail, Tana, Katherine and honorary students Beth and Setareh.
A big thank you to the pack of fearsome (she-) wolves of WCBC, from the Captains to the coxswains, from the sassy strokes to the bossy bows. In particular Sabine, Aarholt, Claudia, John, Miriam, Sofia, Laura H, Laura D and Klara.
An eternal thank you to the environmental PhD diaspora especially Sonya, Ramelina, Baba chan and Kaylene, for sure.
Finally my second family, the Bridgewater clan; Sam, Carolyn, Cassia and Aaron.
Thank you to lycra-clad residents of 70 Cricket Road. Thank you to William, Cicely and needy-cat for hosting me unquestioningly during some difficult times. And to Maryam for opening her home and garden in the last few months, even if bees are only for people who have submitted their thesis.
Thank you to the National Environmental Research Council for funding this DPhil, to Wolfson College, the Linnean Society and the Systematics Association for the Systematics Research Fund grant for funding my trip to St Louis, MO. To the University of Oxford's Access to Learning Fund and Wolfson College hardship fund for financial assistance.
This is dedicated to the next generation; Ivor, Daniel, Cassia, Aaron, Frankles, George, Armon, Elena, Zadie, Ivan, Gabriel, Flynn and Rudy; may there be something left for you to discover.

In memory of my mother, Rose Goodwin, and my stepmother, Jane Goodwin, who both passed away shortly after the completion of this thesis.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

1 Introduction

CONTENTS

1.1 INTRODUCTION

Three hundred years after the birth of Linnaeus, the inventory of all plant species is yet to be completed (Paton *et al.*, 2008). The destruction and damage to natural systems as humans cause an unprecedented loss of species (Pimm *et al.*, 2014) – a sixth mass extinction of life on Earth (Barnosky *et al.*, 2011) – and accelerating climate change (IPCC, 2014) add a desperate urgency for the need to describe the remaining undiscovered species before they become extinct (Prance, 1977). Our ability to understand, measure and evaluate the extent of this 'biodiversity crisis' is hampered by our lack of knowledge of how many species there are on earth (Diamond, 1985). This has led to much commentary on the 'state of taxonomy' (Godfray, 2002; Knapp *et al.*, 2002; Tautz *et al.*, 2003; Scoble, 2004; Wheeler, 2004; Agnarsson and Kuntner, 2007; de Carvalho *et al.*, 2007) including, a lack of taxonomists (Boero, 2001), failure of the traditional taxonomic method (Godfray, 2002) and whether revisions (Smith and Penev, 2011) or revolutions (Godfray, 2002; Causey *et al.*, 2004; Wheeler *et al.*, 2004) in the taxonomic method are required to complete the inventory of life.

However, in this thesis I demonstrate that we may know very little about the process of species discovery (Bebber *et al.*, 2010), in particular the extent of understanding of a species after it is published. In this chapter I review the current literature pertinent to the topic of species discovery with an emphasis on seed plants. Firstly I examine the estimates for the numbers of seed plant species, secondly the ongoing crisis in taxonomy. Thirdly I summarise what is known about three important stages in the process of species discovery; specimen collection, species publication and species understanding. Lastly I introduce the thesis and the main focus of study, *Aframomum*.

1.2 How Many Species? – An Urgent Problem

Despite international declarations, global destruction of habitat continues apace and efforts to preserve the biosphere are generally considered to be inadequate (UNEP, 2012). For example, during the period of the original Global Strategy for Plant Conservation (GSPC) from 2002 to 2010, an area the size of Bangladesh, 13 million hectares of land, was deforested (FAO, 2010). Destruction of tropical regions in particular is of concern as these contain the bulk of undiscovered species (Joppa *et al.*, 2011) and are some of the most threatened habitats on the planet (Myers *et al.*, 2000).

If we are to conserve and protect species then we must know which species are threatened (Prance, 1977; Diamond, 1985). The IUCN Red List of Threatened Species (IUCN, 2016) currently lists 22,253 plant species assessed as threatened with extinction, this is generally agreed to be an underestimate; the species assessed to-date are predominantly from depauperate temperate regions (Bramwell, 2002) and represent a small fraction of all plant species (Brummitt and Bachman, 2010). The total percentage of threatened plant species is considered to be around 20% (Brummitt and Bachman, 2010), but may be anywhere between 15% and 47% (Bramwell, 2002; Pitman and Jørgensen, 2002) and may be higher in certain groups (Goettsch *et al.*, 2015; Darrah *et al.*, 2017). However completion of preliminary IUCN Red List conservation assessments for all plant species (GSPC Target 2, Sharrock, 2012) is hampered by two unknowns: the total number of plant species and the number of plant species described so far. The 2010 Target 1 of the GSPC was to complete “a widely accessible working list of all known plant species...”. The 2020 Target 1 is to complete “an online Flora of all known plants”. The latter target is the first and most fundamentally important task if we are to conserve the world’s flora (Paton *et al.*, 2008). Target 1underpins the other 15 GSPC targets through the provision of baseline information (Paton *et al.*, 2008). For example Target 5 requires protection of “at least 75 per cent of the most important areas for plant diversity of each ecological region” (Sharrock, 2012).

Compilation of a preliminary checklist of accepted species names and synonyms for plants is still progressing (Paton *et al.*, 2008); it was approximately 85% complete by 2010 (Sharrock, 2012). The online checklist, The Plant List (2013), contains over 1 million species names and is being constructed from the World Checklist of Selected Plant Families (WCSP, 2011), group-specific projects such as the World Database of Legumes (ILDIS, 2010) and gaps filled by Tropicos.org (2010) and IPNI (2011). The accuracy of this preliminary checklist is as yet unknown; currently >242,000 species names (22.8%) have yet to be assessed and only 378,591 species names (35.6%) have been assessed with a high degree of confidence (The Plant List, 2013).

As the world checklist remains incomplete the total number of described seed plants remains unknown, but has been estimated to be between 223,000 and 422,000 (Govaerts, 2001; Bramwell, 2002; Thorne, 2002; Scotland and Wortley, 2003; Wortley and Scotland, 2004; Christenhusz and Byng, 2016). The most recent estimates for the number of seed plant species is towards the higher end of this range (370,942, Lughadha *et al.*, 2016), with another

70,000 species still to be discovered (Joppa *et al.*, 2010). It has been suggested that the differences in these estimates reflect the large gaps in our knowledge of tropical plants (Bramwell, 2002) and species-rich genera (Govaerts, 2003), the lack of a central database of accepted names (May, 1988) as well as methodological shortfalls in the way the number is calculated (Scotland and Wortley, 2003; Lughadha *et al.*, 2016). The large number of existing names (Govaerts, 2001) combined with a lack of modern revisions for many taxa (Scotland and Wortley, 2003) mean that synonymy rates are probably high but remain unknown for many groups and are therefore a source of error in any calculations (May and Nee, 1995; Solow *et al.*, 1995).

1.3 TAXONOMY IN CRISIS?

The production of a complete world Flora and accurate preliminary conservation assessments requires comprehensive taxonomic revisions of existing taxa to determine specimens, find new species and review nomenclature. This requires trained taxonomists. However there is a general consensus that the progress to produce a world Flora is being hampered by a 'taxonomic impediment' (de Carvalho *et al.*, 2005; de Carvalho *et al.*, 2007; SCBD, 2010); characterised by a lack of trained taxonomists (Boero, 2001; Paton *et al.*, 2008) and lack of resources (de Carvalho *et al.*, 2007).

There is a perception that taxonomists are becoming endangered (Australian Marine Sciences Association, 2005) due to lack of investment in training (de Carvalho *et al.*, 2007; de Carvalho *et al.*, 2008), meagre employment prospects (de Carvalho *et al.*, 2005; Agnarsson and Kuntner, 2007) and the failure of the citation index system to measure appropriately the value of taxonomic publications (Krell, 2002; Crisci, 2006; Werner, 2006; Agnarsson and Kuntner, 2007; Wägele *et al.*, 2011). Additionally there is a view that the wider scientific community and funding bodies view taxonomists simply as 'service providers' who produce identifications for 'end users' (de Carvalho *et al.*, 2005; de Carvalho *et al.*, 2007) and that there is an imbalance in favour of phylogeny reconstruction (Wortley *et al.*, 2002) over descriptive taxonomy (Boero, 2001) due to a lack of appreciation of species descriptions as rigorous and testable scientific hypotheses (Agnarsson and Kuntner, 2007). Others believe that this 'impediment' is a symptom of a systematic failure of traditional taxonomy and that the system needs to be revolutionised by a combination of new technologies or controversially that traditional taxonomy is redundant and can be entirely replaced by molecular data (Godfray, 2002; Tautz *et al.*, 2003; Causey *et al.*, 2004; Wheeler *et al.*, 2004; Will and Rubinoff, 2004; Goldstein and DeSalle, 2010).

There can be no doubt that there is a decline in taxonomists (Bebber *et al.*, 2014; Villaseñor, 2015) and expertise (Funk, 2014; Deng, 2015) in temperate countries.

1.4 THE PROCESS OF SPECIES DISCOVERY

In this section I discuss what is known about the different stages in the process of species discovery. This process has never been investigated in its entirety, and what research there has been has generally assumed that the process starts with the collections of the first specimen and ends with the publication of a species name. With regards to seed plants I shall consider this process to have three stages: 1) collection of the first specimen, 2) publication of a species, and 3) understanding of a species.

The first two stages are self-explanatory. The first stage, species discovery requires specimens to be collected for study (discussed in 1.4.1). In particular the date of the first specimen collection (the first key event in the process of species discovery) is of particular interest. The first specimen may not be the same specimen as the type specimen (the specimen to which that name is attached). Collection of additional specimens is required for the understanding of the species (discussed in 1.4.3), production of accurate IUCN Red List conservation assessments (Rivers *et al.*, 2011) and species distribution models (Feeley and Silman, 2011) require a minimum of 15 and 20 correctly determined specimens respectively. The second stage, the ‘discovery’ of a species, is defined as the moment a new species name is published, this is the second key event in the process of species discovery (discussed in 1.4.2).

The third stage in the process of species discovery is the development in our understanding of a species (discussed in 1.4.3). This need not be an ‘understanding’ of species in an encyclopaedic sense, for example the detailed knowledge of ecology and population genetics. Understanding a species should include an accurate concept of the species’ range, distribution and rarity, to a greater extent than the rudimentary level often found in the publication of new species names.

1.4.1 SPECIMEN COLLECTION

Specimen collection is an important part of the process of species discovery for seed plants. The volume of specimens held in herbaria is growing (Prance, 2001), however tropical regions remain poorly (Prance, 1977; Prance *et al.*, 2000; Feeley, 2015; Stropp *et al.*, 2016) and unevenly (Schulman *et al.*, 2007; Tobler *et al.*, 2007; Feeley and Silman, 2011; ter Steege *et al.*, 2013) collected.

Historical plant collecting patterns have varied immensely due to a very complex interaction between collecting priorities, social changes and external events over time and space. Even in a small and well-collected country such as the UK collecting patterns have changed tremendously over the past two centuries. Since 1800 there has been a general trend of increasing botanical activity in the UK, from a low level between 1836 and 1870, followed by a large increase, peaking between 1890 and 1910. Botanical activity dropped off briefly during the World Wars, and then continued to increase post- 1950 (Rich, 2006).

In the eighteenth and nineteenth centuries botanical collecting in the UK was primarily by private individuals and for personal herbaria. Enabled by the development of the postal system and expansion of the rail network numerous botanical exchange clubs sprang up in the second half of the nineteenth century (Groom *et al*., 2014) allowing individuals to expand their personal collections. Botany was regarded as wholesome interest amongst the well-educated, thus botanical exchange society membership included people from a relatively wide social background, including clergy and women (Groom *et al*., 2014) thus allowing women a rare opportunity to contribute to science (Lindon *et al*., 2015). This co-ordinated activity in natural history resulted in the zenith of botanical specimen collecting in the UK during the end of the nineteenth and the beginning of the twentieth century, peaking in 1878–1888 (Rich, 2006). Collecting rates dropped off during the World Wars, then post-World War II concerns over conservation and the development of widely available high quality field guides led to a transition from specimen collecting to field recording using record cards (Rich, 2006).

Historical plant collecting outside of the UK has been even more complex, reflecting political and social changes across the world (Stropp *et al*., 2016). The eighteenth and nineteenth centuries was the era of the well-documented ‘big-hitters’ (Bebber *et al*., 2012); prolific collectors who were primarily European, part of long-term expeditions or stationed in remote locations as part of colonial bureaucracy (Fry, 2009). Specimen collecting in this period was motivated by a mixture of genuine interest in natural history and bioprospecting thanks to a complex relationship between European governments, private interests such as the East India Company and amateur botanists (Noltie, 2005). During this period many collectors bought specimens or hired locals to collect specimens for them (Noltie, 2015), assigning their own names and collection numbers to the specimens for distribution to herbaria across Europe. This period of exploration for commercial purposes gradually declined as European colonies sought independence. In the first half of the twentieth century prolific individuals, such as William Schipp, Francis Kingdon-Ward and George Forrest, earnt their living collecting specimens and seeds for horticulture and herbaria under a mixture of private sponsorship and employment directly by major herbaria (Lowden, 1970; Lyte, 1983; Lyte, 1983). After World War II motives for collecting continued to shift; encouraged by the post-World War II spirit of international co-operation and optimism with the formation of bodies such as the UN and efforts to advance science and education around the world. Large numbers of country and regional Flora projects have been initiated since 1950, 18 in Africa alone (Beentje and Smith, 2001), requiring large scale systematic collecting expeditions and increased collaboration between foreign and local botanists and organisations (Wayt Thomas, 2016). The shift of collecting motivated by discovering the natural world rather than profit continued towards end of the twentieth century as the need to answer broader scientific questions rather than just for sake of simply documenting diversity. There are suggestions that the rate of specimen collecting has declined since the late 1990s/early 2000s (Stropp *et al*., 2016; ter Steege *et al*., 2016).

Specimen collection is needed for two different stages for the process of species discovery. Firstly, specimens need to be collected if new species are to be discovered, an estimated 30,000 new species are thought to await discovery still (Bebber *et al.*, 2010). Secondly, many species that are already described but poorly known require further collecting, this is particularly important for geographically restricted species if we are to better understand their distribution. Collecting specimens for these two stages of species discovery may require different skills and collecting priorities.

Some authors suggest that specimens should be collected by amateurs (Pearson *et al.*, 2011; Fontaine *et al.*, 2012b) if we are to collect more specimens of known species. This use of 'citizen science' may utilise any part of the general public. However, it normally implies non-professional groups such as school children, interested amateurs, students or retired professionals. This can have the added benefits of increasing biodiversity awareness among the general population (Basset *et al.*, 2000; Janzen, 2004), making progress towards Target 14 of the GSPC (Sharrock, 2012), and inspiring the next generation of taxonomists (Pearson *et al.*, 2011).

Specimen collection by school children and university students requires organisation, co-ordination and long-term funding. Projects involving school children have collected ecological (Blackawton *et al.*, 2010; Lotto, 2011) and biodiversity (Darwin Initiative, 2008; Gaston, 2012) data for published scientific projects, inspiring young students without conflicting with the existing educational curriculum (Braschler, 2009). Local university students however are rarely considered for long-term tropical field work projects as they soon graduate, typically seeking experience in order to move onto more permanent positions elsewhere (Basset *et al.*, 2000). Webb *et al.* (2010) however suggests that the mobilisation of large numbers of biology students combined with cutting-edge bioinformatics can contribute to rapid, high quality regional biodiversity inventories.

Until recently only developed countries have possessed a middle class who have the time and motivation to pursue an interest in natural history which can be utilised to generate large-scale data sets for use by scientists (Fontaine *et al.*, 2012b). This middle class is already used for a variety of projects across the US (Cohn, 2008) and EU (Fontaine *et al.*, 2012b) such as the annual 'Christmas Bird Count' (National Audubon Society, 2017) and 'Big Garden Birdwatch' (RSPB, 2017) projects. There are also numerous databases which collect observations by the general public on both charismatic (eBird, 2017) and less charismatic taxa (Mushroom Observer, 2017).

However a motivated middle class is generally lacking in developing countries (Basset *et al.*, 2004; Pearson *et al.*, 2011). Instead parataxonomists have been proposed as a new means of conducting rapid and large scale inventories in tropical regions, particularly for botanical and entomological research (Basset *et al.*, 2000; Janzen, 2004; Webb *et al.*, 2010). A parataxonomist is normally an adult who lives locally, with little or no formal education, but who through training and on-the-job experience learns to collect high quality biological information and samples (Basset *et al.*, 2000; Basset *et al.*, 2004). Parataxonomy programmes produce large volumes of data and specimens on a modest budget (Basset *et al.*, 2000) and community participation of parataxonomists can help improve local perceptions of protected areas (Janzen, 2004). However, parataxonomy requires assured long-term funding, technical and social support from a professional researcher for each unit of parataxonomists, and continual feedback from the international scientific community who receive and work with the samples (Janzen, 2004).

Criticism levelled at parataxonomists has focused on the sorting of samples by non-taxonomists into morphospecies, which are supposed to equate to species, but are not always done well (Krell, 2004). In particular the use of morphospecies as a final, 'reliable and conservative' alternative to full species identification has been questioned (Krell, 2004). However the most prominent parataxonomic programmes are primarily about rapid data and specimen collection, with the initial sorts by the parataxonomists being rapidly updated by experts around the world (Basset *et al.*, 2000; Webb *et al.*, 2010).

Parataxonomists normally collect large numbers of specimens as part of local inventory work (Basset *et al.*, 2000; Janzen, 2004; Webb *et al.*, 2010). Further criticism of the use of parataxonomists focuses on the large scale and unfocused nature of their collecting (Bebber *et al.*, 2012). This criticism of parataxonomy stems from a need not to acquire a greater volume of specimens but a greater number of novel specimens (Bebber *et al.*, 2012). However it is clear that long-term parataxonomist programs could be vital to complete botanical inventories in neglected tropical regions and thus help improve the understanding of poorly known species.

Collection of new species may be best achieved by focusing resources on collectors with training (Ahrends *et al.*, 2011) and experience (Bebber *et al.*, 2012). Evidence from type specimens shows that a small number of experienced collectors, or 'big hitters', have made a disproportionately large contribution to the discovery of new species. Successful 'big hitters' combine the experience gained over a lengthy career with high levels of motivation, a natural talent for spotting novelties, and a knowledge of taxonomy and family characters (Bebber *et al.*, 2012). The traditional origin of 'big hitters' as formally-trained botanists from developed countries who have had to learn the tropical flora from scratch appears to be dying out (Whitfield, 2012). However if we are primarily aiming to discover the remaining undescribed seed plant species in tropical countries, e.g. simply aiming to collect novel species, then talented parataxonomists or 'elite parataxonomists' (Webb, 2012) may be our best choice to fill this gap (Pearson *et al.*, 2011). New botanists can be trained rapidly in the principles of family-level tropical plant identification (Harris *et al.*, 2015) and high-quality identification literature such as field guides are an invaluable resource to inexperienced botanists (Hawthorne *et al.*, 2014). For the next generation of 'big hitters', it may be sensible to turn to the residents of biodiverse ecosystems, who may well already know several hundred local plant and animal species (Basset *et al.*, 2000) and who can receive on-the-job training and instructions to only collect new species they encounter.

Specimen collecting for new species should be guided by the knowledge that new species are likely to be restricted in distribution (Roberts *et al.*, 2016) and utilising up-to-date and accurate mapping of hotspots (for example Marshall *et al.*, 2016) and existing collections (for example Feeley, 2015; Stropp *et al.*, 2016).

1.4.2 PUBLICATION OF A NEW SPECIES

1.4.2.1 Specimen identification

Good-quality specimen identifications are vital to the taxonomic process; the discovery of novel species is often not in the field, but often many years later in a herbarium (Bebber *et al.*, 2010). Good-quality specimen identifications require experience, knowledge, and access to often obscure, specialist literature and other well-determined specimens (from the same species and closely related taxa). In botany these factors can restrict this stage to specialists who have the experience, time and resources.

Access to resources is being widened by digitisation programmes of type specimens (JSTOR, 2017), entire herbaria (Chagnoux and Michiels, 2011), out-of-copyright books (Google, 2017a) and taxonomic literature (King *et al.*, 2011; BHL, 2017; JSTOR, 2017). Can these digital resources be combined with processing power of the general public in the identification of botanical specimens? In other scientific fields 'crowd sourcing' or 'distributed problem solving networks' - whether computer (SETI, 2017) or human (Zooniverse, 2017) based - is a well-established way of analysing huge quantities of data. Humans are still considered to be the best solution for many data problems that require image processing and creativity, for example reCAPTCHA (Google, 2017b) an anti-spambot service uses sample text from digitised books to verify the humanity of webform users and provides feedback to optical character recognition (OCR) of the scanned texts. These projects utilise automatic quality control and data verification, and can cover a range of topics including the classification of galaxies, transcription of past climate data from naval logs and categorising Orca communications (Zooniverse, 2017). Anecdotal (Sidlauskas and Vari, 2011) examples of a "Facebook style" crowd-sourced method for identification of plants (Webb *et al.*, 2010) have led to the development of online communities such as iSpot (2017) capable of generating scientifically useable data (Carlson and Holsinger, 2015; Bjørnstad *et al.*, 2016). iSpot succeeds in combining learning technology and crowdsourcing, utilising both beginners and experts and by implementing a reputation system to discriminate between competing determinations of the same observation (Silvertown *et al.*, 2015). Other systems to identify scientifically collected specimens include the collaboration of taxonomic experts to remotely determine field specimens (Webb, 2012) and the use of expert feedback on Tropicos (2017) with its simple and efficient data feedback forms. Automatic identification software for live plant observations is being developed for temperate species (Leafsnap, 2011), however this would be a challenge to translate to the floras of less well-known tropical regions.

The 'power law' distribution of plant abundance, with a few very common species and many very rare species (ter Steege *et al.*, 2013), means that the future of specimen identification may involve crowd-sourcing of identifications of digitised specimens into groups of similar specimens via a Zooniverse type project with expert verification of difficult specimens.

1.4.2.2 Publication

Recent years have seen rapid changes in the way taxonomic output is published with the creation of online taxonomic journals designed to boost the impact factor of taxonomic publications (Phytotaxa, Zootaxa etc) and thus taxonomic careers (Boero, 2001) and the recognition of online publication by the International Code for Botanical Nomenclature (Knapp *et al.*, 2011).

The current citation impact factor system does not recognise the true impact of taxonomic work; taxonomic literature is cited sporadically but has an impact that persists for decades and centuries (Crisci, 2006). Additionally given that a species description is a testable scientific hypothesis (Wheeler, 2004; Agnarsson and Kuntner, 2007) there have been suggestions that the current system should be modified so that original species publications should be cited whenever a species concept is being tested whether this be a new revision or a molecular or ecological examination of the species and its close relatives (Agnarsson and Kuntner, 2007; Wägele *et al.*, 2011). This is already in practice in online journals such as Zootaxa (2015) and Phytotaxa (2015).

Recognition of the bottleneck that traditional publication causes in the species discovery process (Blagoderov *et al.*, 2010) resulted in growing support for (Cressey, 2010) and the acceptance (Knapp *et al.*, 2011) of online publication of new species and combinations. To facilitate this, Scratchpads were developed, first as part of the European-funded initiatives EDIT and now CATE, to move more of the publication process online (Smith and Penev, 2011). The Scratchpad hosts all of the taxonomic information and relevant literature to a group of organisms and acts as a communal workspace, facilitating collaboration and communication between experts (Clark *et al.*, 2009). This 'unitary taxonomy' (Godfray, 2002) is controversial as it entails creating an up-to-date summary of the current literature and taxonomy, the 'first web revision' and taking this as the starting point for all future taxonomic work, effectively wiping the slate clean of the past 250 years. Additionally, the suggestion of a 'consensus taxonomy has led to concerns that it could lead to "authoritarianism and a stifling of innovative taxonomic viewpoints" (Thiele and Yeates, 2002). There are issues still to resolve for this system with citation indexes, tracking contributions to Scratchpads, and getting non-published outputs recognised by funding bodies and institutions (Clark *et al*., 2009).

1.4.2.3 Variables and time lags in the publication of species names

The most studied aspects of the process of species discovery include the authors of species names, the date of publication and the time lag between the collection of the first specimen and the publication of the species name.

There are biases in the authors of species. For example, the authors of plants species names are mainly male (Lindon *et al.*, 2015) and show a 'power law' or 'hollow curve' (Willis, 1922; Dial and Marzluff, 1989) distribution; most authors have published one species name, and a small number of authors have published the majority of species' names (Bebber *et al.*, 2014; Lindon *et al.*, 2015).

There are also factors influencing the date of species publication. The majority of plant species names were published in nineteenth and early twentieth century as access to species-rich tropical regions opened up (Lindon *et al.*, 2015). Species discovery is biased by where a species lives and its overlap with that of taxonomic experts (Isaac *et al.*, 2004), thus species description in biodiverse countries is still hampered by a lack of taxonomists and well-maintained collection infrastructure (Paknia *et al.*, 2015). Taxonomic 'change' is biased towards large-bodied and wide-ranging groups (Isaac *et al.*, 2004). For example large-bodied species are published before smaller bodied species (Gaston, 1991; Blackburn and Gaston, 1994; Gaston and Blackburn, 1994; Blackburn and Gaston, 1995; Gaston *et al.*, 1995a; Reed and Boback, 2002) and species published earlier have more synonyms than species published more recently (Gaston *et al.*, 1995b). Species published more recently are more likely to be geographically restricted (Gaston *et al.*, 1995a; Allsopp, 1997; Roberts *et al.*, 2016) and thus more likely to be at risk of extinction (Roberts *et al.*, 2016) or already extinct (Pimm *et al.*, 2014), indicating that species yet to be described are more likely to be at risk of extinction (Roberts *et al.*, 2016).

The time lag between the collection of the first specimen and the publication of the a new species name, the ‘discovery lag’, is 32 – 39 years for seed plants (Bebber *et al.*, 2010; Fontaine *et al.*, 2012a), similar to that for other taxa (Fontaine *et al.*, 2012a).

1.4.3 UNDERSTANDING A SPECIES

1.4.3.1 Why we need to understand plant species

The 2020 GSPC Target 1 is ambitious, to complete “an online Flora of all known plants” (Sharrock, 2012). The world Flora online will be a hub linking existing botanical institutions and projects (Sharrock *et al.*, 2014), special projects such as new regional Floras (Morim and Lughadha, 2015) and the digitisation of existing Floras (Wayt Thomas and Tulig, 2015) will fill the gaps.

The current guidelines for species descriptions in an online world Flora include a preliminary IUCN Red List conservation assessment (Wayt Thomas and Tulig, 2015), thereby also completing GSPC’s Target 2 “an assessment of the conservation status of all known plant species...” (Sharrock, 2012). Whereas a global checklist of plant names required an assessment of which species names should be accepted, the inclusion of a conservation assessment requires that the online world Flora will require a greater ‘understanding’ of each species. an understanding of basic population structure and species’ range, distribution and rarity. This level of information is not found in most species protologues. Using herbarium specimens we can gain a reliable understanding of a species’ geographical distribution and range (Rivers *et al*., 2010). There could be considered to be two levels of understanding in a species’ geography: 1) a preliminary understanding of the extent of the geographical range, sufficient to produce an accurate IUCN Red List conservation assessment and 2) sufficient understanding to complete a comprehensive species distribution map.

The first level of understanding is relatively straight forward to achieve and is completed before the second. It is possible to produce a rigorous IUCN Red List conservation assessment using a species’ geographical distribution based upon specimens (Willis *et al.*, 2003). Ideally such an assessment should be based on a species’ current spatial distribution, rather than historic records. One solution is to work backwards in time, using the most recent specimens for conservation assessments (Rivers *et al.*, 2010). Recently there have been developments in automated (Quintero *et al.*, 2014) and large scale (Syfert *et al.*, 2014; Darrah *et al.*, 2017) conservation assessments based upon species distribution models. However, the quality of IUCN Red List conservation assessments is strongly influenced by the quality of taxonomy (Kirschner and Kaplan, 2002) and expert aggregated data sets (Beck *et al.*, 2013; Hjarding *et al.*, 2014).

A minimum of 15 specimens is required for an accurate preliminary IUCN Red List conservation assessment (Rivers *et al.*, 2011). However, species with as few as three specimens (i.e. the minimum number required to calculate the extent of occupancy) should be listed in accordance with the results of a preliminary assessment under Criterion B of the IUCN Red List (and not as data deficient) (Forest *et al.*, 2015; Roberts *et al.*, 2016).

There are no established guidelines on when a comprehensive species distribution map is achieved, clearly this could be viewed as a receding target. There might be a minimum number of specimens required to ensure that the distribution map is accurate. For example 20 specimens is considered to be a minimum for accurate species distribution modelling (Feeley and Silman, 2011). Pragmatically such a map could be considered complete when the discovery of degree squares cells within the species’ distribution slows, even as additional specimens continue to be correctly determined. Considering biases in collecting densities (Schulman *et al.*, 2007; Stropp *et al.*, 2016) might also indicate how representative a geographical distribution map is.

1.4.3.2 Existing taxonomic literature

There are many types of taxonomic literature, described in more detail by Frodin (2001) than can be managed here. Put simply taxonomic literature forms a gradient from encyclopaedic well-illustrated accounts through to checklists of species names and text-light and picture-heavy field guides. Taxonomic literature has to find a balance between comprehensiveness and completing the task in a reasonable timeframe.

The two main forms of traditional multi-species taxonomic literature tend to be *Monographs* which encompass a single group, and *Floras* which describe the flora in a geographic region. Traditionally monographs may be more encyclopaedic in scope such as *Hypericum* (Carine and Christenhusz, 2010), and Floras tend to be less comprehensive with a focus on user-friendly diagnostic characters and identification keys such as the *Flora of West Tropical Africa* (Hutchinson and Dalziel, 1968). However this distinction can be blurred in projects such as the *Flora Neotropica* which is defined by geography but is comprehensive in scope (Frodin, 2001).

Monographs and Floras are both expensive and time-consuming (Clark *et al.*, 2009); large Floras are difficult to finish. For example, only seven of 19 African Flora projects had been finished by 2001 (Beentje and Smith, 2001) and few large genera have been monographed since the nineteenth century (Frodin, 2004). Many monographs and Floras are old and out-of-date (Clark *et al.*, 2009) even becoming out-of-date before the project is finished (Beentje and Smith, 2001).

The importance of taxonomic literature such as monographs and Floras cannot be understated, "*Consider the difference they make: chaos before, bedrock after.*" (Beentje and Smith, 2001). Floras and monographs discover many new species; 26% of species names in *Flora Neotropica* were new to science (Wayt Thomas and Tulig, 2015) and 169 names in the recent *Hypericum* monograph were new taxa or new combinations (Tropicos, 2017). They are also important for the huge numbers of other 'taxonomic acts' such as synonymisation (Wortley and Scotland, 2004) and large numbers of correctly determined specimens.

1.5 THIS THESIS

1.5.1 INTRODUCING *AFRAMOMUM*

Aframomum is a genus of tropical plants in the ginger family, Zingiberaceae, found across tropical Africa, the Indian Ocean Islands and Madagascar. The genus contains 61 species (Appendix 1.1), however prior to a recent comprehensive taxonomic revision (Harris and Wortley, in press) the genus was thought to contain only 55 species (WCSP, 2011). The first species described was *Amomum granum-paradisi* by Linneaus in 1753 in the genus *Amomum* Roxb.. In 1904 the African species were split from the Asian species of *Amomum* to form the new genus *Aframomum* K.Schum. (Schumann, 1904). DNA evidence indicates that *Aframomum* is monophyletic (Harris *et al.*, 2000; Kress *et al.*, 2002; Pedersen, 2004; Särkinen *et al.*, 2007; Auvray *et al.*, 2010) and sister to the amphi-Atlantic genus *Renealmia* (Särkinen *et al.*, 2007). Several species in the genus are cultivated (Lock *et al.*, 1977) and have been traded internationally (discussed in detail by Harris and Wortley, in press), of which two species have been introduced to the Americas (Harris and Wortley, in press).

1.5.2 THIS THESIS

In this thesis in order to elucidate aspects of the discovery process in seed plants I investigate in detail the temporal and spatial taxonomic history of *Aframomum* in the context of species discovery for tropical seed plants:

Chapter 2 examines and documents the process of species discovery in a genus of tropical plants, *Aframomum*, through specimens, taxonomic literature and authors of specimen determinations. Chapter 3 examines the generality of the key results for *Aframomum* from Chapter 2 in other seed plants. Chapter 4 documents the number of specimens cited for a set of seed plant species described in *Kew Bulletin* and the time lags inherent in the process of species discovery in *Aframomum*. Finally, Chapter 5 examines the effects of the time lags, documented in Chapter 4, on the understanding of species of *Aframomum* over time. The thesis will finish with a summary of the findings and conclusions (Chapter 6).

Lastly, some clarification on dates referenced in this thesis: determinations made by Harris and Wortley shall be dated as 2014; this is the year in which the monograph (and consequently the determinations on specimens cited by the monograph) was finalised and submitted for publication. As of submission of this thesis (April 2017) the monograph by Harris and Wortley is still awaiting publication, thus the monograph will be referenced throughout as "(Harris and Wortley, in press)". However it is expected that the monograph will be published later this year, thus new species published in the monograph shall be given a publication year of "2017".

1.6 Bibliography

Agnarsson, I. and M. Kuntner (2007). "Taxonomy in a changing world: seeking solutions for a science in crisis." *Systematic Biology* 56: 531–539.

Ahrends, A., *et al*. (2011). "Conservation and the botanist effect." *Biological Conservation* 144 131–140.

Allsopp, P. G. (1997). "Probability of describing an Australian scarab beetle: influence of body size and distribution." *Journal of Biogeography* 24: 717–724.

Australian Marine Sciences Association (2005). "Marine taxonomy in the new millennium." *AMSA Bulletin* 169: 22–27.

Auvray, G., *et al*. (2010). Phylogeny and dating of *Aframomum* (Zingiberaceae). In *Diversity, phylogeny, and evolution in the monocotyledons*. O. Seberg, G. Petersen, A. S. Barfod and J. I. Davis. Aarhus, Denmark, Aarhus University Press: 287–305.

Barnosky, A. D., *et al*. (2011). "Has the Earth's sixth mass extinction already arrived?" *Nature* 471: 51–57.

Basset, Y., *et al*. (2000). "Quantifying biodiversity: experience with parataxonomists and digital photography in Papua New Guinea and Guyana." *BioScience* 50: 899–908.

Basset, Y., *et al*. (2004). "Conservation and biological monitoring of tropical forests: the role of parataxonomists." *Journal of Applied Ecology* 41: 163–174.

Bebber, D. P., *et al*. (2012). "Big hitting collectors make massive and disproportionate contribution to the discovery of plant species." *Proceedings of the Royal Society B: Biological Sciences* 279: 2269–2274.

Bebber, D. P., *et al*. (2010). "Herbaria are a major frontier for species discovery." *PNAS* 107: 22169–22171.

Bebber, D. P., *et al*. (2014). "Author inflation masks global capacity for species discovery in flowering plants." *New Phytologist* 201: 700–706.

Beck, J., *et al*. (2013). "Online solutions and the 'Wallacean shortfall': what does GBIF contribute to our knowledge of species' ranges?" *Diversity and Distributions* 19: 1043–1050.

Beentje, H. and S. Smith (2001). "FTEA and after." *Systematics and Geography of Plants* 71: 265–290.

BHL. (2017). "Biodiversity Heritage Library." Retrieved April 2017, from http://www.biodiversitylibrary.org/.

Bjørnstad, A., *et al*. (2016). "Review of *Afraustraloderes rassei* Bouyer, 2012: description of its female and a new species of *Pixodarus* Fairmaire, 1887 (Coleoptera, Cerambycidae, Prioninae)." *ZooKeys* 558: 77–93.

Blackawton, P. S., *et al*. (2010). "Blackawton bees - Colour and spatial relationships in bees." *Biology Letters* 7: 168–172

Blackburn, T. M. and K. J. Gaston (1994). "Animal body size distributions change as more species are described." *Proceedings of the Royal Society B: Biological Sciences* 257: 293–297.

Blackburn, T. M. and K. J. Gaston (1995). "What determines the probability of discovering species?: A study of South American oscine passerine birds." *Journal of Biogeography* 22: 7–14.

Blagoderov, V., *et al*. (2010). "Streamlining taxonomic publication: a working example with Scratchpads and ZooKeys." *ZooKeys* 50: 17–28.

Boero, F. (2001). "Light after dark: the partnership for enhancing expertise in taxonomy." *Trends in Ecology and Evolution* 16: 266.

Bramwell, D. (2002). "How many plant species are there?" *Plant Talk* 28: 32–34.

Braschler, B. (2009). "Successfully implementing a citizen-scientist approach to insect monitoring in a resource-poor country " *BioScience* 59: 103–104.
Brummitt, N. A. and S. P. Bachman (2010). Plants under pressure – a global assessment. The first report of the IUCN Sampled Red List Index for Plants. UK, Royal Botanic Gardens, Kew: 15.
Carine, M. A. and M. J. M. Christenhusz (2010). "About this volume: the monograph of *Hypericum* by Norman Robson." *Phytotaxa* 4: 1–4.
Carlson, J. E. and K. E. Holsinger (2015). "Extrapolating from local ecological processes to genus-wide patterns in colour polymorphism in South African *Protea*." *Proceedings of the Royal Society B: Biological Sciences* 282: 20150583.
Causey, D., *et al*. (2004). "Museum collections and taxonomy." *Science* 305: 1106–1107.
Chagnoux, S. and H. Michiels (2011). Switching to the fast track: rapid digitization of the world's largest herbarium. TDWG 2011- New Orleans.
Christenhusz, M. J. M. and J. W. Byng (2016). "The number of known plants species in the world and its annual increase." *Phytotaxa* 261: 201–217.
Clark, B. R., *et al*. (2009). "Taxonomy as an eScience." *Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences* 367: 953–966.
Cohn, J. P. (2008). "Citizen science: can volunteers do real research?" *BioScience* 58: 192–197.
Cressey, D. (2010). "Linnaeus meets the internet." *Nature online*.
Crisci, J. V. (2006). "One-dimensional systematist: perils in a time of steady progress." *Systematic Botany* 31: 217–221.
Darrah, S. E., *et al*. (2017). "Using coarse-scale species distribution data to predict extinction risk in plants." *Diversity and Distributions* 23: 435–447.
Darwin Initiative. (2008). "Sheffield scientists help shape South African curriculum." Retrieved May 2012, from http://darwin.defra.gov.uk/news/2008-12/iimbovane/.
de Carvalho, M. R., *et al*. (2008). "Systematics must embrace comparative biology and evolution, not speed and automation." *Evolutionary Biology* 35: 150–157.
de Carvalho, M. R., *et al*. (2007). "Taxonomic impediment or impediment to taxonomy? a commentary on systematics and the cybertaxonomic-automation paradigm." *Evolutionary Biology* 34: 140–143.
de Carvalho, M. R., *et al*. (2005). "Revisiting the taxonomic impediment." *Science* 307: 353.
Deng, B. (2015). "Plant collections left in the cold by cuts. North America’s herbaria wilt under pressure for space and cash." *Nature* 523: 16.
Dial, K. P. and J. M. Marzluff (1989). "Nonrandom diversification with in taxonomic assemblages." *Systematic Biology* 38: 26–37.
Diamond, J. M. (1985). "Taxonomy: How many unknown species are yet to be discovered?" *Nature* 315: 538–539.
eBird. (2017). "eBird." Retrieved April 2017, from http://ebird.org/.
FAO (2010). Global forest resources assessment 2010. Forestry Paper. Rome, Food and Agriculture Organization of the United Nations.
Feeley, K. J. (2015). "Are we filling the data void? an assessment of the amount and extent of plant collection records and census data available for tropical South America." *PLoS ONE* 10: e0125629.
Feeley, K. J. and M. R. Silman (2011). "The data void in modeling current and future distributions of tropical species." *Global Change Biology* 17: 626–630.
Fontaine, B., *et al*. (2012a). "21 years of shelf life between discovery and description of new species." *Current Biology* 22: R943–R944.
Fontaine, B., *et al*. (2012b). "New species in the Old World: Europe as a frontier in biodiversity exploration, a test bed for 21st century taxonomy." *PLoS ONE* 7: e36881.

Forest, F., *et al*. (2015). "Phylogeny, extinction and conservation: embracing uncertainties in a time of urgency." *Philosophical Transactions of the Royal Society B: Biological Sciences* 370: 20140002.
Frodin, D. G. (2001). Guide to standard Floras of the world. Cambridge, UK, Cambridge University Press. 1100.
Frodin, D. G. (2004). "History and concepts of big plant genera." *Taxon* 53: 753–776.
Funk, V. A. (2014). "The erosion of collections-based science: alarming trend or coincidence?" *The Plant Press* 17: 1, 13–14.
Gaston, K. J. (1991). "Body size and probability of description: the beetle fauna of Britain." *Ecological Entomology* 16: 505–508.
Gaston, K. J. (2012). "Iimbovane outreach project: exploring South African biodiversity and change."   Retrieved May 2012, from http://www0.sun.ac.za/Iimbovane/.
Gaston, K. J. and T. M. Blackburn (1994). "Are newly described bird species small-bodied?" *Biodiversity Letters* 2: 16–20.
Gaston, K. J., *et al*. (1995a). "Which species are described first?: The case of North American butterflies." *Biodiversity and Conservation* 4: 119–127.
Gaston, K. J., *et al*. (1995b). "Patterns in species description: a case study using the Geometridae (Lepidoptera)." *Biological Journal of the Linnean Society* 55: 225–237.
Godfray, H. C. J. (2002). "Challenges for taxonomy – The discipline will have to reinvent itself if it is to survive and flourish." *Nature* 417: 17–19.
Goettsch, B., *et al*. (2015). "High proportion of cactus species threatened with extinction." *Nature Plants* 1: 15142.
Goldstein, P. Z. and R. DeSalle (2010). "Integrating DNA barcode data and taxonomic practice: determination, discovery, and description." *Bioessays* 33: 135–147.
Google. (2017a). "Google Books."   Retrieved April 2017, 2017, from http://books.google.com/.
Google. (2017b). "reCAPTCHA."   Retrieved April 2017, 2017, from https://developers.google.com/recaptcha/.
Govaerts, R. (2001). "How many species of seed plants are there?" *Taxon* 50: 1085–1090.
Govaerts, R. (2003). "How many species of seed plants are there?: A response " *Taxon* 52: 583–584.
Groom, Q. *et al*. (2014). "Herbarium specimens reveal the exchange network of British and Irish botanists, 1856–1932." *New Journal of Botany* 4: 95–103.
Harris, D. J., *et al*. (2015). Training in tropical plant identification. In *Descriptive taxonomy: the foundation of biodiversity research*. M. F. Watson, C. H. C. Lyal and C. A. Pendry. Cambridge Cambridge University Press. 84: 160–170.
Harris, D. J., *et al*. (2000). "Rapid radiation in *Aframomum* (Zingiberaceae): evidence from nuclear ribosomal DNA internal transcribed spacer (ITS) sequences." *Edinburgh Journal of Botany* 57: 377–395.
Harris, D. J. and A. H. Wortley (in press). "Monograph of *Aframomum* (Zingiberaceae)." *Systematic Botany Monographs*.
Hawthorne, W. D., *et al*. (2014). "Empirical trials of plant field guides." *Conservation Biology* 28: 654–662.
Heywood, V. (2001). "Floristics and monography-an uncertain future?" *Taxon* 50: 361–380.
Hjarding, A., *et al*. (2014). "Red List assessments of East African chameleons: a case study of why we need experts." *Oryx* 48: 1–7.
Hutchinson, J. and J. M. Dalziel (1968). *Flora of West Tropical Africa* (2nd Ed.). London, Crown Agents for Oversea Governments and Administrations.
ILDIS. (2010). "World Database of Legumes."   Retrieved 25 March 2011, 2011, from http://www.ildis.org/.

IPCC (2014). Climate change 2014: synthesis report. Contribution of working groups I, II and III to the fifth assessment report of the Intergovernmental Panel on Climate Change. Core Writing Team, R. K. Pachauri and L. A. Meyer. Geneva, Switzerland, IPCC: 151.

IPNI. (2011). "The International Plant Names Index." Retrieved 1 October 2011, 2011, from http://www.ipni.org

Isaac, N. J. B., *et al*. (2004). "Taxonomic inflation: its influence on macroecology and conservation." Trends in Ecology and Evolution 19: 464–469.

iSpot. (2017). "iSpot - share nature." Retrieved April 2017, 2017, from http://www.ispotnature.org/.

IUCN. (2016). "IUCN Red List of Threatened Species. Version 2016.3." Retrieved April 2017, from http://www.iucnredlist.org.

Janzen, D. H. (2004). "Setting up tropical biodiversity for conservation through non-damaging use: participation by parataxonomists." *Journal of Applied Ecology* 41: 181–187.

Joppa, L. N., *et al*. (2011). "Biodiversity hotspots house most undiscovered plant species." *PNAS* 108: 13171–13176.

Joppa, L. N., *et al*. (2010). "How many species of flowering plants are there?" *Proceedings of the Royal Society B: Biological Sciences* 278: 554–559.

JSTOR. (2017). "JSTOR Global Plants." Retrieved April 2017, 2017, from http://plants.jstor.org/.

King, D., *et al*. (2011). "Towards the bibliography of life. In *e-Infrastructures for data publishing in biodiversity science*. Smith, V.S. & Penev, L. (Eds)." *ZooKeys* 150: 151–166.

Kirschner, J. and Ž. Kaplan (2002). "Taxonomic monographs in relation to global Red Lists." *Taxon* 51: 155–158.

Knapp, S. D., *et al*. (2002). "Taxonomy needs evolution, not revolution." *Nature* 419: 559.

Knapp, S. D., *et al*. (2011). "Changes to publication requirements made at the XVIII International Botanical Congress in Melbourne—what does e-publication mean for you?" *Phytotaxa* 28.

Krell, F.-T. (2002). "Why impact factors don’t work for taxonomy." *Nature* 415: 957.

Krell, F.-T. (2004). "Parataxonomy vs. taxonomy in biodiversity studies – pitfalls and applicability of ‘morphospecies’ sorting." *Biodiversity and Conservation* 13: 795–812.

Kress, W. J., *et al*. (2002). "The phylogeny and a new classification of the gingers (Zingiberaceae): evidence from molecular data." *American Journal of Botany* 89: 1682–1696

Leafsnap. (2011). "Leafsnap." Retrieved April 2017, 2017, from http://leafsnap.com/.

Lindon, H. L., *et al*. (2015). "Fewer than three percent of land plant species named by women: author gender over 260 years." *Taxon* 2: 209–215.

Linnaeus, C. v. (1753). Species plantarum. Stockholm, Laurentius Salvius. xi, 1200 + xxxi.

Lock, J. M., *et al*. (1977). "The cultivation of melegueta pepper." *Economic Botany* 31: 321–330.

Lotto, R. B. (2011). "Blackawton bees." Retrieved May 2012, 2012, from http://www.lottolab.org/articles/blackawtonbees.asp.

Lowden, R. M. (1970). "William A. Schipp’s botanical explorations in the Stann Creek and Toledo Districts, British Honduras (1929-1935)." *Taxon* 19: 831–861.

Lughadha, E. M. N., *et al*. (2016). "Counting counts: revised estimates of numbers of accepted species of flowering plants, seed plants, vascular plants and land plants with a review of other recent estimates." *Phytotaxa* 272: 082–088.

Lyte, C. (1983). *The plant hunters*. London, Orbis Publishing. 208.

Lyte, C. (1989). *Frank Kingdon-Ward, last of the great plant hunters*. London, John Murray Publishers Ltd. 256.

Marshall, C. A. M., *et al*. (2016). "Bioquality hotspots in the tropical African flora." *Current Biology* 26: 3214–3219.

May, R. M. (1988). "How many species are there on Earth?" *Science* 241: 1441–1449.

May, R. M. and S. Nee (1995). "The species alias problem." *Nature* 378: 447–448.

Morim, M. P. and E. M. N. Lughadha (2015). "Flora of Brazil Online: can Brazil's botanists achieve their 2020 vision?" *Rodriguésia* 66: 1115–1135.

Mushroom Observer. (2017). "mushroomobserver.org."   Retrieved 02 April 2017, 2017, from http://mushroomobserver.org/.

Myers, N., *et al*. (2000). "Biodiversity hotspots for conservation priorities." *Nature* 403: 853–858.

National Audubon Society. (2017). "Christmas bird count."   Retrieved 02 April 2017, 2017, from http://www.audubon.org/conservation/science/christmas-bird-count.

Noltie, H. J. (2005). *The botany of Robert Wight*. In *Regnum Vegetabile* , v. 145. Ruggell: Gantner Verlag. 579.

Noltie, H.J. (2015). *Robert Wight and his European notanical collaborators*. In: Damodaran V., Winterbottom A., Lester A. (eds) *The East India Company and the natural world*. Palgrave Studies in World Environmental History. London, Palgrave Macmillan. p58–79.

Paknia, O., *et al*. (2015). "Lack of well-maintained natural history collections and taxonomists in megadiverse developing countries hampers global biodiversity exploration." *Organisms Diversity & Evolution* 15: 1–11.

Paton, A. J., *et al*. (2008). "Towards Target 1 of the Global Strategy for Plant Conservation: a working list of all known plant species - progress and prospects." *Taxon* 57: 602–611.

Pearson, D. L., *et al*. (2011). "Recovery plan for the endangered taxonomy profession." *BioScience* 61: 58–63.

Pedersen, L. B. (2004). "Phylogenetic analysis of the subfamily Alpinioideae (Zingiberaceae), particularly *Etlingera* Giseke, based on nuclear and plastid DNA." *Plant Systematics and Evolution* 245: 239–258.

Phytotaxa. (2015). "Phytotaxa - information for authors."   Retrieved April 2017, 2017, from http://www.mapress.com/phytotaxa/author.htm.

Pimm, S. L., *et al*. (2014). "The biodiversity of species and their rates of extinction, distribution, and protection." *Science* 344: 1246752.

Pitman, N. C. A. and P. M. Jørgensen (2002). "Estimating the size of the world's threatened flora." *Science* 298: 989.

Prance, G. T. (1977). "Floristic inventory of the tropics: where do we stand?" *Annals of the Missouri Botanical Garden* 64: 659–684.

Prance, G. T. (2001). "Discovering the plant world." *Taxon* 50: 345–358.

Prance, G. T., *et al*. (2000). "The tropical flora remains undercollected." *Annals of the Missouri Botanical Garden* 87: 67–71.

Quintero, E., *et al*. (2014). "A statistical assessment of population trends for data deficient Mexican amphibians." *PeerJ* 2: e703

Reed, R. N. and S. M. Boback (2002). "Does body size predict dates of species description among North American and Australian reptiles and amphibians?" *Global Ecology & Biogeography* 11: 41–47.

Rich, T. C. G. (2006). "Floristic changes in vascular plants in the British Isles: geographical and temporal variation in botanical activity 1836–1988." *Botanical Journal of the Linnean Society* 152: 303–330.

Rivers, M. C., *et al*. (2010). "Subpopulations, locations and fragmentation: applying IUCN Red List criteria to herbarium specimen data." *Biodiversity and Conservation* 19: 2071–2085.
Rivers, M. C., *et al*. (2011). "How many herbarium specimens are needed to detect threatened species?" *Biological Conservation* 144: 2541–2547.
Roberts, D. L., *et al*. (2016). "Threatened or data deficient: assessing the conservation status of poorly known species." *Biodiversity Research* 22: 1–8.
RSPB. (2017). "Big garden birdwatch." Retrieved 02 April 2017, 2017, from https://ww2.rspb.org.uk/get-involved/activities/birdwatch.
Särkinen, T. E., *et al*. (2007). "Recent oceanic long-distance dispersal and divergence in the amphi-Atlantic rain forest genus *Renealmia* L.f. (Zingiberaceae)." *Molecular Phylogenetics and Evolution* 44: 968–980.
SCBD. (2010). "What is the problem? The taxonomic impediment." Retrieved May 2012, 2012, from http://www.cbd.int/gti/problem.shtml.
Schulman, L., *et al*. (2007). "Analysing botanical collecting effort in Amazonia and correcting for it in species range estimation." *Journal of Biogeography* 34: 1388–1399.
Schumann, K. M. (1904). Zingiberaceae. In *Das Pflanzenreich: Regni vegetabilis conspectus*. A. Engler. Leipzig, Wilhelm Engelmann 46: 201–221.
Scoble, M. J. (2004). "Unitary or unified taxonomy?" *Philosophical Transactions of the Royal Society B: Biological Sciences* 359: 699–710.
Scotland, R. W. and A. H. Wortley (2003). "How many species of seed plants are there?" *Taxon* 52: 101–104.
SETI. (2017). "SETI@home." Retrieved 05 April 2017, 2017, from http://setiathome.berkeley.edu/.
Sharrock, S. (2012). Global Strategy for Plant Conservation: a guide to the GSPC - All the targets, objectives and facts. Richmond, Botanic Gardens Conservation International: 36.
Sharrock, S., *et al*. (2014). Plant conservation report 2014: a review of progress in implementation of the Global Strategy for Plant Conservation 2011-2020. Montreal, Canada. 56.
Sidlauskas, B. and R. P. Vari. (2011). "Crowdsourcing via social media allows rapid remote taxonomic identification " Retrieved June 2012, 2012, from http://nmnh.typepad.com/100years/2011/03/crowdsourcing-via-social-media-allows-rapid-remote-taxonomic-identification-.html.
Silvertown, J., *et al*. (2015). "Crowdsourcing the identification of organisms: a case-study of iSpot." *ZooKeys*: 125–146.
Smith, V. S. and L. Penev (2011). "Collaborative electronic infrastructures to accelerate taxonomic research. In *e-Infrastructures for data publishing in biodiversity science*. Smith, V.S. & Penev, L. (Eds)." *ZooKeys* 150: 1–3.
Solow, A. R., *et al*. (1995). "Estimating the rate of synonymy." *Systematic Biology* 44: 93–96.
Stropp, J., *et al*. (2016). "Mapping ignorance: 300 years of collecting flowering plants in Africa." *Global Ecology and Biogeography* 25: 1085–1096.
Syfert, M. M., *et al*. (2014). "Using species distribution models to inform IUCN Red List assessments." *Biological Conservation* 177: 174–184.
Tautz, D., *et al*. (2003). "A plea for DNA taxonomy." *Trends in Ecology and Evolution* 18: 70–74.
ter Steege, H., *et al*. (2013). "Hyperdominance in the Amazonian tree flora." *Science* 342: 1243092.
ter Steege, H., *et al*. (2016). "The discovery of the Amazonian tree flora with an updated checklist of all known tree taxa." *Scientific Reports* 6: 29549.

The Plant List. (2013). "Version 1.1." Retrieved 03 April 2017, 2017, from http://www.theplantlist.org/.
Thiele, K. and D. Yeates (2002). "Tension arises from duality at the heart of taxonomy." *Nature* 419: 337.
Thorne, R. F. (2002). "How many species of seed plants are there?" *Taxon* 51 511–512.
Tobler, M., *et al*. (2007). "Implications of collection patterns of botanical specimens on their usefulness for conservation planning: an example of two neotropical plant families (Moraceae and Myristicaceae) in Peru." *Biodiversity and Conservation* 16: 659–677.
Tropicos. (2017). Retrieved April 2017, 2017, from http://www.tropicos.org/.
Tropicos.org. (2010). Retrieved March 2011, 2010, from http://www.tropicos.org/.
UNEP (2012). Global Environmental Outlook 5: environment for the future we want. Nairobi, Kenya, United Nations Environment Programme: 528.
Villaseñor, J. L. (2015). "¿La crisis de la biodiversidad es la crisis de la taxonomía?" *Botanical Sciences* 93: 1–12.
Wägele, H., *et al*. (2011). "The taxonomist - an endangered race. A practical proposal for its survival." *Frontiers in Zoology* 8: 25.
Wayt Thomas, W. (1999). "Conservation and monographic research on the flora of Tropical America. " *Biodiversity and Conservation* 8: 1007–1015.
Wayt Thomas, W. (2016). "125 years of floristic research and collecting at The New York Botanical Garden. " *Brittonia* 68: 222–229.
Wayt Thomas, W. and M. Tulig (2015). "Hard copy to digital: Flora Neotropica and the World Flora Online." *Rodriguésia* 66: 983–987.
WCSP. (2011). "World checklist of selected plant families." Retrieved March 2011, 2011, from http://www.kew.org/wcsp/
Webb, C. O. (2012). "The future of plant collecting: a role for 'elite parataxonomists'." Retrieved May 2012, 2012, from http://arboretum.harvard.edu/the-future-of-plant-collecting-a-role-for-elite-parataxonomists/.
Webb, C. O., *et al*. (2010). "Biodiversity inventory and informatics in Southeast Asia." *Biodiversity and Conservation* 19: 955–997.
Werner, Y. L. (2006). "The case of impact factor versus taxonomy: a proposal " *Journal of Natural History* 40: 1285–1286.
Wheeler, Q. D. (2004). "Taxonomic triage and the poverty of phylogeny." *Philosophical Transactions of the Royal Society B: Biological Sciences* 359: 571–583.
Wheeler, Q. D., *et al*. (2004). "Taxonomy: impediment or expedient?" *Science* 303: 285.
Whitfield, J. (2012). "Superstars of botany: rare specimens." *Nature* 484: 436–438.
Will, K. W. and D. Rubinoff (2004). "Myth of the molecule: DNA barcodes for species cannot replace morphology for identification and classification." *Cladistics* 20: 47–55.
Willis, F., *et al*. (2003). "Defining a role for herbarium data in Red List assessments: a case study of *Plectranthus* from eastern and southern tropical Africa." *Biodiversity & Conservation* 12: 1537–1552.
Willis, J. C. (1922). *Age and area; a study in geographical distribution and origin of species*. London, Cambridge University Press. 284.
Wortley, A. H., *et al*. (2002). "Taxonomy and phylogeny reconstruction: two distinct research agendas in systematics." *Edinburgh Journal of Botany* 59: 335–349.
Wortley, A. H. and R. W. Scotland (2004). "Synonymy, sampling and seed plant numbers." *Taxon* 53: 478–480.
Zooniverse. (2017). "Zooniverse - real science online." Retrieved 05 April 2017, 2017, from https://www.zooniverse.org/.
Zootaxa. (2015). "Zootaxa - information for authors." Retrieved April 2017, 2017, from http://www.mapress.com/zootaxa/support/author.html.

2 *Aframomum*, the history of a taxon

CONTENTS

2.1 INTRODUCTION

We know surprisingly little about the natural world (Heywood, 2001). Vascular plants are considered to be one of the best known taxa, however only 80 – 90% (Joppa *et al.*, 2010) of the estimated 380,000 species in existence (Lughadha *et al.*, 2016) are thought to have been discovered. Less than 20,000 species of flowering plant have had an IUCN Red List conservation assessment (IUCN, 2016) and 74% of tropical species have been collected so infrequently that they are effectively invisible to climate modelling (Feeley, 2015).

The discovery rate for new species of flowering plants has remained at around 2,000 per year for the last 30 years (Bebber *et al.*, 2014). It is not clear how to speed the process of species discovery up, or how to better improve the understanding of existing species. What research there has been into the process of species discovery has mainly focused on investigating factors associated with the date of formal publication of new species. This has revealed there are certain biases and time lags within the species discovery process. There is an average 32 – 39 year lag between the first specimen collection and the publication of the new species (Bebber *et al.*, 2010; Fontaine *et al.*, 2012). Species are discovered earlier or later than others depending on the size of the organism (Gaston and Blackburn, 1994; Gaston *et al.*, 1995a; Gaston *et al.*, 1995b), and the size of the organism's geographical range (Gaston and Blackburn, 1994; Gaston *et al.*, 1995a; Gaston *et al.*, 1995b) and biogeographical zone (Gaston *et al.*, 1995b). There are also biases amongst the people who discover new species. Most new species have been named by a small number of extremely experienced individuals (Bebber *et al.*, 2012) consequently most authors have published only one new species (Bebber *et al.*, 2012; Lindon *et al.*, 2015) and the majority of all authors are male (Lindon *et al.*, 2015).

To date there has been no thorough published investigation into the history of a taxonomic group focussing on individual specimens.

In this chapter the history of *Aframomum* names, specimens and literature is explored in detail. The genus *Aframomum* from the ginger family (Zingiberaceae) revised at the Royal Botanic Garden Edinburgh by Harris and Wortley (in press) provided an opportunity to do just that. Using a comprehensive taxonomic account such as Harris and Wortley (in press) provided a baseline to allow the comparison between a modern comprehensive revision, where all of the specimens available across the entire geographic range had been examined by the same authors, and the historical determinations of the same specimens. *Aframomum* was also chosen because it is a moderately-sized tropical group of 61 species; tropical plants are considered to be poorly known (Heywood, 2001) yet comprise approximately two thirds of the diversity of the global vascular flora (Raven, 1988; Wayt Thomas, 1999; Govaerts, 2001) and are more threatened (Myers *et al.*, 2000) than their temperate counterparts.

This chapter investigates how the understanding of *Aframomum* developed over time by examining:

- The accumulation of species names, specimens, and specimen determinations over time.
- The authors who identified and determined *Aframomum* specimens.
- The taxonomic accounts of *Aframomum*.

The first section in this chapter, ‘History of specimens, names and determinations in *Aframomum*’, has been published in ‘Widespread mistaken identity in tropical plant collections’ (Goodwin *et al.*, 2015). I am the main author of this paper and responsible for the work in the paper.

2.2 Materials and Methods

2.2.1 History of specimens, names and determinations in *Aframomum*

2.2.1.1 History of species names in *Aframomum*

The accumulation of *Aframomum* and African *Amomum* species names was investigated by plotting the publication dates of the names over time. Species names were recorded by their currently accepted status as either ‘accepted’, ‘heterotypic synonym’ or ‘excluded’, following Harris and Wortley (in press). *Amomum* basionyms and their *Aframomum* combinations were treated as one name and therefore as accepted.

2.2.1.2 History of specimen collection in *Aframomum*

The accumulation of *Aframomum* specimens was investigated by plotting the collection dates of the specimens over time.

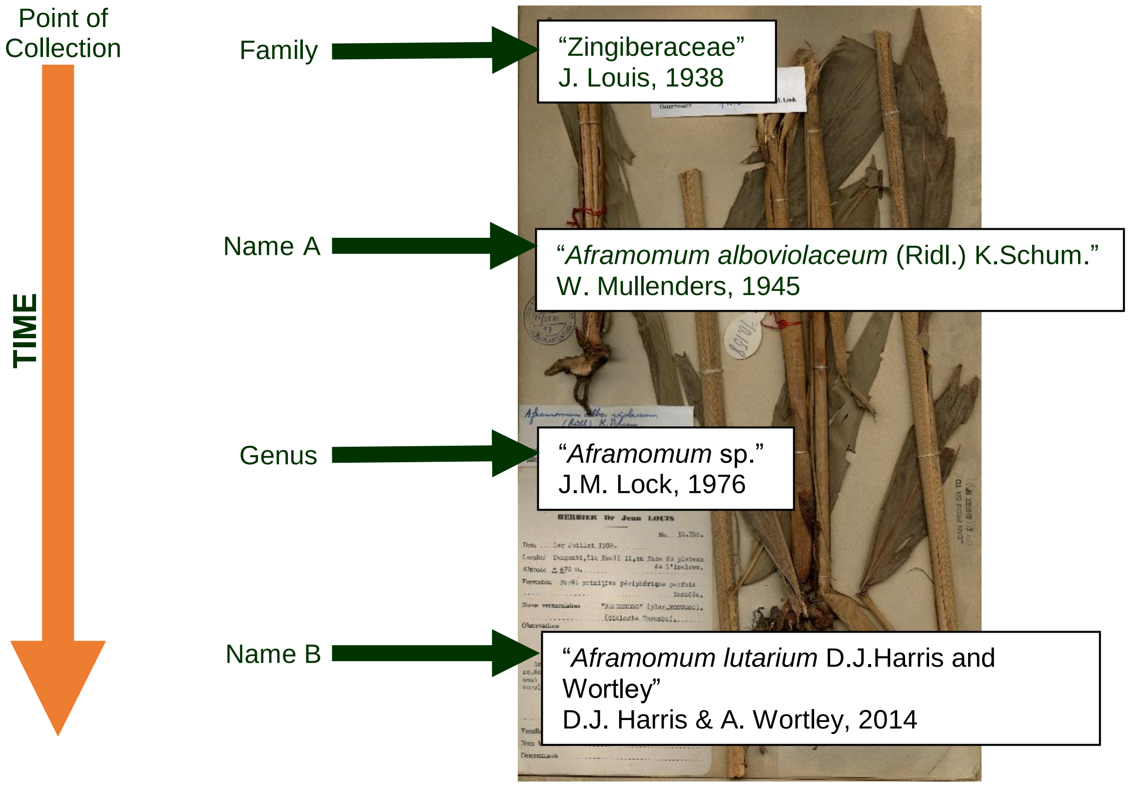


Figure 2.1 Visualisation of determination slips on a specimen of *Aframomum*, J. Louis 10158 (BR). In 1938 when the plant was collected it was determined to family, as Zingiberaceae, by the collector J. Louis. In 1945 it was determined as *Aframomum alboviolaceum* (Ridl.) K.Schum. by W. Mullenders. Thirty-two years later, in 1976, it was recognised as not fitting any existing species concepts and re-determined as *Aframomum* sp. by J.M. Lock. In 2014 the plant was recognised as a new species, *Aframomum lutarium* D.J.Harris and Wortley, by Harris and Wortley (in press) as part of a revision of the genus *Aframomum*.

2.2.1.3 History of *Aframomum* determinations

To document and describe the complete determination history of *Aframomum*, the complete determination data from all determination data from all available specimens in all available collections was recorded, including species name, date and including species name, date and the name of the author of the determination (

Figure 2.1). This did not include any names which specimens had been filed-under in a herbarium if it was not recorded on the specimen. The genus *Aframomum* was revised between 1998 and 2015 by Harris and Wortley (in press), allowing access (2011 – 2012) to the large volume of specimens (3,176 specimen collections, 4,550 including duplicates) from 40 herbaria in 21 countries gathered at the Royal Botanic Garden Edinburgh (E). The scientific names of all determinations were then classified as either ‘correct’, ‘synonym’, ‘indeterminate’ or ‘other’ relative to the determination in the current monograph (Harris and Wortley, in press). Basionyms of the correct name based on *Amomum* were treated as the correct name.

The specimen and determination data were filtered to include only specimens for which both A) the year of collection and B) the year of every determination are recorded (1,492 specimen collections, 1,779 specimen duplicates). The accumulation of specimens and the class of determination were scored and plotted over time.

From the full set of determination data the mean time lag between the year of collection and the year of first correct determination was calculated.

2.2.2 AUTHORS OF DETERMINATIONS

To examine the behaviour and traits of the authors contributing significant numbers of determinations to specimens the number of determinations made by every individual author who had determined an *Aframomum* specimen was counted and recorded. The number of determinations per individual author was plotted. Authors were then filtered by date (restricted to authors active after 1900, because all authors active prior to 1900 had at least one undated determination) and number of contributed determinations (≥20 to identify and quantify the extent of determinations of authors who made significant contributions to the determinations on specimens).

The filtered authors and their determinations were investigated in the following five ways:

- To document the contribution of authors, the total number of determinations authored and the total number of specimens determined were recorded.
- To analyse the geographical breadth of their work the number of herbaria from which the specimens were from and the number of countries the specimens were collected from were recorded.
- To examine whose collections these authors were determining the number (and percentage) of determinations which each author made on specimens collected by the author and on specimens collected by other people were recorded.
- To investigate each author’s expertise the number of different species names which each author determined were recorded. The percentage of determinations which were ‘correct’, ‘incorrect’, ‘heterotypic synonym’ or ‘indeterminate’ (*Aframomum* sp or Zingiberaceae) were recorded.

The authors and their determination information were examined for any general patterns in behaviour, the authors were then grouped by shared behaviour in order to discuss the general patterns.

2.2.3 PAST TAXONOMIC ACCOUNTS

To document and describe the accumulation of taxonomic knowledge over time five major taxonomic accounts were compared in detail. The taxonomic accounts were:

- *Flora of Tropical Africa* account of *Amomum* by Baker (1898)
- *Das Pflanzenreich* account of *Aframomum* by Schumann (1904)
- *Flora of West Tropical Africa* 1st edition account of *Aframomum* by Hutchinson and Dalziel (1936a)
- *Flora of West Tropical Africa* 2nd edition account of *Aframomum* by Hepper (1968)
- *Flora of Tropical East Africa* account of *Aframomum* by Lock (1985)

These taxonomic accounts are a mixture of full genus revisions and regional Flora accounts. Single-country Floras, such as the *Flore du Cameroun* (Koechlin, 1965), were not considered for pragmatic reasons - there are many country-level Floras yet they cover relatively few species.

2.2.3.1 Coverage of the taxonomic accounts

To document and compare the scope of the five past taxonomic accounts and Harris and Wortley (in press) the geographic area (i.e. list of countries) covered, and numbers of names treated, names accepted and specimens cited per accepted species were counted and recorded. The number of literature citations calculated as the total number of literature citations in each species treatment (a single reference may be cited under multiple species) was recorded.

2.2.3.2 What did the taxonomic accounts get right?

2.2.3.2.1 Names

To compare the past taxonomic accounts' concepts of *Aframomum* species with the current understanding the species names accepted in the past taxonomic accounts were compared to the treatment of the names in Harris and Wortley (in press). All names accepted by each taxonomic account were recorded and classified as 'correct', 'synonym', or 'excluded' relative to the assessment of the name in Harris and Wortley (in press).

2.2.3.2.2 Specimens

To compare the past taxonomic accounts' understanding of *Aframomum* with the current understanding the specimens cited in each taxonomic account were compared to the interpretation of those names and specimen determinations in Harris and Wortley (in press). All citations on all specimens in each taxonomic account were recorded and classified as 'correct', 'synonym', 'excluded', 'incorrect', or 'not seen' relative to the determination of the specimen in Harris and Wortley (in press). *Amomum* names in the *Flora of Tropical Africa* account all followed their status in Harris and Wortley (in press) except basionyms of the correct determination which were classified as correct.

2.2.3.3 Which names contained mixed species concepts in the taxonomic accounts?

To investigate which species names have historically contained mixed species concepts and incorrect specimen determinations all the specimens cited and their determinations in the past taxonomic accounts were analysed in detail.

The overall percentages of specimen determination quality (documented in 2.2.3.2.2) were described.

The number of specimens determined as mixed collections by Harris and Wortley (in press) cited in each taxonomic account was recorded. The number of specimens determined as mixed collections by Harris and Wortley (in press) which were cited and recognised as mixed collections by each taxonomic account was recorded.

The number of specimens cited per species name was documented. The determination of each specimen was classified relative to the determination of that specimen in Harris and Wortley (in press) as either 'correct', 'synonym', 'excluded', 'incorrect' (labelled as 'wrong'), or 'not seen'. These specimens and their classified determinations were then grouped by their determination in the past taxonomic accounts. When two or more specimens with different names belonging to the same class then the names were numbered, for example as 'synonym 1' and 'synonym 2' etc. The results were plotted to visualise the numbers of specimens cited per species and colour coded relative to their treatment in Harris and Wortley (in press).

2.2.3.4 Which currently accepted species names have caused problems in the past taxonomic accounts?

To investigate which species names accepted by Harris and Wortley (in press) have caused problems in the past taxonomic accounts all the cited specimens and their determinations in the past taxonomic accounts were analysed in detail.
The determination of each specimen cited in the past taxonomic accounts was classified relative to the determination of that specimen in Harris and Wortley (in press) as either ‘correct’, ‘synonym’, ‘excluded’ or ‘incorrect’ (labelled as ‘wrong’). These specimens and their classified determinations were then grouped by the determination of that specimen in Harris and Wortley (in press). When two or more different species names belong to the same class then the names were numbered, for example as ‘wrong 1’ and ‘wrong 2’ etc. The results were plotted to visualise the numbers of specimens cited per species and colour coded relative to their treatment in Harris and Wortley (in press).

2.3 RESULTS AND DISCUSSION

2.3.1 HISTORY OF SPECIMENS, NAMES AND DETERMINATIONS IN *AFRAMOMUM*

Aframomum is a genus of 61 species accepted by Harris and Wortley (in press) (Appendix 1.1) with 112 other names associated with the genus which are basionyms, synonyms (heterotypic and homotypic) or excluded (either invalidly or illegitimately published) (Appendix 2.1.1). The currently accepted species of *Aframomum* were published between 1782 and the present. Just over half of the *Aframomum* species have restricted geographic ranges and are considered to be globally rare, occupying eight or less degree squares (Black Star = 7 species and Gold Star = 28 species, following Hawthorne and Marshall, 2016) (Appendix 1.1) . The remaining species are widespread (Blue Star = 16 species) or very widespread (Green Star = 10 species).

2.3.1.1 History of species names in *Aframomum*

In this section I enumerate a detailed account of publication of all species names in *Aframomum* over time.

The first species described was *Aframomum granum-paradisi* by Linneaus in 1753 in the genus *Amomum* Roxb. (as *Amomum granum-paradisi*), a further 30 African *Amomum* species were described sporadically over the following 140 years (Figure 2.2A and C). During a twenty-year period, 1890-1910, the rate of species description accelerated dramatically with the publication of 69 new species by several different authors including the *Flora of Tropical Africa* account (Baker, 1898) and in *In Das Pflanzenreich* (Schumann, 1904) (Figure 2.2D, 'I' and 'II' respectively), the majority of these names are now considered to be synonyms (Figure 2.2C). During this period, the African species were split from the rest of *Amomum* to form the new genus *Aframomum* K.Schum. (Schumann, 1904) (Figure 2.2B). Species publication slowed dramatically between 1910 and 1950, with long periods of inactivity punctuated by the occasional publication of single species (Figure 2.2C). The rate of species description started to ramp up again in the second part of the twentieth century with the genus featuring in several large Flora projects including the *Flora of West Tropical Africa* (2nd edition) (Hepper, 1968) and the *Flora of Tropical East Africa* (Lock, 1985) (Figure 2.2D, 'IV' and 'V'). At the end of the twentieth century two botanists started the process of fully revising the genus, J.M. Lock in the mid-1970s (who also provided the treatment of the genus for the *Flora of Tropical East Africa*, Figure 2.2D, 'V') and M.M. Dhetchuvi in the mid-1990s (a PhD student in Brussels). Both individuals started the process of examining specimens across the range of the species and were able to publish several new species each and synonymise many of the existing names (Lock and Hall, 1973; Lock, 1978a; Lock, 1978b; Lock, 1978c; Lock, 1979; Lock, 1980; Lock, 1984; Lock, 1985; Poulsen and Lock, 1997; Poulsen and Lock, 1999; Dhetchuvi and Fischer, 2006; Dhetchuvi *et al.*, 2011) (Figure 2.2C). The genus was completely revised between 1998 and 2015 by Harris and Wortley (in press) (Figure 2.2D, 'VI').

This history of publication of currently accepted species names appears to be a straightforward narrative of species published over time punctuated by plateaus and sudden surges in activity (Figure 2.2A). However at most points in history at least 50% of *Aframomum* and *Amomum* names in existence were names that are now considered to be synonyms (N = 47) or excluded (N = 12) (Figure 2.2C). In the early 1800s the number of synonyms and excluded names rose quicker than the currently accepted names, reaching ten by 1817. The rate of publication of synonyms and excluded names then slowed and was briefly surpassed by the currently accepted names. The rate of synonym publication then accelerated, doubling from 24 in 1903 to 48 in 1909, partially due to the publication of *Das*

Pflanzenreich in 1904 (Figure 2.2D). The accumulation of synonymous and excluded names levelled off at 53 by 1930 and, bar a small increase in the mid-1970s to 59, remained constant in the latter part of the twentieth century, whereas the number of currently accepted names continued to increase (Figure 2.2C).

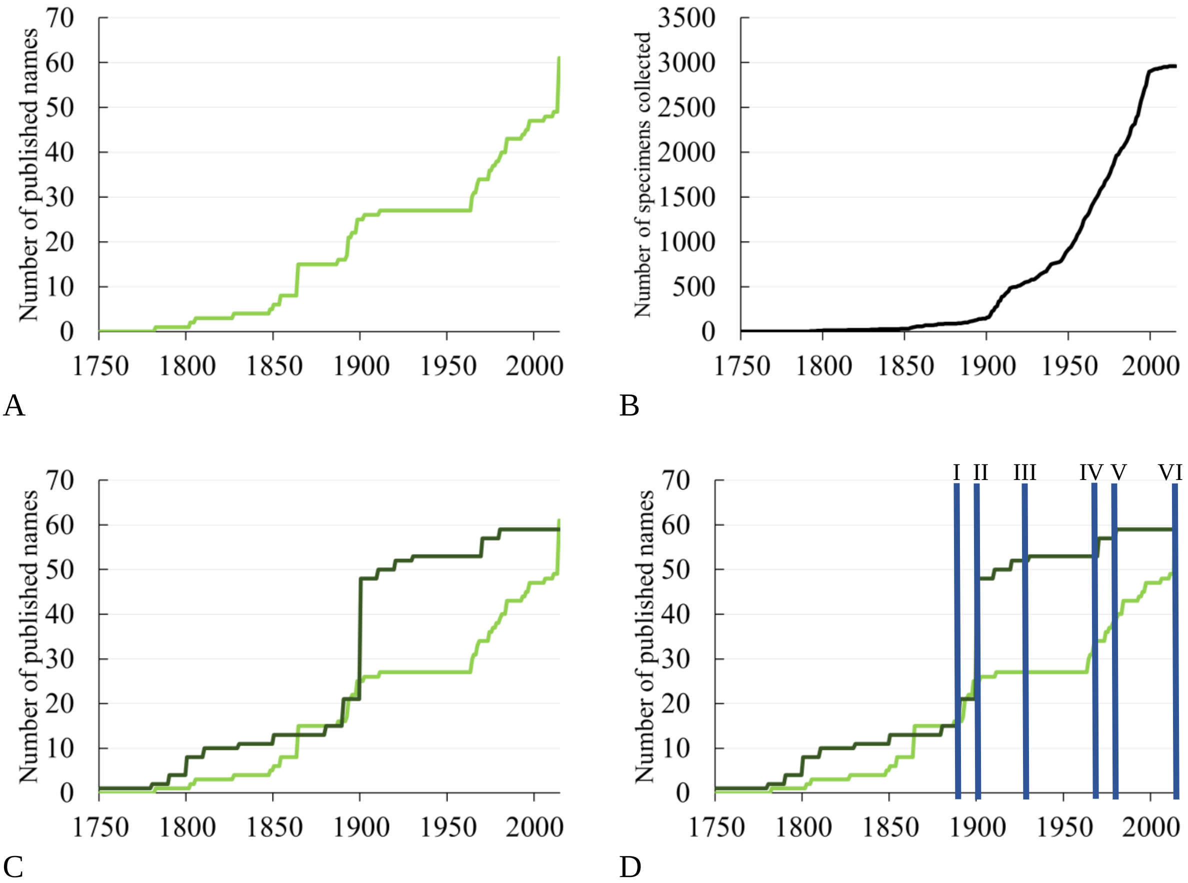


Figure 2.2 The understanding of a taxonomic group over time appears to be a straightforward accumulation of knowledge as *Aframomum* species are described (A) and specimens collected (B) between 1750 and 2015, however the reality is more complex; large numbers of synonymous and excluded names are also published (C) and there are irregular taxonomic and floristic revisions of the genus (D) which may or may not contribute new species names. (A) Accumulation of published *Aframomum* species that are currently accepted by Harris and Wortley (in press) between 1800 and 2015 (N = 61). (B) Accumulation of *Aframomum* specimens collected between 1750 and 2015 (N = 2,961). (C) Accumulation of published *Aframomum* and *Amomum* species names that are currently accepted including basionyms (light green, N = 61) or considered to be synonyms or excluded (dark green, N = 59) by Harris and Wortley between 1750 and 2015. (D) The accumulation of names currently considered to be accepted or synonyms and excluded with six major taxonomic publications indicated; 'I' *Flora of Tropical Africa* (Baker, 1898), 'II' *Das Pflanzenreich* (Schumann, 1904), 'III' *Flora of West Tropical Africa* 1st Ed. (Hutchinson and Dalziel, 1936b), 'IV' *Flora of West Tropical Africa* 2nd Ed. (Hepper, 1968), 'V' *Flora of Tropical East Africa* (Lock, 1985), 'VI' *Aframomum* Monograph (Harris and Wortley, in press).

2.3.1.2 History of specimen collection in *Aframomum*

In this section I describe in narrative form the accumulation of *Aframomum* specimens over time (Figure 2.2B). The first specimens were collected by Afzelius from Sierra Leone in the 1790s. Several *Aframomum* specimens collected by Afzelius record a collection date of 1700, however as Afzelius was not born until 1750 (Tropicos, 2017), these are discounted. Low numbers of specimens (one or two a year on average) were consistently collected throughout the 1800s by a small number of collectors across Africa. Rates of specimen collection started to accelerate (ten to twenty per year) in the first half of the 1900s, despite two periods of disruption caused by the two World Wars where the accumulation temporarily plateaued. In the early 1950s rates of specimen collection accelerated sharply (thirty specimens per year) and continued to increase towards the end of the twentieth century (up to fifty specimens per year).

The number of *Aframomum* specimens in existence (Figure 2.2B) doubled between 1966 and 2000. This increase in specimens is reflected in the number of specimens studied per species in taxonomic revisions. The current revision (Harris and Wortley, in press) of *Aframomum* studied more than 3,000 specimens and cited more than 2,700, an average of 45 specimens for every recognised species. Whereas the previous complete taxonomic treatment of the genus (Schumann, 1904) in 1904 studied 107 specimens, primarily from the Berlin herbarium, on average only 2.5 specimens for every species accepted by that revision (Table 2.1).

Table 2.1 Comparison of literature cited, names treated and accepted, and specimens cited between two revisions of the genus *Aframomum*; Schumann (1904) and Harris and Wortley (in press). Number of literature citations is the total number of literature citations in each species treatment, i.e. the number of unique citations per species, however a single reference may be cited in multiple species. *Schumann 1904 partially accepts 6 additional species which cite 5 specimens and 6 further literature citations.

	Schumann (1904)	Harris and Wortley (In Press)
Total number of literature citations	110	211
Mean number of literature citations per accepted name (± standard deviation)	2.4 (±2.9)	3.5 (±3.7)
Total number of names accepted	42*	61
Total number of names treated (incl. accepted)	99	173
Total number of specimens cited	107	2,750
Mean number of specimens cited per accepted name (± standard deviation)	2.5 (±2.4)	45.1 (±66.0)

2.3.1.3 History of *Aframomum* determinations

Here is presented an examination (Figure 2.3) of the complete determination history of all names for all specimens of *Aframomum* with dates when names were assigned. The quality of determinations on specimens improved over time (Appendix 2.1.2). However before the recent monograph (Harris and Wortley, in press) less than 50% of specimens were correctly determined, the remaining specimens were either incorrectly determined (other), determined to genus or family (indeterminate) or given a name which was a synonym of the correct name (Appendix 2.1.2). Before 1970 the percentage of specimens with the correct name was 10-13%; subsequent increases in the quality of determinations (up to 42%) prior to the current revision coincided with periods of focused effort by single individuals who partially revised the group in the mid-1970s and early 1990s (discussed in 0). The mean time lag for a specimen to acquire the correct determination was 37.8 years (N = 2,169, SD = 35).

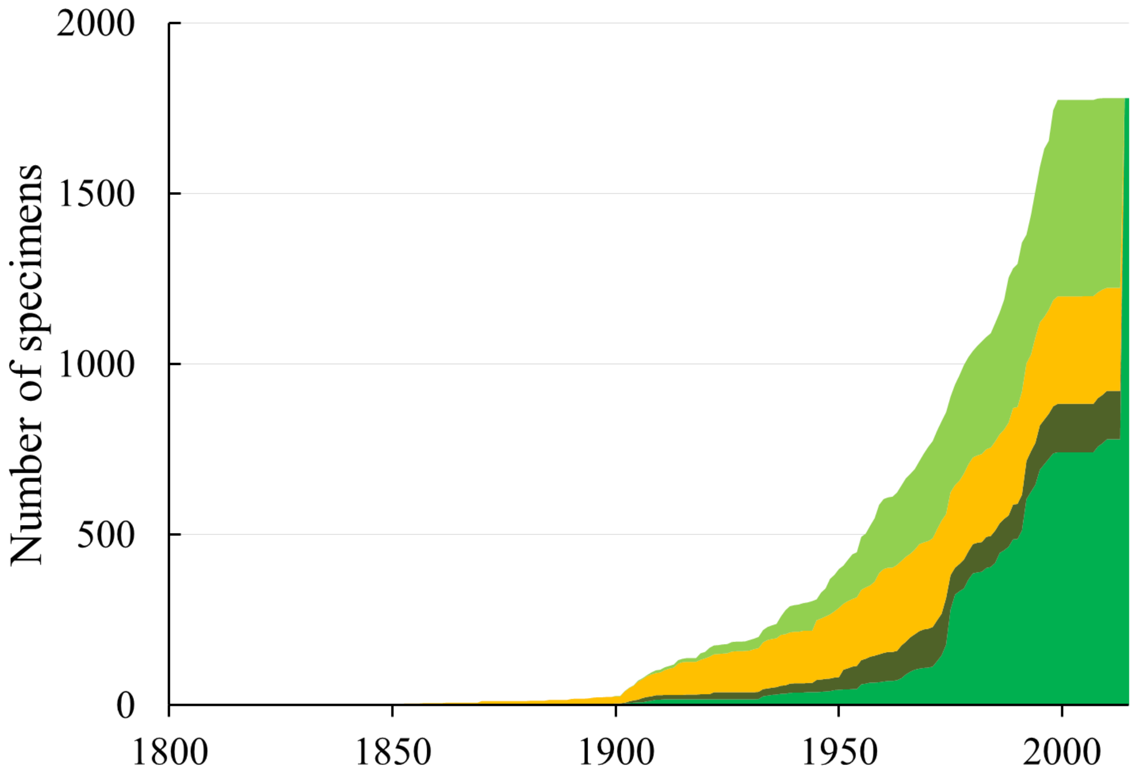


Figure 2.3 The history of *Aframomum* specimens and their determinations. Accumulation of *Aframomum* specimens and their determinations which are either correct (mid-green), synonymous (dark green), other (orange) or indeterminate (light green) relative to Harris and Wortley (in press) between 1800 and 2015 (N = 1,779).

2.3.1.4 Discussion

The examination of the history of species names, specimens and their determinations presented here shows that rather than a straight-forward accumulation of knowledge, the discovery of *Aframomum* has been a piecemeal and fragmentary process.

It is commonly assumed that knowledge of a given taxon improves steadily over time. When the history of a well understood taxon is investigated it is often carried out by examining the accumulation of accepted species names over time. The accumulation of species names increases constantly, punctuated by the occasional floristic and taxonomic revision, and reaches asymptote as the last few species are discovered (Gaston *et al.*, 1995b; Fattorini *et al.*, 2012). However, the rates of species description can vary spatially and temporally (Gaston *et al.*, 1995b; Scoble *et al.*, 1995; Sihvonen and Siljander, 2005) as shifting research foci (Gaston *et al.*, 1995b) and global events (Hortal *et al.*, 2008; Fattorini *et al.*, 2012) cause fluctuations. The history of species discovery in *Aframomum* was more complicated; the apparently straight forward accumulation of currently accepted species names (Figure 2.2A) hides the real underlying complexity. At any given point more than 50% of *Aframomum* names in existence were actually names which are currently considered to be synonyms or are excluded (Figure 2.2C). This misinformation is problematic to non-experts who cannot easily differentiate between species names which are now considered to be accepted, synonyms or excluded. And this confusion is alarming because this is in a group whose 60% synonymy rate (including *Alexis* and *Cardamom* synonyms) is slightly lower than the average for plants (65%, Bramwell, 2002; Thorne, 2002; Scotland and Wortley, 2003; Wortley and Scotland, 2004; The Plant List, 2013).

Species accumulation curves can be used to extrapolate the total number of species in a taxon or geographical area (Gaston *et al.*, 1995b; Sihvonen and Siljander, 2005; Choi, 2006;

Fattorini *et al.*, 2012) despite the problems of synonymy (Scoble *et al.*, 1995), fitting models (Fattorini *et al.*, 2012) and being uninformative except when near asymptote (Bebber *et al.*, 2007; Fattorini *et al.*, 2012). However if species accumulation curves are unrepresentative of the true history of species discovery then their usefulness is decreased.

The accumulation of specimens over time was also more complex than anticipated. The exponential growth in the number of specimens which occurred in the second half of the twentieth century led to a doubling in the number of specimens between 1966 and 2000. This result was striking; it had been anticipated that there had been an increase, but not to this extent. This increase is probably a result of the post-World War II trend away from individual collectors and towards large, organised specimen-collecting expeditions and collaboration between international and regional herbaria (Wayt Thomas, 2016) for Floras (Beentje and Smith, 2001).

This doubling in the number of specimens was important to the process of species discovery. As highlighted in the comparison (Table 2.1) of the two full monographs of *Aframomum* (Schumann, 1904; Harris and Wortley, in press) where the most recent monograph examined an order of magnitude more specimens. The *Das Pflanzenreich* account cites a low number of specimens because there were few specimens in existence and Schumann only cited material from the Berlin herbarium. Many recent taxonomic accounts such as *Flora Neotropica* have a policy of only citing a selection of representative specimens. This is not the case with the *Das Pflanzenreich* account; Schumann cited multiple specimens from the same country under the same species name.

The increase in the number of specimens available between the two accounts should mean that a more complete understanding of each species is achieved in Harris and Wortley (in press). This is important when few specimens are thought to be available for many rare species (Feeley and Silman, 2011; ter Steege *et al.*, 2013).

The unique examination of the entire history of all determinations applied to the specimens revealed that the accumulation of specimens provides a simplified history of *Aframomum* specimens. Before a full taxonomic revision <50% of *Aframomum* specimens had the correct determination, in the absence of any partial revision <15% had the correct name. This analysis does not include specimens from other genera and families which had been mistakenly determined as *Aframomum*. This result means that at any point in history the majority of specimens did not have the correct species name, casting doubt on levels of understanding about *Aframomum* in the past.

Finally, the average time lag of 38 years to achieve the correct determination on a specimen, is comparable to that of the species discovery lag for vascular plants 32 – 39 years (Bebber *et al.*, 2010; Fontaine *et al.*, 2012). If these patterns are widespread the determination lag and the low percentage of correct determinations may have implications for our understanding of species in groups which have not been revised recently. Combined with the doubling of the number of specimens in the latter part of the twentieth century means that many species rich groups, even relatively recently revised groups, may need revision again.

2.3.2 AUTHORS OF DETERMINATIONS

In this section I examine the authors of determinations on *Aframomum* specimens. Of the 653 people who authored 13,705 determinations on 4,028 *Aframomum* specimens between 1792 and 2014 the majority of authors (88%) contributed very few determinations (<10) to specimens, a few authors (0.74%) made huge numbers of determinations ($\geq$100) (Figure 2.4A).

In this section I examine the characteristics of the most prolific authors (N = 29) who contributed 20 or more determinations to *Aframomum* specimens between 1900 and 2015.

These prolific authors' exhibit characteristics as part of a continuum, however there appear to be four general categories of authors which can be classified based upon the breadth of their contribution, geographical coverage, and taxonomic expertise.

2.3.2.1 'General specimen collectors'

Eighteen authors contributed significant numbers of determinations to *Aframomum* specimens were classified as 'general specimen collectors'. This category are authors who contributed to our understanding of *Aframomum* primarily by collecting and determining their own specimens, they may be botanical experts in other taxa or simply individuals conducting floristic surveys for some other research purpose.

The main attributes of a 'general specimen collector' was that they determined relatively few specimens (M = 33.5, Figure 2.4B) and they mainly determined specimens which they had collected (M = 99.4%, Figure 2.4D). The majority of specimens were determined to family or genus only (M = 53%, Figure 2.4E) and they determined a small number of different species-level names; on average each author only determined 2.7 species (Figure 2.4F). The species level determinations were mainly incorrect (M = 37% of all determinations), few specimens were determined correctly (M = 8%) or as heterotypic synonyms (M = 2%, Figure 2.4E). In addition, the general specimen collectors determined specimens from a small number of herbaria (M = 4.2) and a small number of countries (M = 1.7, Figure 2.4C).

2.3.2.2 'General taxonomists'

Six authors contributed significant numbers of determinations to *Aframomum* specimens were classified as 'general taxonomists', these were botanists who specialised in floristic inventories and surveys.

Authors in this category determined more specimens than 'general specimen collectors' (M = 47.5, Figure 2.4B) and determined a significant number of specimens collected by other botanists (M = 34.1%, Figure 2.4D). These authors determined a larger number of different species than 'general specimen collectors' (M = 10.7, Figure 2.4F) and relatively few specimens to family or genus (M = 16.3%, Figure 2.4E). The species-level determinations were distributed evenly between incorrect (M = 31.7%), correct (M = 24.7%) or heterotypic synonyms (M = 27.1%, Figure 2.4E). Specimens determined were from a small number of herbaria (M = 5.0) and a small number of countries (M = 3.3, Figure 2.4C).

2.3.2.3 'Flora writers'

Two authors were identified as writers of the *Aframomum* account for the two editions of the *Flora of West Tropical Africa*. These authors made the highest proportion of determinations on specimens collected by other botanists (M = 90.3%, Figure 2.4D). The Flora writers determined a large number of different species names (M = 15.5, Figure 2.4F) and they rarely determined specimens to family or genus (M = 11.8%, Figure 2.4E). The species-level determinations were generally correct (M = 46.4%) compared with Harris and Wortley (in press), with fewer specimens determined incorrectly (M = 23.0%) or as synonyms (M = 18.8%, Figure 2.4E). They determined specimens from a large number of different herbaria (M = 7.5) and countries (M = 8.5, Figure 2.4C).

2.3.2.4 'Revision writers'

Three authors contributed the vast bulk of determinations to *Aframomum* specimens and who were identified as the writers of partial or full revisionary taxonomic accounts of

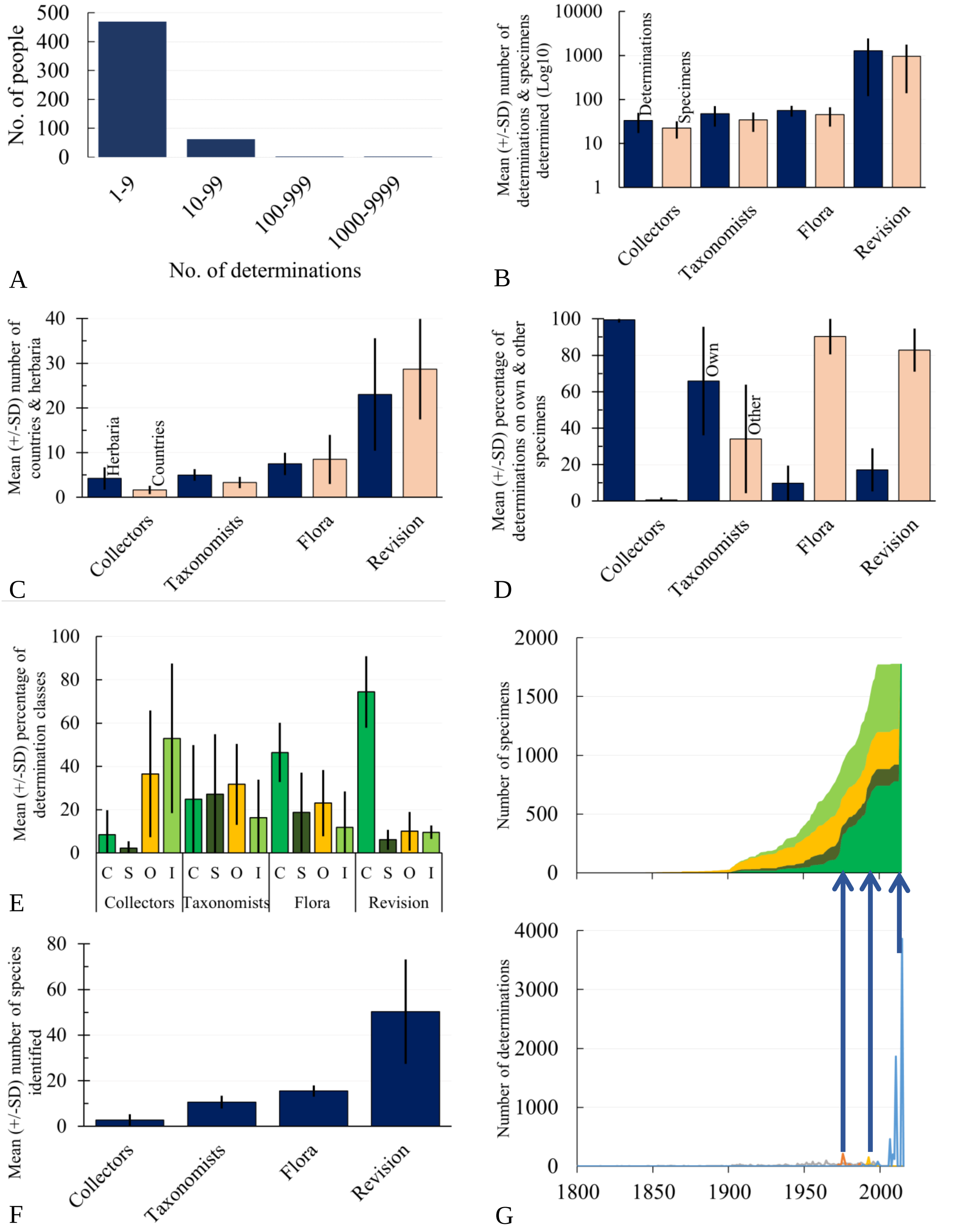


Figure 2.4 Variables defining the different categories of authors of determinations on *Aframomum* specimens. (A) Numbers of determinations made per person. (B) Mean number of determinations made (dark blue), and specimens (pink) determined by each category of author (log10 scale). (C) Mean number of herbaria (dark blue) where the specimens were housed by each category of author of countries (pink) and where the specimens were collected from. (D) Percentage of determinations made on own (dark blue) and other people's (pink) specimens by each category of author. (E) Mean percentage of determinations which were either correct (mid-green), synonyms (dark green), other (orange) or indeterminate (light green) relative to Harris and Wortley (in press) by each category of author. (F) Mean number of species determined by each category of author. (G) Numbers of and quality of determinations on *Aframomum* specimens (upper) compared to numbers of determinations per year (lower) between 1800 and 2015. Spikes in determination activity dominated by three authors (Lock – orange, Dhetchuvi – yellow, Harris – blue) against the background rate (grey) coincide with sudden increases in the number of correct determinations (mid-green) against synonyms (dark green), other (orange) and indeterminate (light green).

Aframomum. These authors made substantial numbers of determinations (*M* = 1,274.3, Figure 2.4B) on specimens from many herbaria (*M* = 23.0) and countries (*M* = 28.7, Figure 2.4C). Primarily the determinations were made on specimens collected by other botanists (*M* = 82.8%, Figure 2.4D). These authors determined the largest number of different species names (*M* = 50.3, Figure 2.4F) and the lowest percentage of specimens determined to family or genus (*M* = 9.6%, Figure 2.4E). The specimens determined to species were mainly determined correctly (*M* = 74.4%), with few determined incorrectly (*M* = 10%) or as heterotypic synonyms (*M* = 6.1%, Figure 2.4E).

The disproportionate number of determinations made by these authors can be seen against the background rate of all *Aframomum* determinations (Figure 2.4G) and the spikes in activity correlate with sudden improvements in determination quality.

2.3.2.5 Discussion

The examination of authors and their determinations on *Aframomum* specimens presented here has shown that very few authors contribute most of the determinations and only the most experienced authors made correct determinations.

The data on the authors of determinations on *Aframomum* specimens presented here shows a hollow curve distribution (Willis, 1922) where the majority of authors made very few determinations and a few authors were disproportionately responsible for the overwhelming majority of determinations (Figure 2.4A). This means that of the hundreds of authors who made determinations on specimens of *Aframomum*, a tiny number of authors were responsible for the majority of good and bad determinations. Thus if we are to understand what kind of author produced the best quality determinations, then we need to understand the characteristics of the most prolific authors.

The most prolific authors encompassed a range of different qualities and characteristics, however for the purposes of analysis they were divided into four broad categories; ‘general specimen collectors’, ‘general taxonomists’, ‘Flora writers’, and ‘revision writers’.

‘General specimen collectors’ almost exclusively determined specimens which they had collected, consequently these authors gained little taxonomic experience of *Aframomum* and determined most specimens to genus or family-level. When ‘general specimen collectors’ did make species-level determinations they were mainly incorrect. ‘General taxonomists’ also had relatively little experience with the genus, however they determined the majority of specimens to species level using names which were equal parts correct, incorrect and synonyms. This category also included one author (Poulsen) who later became a specialist in Zingiberaceae in S.E. Asia but encountered *Aframomum* during his early career before he developed his expertise in the taxon. This suggests that authors who have little taxonomic experience of an unrevised group such as *Aframomum* do not tend to put species-level names on specimens, and when they do, they do not use the correct name.

Specimen determinations were most productive when made by authors who were conducting a taxonomic revision on the group; these were the only types of authors who consistently determined more than half of their species-level determinations correctly. Whether working on a Flora account or a full taxonomic revision these authors determined the largest number of species names (Figure 2.4F) across a large number of specimens from many herbaria and different countries (Figure 2.4C). ‘Revision writer’s’ greater experience (in terms of numbers of specimens seen, numbers of different herbaria visited, and numbers of different taxa seen, Figure 2.4B, C and F) meant that they were able to determine a higher percentage of specimens correctly than ‘Flora writers’. Also importantly ‘revision writer’s’ had a greater experience of *Aframomum* in the field (Figure 2.4D) which would have allowed them to observe both living plants and the changes made to characters on living material by the

drying process, thus allowing better interpretation of other botanists' collections and descriptions (Harris and Wortley, in press).
Three big spikes in correct determinations (Figure 2.4G) were directly attributable to three sets of taxonomists working on the genus; the 'revision writers' Lock (1970 – mid 1990s), Dhetchuvi (1990s) and Harris and Wortley (1990 – 2015). This data shows that not only did a few individuals contribute disproportionately to the number of determinations but also that only those individuals who made huge numbers of determinations (and thus gained experience of the genus) contributed a large proportion of correct determinations. This result confirms that shown for the contribution of experienced botanists to the collection of type specimens (Bebber *et al.*, 2012), reinforcing the idea that a botanist's understanding of a taxon becomes better with experience over a lifetime, across taxa and across geography.

2.3.3 PAST TAXONOMIC ACCOUNTS

2.3.3.1 Coverage of the taxonomic accounts

Here I introduce the five past taxonomic accounts by briefly summarising the coverage of the taxonomic accounts investigated in this chapter and the Harris and Wortley (in press) account. I will compare the numbers of names, specimens, and literature citations treated by each account. I will briefly summarise which countries were treated by each account and compare how many names were treated as accepted, basionyms, synonyms and as doubtful.excluded by each account (Figure 2.5 and Figure 2.6).

2.3.3.1.1 Flora of Tropical Africa

The *Flora of Tropical Africa* account by Baker (1898) was published shortly before the publication of the genus *Aframomum*, thus the *Aframomum* species covered by this account are treated as the African species of the Paleotropical genus *Amomum*. These *Amomum* species combinations are classified here following Harris and Wortley (in press), with the exception of the basionyms of correct names which are classified as correct. The *Flora of Tropical Africa* account treated 41 species names and one infraspecific name, cited 77 specimens, contained 71 literature citations (Figure 2.5.1A) and covered all countries in continental tropical Africa (Figure 2.5.1B). The *Flora of Tropical Africa* cited an average of 3.1 specimens per accepted name. Of the 42 names treated by the account 25 (60%) were accepted (Figure 2.5.1C), eleven (26%) were treated as synonyms and six names (14%, purple in Figure 2.5.1C) were treated as accepted but "imperfectly known" species.

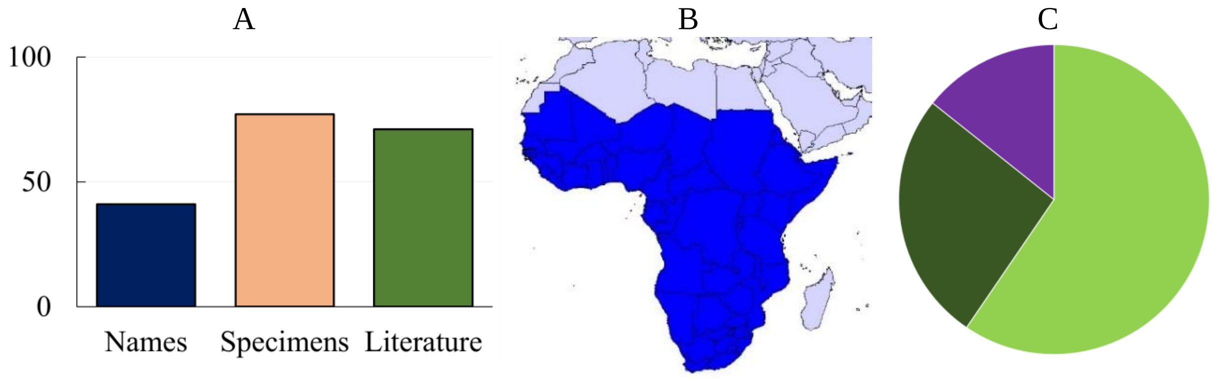
2.3.3.1.2 Das Pflanzenreich

The *Das Pflanzenreich* account by Schumann (1904) created the new genus *Aframomum* by splitting off the African species of *Amomum* from the rest of the genus. This account treated 99 names, cited 107 specimens, contained 110 literature citations (Figure 2.5.2A) and covered the full geographical range of *Aframomum*, including all countries in continental tropical Africa, Madagascar and the Indian Ocean islands (Figure 2.5.2B).
The account cited an average of 2.4 specimens per accepted name. Of the 99 names treated by the account it accepted 44 (44%) names, treated 34 (34%) as basionyms, 16 (16%) as synonyms and excluded five (5%) names (Figure 2.5.2C).

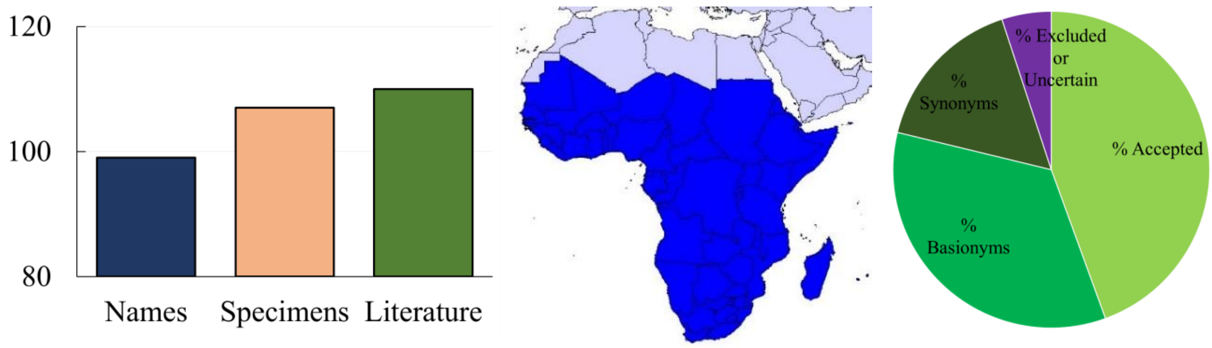
2.3.3.1.3 Flora of West Tropical Africa 1st ed.

The *Flora of West Tropical Africa* 1st ed. account by Hutchinson and Dalziel (1936a) covered *Aframomum* in the Upper Guinea region of West tropical Africa (Figure 2.5.3B) and treated 53 names, cited 74 specimens and contained 79 literature citations (Figure 2.5.3A). The *Flora of West Tropical Africa* 1st ed. cited an average of 3.9 specimens per accepted name. Of the

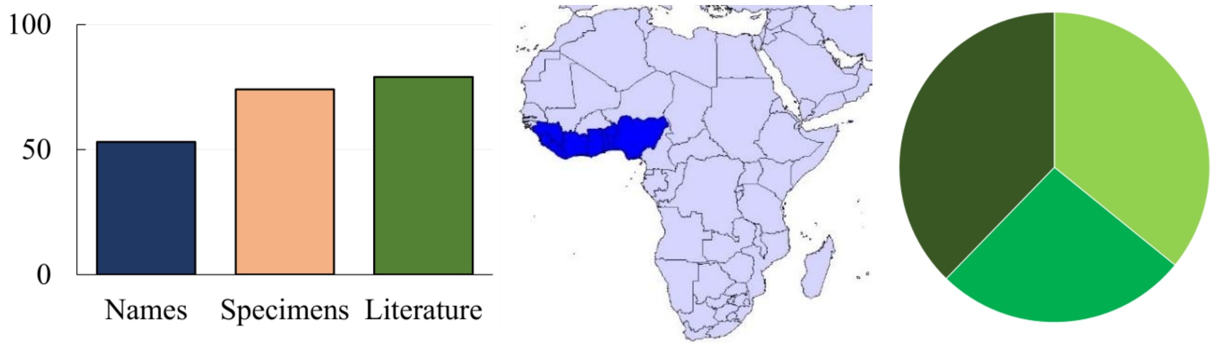
53 names treated by the account it treated 19 (36%) as accepted, 14 (26%) as basionyms and 20 (38%) as synonyms (Figure 2.5.3C).



2.5.1 Flora of Tropical Africa



2.5.2 Das Pflanzenreich



2.5.3 Flora of West Tropical Africa 1st ed.

Figure 2.5 Coverage of the *Flora of Tropical Africa*, *Das Pflanzenreich* and *Flora of West Tropical Africa* 1st ed treatments of *Aframomum* examined here. (A) Total number of names treated (blue), total number of specimens cited (pink) and literature references (green) in each account. (B) Geographical coverage by country. (C) The percentage of species names treated by each account which are considered to be accepted (light green), basionyms (mid-green), synonyms (dark green) and invalid or excluded (purple) by that account.

2.3.3.1.4 Flora of West Tropical Africa 2nd ed.

The *Flora of West Tropical Africa* 2nd ed. account by Hepper (1968) covered *Aframomum* in a slightly larger concept of West Africa than the 1st edition by including Cameroon (Figure 2.6.1B) and treated 56 names, cited 178 specimens and contained 108 literature citations (Figure 2.6.1A). The *Flora of West Tropical Africa* 2nd ed. cited an average of 8.9 specimens per accepted name. Of the 56 names treated by the account it accepted 20 (36%) names, treated 14 (25%) as basionyms and 22 (39%) as synonyms (Figure 2.6.1C).

2.3.3.1.5 Flora of Tropical East Africa

The *Flora of Tropical East Africa* account by Lock (1985) covered *Aframomum* in the tropical East African countries of Tanzania, Kenya and Uganda (Figure 2.6.2B), and treated 44 names, cited 89 specimens and contained 76 literature citations (Figure 2.6.2A). The *Flora of Tropical East Africa* cited an average of 5.9 specimens per accepted name. Of the 44 names treated by the account it accepted 15 (34%) species, treated eight (18%) as basionyms, 20 (45%) as synonyms and one name (2%) as excluded (Figure 2.6.2C).

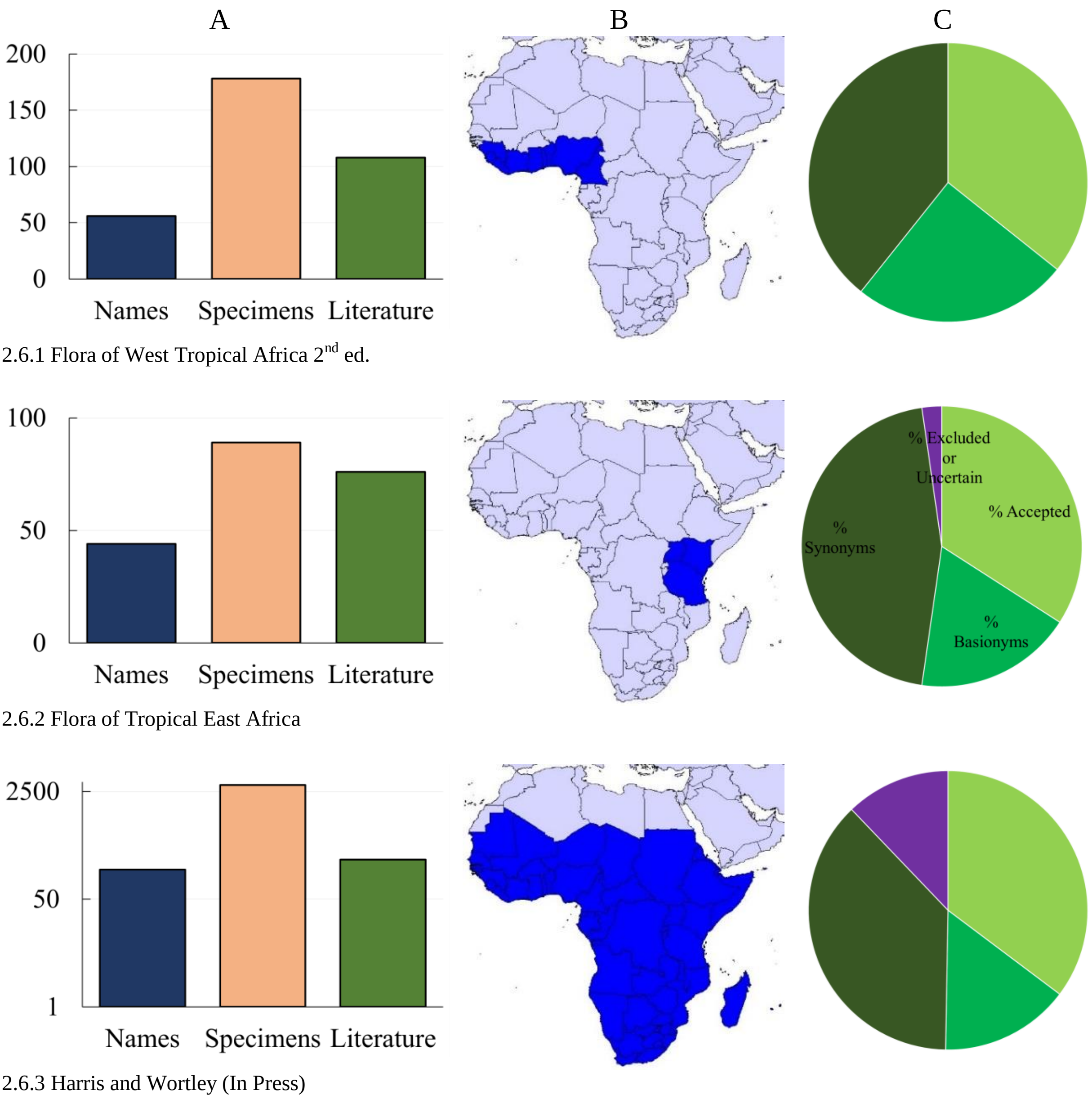


Figure 2.6 Coverage of the *Flora of West Tropical Africa 2nd ed*, *Flora of Tropical East Africa* and Harris and Wortley (in press) treatments of *Aframomum* examined here. (A) Total number of names treated (blue), total number of specimens cited (pink) and literature references (green) in each account, 2.6.3 Harris and Wortley has a log10 scale. (B) Geographical coverage by country. (C) The percentage of species names treated by each account which are considered to be accepted (light green), basionyms (mid-green), synonyms (dark green) and invalid or excluded (purple) by that account.

2.3.3.1.6 Harris and Wortley (In Press)

These five historical taxonomic accounts will be compared to the recently completed monograph of *Aframomum* (Harris and Wortley, in press). The Harris and Wortley (in press) monograph covered the entire range of *Aframomum* in tropical Africa, Madagascar and the Indian Ocean islands (Figure 2.6.3B) and treated 173 names, cited 3,176 specimens and contained 211 literature citations (Figure 2.6.3A). Of the 173 names treated by Harris and Wortley (in press) it accepted 61 (35%) names, treated 26 (15%) as basionyms, 65 (38%) as synonyms and 21 names (12%) as excluded (Figure 2.6.3C), these names were from four genera; *Aframomum* (99), *Amomum* (53), *Cardamomum* (19), and *Alexis* (two) (Appendix 2.1.1).

2.3.3.2 What did the taxonomic accounts get right?

Here I briefly summarise the names accepted by each past taxonomic account and the status of these names in Harris and Wortley (in press). This is followed by a general comparison of the determinations of the specimens cited in each taxonomic account with the determinations applied to those specimens by Harris and Wortley (in press).

2.3.3.2.1 Names

All past taxonomic accounts accepted more than 50% of correct species names *sensu* Harris and Wortley (in press) (Figure 2.7A). The *Flora of Tropical Africa* account correctly accepted 77% of the names, the percentage dropped to 52% in *Das Pflanzenreich* and increased steadily over the following accounts to 87% in the *Flora of Tropical East Africa* in 1985.

Overall the nomenclature improved over time – the number of names that were treated as accepted by the past taxonomic accounts but that are currently considered to be excluded (Figure 2.7A, purple) or heterotypic synonyms (Figure 2.7A, dark green) by Harris and Wortley declined over time. Two (8%) excluded names were accepted in *Flora of Tropical Africa*, five (10%) in *Das Pflanzenreich* and just one (5%) in the *Flora of West Tropical Africa* 1st ed.. Excluded names were no longer accepted by the *Flora of West Tropical Africa* 2nd ed. (1968) and onwards. The number of heterotypic synonyms accepted in the taxonomic accounts fell from 25 (52%) in *Das Pflanzenreich*, to just two (13%) names by the *Flora of Tropical East Africa* account.

The exception to the general trend of improvement was the *Das Pflanzenreich* (1904) account; this account was responsible for the publication of seven new heterotypic synonyms (Figure 2.7A, dark green) and cited more excluded names and heterotypic synonyms than the *Flora of Tropical Africa* account.

2.3.3.2.2 Specimens

The quality of specimen determinations increased over time; the percentage of correctly determined specimens increased over time, and the percentages of specimens determined under heterotypic synonyms, incorrect and excluded names declined over time.

The majority of the past taxonomic accounts determined less than 50% of the cited specimens correctly (Figure 2.7B, light green), only the most recent taxonomic account (*Flora of Tropical East Africa*) correctly determined more than 70% of the specimens cited. The percentage of correctly determined specimens was 42% for the *Flora of Tropical Africa*, declined for the next two accounts (34% in *Das Pflanzenreich* and 32% in *Flora of West Tropical Africa* 1st ed.) and improved again for the 2nd *Flora of West Tropical Africa* account (49%).

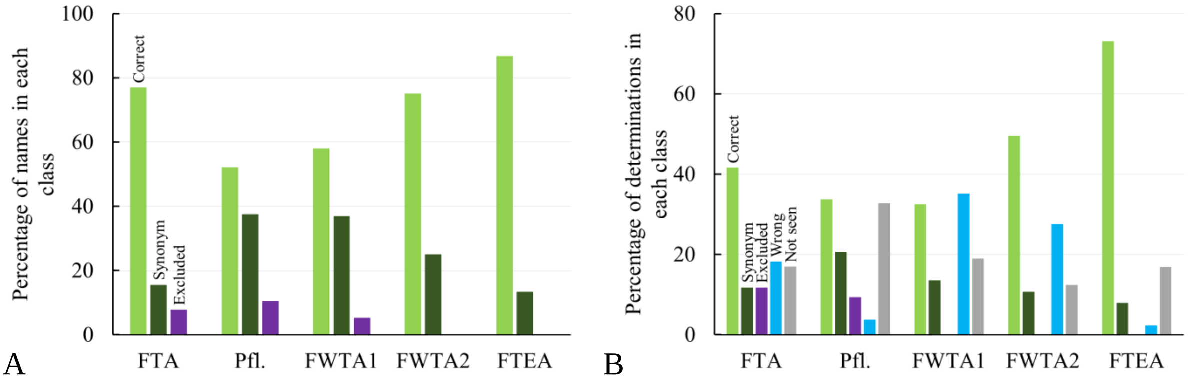


Figure 2.7 Percentages of names treated as accepted and determinations of specimens cited in each account relative to Harris and Wortley (in press). (A) Percentages of species names accepted in past taxonomic accounts which are correct (light green), synonyms (dark green), or excluded (purple) *sensu* Harris and Wortley. (B) Percentages of determinations on specimens cited in past taxonomic accounts which are considered to be correct (light green), synonyms (dark green), excluded (purple), incorrect (blue) or not seen (grey) *sensu* Harris and Wortley. Where 'FTA' = *Flora of Tropical Africa*, 'Pfl.' = *Das Pflanzenreich*, 'FWTA1' = *Flora of West Tropical Africa 1st ed*., 'FWTA2' = *Flora of West Tropical Africa 2nd ed*., and 'FTEA' = *Flora of Tropical East Africa*.

All the past taxonomic accounts determined a substantial number of specimens as names which are now considered to be a heterotypic synonym of the correct name for that specimen (Figure 2.7B, dark green). This percentage decreased over time from 21% in *Das Pflanzenreich* (1904) to 8% in *Flora of Tropical East Africa* (1985).

The two earliest taxonomic accounts (in 1898 and 1904) determined specimens as species names considered to be excluded by Harris and Wortley (Figure 2.7B, purple).

The percentage of specimens incorrectly determined in each taxonomic account was highly variable (Figure 2.7B, blue) however the percentage did generally decline over time. The percentage of incorrectly determined specimens decreased from 35% in the *Flora of West Tropical Africa* 1st ed. in 1936 to 2% in the *Flora of Tropical East Africa* in 1985. The proportion of incorrect determinations in the second earliest taxonomic account, *Das Pflanzenreich*, was surprisingly low; however this taxonomic account cited only one specimen per species name for many of its accepted species. The *Das Pflanzenreich* account cites a low number of specimens because there were few specimens in existence and Schumann only cited material from the Berlin herbarium, Schumann did cite multiple specimens from the same country under the same species name. So many of specimens cited in this taxonomic account may have been type specimens.

The substantial number of specimens cited by each treatment which had not been seen by Harris and Wortley (in press) (Figure 2.7B, grey) is due to the large number of specimens presumed to have been destroyed at the Berlin herbarium (B) during World War II, many of these specimens were types.

2.3.3.3 Which names contained mixed species concepts in the taxonomic accounts?

I present a detailed analysis of the determinations of specimens cited in each taxonomic account in Appendices 2.3.1 and 2.3.2. Here I present a brief summary of this analysis with a focus on the species names which contained mixed species concepts in the past taxonomic accounts (detailed in Appendix 2.3.1).

Many different species names (22) contained incorrect determinations in the past taxonomic accounts (Table 2.2), these names represent 18 different species *sensu* Harris and Wortley (in press). Six of these names appeared partially (*A. angustifolium*, *A. leptolepis*, and *A. strobilaceum*) or entirely (*A. exscapum*, *A. alboviolaceum*, and *A. limbatum*) under names now considered to be heterotypic synonyms. Three names appeared partially (*A.*

angustifolium and *A. leptolepis*) or entirely (*A. melegueta*) as basionyms of currently accepted names (Table 2.2). The 18 species accepted by Harris and Wortley were all published early (M = 1860.3, range 1782 – 1898) and tended to be widespread in range (M = 27.1 degree squares, range 4 – 105, Table 2.2); 13 of the species had a medium to widespread geographical range (Blue or Green Stars occupying >8 degree squares).

Table 2.2 The 22 *Aframomum* and *Amomum* species names which contained incorrect determinations ("errors") in past taxonomic accounts, their geographical range and year of publication demonstrating that many of these problematic names were published early or were relatively widespread. *Aframomum* and *Amomum* names accepted by historical taxonomic accounts (with the accepted name of heterotypic synonyms in parentheses) which contain at least one incorrectly determined specimen compared to Harris and Wortley (in press), details of the incorrectly determined specimens are provided in Appendix 2.3.7. Names currently considered to be heterotypic synonyms have the currently accepted name in parentheses, extent of geographical range (number of degree squares occupied) and year of publication (with the date of the current combination in parentheses) of each currently accepted species appears once either under the accepted name, or basionym, or heterotypic synonym (in order of priority).

Species	**Geographical range**	**Year of publication (Comb. Nov.)**	**Number of errors**
Aframomum baumannii K.Schum. (*A. angustifolium)*			2
Aframomum citratum (J.Pereira) K.Schum.	12	1850 (1904)	3
Aframomum cuspidatum (Gagnep.) K.Schum. (*A. exscapum)*	12	1805 (1967)	1
Aframomum dalzielii Hutch. (*A. leptolepis)*			1
Aframomum daniellii (Hook.f.) K.Schum.	54	1854 (1904)	2
Aframomum elliotii (Baker) K.Schum.	4	1898 (1904)	1
Aframomum erythrostachyum Gagnep. (*A. strobilaceum)*			1
Aframomum glaucophyllum (K.Schum.) K.Schum.	19	1893 (1904)	1
Aframomum latifolium (Afzel.) K.Schum. (*A. alboviolaceum)*	29	1887 (1904)	2
Aframomum leptolepis (K.Schum.) K.Schum.	8	1893 (1904)	2
Aframomum longiscapum (Hook.f.) K.Schum.	6	1854 (1904)	2
Aframomum luteoalbum (K.Schum.) K.Schum.	24	1892 (1904)	1
Aframomum lycobasis K.Schum. (*A. limbatum)*	54	1864 (1904)	1
Aframomum mala (K.Schum. ex Engl.) K.Schum.	8	1895 (1904)	1
Aframomum pilosum (Oliv. & D.Hanb.) K.Schum.	8	1864 (1904)	1
Aframomum sceptrum (Oliv. & D.Hanb.) K.Schum.	55	1864 (1904)	3
Aframomum strobilaceum (Sm.) Hepper	14	1802 (1967)	1
Aframomum subsericeum (Oliv. & D.Hanb.) K.Schum.	17	1864 (1904)	2
Aframomum sulcatum (Oliv. & D.Hanb. ex Baker) K.Schum.	13	1898 (1904)	3
Amomum angustifolium Sonn.	105	1782 (1904)	1
Amomum leptolepis K.Schum.			1
Amomum melegueta Roscoe	56	1827 (1904)	1

2.3.3.4 Which names contained incorrect determinations in the taxonomic accounts?

Here I present a detailed analysis of the species which contain the most incorrect determinations in past taxonomic accounts (detailed in Appendix 2.3.2).
More than half (38) of the 61 *Aframomum* species accepted by Harris and Wortley (in press) were represented by specimens in at least one of the past taxonomic accounts (Appendix 2.3.6), of these species 14 had specimens which were cited as two or more different names in

at least one taxonomic account (Table 2.3). These species tended to have a widespread geographical range (Table 2.3), occupying a mean of 33.3 degree squares (range 8 – 105), this was considerably higher than average for all *Aframomum* species (14.5 degree squares) and 13 of the species had a medium to widespread geographical range (Blue or Green Stars occupying >8 degree squares). Most of these species were published early, before the first taxonomic account (in *Amomum*), except for *A. sulcatum* published in the *Flora of Tropical Africa* in 1898 (in *Amomum*) and *A. chrysanthum* published by Lock in 1978 (Table 2.3).
The incorrect use of names on specimens in past taxonomic accounts involved a mixture of incorrect determinations, heterotypic synonyms and excluded names.
Specimens were cited as excluded names in the two earliest accounts (as documented in section 2.2.3.2.1). Four species (*A. alboviolaceum*, *A. exscapum*, *A. sceptrum* and *A. strobilaceum*) had specimens which were determined as *A. granum-paradisi*. *A. sceptrum* was also determined as *A. cereum* (in the *Das Pflanzenreich* account) (Appendix 2.3.6).
Specimens belonging to seven species (*A. alboviolaceum, A. angustifolium, A. daniellii, A. exscapum, A. leptolepis*, *A. limbatum,* and *A. strobilaceum*) were cited under both incorrect names and heterotypic synonyms of the correct name (Appendix 2.3.6). Specimens belonging to four species (*A. chrysanthum*, *A. citratum, A. subsericeum*, and *A. sulcatum*) were cited just under incorrect name(s) and specimens belonging to three species (*A. giganteum, A. melegueta* and *A. sceptrum*) were cited just under heterotypic synonym(s) of the correct name (Appendix 2.3.6).
Twenty names treated in the past taxonomic accounts cited specimens which are currently considered to belong to two or more different species (Appendix 2.3.7).
Ten species (indicated with a "*" in Table 2.3) contain both mixed species concepts and incorrect determinations; nine of these species had a medium or widespread geographical range (Blue or Green Star species occupying >8 degree squares (Table 2.2).

2.3.3.5 Discussion

In this section I have analysed the names accepted and specimens cited in five major taxonomic accounts of *Aframomum* compared with Harris and Wortley (in press). For the first part I examined the names and specimens generally. Then, for the second part I examined the specimen citations within each species name allowing me to investigate where the incorrect determinations were located and which species contained mixed species concepts. To my knowledge taxonomic accounts have never been examined in this way before.
The first part shows that the quality of names accepted and determinations on specimens cited in past taxonomic accounts improved over time. The apparently haphazard taxonomic process, involving different authors based at different institutions over time, was effective at improving the quality of nomenclature. For example, by increasing the proportion of correctly accepted species and decreasing the proportion of species names currently considered to be excluded or doubtful (Figure 2.7A).
The second part, a unique analysis of specimen determinations cited in the literature, demonstrates that the raw numbers of correct and incorrect determinations (found in the first part) hides the complexity of the determinations within each species name, and the consequent confusion in the literature (Appendix 2.3, Figures 1 – 10). All of the past taxonomic accounts (except the most recent, the *Flora of Tropical East Africa*) cited many specimens under a single species name which are now considered to be multiple different species.
The data presented here has provided a series of snapshots of expert opinions concerning part or all of *Aframomum* over the last 120 years.

Table 2.3 The 14 *Aframomum* species names which had mixed species concepts in past taxonomic accounts, their geographical range and year of publication demonstrating that many of these problematic names were published early or were relatively widespread. The *Aframomum* names currently accepted by Harris and Wortley (in press) which were represented by specimens determined as two or more different names in past taxonomic accounts, the number of different names applied in each account are detailed in Appendix 2.3.6, extent of geographical range (number of degree squares occupied) and year of publication (with the date of the current combination in parentheses) of each currently accepted species. Species which occur in both Table 2.2 and Table 2.3 are indicated by a '*'.

Species	**Geographical range**	**Year of publication (Comb. Nov.)**	**Number of species concepts**
Aframomum alboviolaceum (Ridl.) K.Schum. *	28	1887 (1904)	16
Aframomum angustifolium (Sonn.) K.Schum. *	105	1782 (1904)	9
Aframomum chrysanthum Lock	15	1978	7
Aframomum citratum (J.Pereira) K.Schum. *	12	1850 (1904)	4
Aframomum daniellii (Hook.f.) K.Schum. *	54	1854 (1904)	13
Aframomum exscapum (Sims) Hepper *	12	1805 (1967)	10
Aframomum giganteum (Oliv. & D.Hanb.) K.Schum.	23	1864 (1904)	3
Aframomum leptolepis (K.Schum.) K.Schum. *	8	1893 (1904)	5
Aframomum limbatum (Oliv. & D.Hanb.) K.Schum.	54	1864 (1904)	18
Aframomum melegueta (Roscoe) K.Schum. *	56	1827 (1904)	5
Aframomum sceptrum (Oliv. & D.Hanb.) K.Schum. *	55	1864 (1904)	6
Aframomum strobilaceum (Sm.) Hepper	14	1802 (1967)	10
Aframomum subsericeum (Oliv. & D.Hanb.) K.Schum. *	17	1864 (1904)	2
Aframomum sulcatum (Oliv. & D.Hanb. ex Baker) K.Schum. *	13	1898 (1904)	5

It is promising that the species concepts have converged overtime towards that of Harris and Wortley, suggesting that the Harris and Wortley account may not be that far off the true state of *Aframomum*. However, this data demonstrates that there has been plenty of confusion in the system. There are large numbers of species with mixed species concepts and many incorrectly cited specimens.

The confusion, specimens being cited as a mixture of synonyms and incorrect names, appears more or less confined to widespread species (nine of the species were Green or Blue Star species) which have been published before 1900, including *A. alboviolaceum*, *A. angustifolium*, *A. daniellii*, *A. melegueta* and *A. sceptrum*. This analysis suggests that although it is widely acknowledged that widespread species are discovered earlier (Blackburn and Gaston, 1994; Gaston and Blackburn, 1994; Blackburn and Gaston, 1995; Gaston *et al.*, 1995a), the early discovery of a species does not necessarily mean that a widespread species is understood correctly.

There are some odd results within these general trends. One taxonomic account examined here, *Das Pflanzenreich* from 1904, bucked the trend of general improvement by publishing and accepting more heterotypic synonyms than the previous account (*Flora of Tropical Africa*). Consequently the *Das Pflanzenreich* account correctly accepted fewer species names (Figure 2.7A). When examining the specimens cited, the same account correctly determined a large percentage of specimens (Figure 2.7B) and determined very few specimens with the incorrect name. Whereas, the later *Flora of West Tropical Africa* accounts (1936 and 1968) determined many more specimens under the incorrect name. This can be explained by a combination of different coverage (Figure 2.5), methodology and specimens seen between the taxonomic accounts:

Firstly, the methods used and coverage varied between the accounts; for example, the *Flora of West Tropical Africa* accounts were rapid, herbarium-based revisions (most of the specimens examined were from the author's home herbarium). Only specimens from a geographical restricted area were examined, thus the author can only cover some species in a group and only part of the ranges of many of the widespread species. Commonly limited time to complete and space in Flora accounts requires that only a sample of representative specimens are cited in each species account. The *Flora of Tropical East Africa* account is the only account examined here where such a policy is clearly applied. The rapid nature of the *Flora of West Tropical Africa* accounts suggest that representative citation would have been applicable here, however the presence of multiple specimens cited from the same locations in the same countries suggest this methodology was not applied. Likewise, multiple specimens cited from the same location in the two earliest accounts (the *Flora of Tropical Africa* and *Das Pflanzenreich*) suggest a lack of available herbarium material rather than representative specimen citation explains the low numbers of specimens cited.

There is a huge improvement in the quality of names and specimen determinations between the 2nd edition of the *Flora of West Tropical Africa* in 1968 and the *Flora of Tropical East Africa* in 1985, which (despite treating a different geographical region of Africa) does treat a comparable number of species. This is probably due to the *Flora of Tropical East Africa* account being part of a series of publications revising *Aframomum* across Africa by the same author (Lock and Hall, 1973; Lock and Hall, 1975; Lock, 1976; Lock *et al*., 1977; Lock, 1978c; Lock, 1978a; Lock, 1978b; Lock, 1979; Lock, 1980; Lock, 1984) in contrast to the *Flora of West Tropical Africa* accounts. In comparison the *Flora of Tropical Africa, Das Pflanzenreich* and Harris and Wortley (in press) all covered the entirety of tropical Africa.

Secondly, the numbers of specimens cited in each account varies massively and this does not always seem to have the expected consequences. In the first section of this chapter (2.3.1.2) it was found that the number of specimens of *Aframomum* collected accelerated sharply in the second half of the twentieth century, doubling between 1966 and 2000. The increase in the number of specimens can also be seen in numbers of specimens cited per species (Figure 2.5) in the *Flora of West Tropical Africa* accounts (1936 and 1968) compared with earlier the *Flora of Tropical Africa* or *Das Pflanzenreich* accounts (1898 and 1904). However within these taxonomic accounts the increase in the number of specimens appears to have resulted in the numbers of mixed species concepts actually getting worse during the mid-twentieth century. The numbers of specimens examined for each subsequent account increased; the mean number of species increased from 3.1 in *Flora of Tropical Africa* (1898) and 2.4 in *Das Pflanzenreich* (1904) to 8.9 by *Flora of West Tropical Africa* 2nd ed. (1968) and 5.9 in *Flora of Tropical East Africa* (1985).

It is expected that the quality of a taxonomic accounts will improve with more specimens available to examine. When there are fewer specimens available to examine there can be more instances of singleton species – species with just one specimen cited – and in some instances these are the type specimens. The *Das Pflanzenreich* account for example, cited many type specimens, in which case the determination has to be correct by definition. Thus the relatively high percentage of correct determinations in *Das Pflanzenreich* may simply be an artefact. For regional Flora accounts the citing of a single specimen may just be a pragmatic response to a lack of collections for that species from the geographical area of interest.

2.4 CONCLUSIONS

The first target of the Global Strategy for Plant Conservation (GSPC) is to produce "an online Flora of all known plants" by 2020 (Sharrock, 2012), this target underpins the other 15 conservation targets. However, in this chapter a detailed examination of the history of a genus of tropical plants through the names, specimens, determinations, authors of the determinations and past taxonomic accounts has revealed two things: Firstly, in the absence of a recent comprehensive taxonomic revision there are large levels of confusion in the system. More than half of the *Aframomum* specimens in herbaria do not have the correct name prior to being monographed and confusion in names and determinations is fragmentary and mixed up with misinformation across specimens and collections in different herbaria and relevant taxonomic literature. The long time lag to correctly determine a specimen (38 years) indicates that the discovery lag of 35 years (Bebber *et al.*, 2010; Fontaine *et al.*, 2012) may just be the first stage in a series of time lags before a species can be fully understood and known. Secondly, that the rate of specimen collection in *Aframomum* accelerated rapidly in the second half of the twentieth century, leading a doubling in the number of specimens between 1966 and 2000. These two results suggest that the 2020 target of an online Flora is very ambitious.

Improvements in the quality of specimen determinations and literature do occur over time, the fastest improvements occur when a few individuals are able to gain experience and focus their efforts on the group. However, the data on specimen determinations presented here suggests that the efforts of single individuals were overwhelmed by the doubling of *Aframomum* specimens between 1966 and 2000. More alarmingly it is not clear where the new experts are going to come from. There is pressure on modern academics to publish high impact papers and a reluctance to invest in the experience across a lifetime, taxa and geography which is needed to build-up expertise.

2.5 BIBLIOGRAPHY

Baker, J. G. (1898). Order CXXXIV. *Scitamineae*. In *Flora of Tropical Africa*. W. T. Thiselton-Dyer. London, Lovell Reeve. 7: 293–331.

Bebber, D. P., *et al*. (2012). "Big hitting collectors make massive and disproportionate contribution to the discovery of plant species." *Proceedings of the Royal Society B: Biological Sciences* 279: 2269–2274.

Bebber, D. P., *et al*. (2010). "Herbaria are a major frontier for species discovery." *PNAS* 107: 22169–22171.

Bebber, D. P., *et al*. (2007). "Predicting unknown species numbers using discovery curves." *Proceedings of the Royal Society B: Biological Sciences* 274: 1651–1658.

Bebber, D. P., *et al*. (2014). "Author inflation masks global capacity for species discovery in flowering plants." *New Phytologist* 201: 700–706.

Beentje, H. and S. Smith (2001). "FTEA and after." *Systematics and Geography of Plants* 71: 265–290.

Blackburn, T. M. and K. J. Gaston (1994). "Animal body size distributions change as more species are described." *Proceedings of the Royal Society B: Biological Sciences* 257: 293–297.

Blackburn, T. M. and K. J. Gaston (1995). "What determines the probability of discovering species?: A study of South American oscine passerine birds." *Journal of Biogeography* 22: 7–14.

Bramwell, D. (2002). "How many plant species are there?" *Plant Talk* 28: 32–34.

Choi, S.-W. (2006). "Patterns of species description and species richness of Geometrid moths (Lepidoptera: Geometridae) on the Korean Peninsula." *Zoological Science* 23: 155–160.

Dhetchuvi, J.-B. and E. Fischer (2006). "A new species of *Aframomum* (Zingiberaceae) from Nyungwe National Park/Rwanda." *Systematics and Geography of Plants* 76: 241–245.

Dhetchuvi, J.-B., *et al*. (2011). "A new species of *Aframomum* (Zingiberaceae) from Central Africa." *Phytotaxa* 28: 31–34.

Fattorini, S., *et al*. (2012). "Tackling the taxonomic impediment: a global assessment for ant-nest beetle diversity (Coleoptera: Carabidae: Paussini)." *Biological Journal of the Linnean Society* 105: 330–339.

Feeley, K. J. (2015). "Are we filling the data void? an assessment of the amount and extent of plant collection records and census data available for tropical South America." *PLoS ONE* 10: e0125629.

Feeley, K. J. and M. R. Silman (2011). "The data void in modeling current and future distributions of tropical species." *Global Change Biology* 17: 626–630.

Fontaine, B., *et al*. (2012). "21 years of shelf life between discovery and description of new species." *Current Biology* 22: R943–R944.

Gaston, K. J. and T. M. Blackburn (1994). "Are newly described bird species small-bodied?" *Biodiversity Letters* 2: 16–20.

Gaston, K. J., *et al*. (1995a). "Which species are described first?: The case of North American butterflies." *Biodiversity and Conservation* 4: 119–127.

Gaston, K. J., *et al*. (1995b). "Patterns in species description: a case study using the Geometridae (Lepidoptera)." *Biological Journal of the Linnean Society* 55: 225–237.

Goodwin, Z. A., *et al*. (2015). "Widespread mistaken identity in tropical plant collections." *Current Biology* 25: R1066–R1067.

Govaerts, R. (2001). "How many species of seed plants are there?" *Taxon* 50: 1085–1090.

Groom, Q. *et al*. (2014). “Herbarium specimens reveal the exchange network of British and Irish botanists, 1856–1932.” *New Journal of Botany* 4: 95–103.

Harris, D. J. and A. H. Wortley (in press). "Monograph of *Aframomum* (Zingiberaceae)." *Systematic Botany Monographs*.
Hawthorne, W. D. and C. A. M. Marshall (2016). A manual for Rapid Botanic Survey (RBS) and measurement of vegetation bioquality. Published online, Department of Plant Sciences, University of Oxford, U.K. 56.
Hepper, F. N. (1968). 3. *Aframomum*. In *Flora of West Tropical Africa*. London, Crown Agents for Oversea Governments and Administrations. 3: 72–77.
Heywood, V. (2001). "Floristics and monography-an uncertain future?" *Taxon* 50: 361–380.
Hortal, J., *et al*. (2008). "Historical bias in biodiversity inventories affects the observed environmental niche of the species." *Oikos* 117: 847–858.
Hutchinson, J. and J. M. Dalziel (1936a). 1. *Aframomum*. In *Flora of West Tropical Africa*. London, Crown Agents for the Colonies. 2: 329–331.
Hutchinson, J. and J. M. Dalziel (1936b). *Aframomum*. In *Flora of West Tropical Africa*. London, Crown Agents for the Colonies. Appendix: 470–472.
IUCN. (2016). "IUCN Red List of Threatened Species. Version 2016.3." Retrieved April 2017, from http://www.iucnredlist.org.
Joppa, L. N., *et al*. (2010). "How many species of flowering plants are there?" *Proceedings of the Royal Society B: Biological Sciences* 278: 554–559.
Koechlin, J. (1965). Scitamineae. In *Flore du Cameroun*. Paris, Museum National d'histoire Naturelle. 4: 19–95.
Lindon, H. L., *et al*. (2015). "Fewer than three percent of land plant species named by women: author gender over 260 years." *Taxon* 2: 209–215.
Linnaeus, C. v. (1753). *Species plantarum*. Stockholm, Laurentius Salvius. xi, 1200 + xxxi.
Lock, J. M. (1976). "Notes on East African species of *Aframomum* (Zingiberaceae)." *Kew Bulletin* 31: 263–271.
Lock, J. M. (1978a). "Notes on the genus *Aframomum* (Zingiberaceae). 2. The Ethiopian species." *Bulletin du Jardin Botanique National de Belgique* 48: 387–391.
Lock, J. M. (1978b). "Notes on the genus *Aframomum* (Zingiberaceae). 3. Two new species from West Africa." *Bulletin du Jardin Botanique National de Belgique* 48: 393–398.
Lock, J. M. (1978c). "Notes on the genus *Aframomum* (Zingiberaceae): 1. The species related to *Aframomum polyanthum* (K. Schum.) K. Schum. ." *Bulletin du Jardin Botanique National de Belgique* 48: 129–134.
Lock, J. M. (1979). "Notes on the genus *Aframomum* (Zingiberaceae). 4. The savanna species." *Bulletin du Jardin Botanique National de Belgique* 49: 179–184.
Lock, J. M. (1980). "Notes on *Aframomum* (Zingiberaceae) in West Africa, with a new key to the species." *Kew Bulletin* 35: 299–313.
Lock, J. M. (1984). "Notes on East African Zingiberaceae." *Kew Bulletin* 39: 837–843.
Lock, J. M. (1985). Zingiberaceae. In *Flora of Tropical East Africa*. R. M. Polhill. Rotterdam, A.A. Balkema. Zingiberaceae: 22–37.
Lock, J. M. and J. B. Hall (1973). "Three new species of *Aframomum* K.Schum. (Zingiberaceae) from Ghana, with notes on spherical geocarpic fruits in the genus." *Kew Bulletin* 28: 441–449.
Lock, J. M. and J. B. Hall (1975). "Taxonomic studies in the genus *Aframomum* (Zingiberaceae)." *Boissiera* 24: 225–231.
Lock, J. M., *et al*. (1977). "The cultivation of melegueta pepper." *Economic Botany* 31: 321–330.
Lughadha, E. M. N., *et al*. (2016). "Counting counts: revised estimates of numbers of accepted species of flowering plants, seed plants, vascular plants and land plants with a review of other recent estimates." *Phytotaxa* 272: 082–088.

Myers, N., *et al*. (2000). "Biodiversity hotspots for conservation priorities." *Nature* 403: 853–858.
Poulsen, A. D. and J. M. Lock (1997). "New species and new records of Zingiberaceae and Costaceae from tropical East Africa." *Kew Bulletin* 52: 601–616.
Poulsen, A. D. and J. M. Lock (1999). A review of African forest Zingiberaceae. In *African plants: biodiversity, taxonomy and uses: proceedings of the 1997 AETFAT congress, Harare, Zimbabwe*. J. R. Timberlake and S. Kativu. Kew, Royal Botanic Gardens, Kew: 51–64.
Raven, P. H. (1988). "Tropical floristics tomorrow." *Taxon* 37: 549–560.
Schumann, K. M. (1904). Zingiberaceae. In *Das Pflanzenreich: Regni vegetabilis conspectus*. A. Engler. Leipzig, Wilhelm Engelmann 46: 201–221.
Scoble, M. J., *et al*. (1995). "Using taxonomic data to estimate species richness in Geometridae " *Journal of the Lepidopterists' Society* 49: 136–147
Scotland, R. W. and A. H. Wortley (2003). "How many species of seed plants are there?" *Taxon* 52: 101–104.
Sharrock, S. (2012). Global Strategy for Plant Conservation: a guide to the GSPC - All the targets, objectives and facts. Richmond, Botanic Gardens Conservation International: 36.
Sihvonen, P. and M. Siljander (2005). "Species diversity and geographical distribution of Scopulini moths (Lepidoptera: Geometridae, Sterrhinae) on a world-wide scale." *Biodiversity & Conservation* 14: 703–721.
Stropp, J., *et al*. (2016). "Mapping ignorance: 300 years of collecting flowering plants in Africa." *Global Ecology and Biogeography* 25: 1085–1096.
ter Steege, H., *et al*. (2013). "Hyperdominance in the Amazonian tree flora." *Science* 342: 1243092.
The Plant List. (2013). "Version 1.1." Retrieved April 2017, from http://www.theplantlist.org/.
Thorne, R. F. (2002). "How many species of seed plants are there?" *Taxon* 51 511–512.
Tropicos. (2017). Retrieved April 2017, from http://www.tropicos.org/
Wayt Thomas, W. (1999). "Conservation and monographic research on the flora of Tropical America." *Biodiversity and Conservation* 8: 1007–1015.
Wayt Thomas, W. (2016). "125 years of floristic research and collecting at The New York Botanical Garden. " *Brittonia* 68: 222–229.
Willis, J. C. (1922). *Age and area; a study in geographical distribution and origin of species*. London, Cambridge University Press. 284.
Wortley, A. H. and R. W. Scotland (2004). "Synonymy, sampling and seed plant numbers." *Taxon* 53: 478–480.

3 Widespread mistaken identity in tropical plant collections

CONTENTS

3.1 INTRODUCTION

In Chapter 2 detailed examination of the history of herbarium specimens and literature revealed much uncertainty in the historical understanding of *Aframomum*. The focused efforts of a few experts in the 1970s and 1990s to revise the genus considerably improved understanding of *Aframomum*, however this was overwhelmed by a doubling in the number of *Aframomum* specimens between 1966 and 2000.

These results have profound implications for the process of species discovery and the completion of targets 1 and 2 of the Global Strategy for Plant Conservation (Sharrock, 2012) if these patterns are found to be universal across the seed plants. However, such results need to be generalised to other groups and other areas, as it is possible that the patterns observed are unique to *Aframomum* or caused by the history of specimen collecting in tropical Africa. This chapter investigates the universality of the pattern of uncertainty in specimen determinations and rapid specimen accumulation in the late twentieth century amongst seed plants.

Most of this chapter has been published as ‘Widespread mistaken identity in tropical plant collections’ (Goodwin *et al.*, 2015). I am the main author of this paper and responsible for the work in the paper. For section 0 the code in BRAHMS to extract the data was written by D. Filer under my guidance.

3.2 MATERIALS AND METHODS

3.2.1 DOCUMENTING UNCERTAINTY IN NATURAL HISTORY COLLECTIONS

To document the uncertainty in the names of seed plant herbarium specimens three different analyses were conducted to:

- Examine the complete determination history of a subset of species in two genera (*Hypericum* and *Inga*).
- Examine levels of inconsistency in the determination between duplicate specimens of Dipterocarpaceae in different herbaria.
- Examine the status of names used on specimens in GBIF in *Ipomoea* and *Aframomum*.

These taxa were chosen for pragmatic reasons, primarily due to data availability. *Inga* and *Hypericum* were investigated at MO because they were two species-rich genera which had been recently revised so the current filing names for the specimens should have been accurate and which initial inspection of the herbarium catalogue (Tropicos, 2017) indicated should be well represented in the MO herbarium. Dipterocarpaceae was investigated because it was a large tropical family which was considered to be well-known and which is particularly diverse in SE Asia, a region where multiple local and regional herbaria have accessible BRAHMS-based herbarium databases. For the GBIF study; *Ipomoea*, another diverse tropical group, was being revised in the Neotropics by John Wood at the University of Oxford. *Aframomum* was investigated in GBIF because it is well-known in this study and would be interesting to compare this with a group such as *Ipomoea* where it was not understood how well or poorly the group was understood.

3.2.1.1 The history of *Inga* and *Hypericum* specimen determinations

To generalise the results from the investigation into the complete determination history of *Aframomum* (Chapter 2) the analysis was repeated for a sample of species and specimens from two other recently revised genera: tropical *Inga* (Pennington, 1997) and temperate *Hypericum* (Carine and Christenhusz, 2010). Determinations were examined for collections of *Inga* (512 specimens, 531 duplicates) and *Hypericum* (366 specimens, 376 duplicates) held in the herbarium of Missouri Botanical Garden (MO) in March 2015.

3.2.1.1.1 Data management and recording

Specimen and determination information was assembled in purpose-built databases in BRAHMS (Filer, 2015). *Hypericum* specimen records were downloaded from the MO online herbarium catalogue (Tropicos, 2017), formatted, and imported into BRAHMS. A copy of the *Inga* database (Pennington, 1995) containing information from the monograph of the same genus (Pennington, 1997) was downloaded and supplemented with *Inga* specimen records downloaded from the MO online herbarium catalogue (Tropicos, 2017).

Herbarium specimens in the MO herbarium were examined (detailed in 3.2.1.1.2) and the determination history for each specimen recorded in the database. The records for most specimens were present in the database due to the incorporation of the MO herbarium catalogue records. However, when a specimen which was not present in the database was seen in the herbarium then a new specimen record was added to the database and only basic details were recorded, including the first collector name, collection number, date of collection, country and current filing name.

The entire determination history of every sheet seen at MO in 2015 was recorded; including species name, date and name of the author of the determination on each specimen. The scientific names given in all determinations were then classified as either ‘accepted’, ‘synonym’, ‘indeterminate’ or ‘other’ relative to the current filing name and the status of that name in the recent monographs (Robson, 1990; Robson, 1993; Robson, 1996; Pennington, 1997; Robson, 2001; Robson, 2002; Robson, 2006; Robson, 2010a; Robson, 2010b). The determination data were then cleaned and processed as described in Chapter 2.

3.2.1.1.2 Sampling

Specimens in the MO herbarium are organised within each family alphabetically by genus, geographical region and then alphabetically by species name (Missouri Botanical Gardens, 2013). The geographical regions are organised in the following order: North America, Central America including Mexico, Panama, West Indies, South America, Europe, Asia, Africa (in part), Southern Africa, Madagascar and Oceania.

Species of *Inga* were selected to represent A) the different regions of the Americas and B) a mix of geographically widespread (Green and Blue Star, following Hawthorne and Marshall, 2016) and restricted (Gold and Black Star) species (Appendix 3.1.1) following distribution data available in the *Inga* Monograph (Pennington, 1997).

Species of *Hypericum* were sampled to obtain coverage of both tropical montane and temperate regions across different continents (Appendix 3.1.2) following distribution data available in the *Hypericum* Monograph (Robson, 1985; Robson, 1993; Robson, 1996; Robson, 2001; Robson, 2002; Robson, 2006; Robson, 2010a; Robson, 2010b).

The first species seen in the herbarium were examined. Thus the bulk of species examined were towards the start of the alphabet. The number of specimens examined with a complete determination history (i.e. where a date was present for every determination recorded) for each species in the MO herbarium is provided in Appendices 3.1.1 and 3.1.2. The total number of specimens present for each species is also provided.

For geographically widespread species with hundreds of specimens, such as *Inga vera* Kunth and *Hypericum ascyron* L., a small number of specimens from each geographical region or continent across the species’ geographical range were sampled. For geographically restricted species with small numbers of specimens, such as *Inga aliena* J.F. Macbride and *Hypericum callacallanum* N. Robson, then all available specimens were recorded.

The determination history of *Inga* and *Hypericum* was examined in two ways:

3.2.1.1.3 Determination history

The specimen and determination data were filtered to include only specimens for which both A) the year of collection and B) the year of every determination are recorded (*Hypericum* 366 specimen collections, 376 sheets; *Inga* 500 specimen collections, 527 sheets). The accumulation of specimens and the class of determination were scored and plotted over time.

3.2.1.1.4 Time lag between collection and correct determination of specimens

The mean time lag between the year of collection and the first year in which the current determination was applied to each specimen was calculated for all specimens of *Hypericum* and *Inga*.

3.2.1.2 Dipterocarpaceae determinations across herbaria

To assess the percentage of different names on duplicate specimens housed in different herbaria, data for 58,860 herbarium specimens of Dipterocarpaceae were acquired from nine herbaria (E, KEP, L, MO, SAN, SAR, SING, U, WAG). The specimen data were imported and combined into a single database in BRAHMS and matched for collection number and year of collection to identify specimen records from different herbaria which were duplicates of the same collection. The code in BRAHMS to match the specimens and compare specimen determinations was written and developed in collaboration with D. Filer. The 9,222 matched collections of 21,075 specimens were then flagged when one or more specimens had a different determination at genus or species level. The numbers of specimens matched across different herbaria with the same and different determination were recorded.

3.2.1.3 *Ipomoea* and *Aframomum* names in GBIF

To assess the quality of names used on specimen records provided in GBIF, occurrence data for *Ipomoea* ('Scientific name' = '*Ipomoea*' and 'Basis of record' = 'Specimen', access date 9th December 2014) and *Aframomum* ('Scientific name' = '*Aframomum*' and 'Basis of record' = 'Specimen', access date 28th October 2014) were downloaded from GBIF (Data CD), records were filtered by location (*Aframomum* restricted to Africa, *Ipomoea* restricted to Americas). Then the names were assessed against recent and ongoing taxonomic revisions (Wood *et al.*, 2015; Harris and Wortley, in press) and scored as 'accepted' (including basionyms), 'synonym', 'unknown' or 'excluded'. The number of each type of name in use were determined as 'accepted', 'synonym', 'unknown' or 'excluded' were counted. The number of specimens determined as 'accepted', 'synonym', 'unknown', 'excluded' or 'indeterminate' (to genus only) were counted.

3.2.2 Accumulation of specimens and herbaria over time

To document the rates of specimen accumulation across the herbarium collections of seed plants three investigations were conducted to:

- Examine the accumulation of seed plant specimens prior to 2000 in a selection of taxa and regions from around the world.
- Examine the numbers of specimens received by a selection of international and regional herbaria from 1974 onwards.
- Examine the accumulation of herbaria worldwide from 1550 onwards.

3.2.2.1 Accumulation of specimens

To document plant specimen collection rates until 2000, collection years for twelve specimen data sets were downloaded from online databases (Appendix 3.2.1) for seven groups, four regional floras and a global aggregated online dataset. The taxa and floras cover a range of distributions – northern temperate (Rocky Mountain Herbarium), tropical African (*Aframomum* and Gabon), tropical Asian (*Aglaia* and Singapore Botanic Garden Herbarium), tropical American (*Inga*, *Leucaena*, and Belize), pantropical (Dipterocarpaceae and *Ipomoea*), and global (Conifers of the World) – and habits – trees (*Aglaia*, Conifers, Dipterocarpaceae, *Inga* and *Leucaena*), herbs (*Aframomum*), and climbers (*Ipomoea*). The GBIF data were occurrence data downloaded using two filters: 'scientific name' = 'Plantae (Kingdom)' and 'basis of record' = 'specimen' (access date 10th February 2015). Cumulative numbers of specimens collected per year between 1700 and 2000 were plotted for each dataset. Data were only plotted to 2000 due to the lag in specimens being accessioned into herbaria and digitised, two datasets (*Inga* and *Leucaena*) only include data up to 1994 and 1996 respectively.

3.2.2.2 Recent accumulation of specimens

To document specimen accumulation rates in herbaria post-2000 current herbarium growth rates were obtained by surveying official documentation or consulting collection managers at major international herbaria to estimate the current size of their collection and the average numbers of specimens received annually between 2004 and 2013.
To examine whether or not specimen accumulation rates in herbaria changed from the mid-1970s to 2014, an examination of individual herbaria growth rates over time was conducted by updating a table from Prance (2001) using 2014 data from *Index Herbariorum* (Thiers,

2015). Using this the mean annual increase in specimens between 1974 – 1990 and 1990 – 2014 was calculated.

3.2.2.3 Accumulation of herbaria

To document accumulation of herbaria worldwide herbarium foundation dates, status and locations were downloaded from *Index Herbariorum* (Thiers, 2015). The accumulation of herbaria was plotted over time, the mean and standard deviation of foundation dates of herbaria were calculated globally and per continent.

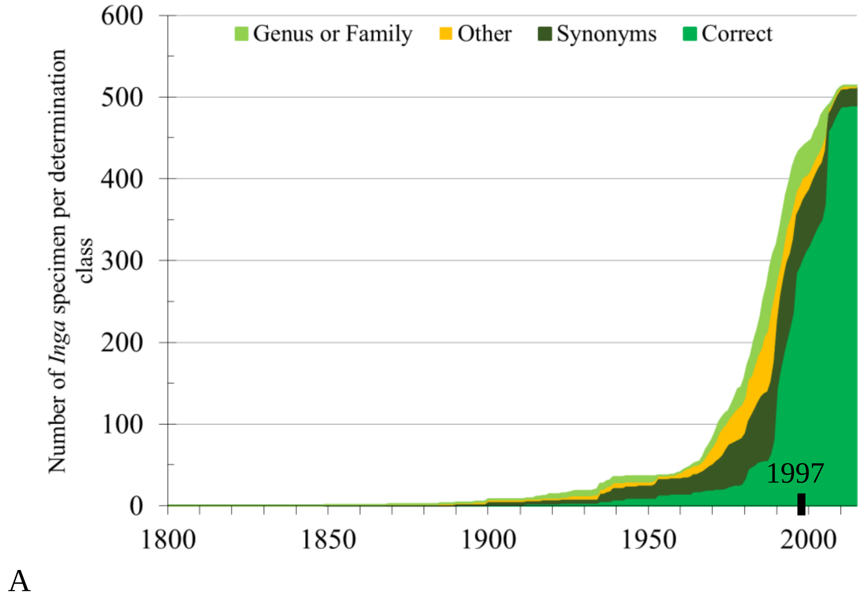
3.3 Results and Discussion

3.3.1 Documenting uncertainty in natural history collections

Here I investigate levels of uncertainty in the taxonomy and nomenclature on plant specimens in three different ways to verify the generality of the uncertainty in *Aframomum* specimens documented in Chapter 2.

3.3.1.1 History of *Inga* and *Hypericum* specimen determinations

The neotropical genus *Inga* (Figure 3.1A) shows a similar pattern in the history of specimen determination and accumulation to that of *Aframomum* (Chapter 2); there is a dramatic increase in the percentage of specimens with a name which is currently considered to be accepted pre-revision (21 – 36%, 1900 – 1989, Appendix 3.1.3A) to post-revision (71 – 95%,



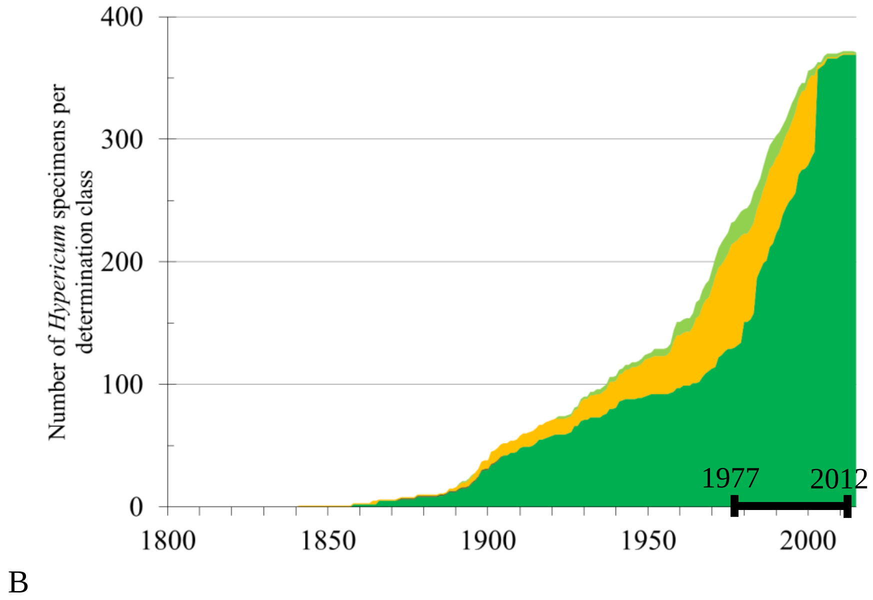


Figure 3.1 Documenting uncertainty in *Inga* and *Hypericum*. Accumulation of (A) *Inga* (*N* = 530) and (B) *Hypericum* (*N* = 372) specimens and their determinations classes relative to the filing names and relevant monographs (see 3.2.1.1) between 1800 and 2015. Monograph publication dates indicated for *Inga* (1997) and *Hypericum* (1977 – 2012).

1990 – 2015).
The predominantly temperate genus *Hypericum* (Figure 3.1B) had a higher percentage of specimens under names which are considered to be accepted pre-revision during the twentieth century (58 – 82%, Appendix 3.1.3B) than for *Aframomum* and *Inga*. The percentage of accepted names on *Hypericum* specimens improved further in the late 1990s, rising to >90%. *Inga* specimens tended to have been collected much later (*M* = 1982.7, *SD* = 20.8, range 1849 – 2011) than *Hypericum* specimens (*M* = 1958.7, *SD* = 36.4, 1841 – 2011) and also showed a marginally shorter time lag to the correct determination of 9.5 years (*SD* = 15.8) compared to 13.1 years (*SD* = 20.9).

3.3.1.2 Dipterocarpaceae determinations across herbaria

A total of 58,860 specimens of Dipterocarpaceae were collated from nine international and regional herbaria, 21,075 specimens were identified as being duplicate specimens of 9,222 different collections. Of these 9,222 collections, 29.1% of them had different generic and/or specific names between duplicates in different herbaria (Figure 3.2A, Appendix 3.1.5).

3.3.1.3 *Ipomoea* and *Aframomum* names in GBIF

Examination of the 91 *Aframomum* names on specimens from Africa and 560 *Ipomoea* names from the Americas in GBIF (Figure 3.2B) revealed a large proportion of the names to be synonyms (*Aframomum* 43%, *Ipomoea* 40%) and to a lesser extent invalid, erroneous or unrecognised names (*Aframomum* 3%, *Ipomoea* 16%, ‘excluded’ in Figure 3.2B) and unknown names (*Aframomum* 0.1%, *Ipomoea* 0.9%, Appendix 3.1.4).

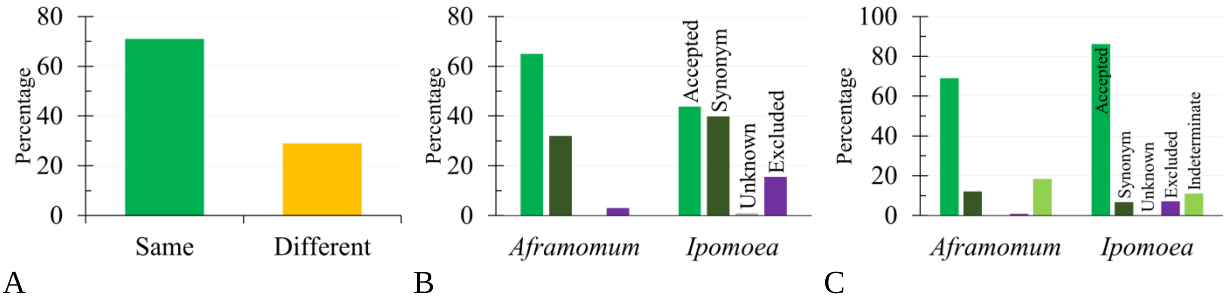


Figure 3.2 Documenting uncertainty in specimens between herbaria and in GBIF. (A) Percentages of determinations on specimens of Dipterocarpaceae which are same (green) or different (orange) between duplicate specimens held in different herbaria. (B) Quality of names (percentage) in use on specimens in GBIF for *Aframomum* and *Ipomoea* (from the Americas) which are considered to be accepted (mid green), synonyms (dark green), unknown (grey) or excluded (purple). (C) Percentage of *Aframomum* and *Ipomoea* (from the Americas) specimens in GBIF which have names which are considered to be accepted (mid green), synonyms (dark green), unknown (grey), excluded (purple) or indeterminate (light green).

The majority of specimens for both species were filed under accepted names (*Aframomum* including basionyms of accepted names 69%, *Ipomoea* 86%, Figure 3.2C), the remainder of the specimens were filed under names which are considered to be synonyms (*Aframomum* 12%, *Ipomoea* 7%), excluded including invalid or erroneous names (*Aframomum* 1%, *Ipomoea* 7%), and a substantial percentage had genus level determinations (*Aframomum* 18%, *Ipomoea* 11%).

3.3.1.4 Discussion

In this section I investigated the levels of taxonomic and nomenclatural uncertainty associated with seed plant specimens in three different ways.
Firstly, the complete determination history of a sample of *Hypericum* and *Inga* specimens were investigated as a direct comparison to the analysis of *Aframomum* specimen

determinations in Chapter 2. The *Inga* specimens examined show substantial uncertainty in specimen determination. Prior to Pennington's 1997 taxonomic revision more than 50% of the specimens did not have a name which is currently considered to be the accepted name. This is similar to the result found for *Aframomum* in Chapter 2. The proportion of correct names on specimens was higher in *Hypericum* than that for *Inga* and *Aframomum* for much of the twentieth century. This may be due to *Hypericum* being widespread in the northern temperate zones (Mabberley, 1990) rather than the poorly known tropical regions (Heywood, 2001) like *Inga* and *Aframomum*, the large proportion of older specimens (Figure 3.1B) and the long-term effort to revise *Hypericum* (33 years, Carine and Christenhusz, 2010).
There is one difference between the *Aframomum* data examined in Chapter 2 and the *Inga* and *Hypericum* data examined in this chapter. The historical determinations on each *Aframomum* specimen were compared with the determination given to that specimen collection in the recent monograph (Harris and Wortley, in press). Whereas for *Inga* and *Hypericum*, the historical determination data was compared to the current filing name of the specimen and the current status of that filing name. This is different in two ways; not all of the *Inga* and *Hypericum* specimens had been determined by the botanists who have revised the two genera, and a few of the filing names are considered to be synonyms and are not accepted by the recent monograph. However, the important principle remains that both analyses examine past determinations compared to the current determination.
Secondly, I measured the relative inconsistency of names given to the same collections of Dipterocarpaceae housed at different herbaria. This data indicates that the same general pattern of uncertainty found in *Aframomum* occurs in other tropical taxa. In this case 29% of 9,222 collections had different names in different herbaria and this must indicate a high degree of misidentification even before considering the possibility that all the determinations could be wrong. This is alarming because the Dipterocarpaceae is a relatively well understood tropical group having been recently revised (Ashton, 1982; Ashton, 2004) due to their being an economically important source of timber (Appanah, 1998). This result suggests that while recently revised groups such as the Dipterocarpaceae may not need a full revision there is still a need for experts to keep checking the names on specimens across collections around the World. The current system for comparing specimens with each other, with literature, and by experts has failed to keep names consistent across all specimens within the same collection. Whether this is due to too many specimens scattered over too many herbaria for experts to examine them all, inadequate identification literature or maybe a combination of the two is hard to tell with this data. However, the integration of online databases should assist with the comparison of specimen names between collections in the future.
Thirdly, I investigated the quality of names in use on specimens in GBIF. This data demonstrated that errors with specimen names are inherited by online aggregator datasets, leading to the potential use of erroneous data. The large proportion of *Aframomum* and *Ipomoea* names associated with specimens in GBIF which are synonyms, invalid, erroneous or unknown names indicates that the taxonomic uncertainty documented here on *Aframomum* and *Inga* specimens are present in online aggregated databases such as GBIF too (Hjarding *et al.*, 2014).
The results were different when I examined the numbers of specimens associated with each type of name; the majority of *Ipomoea* (86.2%) and *Aframomum* (67.8%) specimens in GBIF were associated with names which were accepted. This may be due to a high proportion of specimens filed under the names of widespread accepted species names (ter Steege *et al.*, 2013). Seven (1.1%) *Ipomoea* names had more than 1,000 specimens each in GBIF (one species had >7,000 specimens), all seven names were accepted species which are either pantropical, circum-Caribbean or cultivated (J.R.I. Wood, pers. comm.). This does not mean that the determinations are correct, just that most specimens were filed under a few accepted

names. The results for *Inga* and *Aframomum* (Chapter 2) indicate that a substantial proportion of the determinations under accepted names will be misidentifications. In addition a significant proportion of the specimens in GBIF were still unidentified to species or were determined as names which were synonyms, excluded or unknown.

The GBIF data is important because there has been copious criticism of incomplete records (Mesibov, 2013; Otegui *et al.*, 2013), geographic bias (Yesson *et al.*, 2007; Collen *et al.*, 2008; Beck *et al.*, 2013; Otegui *et al.*, 2013; Ferro and Flick, 2015), small numbers of useable records (Edwards and Smith, 2010; Feeley and Silman, 2011; Feeley, 2015; Stropp *et al.*, 2016) and the poor quality of geographic data (Mesibov, 2013; Hjarding *et al.*, 2014; Maldonado *et al.*, 2015) in aggregated online databases such as GBIF. This study adds to the evidence (Otegui *et al.*, 2013; Hjarding *et al.*, 2014) that poor quality determinations and taxonomy also affects such data.

The poor data quality (Mesibov, 2013; Otegui *et al.*, 2013) of records in aggregated databases and consequential wastage of unusable specimen records (Edwards and Smith, 2010; Feeley and Silman, 2011; Feeley, 2015; Stropp *et al.*, 2016) was an issue in this study. Originally the analysis of *Aframomum* specimen records in GBIF was intended to match up and compare the determinations of the specimens which are held in both GBIF and the *Aframomum* project database. However the quality of *Aframomum* specimen records in GBIF was too low to allow this. The GBIF data suffered the problems commonly associated with large specimen datasets such as spelling, missing information, accuracy of geographical information and widely varying interpretation of text and numbers for example collection numbers with prefixes and suffixes and collection dates. In addition these problems were inconsistent between different data providers within the GBIF dataset.

The three sets of results presented in this section indicate that the historical patterns of uncertainty in specimen collections found for *Aframomum* in Chapter 2 are representative and can be generalized to other tropical natural history collections of plants. The *Inga* and *Hypericum* data investigated here support the analysis in Chapter 2 that more than 50% of seed plant specimens in natural history collections may not have the correct name in the absence of a comprehensive taxonomic revision. The *Hypericum* results indicate that these high proportions of specimens without correct names may be more prevalent in tropical taxa than temperate. The pattern documented here for seed plants may also be true and possibly worse for insects (Meier and Dikow, 2004) and fungi (Ainsworth *et al.*, 2013; Dentinger and Suz, 2014) given their greater numbers of taxa, lower numbers of specialists and their higher number of undescribed taxa (Mora *et al.*, 2011; Scheffers *et al.*, 2012).

The results here also show that improvements in the understanding of a group do not necessarily result in accurate names in all herbaria even with economically important groups such as the Dipterocarps which have been recently revised (Ashton, 1982; Ashton, 2004). This uncertainty is transferred to online aggregated databases, the route by which most non-specialist users will access the data (Edwards and Smith, 2010; Khoury *et al.*, 2015).

3.3.2 Accumulation of specimens and herbaria over time

Here I investigate the accumulation of specimens and herbaria over time in order to verify the generality of the huge increase in the accumulation of *Aframomum* specimens during the twentieth century documented in Chapter 2.

3.3.2.1 Accumulation of specimens

The number of tropical plant specimens in herbaria has grown enormously in the latter part of the twentieth century, with a doubling of the number of specimens stored in herbaria between 1970 and 2000. This pattern can be seen in a range of taxa (Figure 3.3A – G), geographical regions (Figure 3.3H – K) and in the 31 million plant specimens currently available in GBIF

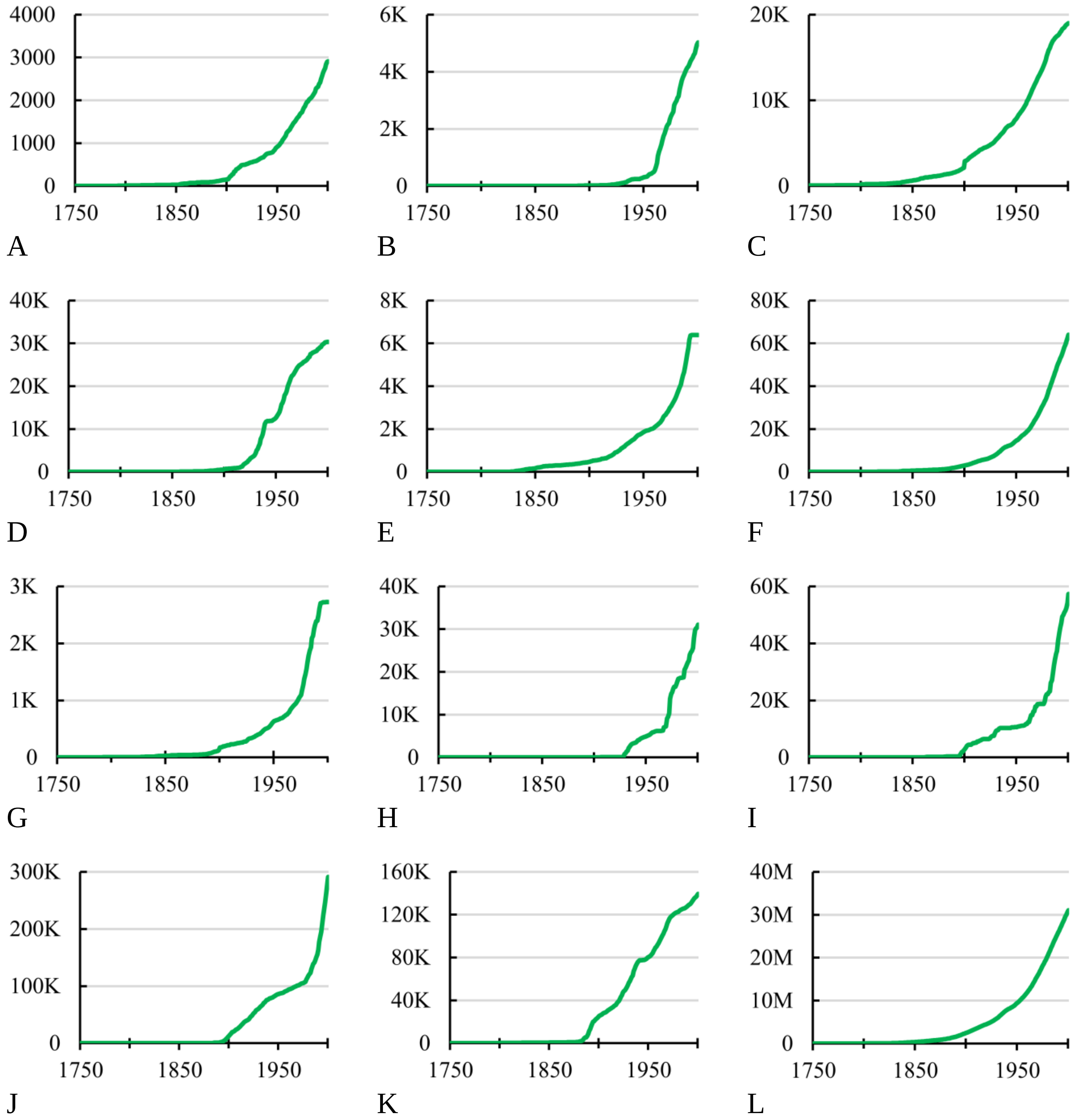


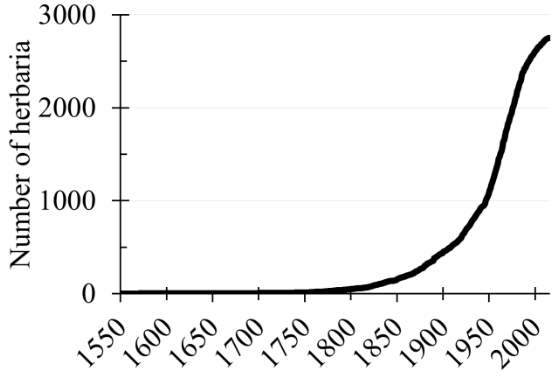
Figure 3.3 Accumulation of specimens over time in a range of taxa (A-G), geographical areas (H-K) and all plant records in GBIF (L). (A) *Aframomum*; *N* = 2,910, first collection in 1700, 50% collected in 1966 (B) *Aglaia*: *N* = 5,113, first collection in 1809, 50% collected in 1977 (C) Conifers of the World: *N* = 19,486, first collection in 1587, 50% collected in 1960 (D) Dipterocarpaceae: *N* = 30,367, first collection in 1818, 50% collected in 1955 (E) *Inga*: *N* = 6,393, first collection in 1792, 50% collected in 1977 (F) *Ipomoea* (GBIF): *N* = 63,996, first collection in 1712, 50% collected in 1977 (G) *Leucaena*: *N* = 2,803, first collection in 1783, 50% collected in 1979 (H) Belize: *N* = 38,456, first collection in 1840, 50% collected in 1987 (I) Gabon: *N* = 73,701, first collection in 1846, 50% collected in 1983 (J) Rocky Mountain Herbarium: *N* = 291,167, first collection in 1711, 50% collected in 1988 (K) SING Herbarium: *N* = 139,398, first collection in 1733, 50% collected in 1936 (L) GBIF (Plantae), all plant specimens in GBIF: *N* = 31,068,510, first collection in 1600, 50% collected in 1969.

(Figure 3.3L). This pattern is weaker in temperate collections from the Rocky Mountains (Figure 3.3J).

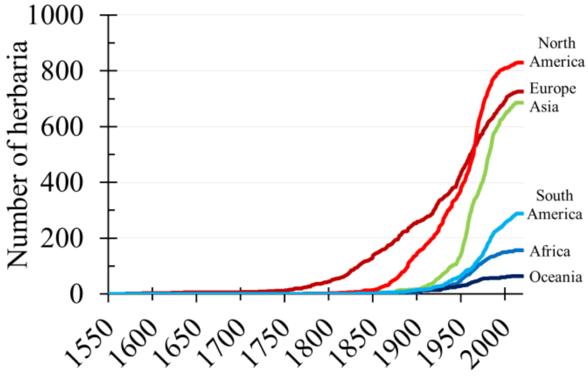
3.3.2.2 Recent accumulation of specimens

The number of new specimens arriving at many international herbaria in the last decade (2004 – 2013) is very high (Table 3.1) suggesting that the pattern of a huge increase in specimen numbers seen in the last 30 years of the twentieth century is continuing into the twenty first century. By their own estimates, large international herbaria around the world are growing by tens of thousands of specimens every year.

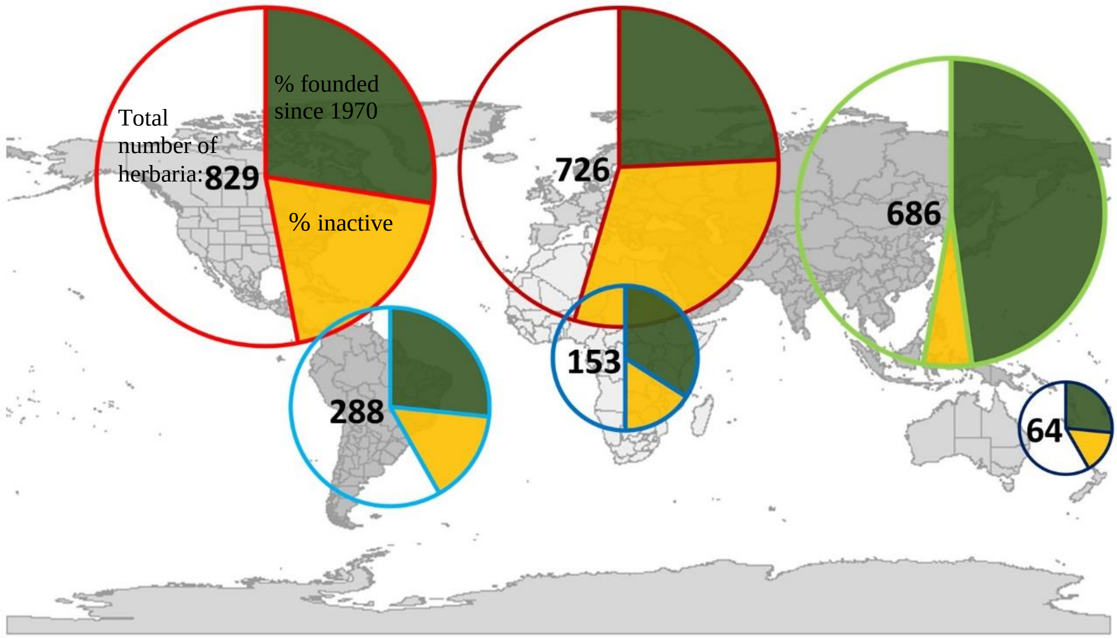
However, this pattern is complex, varying geographically and temporally (Table 3.2): Between 1974 and 1990 herbaria across the world from a mixture of richer temperate countries (CHR and NY), Asia (PE and KLU), Africa (EA) and Latin America (MEXU, RB and CR) were receiving large numbers of specimens. However, over the turn of the century the pattern changed. Between 1990 and 2014, regional herbaria across Central and South America (COL, MEXU and BR), Africa (AE) and Asia (BO) grew rapidly, receiving higher numbers of specimens than in the previous period. However, the bulk of the herbaria appear to have received fewer specimens per year in the period 1990 to 2014, some dramatically so (FHI and LAE). Uniquely, the NY herbarium appears to have grown consistently throughout the 40 year period with approximately 80,000 new specimens a year.



A



B



C

Figure 3.4 Accumulation of herbaria over time. Numbers of herbaria (A) globally and (B) per continent between 1550 and 2015 and (C) total number currently extant herbaria indicating percentage founded since 1970 (dark green) and percentage of herbaria which are currently registered as inactive (yellow). Where Africa (mid blue) N = 153, first herbarium founded in 1860, 50% founded in 1962, Asia (light green) N = 686, first herbarium founded in 1793, 50% founded in 1967, Europe (maroon) N = 726, first herbarium founded in 1569, 50% founded in 1937, North America (red) N = 829, first herbarium founded in 1771, 50% founded in 1956, Oceania (dark blue) N = 64, first herbarium founded in 1853, 50% founded in 1955, and South America (light blue) N = 288, first herbarium founded in 1831, 50% founded in 1975.

Table 3.1 Growth of selected herbaria between 2004 and 2013. Indicating estimated total in 2014 and estimated number of new specimens per year.

Herbarium, Country	Acronym	Total	Annual increase (2004 – 2013)
Royal Botanic Gardens, Kew, UK	K	7,000,000	30,000
Royal Botanic Garden Edinburgh, UK	E	3,000,000	10,000
Missouri Botanical Garden, USA	MO	5,870,000	58,000
New York Botanical Garden, USA	NY	7,300,000	51,244
Muséum National d'Histoire Naturelle, France	P	8,000,000	10,000
Smithsonian Institution, USA	US	4,340,000	20,000
National Autonomous University of Mexico, Mexico	MEXU	1,300,000	25,000
Institute of Botany, Chinese Academy of Sciences, Beijing, China	PE	2,500,000	30,000
Botanic Garden Meise, Belgium	BR	4,000,000	27,000

Table 3.2 Growth of selected herbaria between 1974, 1990 and 2014. Indicating number of collections, percentage growth for each period and mean number of new specimens per year over the 40 year period; an update of Table 1 from Prance (2001), original data from Holmgren and Keuken (1974), Holmgren and Holmgren (1990) and Thiers (2015) except 2014 data for PE from institution's own website (Zhang, 2015).

Herbarium, Country	Acronym	No. of collections 1974	No. of collections 1990	No. of collections 2014	% Growth 1974 – 1990	% Growth 1990 – 2014	Mean number of new specimens per year 1974 – 1990	Mean number of new specimens per year 1990 – 2014
Bogor, Indonesia	BO	1,500,000	1,600,000	2,000,000	7%	20%	6,250	16,667
Bogota, Colombia	COL	130,000	330,000	500,000	153%	34%	12,500	7,083
Christchurch, New Zealand	CHR	250,000	493,000	600,000	97%	18%	15,188	4,458
Beijing, China	PE	750,000	1,800,000	2,600,000	140%	31%	65,625	33,333
Ibadan, Nigeria	FHI	80,000	103,500	105,000	29%	1%	1,469	63
Lae, Papua N.G.	LAE	200,000	290,000	300,000	45%	3%	5,625	417
Kuala Lumpur, Malaysia	KLU	20,000	38,000	63,000	90%	40%	1,125	1,042
Mexico City, Mexico	MEXU	185,000	550,000	1,400,000	197%	61%	22,813	35,417
Nairobi, Kenya	EA	300,000	500,000	1,000,000	66%	50%	12,500	20,833
New York, USA	NY	4,000,000	5,300,000	7,300,000	33%	27%	81,250	83,333
Rio de Janeiro, Brazil	RB	165,444	300,000	550,000	81%	45%	8,410	10,417
San Jose, Costa Rica	CR	65,000	175,000	255,000	69%	31%	6,875	3,333
Sydney, Australia	NSW	750,000	1,000,000	1,200,000	33%	17%	15,625	8,333

3.3.2.3 Accumulation of herbaria

There are 3,870 herbaria worldwide currently registered in *Index Herbariorum* (Thiers, 2015), 3,133 of these herbaria are considered to be active, of which the year of foundation is known for 2,750. The remaining 737 herbaria are registered as inactive.

The oldest herbarium in the world is the Naturkundemuseum im Ottoneum in Kassel, Germany, founded in 1569 and the mean foundation date for herbaria globally is 1944.8 (SD = 50.2). However, number of herbaria in the world has increased enormously during the late twentieth century (N = 2,750, Figure 3.4A), doubling between 1957 and 2000.

The age of herbaria varies geographically; herbaria tend to have been founded more recently in Africa (M = 1957, SD = 28.9), Asia (M = 1964, SD = 27.8) and South America (M = 1967, SD = 32.1) than those in Europe (M = 1916, SD = 70.2) and to a lesser extent North America (M = 1943, SD = 39.2) (Figure 3.4B, Appendix 3.2.2). Asian (47.8%, Figure 3.4C) and South American (58.7%) have the highest proportions of herbaria founded since 1970. In contrast, the continents with the highest proportion of inactive herbaria are Europe (30%) and North America (19.4%, Figure 3.4).

3.3.2.4 Discussion

In this section I investigated specimen accumulation rates across different taxa, geographical regions and herbaria. This data indicates that the doubling of the number of *Aframomum* specimens since 1966 documented in Chapter 2 is not confined to *Aframomum*. This pattern can be seen in a range of taxa, geographical regions and in the 31 million plant specimens currently available in GBIF. Patterns in temperate regions are not so clear-cut, as exemplified by the relatively well-documented Flora of the Rocky Mountains (Figure 3.3J) and previously reported in the UK (Rich, 2006) where observational data have largely replaced specimen data.

The numbers of new specimens arriving at major herbaria indicate that this pattern continued into the early twenty first century. Data from major international herbaria indicated that they currently receive large numbers of specimens. However, examination of the data for two consecutive time periods from more regional herbaria shows how the numbers of specimens arriving at herbaria varies temporally and geographically. The regional herbaria showed dramatic differences in the numbers of specimens received per year between the two study periods. For example herbaria such as Bogor, Mexico and Nairobi showed a dramatic increase, whereas Lae and Ibadan showed a dramatic decrease. Large international herbaria, such as New York, seem less prone to such fluctuations because they receive collections from around the world and may benefit from more consistent long-term funding. Overall the rates of specimen collection appear not to have declined recently, contradicting some recent studies (Stropp *et al.*, 2016; ter Steege *et al.*, 2016) and both international and regional herbaria continue to remain important to biodiversity research (Colombo *et al.*, 2016; Wayt Thomas, 2016).

The increase in the number of herbaria worldwide during the twentieth century, doubling between the 1959 and 2000 may have contributed to the increase in specimens observed in 3.3.2.1. This pattern also varies somewhat geographically with the numbers of herbaria in tropical regions growing faster since 1970 than those in temperate regions. Herbaria in North America and Europe are not only older but also more likely to be registered as inactive. The number of inactive herbaria may represent an underestimate as *Index Herbariorum* relies on self-reporting from herbaria. This reflects a shift in expertise and research priorities from temperate regions (Funk, 2014; Deng, 2015) to tropical middle income countries observed elsewhere (Zhang *et al.*, 2014).

One would think that a huge influx of specimens into natural history collection would improve knowledge of the natural world. However as documented in the first section of this chapter and Chapter 2, there are huge levels of uncertainty in the names on those specimens. In an era where the numbers of taxonomists is declining (Bebber *et al.*, 2014; Villaseñor, 2015) and the reluctance to invest in individual expertise (Ahrends *et al.*, 2011; Bebber *et al.*, 2012) and natural history collections (Funk, 2014; Paknia *et al.*, 2015) is increasing then the numbers of incoming specimens is probably overwhelming taxonomic capacity and consequently the ability to improve the quality of determinations on specimens. The data presented suggests that many tropical plant groups not recently revised (i.e. since 1970) may need revising again. A comprehensive taxonomic revision not only improves specimen determinations but it can provide the base for further species discovery (Prance, 1977; Dexter *et al.*, 2010).

3.4 CONCLUSIONS

Much uncertainty in names and the substantial increase in the number of specimens observed in *Aframomum* appears to be a general trend across geography and taxa within the seed plants, especially in the Tropics. Firstly, that the current system for updating names on the influx of specimens is not working efficiently, even for 'well known' groups such as the Dipterocarpaceae. Secondly, that even if it were working efficiently, the taxonomy of many groups is so poorly known that existing knowledge of many groups does not allow for accurate identification of specimens. Thus groups not revised 'recently' need to be comprehensively revised. The quality of determinations on specimens can be improved by comprehensive taxonomic revisions and specimen determinations being compared and updated across integrated online collection databases. This taxonomic work needs to continue as more specimens are collected.

This overwhelming uncertainty and increasing volume of specimens against a decrease in taxonomic capacity (Bebber *et al.*, 2014; Villaseñor, 2015) is poorly timed with extinction crisis (Pimm *et al.*, 2014) and the rise in use of online 'big' data. This uncertainty in existing collections of plant specimens is a major barrier to the 2020 completion of targets 1 and 2 of the Global Strategy for Plant Conservation to complete "an online Flora" and "an assessment of the conservation status of all known plant species" (Sharrock, 2012).

3.5 FUNDING

ZAG's visit to Missouri Botanical Gardens, St Louis, in March 2015 was funded by a Systematics Research Fund grant of £600 from the Linnean Society and the Systematics Association and a £250 travel grant from Wolfson College, Oxford.

3.6 BIBLIOGRAPHY

Ahrends, A., *et al*. (2011). "Conservation and the botanist effect." *Biological Conservation* 144 131–140.

Ainsworth, A. M., *et al*. (2013). "Red List of Fungi for Great Britain: Boletaceae. A pilot conservation assessment based on national database records, fruit body morphology and DNA barcoding. " *JNCC* 14: 37.

Appanah, S. (1998). Introduction. In *A review of Dipterocarps taxonomy, ecology and silviculture*. Bogor, Indonesia, Center for International Forestry Research: 1–4.

Ashton, P. S. (1982). Dipterocarpaceae. In *Flora Malesiana*. C. G. G. J. Van Steenis. The Hague, Martinus Nijhoff Pulishers. 9: 237–552.

Ashton, P. S. (2004). Dipterocarpaceae. In *Tree flora of Sabah and Sarawak*. E. Soepadmo, L. G. Saw and R. C. K. Chung. Kuala Lumpur, Malaysia, Government of Malaysia. 5: 63–388.

Bebber, D. P., *et al*. (2012). "Big hitting collectors make massive and disproportionate contribution to the discovery of plant species." *Proceedings of the Royal Society B: Biological Sciences* 279: 2269–2274.

Bebber, D. P., *et al*. (2014). "Author inflation masks global capacity for species discovery in flowering plants." *New Phytologist* 201: 700–706.

Beck, J., *et al*. (2013). "Online solutions and the ‘Wallacean shortfall’: what does GBIF contribute to our knowledge of species' ranges?" *Diversity and Distributions* 19: 1043–1050.

Carine, M. A. and M. J. M. Christenhusz (2010). "About this volume: the monograph of *Hypericum* by Norman Robson." *Phytotaxa* 4: 1–4.

Collen, B., *et al*. (2008). "The tropical biodiversity data gap: addressing disparity in global monitoring." *Tropical Conservation Science* 1: 75–88.

Colombo, B., *et al*. (2016). "An inventory of the Bignoniaceae from the Brazilian state of Rio Grande do Norte highlights the importance of small herbaria to biodiversity studies." *Phytotaxa* 278: 19–28.

Deng, B. (2015). "Plant collections left in the cold by cuts. North America’s herbaria wilt under pressure for space and cash." *Nature* 523: 16.

Dentinger, B. T. M. and L. M. Suz (2014). "What’s for dinner? Undescribed species of porcini in a commercial packet." *PeerJ* 2: e570.

Dexter, K. G., *et al*. (2010). "Using DNA to assess errors in tropical tree identifications: How often are ecologists wrong and when does it matter?" *Ecological Monographs* 80: 267–286.

Edwards, E. J. and S. A. Smith (2010). "Phylogenetic analyses reveal the shady history of C4 grasses." *Proceedings of the National Academy of Sciences* 107: 2532–2537.

Feeley, K. J. (2015). "Are we filling the data void? an assessment of the amount and extent of plant collection records and census data available for tropical South America." *PLoS ONE* 10: e0125629.

Feeley, K. J. and M. R. Silman (2011). "The data void in modeling current and future distributions of tropical species." *Global Change Biology* 17: 626–630.

Ferro, M. L. and A. J. Flick (2015). "“Collection bias” and the importance of natural history collections in species habitat modeling: a case study using *Thoracophorus costalis* Erichson (Coleoptera: Staphylinidae: Osoriinae), with a critique of GBIF.org." *The Coleopterists Bulletin* 69: 415–425.

Filer, D. (2015). BRAHMS. Department of Plant Sciences, University of Oxford, Oxford. 7.6.

Funk, V. A. (2014). "The erosion of collections-based science: alarming trend or coincidence?" *The Plant Press* 17: 1, 13–14.

Goodwin, Z. A., *et al*. (2015). "Widespread mistaken identity in tropical plant collections." *Current Biology* 25: R1066–R1067.

Harris, D. J. and A. H. Wortley (in press). "Monograph of *Aframomum* (Zingiberaceae)." *Systematic Botany Monographs*.

Hawthorne, W. D. and C. A. M. Marshall (2016). A manual for Rapid Botanic Survey (RBS) and measurement of vegetation bioquality. Published online, Department of Plant Sciences, University of Oxford, U.K. 56.

Heywood, V. (2001). "Floristics and monography-an uncertain future?" *Taxon* 50: 361–380.

Hjarding, A., *et al*. (2014). "Red List assessments of East African chameleons: a case study of why we need experts." *Oryx* 48: 1–7.

Holmgren, P. K. and N. H. Holmgren (1990). Index Herbariorum: part 1: the herbaria of the world. Bronx, New York Botanical Garden. 693.

Holmgren, P. K. and W. Keuken (1974). Index Herbariorum: part 1: the herbaria of the world. Utrecht, Oosthoekj Scheltema & Holkema. vii + 397.

Khoury, C. K., *et al*. (2015). "Distributions, ex situ conservation priorities, and genetic resource potential of crop wild relatives of sweetpotato [*Ipomoea batatas* (L.) Lam., I. series Batatas]." *Frontiers in Plant Science* 6: 251.

Mabberley, D. J. (1990). *The plant-book: a portable dictionary of the higher plants*. Cambridge, UK, Cambridge University Press. 707.

Maldonado, C., *et al*. (2015). "Estimating species diversity and distribution in the era of big data: to what extent can we trust public databases?" *Global Ecology and Biogeography* 24: 973–984.

Meier, R. and T. Dikow (2004). "Significance of specimen databases from taxonomic revisions for estimating and mapping the global species diversity of invertebrates and repatriating reliable specimen data." *Conservation Biology* 18: 478–488.

Mesibov, R. (2013). "A specialist's audit of aggregated occurrence records." *ZooKeys* 293: 1–18.

Missouri Botanical Gardens (2013). Herbarium rules and procedures. St Louis, Missouri Botanical Gardens.

Mora, C., *et al*. (2011). "How many species are there on Earth and in the ocean?" *PLoS Biology* 9: e1001127.

Otegui, J., *et al*. (2013). "Assessing the primary data hosted by the Spanish node of the Global Biodiversity Information Facility (GBIF)." *PLoS ONE* 8: e55144.

Paknia, O., *et al*. (2015). "Lack of well-maintained natural history collections and taxonomists in megadiverse developing countries hampers global biodiversity exploration." *Organisms Diversity & Evolution* 15: 1–11.

Pennington, T. D. (1995). "The genus *Inga*."   Retrieved April 2015, from http://herbaria.plants.ox.ac.uk/bol/inga

Pennington, T. D. (1997). *The genus Inga*. UK, Royal Botanic Gardens, Kew. 844.

Pimm, S. L., *et al*. (2014). "The biodiversity of species and their rates of extinction, distribution, and protection." *Science* 344: 1246752.

Prance, G. T. (1977). "Floristic inventory of the tropics: where do we stand?" *Annals of the Missouri Botanical Garden* 64: 659–684.

Prance, G. T. (2001). "Discovering the plant world." *Taxon* 50: 345–358.

Rich, T. C. G. (2006). "Floristic changes in vascular plants in the British Isles: geographical and temporal variation in botanical activity 1836–1988." *Botanical Journal of the Linnean Society* 152: 303–330.

Robson, N. K. B. (1985). "Studies in the genus *Hypericum* L. (Guttiferae). 3. Sections 1. Campylosporus to 6a. Umbraculoides." *Bulletin of the British Museum (Natural History). Botany* 12: 163–325.
Robson, N. K. B. (1990). "Studies in the genus *Hypericum* L. (Guttiferae). 8. Sections 29. Brathys (part 2) and 30. Trigynobrathys." *Bulletin of the British Museum (Natural History). Botany* 20: 1–151.
Robson, N. K. B. (1993). "Studies in *Hypericum*: validation of new names." *Bulletin of the British Museum (Natural History). Botany* 23: 67–70.
Robson, N. K. B. (1996). "Studies in the genus *Hypericum* L. (Guttiferae): 6. Sections 20. Myriandra to 28. Elodes." *Bulletin of the British Museum (Natural History). Botany* 26: 110–112.
Robson, N. K. B. (2001). "Studies in the genus *Hypericum* L. (Guttiferae). 4(1). Sections 7. Roscyna to 9. Hypericum sensu lato (part 1)." *Bulletin of the British Museum (Natural History). Botany* 31: 37–88.
Robson, N. K. B. (2002). "Studies in the genus *Hypericum* L. (Guttiferae). 4(2). Section 9. Hypericum sensu lato (part 2): subsection 1. Hypericum series 1. Hypericum." *Bulletin of the British Museum (Natural History). Botany* 32: 61–123.
Robson, N. K. B. (2006). "Studies in the genus *Hypericum* L. (Clusiaceae). 4(3). Section 9. Hypericum sensu lato (part 3): subsection 1. Hypericum series 2. Senanensia, subsection 2. Erecta and section 9b. Graveolentia." *Systematics and Biodiversity* 4: 19–98.
Robson, N. K. B. (2010a). "Studies in the genus *Hypericum* L. (Hypericaceae) 5(1). Sections 10. Olympia to 15/16. Crossophyllum." *Phytotaxa* 4: 5–126.
Robson, N. K. B. (2010b). "Studies in the genus *Hypericum* L. (Hypericaceae) 5(2). Sections 17. Hirtella to 19. Coridium." *Phytotaxa* 4: 127–258.
Scheffers, B. R., *et al*. (2012). "What we know and don't know about Earth's missing biodiversity." *Trends in Ecology and Evolution* 27: 501–510.
Sharrock, S. (2012). *Global Strategy for Plant Conservation: a guide to the GSPC - All the targets, objectives and facts*. Richmond, Botanic Gardens Conservation International: 36.
Stropp, J., *et al*. (2016). "Mapping ignorance: 300 years of collecting flowering plants in Africa." *Global Ecology and Biogeography* 25: 1085–1096.
ter Steege, H., *et al*. (2013). "Hyperdominance in the Amazonian tree flora." *Science* 342: 1243092.
ter Steege, H., *et al*. (2016). "The discovery of the Amazonian tree flora with an updated checklist of all known tree taxa." *Scientific Reports* 6: 29549.
Thiers, B. M. (2015). "Index Herbariorum: a global directory of public herbaria and associated staff." Retrieved February 2015, from http://sweetgum.nybg.org/ih/.
Tropicos. (2017). Retrieved April 2017, from http://www.tropicos.org/.
Villaseñor, J. L. (2015). "¿La crisis de la biodiversidad es la crisis de la taxonomía?" *Botanical Sciences 93: 1–12.*
Wayt Thomas, W. (2016). "125 years of floristic research and collecting at The New York Botanical Garden." *Brittonia* 68: 222–229.
Wood, J. R. I., *et al*. (2015). "*Ipomoea* (Convolvulaceae) in Bolivia." *Kew Bulletin* 70: 1–124.
Yesson, C., *et al*. (2007). "How global Is the Global Biodiversity Information Facility? ." *PLoS ONE* 2: e1124.
Zhang, X. (2015). "Chinese National Herbarium." Retrieved 2015, from http://pe.ibcas.ac.cn/pe/eng.html.
Zhang, Z.-Q., *et al*. (2014). "The making of world's largest journal in systematic botany." *Phytotaxa* 191: 1–9.

4 How long does it take to 'know' a species?

CONTENTS

4.1 INTRODUCTION

Species are the fundamental units of biodiversity; existing knowledge of species diversity, abundance and geographic distribution comprise our understanding of the natural world (Prance, 1994). Despite the importance of species, the process of species discovery remains poorly understood and documented.

The process of species discovery is recognised to start with the collection of the first specimen, and a new species is considered to be discovered when the new species has been published (Bebber *et al*., 2010; Fontaine *et al*., 2012). When a new species is published, the protologue usually contains a brief English or Latin diagnosis (McNeill *et al*., 2012). The diagnosis provides a brief description of the plant's morphology and details how to differentiate species it from similar species, a complete physical description of the plant is usually also provided. Do we fully know a species with a description of its morphology, are there other ways we can further 'know' a species? If we are to understand a species' role within the surrounding ecosystem then we would need to know its preferred habitat, life history, potential herbivores, mutualistic interactions with other organisms including mycorrhizal fungi, pollinators and seed dispersers. Another way to 'know' a new species might be to examine the genetics of individuals from across the geographical range and morphological variation of the species to establish its relationships within its genus and to discover closely related sister species. At a different scale to examine genetic markers from multiple individuals within multiple populations of the species to examine the genetic structure of the species across its geographical distribution. However to 'know' a species' ecology in depth can require years of field studies and genetics studies require multiple specimens with well-preserved DNA. To understand a species reliably based only on herbarium specimens one can make an accurate morphological description and geographical distribution (Rivers *et al*., 2010).

In this chapter I will examine two aspects of the species discovery process, firstly whether the information provided in the publication of a species name is sufficient to consider that species as 'known'. Secondly, how long does it take for a species to be 'known', in order to investigate the latter the process of species discovery is considered to be characterised by four key events (Figure 4.1):

- When the first specimen is collected.
- When the species name is published.
- When the species has an accurate conservation assessment.
- When the species has a comprehensive distribution map.

The collection of the first specimen of a species can be considered as the start of species discovery. The availability of a comprehensive distribution map can be considered the end-point of species discovery and that the species is now comprehensively 'known' geographically. These four key events represent important temporal landmarks in the process of species discovery which may take many years to complete. There are time lags between the collection of the first specimen and the following three key events (Figure 4.1). Time lag 3, the 'knowledge lag', between the first event and the fourth event, the completion of a comprehensive map, is the length of time that it takes to fully 'know' a species. Only one of these time lags has been investigated prior to this study; time lag 1, the 'discovery lag' between the collection of the first specimen of a vascular plant species and the new name being published which is on average 32 (Bebber *et al.*, 2010; Fontaine *et al.*, 2012) or 39 years (Bebber *et al.*, 2010), and only 14% of species being described within 5 years of the first specimen being collected (Bebber *et al.*, 2010).

Some of these key events must occur sequentially. For example the first specimen must have been collected to allow the publication of the species name to occur. The collection of the specimens to produce an accurate conservation map or comprehensive distribution map can occur before publication. However, accurate conservation map or comprehensive distribution map cannot be produced based upon determined or determined correctly specimens until the species name has been published.

The collection of the first specimen of a species and the publication of the species' name are discrete single events and can be associated with an accurate date. The third and fourth key events, and consequently the second and third time lags, are more complex as the timing of these key events are staggered and more difficult to measure. An accurate conservation assessment, for example, requires a minimum of 15 specimens (Rivers *et al.,* 2011), this can be achieved not only when 15 specimens are collected, or even when 15 specimens are determined, but when 15 specimens are correctly determined (Figure 4.1). Likewise a comprehensive map is achieved when a sufficient number of specimens across the entire species' geographical distribution are correctly determined.

In this chapter I seek to elucidate the temporal dynamics of the process of species discovery from the first specimen being collected to the stage when an accurate distribution map can be produced for species of the genus *Aframomum*. In particular, by investigating when accurate conservation assessments or comprehensive distribution maps are achieved and placing these events in context with the first specimen being collected and publication of the species name, I ask the question, how long does it take to 'know' a species?

Figure 4.1 How long does it take to 'know' a species? The first herbarium specimen of the species is collected (first key event), on average 32-39 years later (lag 1) the new species is formally described and published (second key event). Over time (lag 2) fifteen specimens of the species are collected, determined, and eventually determined correctly (third key event) allowing the production of an accurate conservation assessment. Sometime later (lag 3) enough specimens have been collected, determined, and eventually determined correctly (fourth key event) that a comprehensive distribution map can be produced.

4.2 Materials and Methods

4.2.1 The number of specimens cited in a protologue

To document the numbers of specimens cited in a protologue, the numbers of specimens cited per new seed plant species' name published in *Kew Bulletin* between 1970 and 2010 was recorded.
The mean number (and standard deviation) of specimens cited per species protologue was calculated. The numbers of species protologues which cited sufficient numbers of specimens for IUCN Red List conservation assessments (10 and 15, Rivers *et al.*, 2011) and for species distribution modelling (20, Feeley and Silman, 2011) were recorded.

4.2.2 Time lag 1 – Publication of a species

Time lag 1, the time lag between the first specimen collection of a species and the publication of that species name, was calculated for all *Aframomum* species. New species published in Harris and Wortley (in press) are due to be published in 2017, this is used as the publication date for these species. The mean time lag was then calculated for all species of *Aframomum*, for *Aframomum* species with a minimum of 10, 15 or 20 specimens and geographically widespread, medium or restricted *Aframomum* species which occupy >24 (Green Star, following Hawthorne and Marshall, 2016), 24 – 9 (Blue Star) and 9> (Black and Gold Star) degree squares respectively. Two species, *Aframomum angustifolium* (Sonn.) K.Schum. and *Aframomum citratum* (J.Pereira) K.Schum., were excluded from this analysis because the date of collection for the first specimen is not known.

4.2.3 Time lag 2 – Collection and determination of 15 specimens

Time lag 2, the time lag between the first specimen collection of a species and the correct determination of the first 15 specimens, was calculated for all *Aframomum* species. To document the dates when 15 specimens were collected, determined and correctly determined, the complete determination data from all available *Aframomum* specimens in all available collections was recorded, including species name, date and the name of the author of the determination. Determinations of synonyms were not included as correct determinations.
The genus *Aframomum* was revised between 1998 and 2015 by Harris and Wortley (in press), allowing access (2011 – 2012) to the large volume of specimens (3,176 specimen collections, 4,550 including duplicates) from 40 herbaria in 21 countries gathered at the Royal Botanic Garden Edinburgh (E). The scientific names of all determinations were then classified as either 'correct', 'synonym', 'indeterminate' or 'other' relative to the determination in the current monograph (Harris and Wortley, in press). Basionyms of the correct name based on *Amomum* were treated as the correct name.
The specimen and determination data were filtered to include only specimens for which both A) the year of collection and B) the year of every determination are recorded (1,492 specimen collections, 1,779 specimen duplicates).
This determination data was then filtered in three different ways for each species:
1 – To document the accumulation of specimens collected over time, the year in which each correctly determined specimen was collected was counted and recorded.
2 – To document the accumulation of determinations on specimens over time, the determination data was filtered for each species name by all determinations (incorrect and correct), the resulting number of specimens per year was counted and recorded.
3 – To document the accumulation of correct determinations on specimens over time, the determination data was filtered for each species name by correct determinations, the resulting number of specimens per year was counted and recorded.

From the data under each filter the year when the first 10, 15 and 20 specimens were collected, determined, and determined correctly were recorded. The time lag between the year in which the first specimen was collected and these dates, time lag 2, was calculated for each species and the mean time lag calculated.

4.2.4 TIME LAG 3 – COLLECTION AND DETERMINATION OF ENOUGH SPECIMENS FOR THE COMPREHENSIVE GEOGRAPHICAL DISTRIBUTION

To document the dates when the comprehensive distribution map was achieved for each species the data set assembled in section 4.2.3 was used to record the year when the first specimens were collected, determined, and determined correctly in each degree square. The time lag was then calculated between the year of the first specimen collection and these dates. Time lag 3, the time lag to acquire the comprehensive distribution map for each species, was calculated by recording the first correct determination of a specimen in the last degree square to be discovered. The average of these time lags was then calculated for all species of *Aframomum*, for *Aframomum* species with a minimum of 10, 15 or 20 specimens and geographically widespread, medium or restricted *Aframomum* species.

4.3 RESULTS AND DISCUSSION

4.3.1 THE NUMBER OF SPECIMENS CITED IN A PROTOLOGUE

Here I examine the number of specimens cited per new species name published in *Kew Bulletin* between 1970 and 2010. A total of 3,305 protologues of seed plant species' names were published between 1970 and 2010 in *Kew Bulletin*, the number of specimens cited per species protologue ranged from 1 to 155 with a mean of 4.9 (*SD* = 7.06) specimens cited per species. The number of specimens cited per species is a power law or hollow curve distribution (Willis, 1922; Dial and Marzluff, 1989) (Figure 4.2); most species' protologues cited few specimens (89% cited <10 specimens), and very few species' protologues cited many specimens (2.75% cited >20 specimens). The majority of species protologues (93.8%) cited fewer than 15 specimens, the number required to produce an accurate conservation assessment.

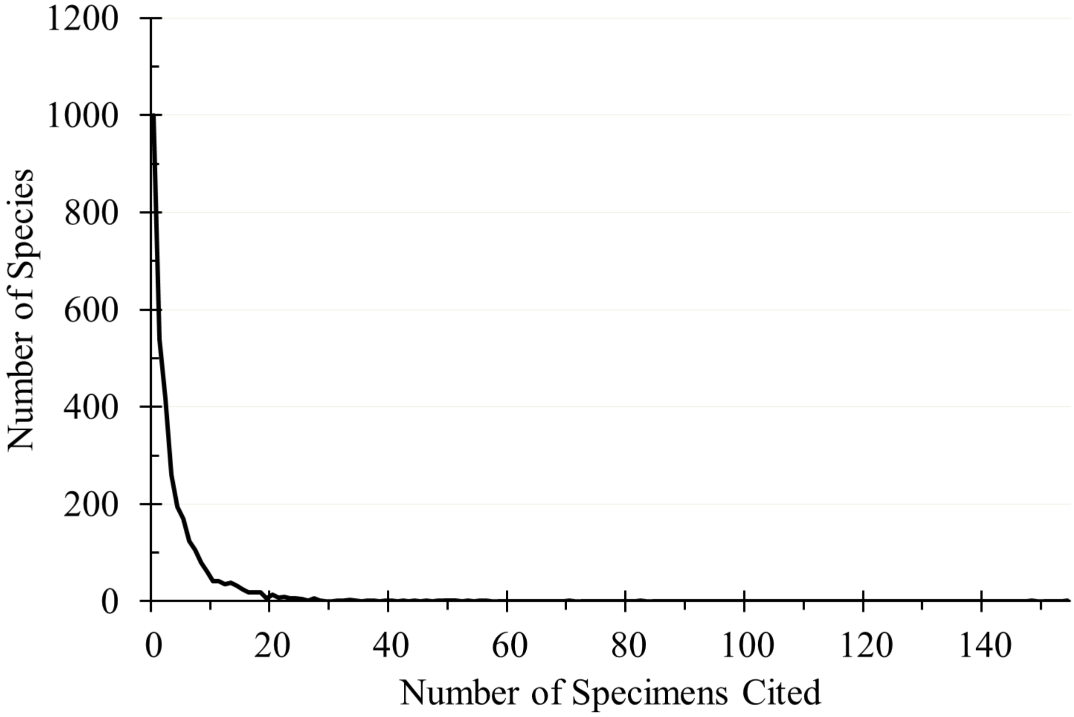


Figure 4.2 Numbers of specimens cited per new seed plant species' names published in *Kew Bulletin*, between 1970 and 2010, *N* = 3,305.

4.3.2 TIME LAG 1 – PUBLICATION OF A SPECIES

Here I examine time lag 1; the time lag between the collection of the first specimen and the publication of the species name in *Aframomum* (Appendix 4.2). The mean year of first specimen collection was 1897.7 (*N* = 59, *SD* = 63.2, range 1700 – 2003) and the mean year of publication was 1938.5 (*SD* = 64.95, range 1802 – 2017), and time lag 1 for all *Aframomum* species was 40.8 years (*N* = 59, *SD* = 40.1).

Similar time lags were found for *Aframomum* species with a minimum of 10 (*N* = 37, *M* = 46.0, *SD* = 42.6), 15 (*N* = 27, *M* = 43.3, *SD* = 45.8) and 20 (*N* = 25, *M* = 42.1, *SD* = 45.6) specimens. Geographically widespread species (*N* = 9, *M* = 36.7, *SD* = 55.6) had a smaller publication time lag than *Aframomum* species with medium (*N* = 14, *M* = 46.2, *SD* = 40.5) or restricted (*N* = 33, *M* = 42.4, *SD* = 35.1) distributions.

4.3.3 TIME LAG 2 – COLLECTION AND DETERMINATION OF 15 SPECIMENS

Here I examine time lag 2; the time lag(s) between the collection of the first specimen and the collection, determination, and correct determination of the first 15 specimens in *Aframomum*. For the species of *Aframomum* which had 15 or more specimens available in the dataset (*N* = 29) the first specimens were collected in the late nineteenth to early twentieth century (*M* = 1899.9, *SD* = 43.7) and it took an average of 65 years (*SD* = 33.8) for the first 15 specimens to be collected (*M* = 1963.5, *SD* = 24.5, Appendix 4.1). However the time taken for the first 15 specimens to be determined increased the time lag to 93.4 years (*SD* = 33.8). The time lag from the collection of the first specimen to the correct determination of 15 specimens, time lag 2, was 100.8 years (*SD* = 38.8). This means that the average additional time lag between the collection of the first 15 specimens and the correct determination of the first 15 specimens was 35.8 years.

Similar time lags were observed for the first collection, determination and correct determination of 10 and 20 specimens (Appendix 4.2).

4.3.4 TIME LAG 3 – COLLECTION AND DETERMINATION OF ENOUGH SPECIMENS FOR THE COMPREHENSIVE GEOGRAPHICAL DISTRIBUTION

Here I examine time lag 3; the time lag(s) between the collection of the first specimen and the collection, determination, and correct determination of the complete geographical distribution (Appendix 4.2).

For the comprehensive distribution map of a species to be known the last degree square within the species' geographic distribution needs to have been discovered. For species with 15 or more specimens (*N* = 29) the mean year that the last degree square was collected was 1992.6 (*N* = 29, *SD* = 8.0), 89.8 years (*SD* = 42.0) after the first specimen was collected. The specimen was determined and determined correctly a further 20.4 years (*M* = 2013.1, *SD* = 3.7) later. Thus time lag 3, from the collection of the first specimen to the completion of a species' distribution map, was 110.2 years (*SD* = 39.9).

Similar time lags (Appendix 4.2) from the collection of the first specimen to the completion of the geographic distribution were found for all species (*N* = 56, *M* = 114.5, *SD* = 65.0, range 4 - 314), and species with at least 10 (*N* = 39, *M* = 101.0, *SD* = 39.9) or 20 specimens (*N* = 27, *M* = 110.4, *SD* = 41.2). Geographically restricted species (*N* = 33, *M* = 55.0, *SD* = 41.1) had a shorter time lag than *Aframomum* species with medium (*N* = 14, *M* = 106.5, *SD* = 38.2) or widespread (*N* = 9, *M* = 128.7, *SD* = 34.3) distributions.

14.2% (8) of all *Aframomum* species had a complete distribution map in less time that it takes for the average *Aframomum* species to be discovered (40 years).

4.3.5 DISCUSSION

The results I present here show for the first time a detailed examination of the time lags in the discovery of a species. The numbers of specimens cited in *Kew Bulletin* seed plant protologues was used to examine how well a species is 'known' at publication. The complete specimen determination history of *Aframomum* specimens, compiled in Chapter 2, was used to calculate the time lags between four key events in the process of species discovery: The collection of the first specimen, the publication of the species name, the first accurate IUCN Red List conservation assessment, and the completion of a comprehensive distribution map. The results presented suggest that the majority of seed plants species may not be fully 'known' in two different ways. Firstly, the majority of seed plant protologues (94%) are published before sufficient numbers of specimens to produce an accurate IUCN Red List conservation assessment have been collected. Secondly, that that the 'knowledge lag' (time lag 3) to know a species properly is more than 100 years, this is much longer than the previously documented ‘discovery lag’ (time lag 1) (Bebber *et al.*, 2010; Fontaine *et al.*, 2012).

The first result is striking because the vast majority of new seed plant species published in *Kew Bulletin* cited very few specimens. To perform an accurate IUCN Red List conservation assessment (Rivers *et al.*, 2011) requires a minimum of 15 specimens and to produce an accurate species distribution model has been estimated to require 20 specimens (Feeley and Silman, 2011). Yet nearly 90% of the species protologues cited fewer than 10 specimens. This indicates that the ‘discovery lag’ (time lag 1), between the first collection of a species and the species’ formal publication, is not the same as the ‘knowledge lag’ (time lag 3) for most seed plant species. And this supports the observation that most vascular plant species are poorly known (Heywood, 2001) and are known from few specimens (Feeley and Silman, 2011; ter Steege *et al.*, 2013).

Protologues remain a critical event in the process of discovery of a new species; the publication of a new species must occur before any meaningful investigation can be made into the species. However, a more complete understanding of a species can only occur by the completion of the third and fourth key events, the production of an accurate conservation assessment and the production of a comprehensive distribution map. This result indicates that these key events occur after the publication of the protologue for most seed plant species.

The second result shows that not only is the ‘knowledge lag’ long but it is also staggered. The mean time lags from the collection of the first specimen to the possibility of the production of an accurate IUCN Red List conservation assessment with 15 or more specimens was long, 101 years. However part of time lag 2 was the time between the collection and the correct determination of the 15 specimens, this was 29 – 35 years. The mean ‘knowledge lag’, time lag 3, for all species of *Aframomum* was 115 years, the time lag between the collection and the correct determination of the collection and correct determination of the specimens in the last degree square was ~20 years.

The short time lag between the potential for IUCN Red List conservation assessment and the completion of the species’ distribution map (~9 years) may be a function of the exponential growth in herbarium specimens documented in Chapter 2.

Can we consider these findings in *Aframomum* specimens to be representative of all seed plants?

Firstly the analysis of the *Kew Bulletin* data shows that very few seed plant protologues cited enough specimens to produce an accurate conservation assessment thus the ‘knowledge lag’ (lags 2 and 3) for the majority of species is longer than the ‘discovery lag’ (time lag 1). The ‘discovery lag’ in the *Kew Bulletin* protologue data studied here is slightly longer than that for monographs (Bebber *et al.*, 2010) but can be considered to be representative of all seed plant protologue data because it covers a wide range of taxa and geography. In addition, the *Kew Bulletin* data supports the *Aframomum* data by the fact that <15% of *Aframomum* species had a completed comprehensive distribution map (the fourth key event) in less than 40 years, the mean time lag for an *Aframomum* species to be published (time lag 1).

Secondly the ‘discovery lag’ of *Aframomum* (40.8 years) is only slightly longer on average compared to that of other groups in monographs and *Kew Bulletin* (35 years, Bebber *et al.*, 2010), thus suggesting that the ‘knowledge lag’ for *Aframomum* is comparable to other taxa.

One issue with the data used in this analysis is that it is a subset (approximately 50%) of all *Aframomum* specimens; only 1,779 specimens had a complete set of dates for every determination. Of this subset of data, only species with a minimum of 15 (10 or 20) specimens in the analysed subset could be investigated for time lag 2. The main consequence of this is that the dates for the collection, determination and correct determination of 15 (10 or 20) specimens represents the latest possible dates that these key events were completed. In

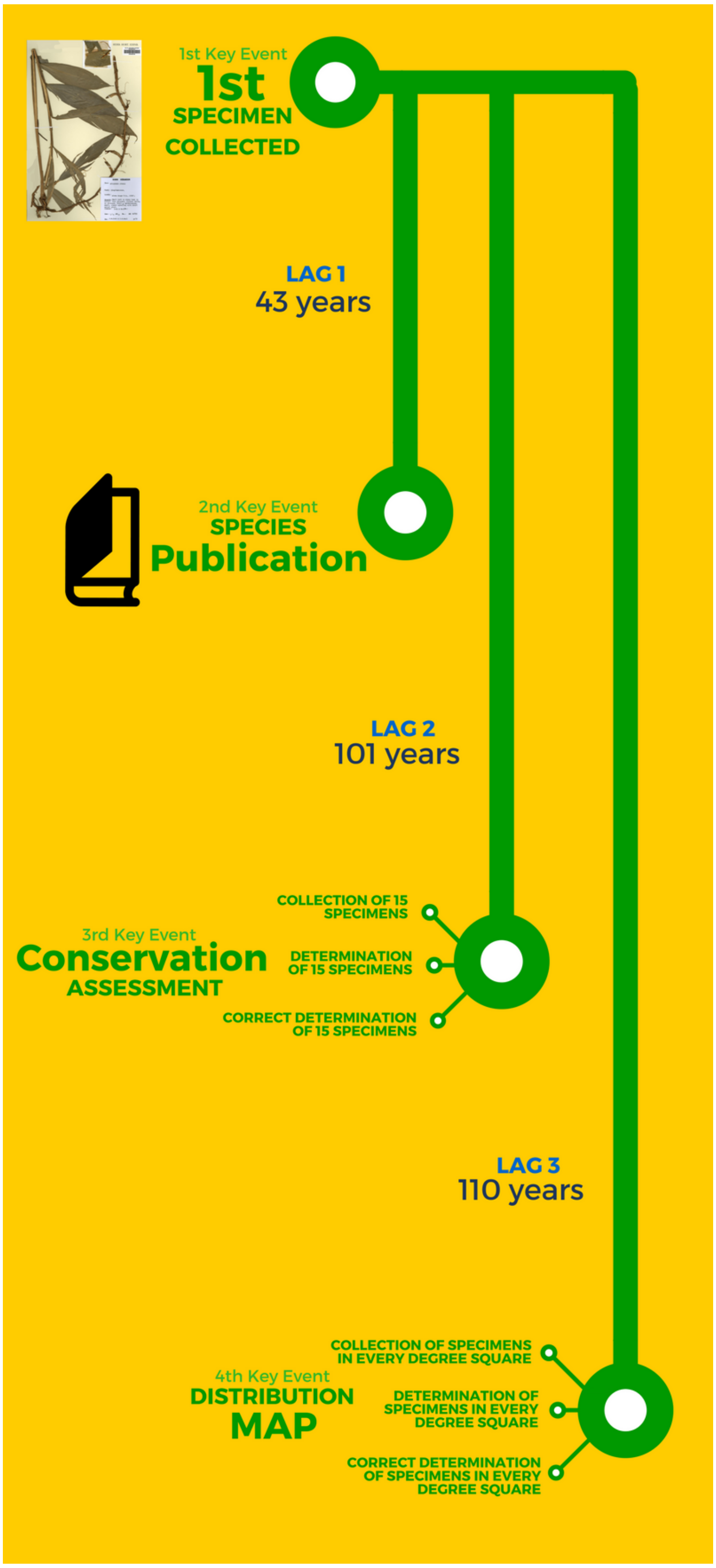


Figure 4.3 How long does it take to 'know' a species of *Aframomum*? (Where the *Aframomum* have 15 or more specimens available). The first herbarium specimen of the species is collected (first key event), on average 43 years later (lag 1) the new species is formally described and published (second key event). On average 60 years later (lag 2) fifteen specimens of the species have been collected, determined, and determined correctly (third key event) allowing the production of an accurate conservation assessment. A further 9 years later on average (lag 3) enough specimens have been collected, determined, and determined correctly (fourth key event) that a comprehensive distribution map can be produced.

particular, because specimens collected pre-1900 were more likely to not have a complete determination history. However, it is clearly shown that the subset of species with a minimum of 15 specimens analysed have time lags 1, 2 and 3 comparable to that of all *Aframomum* species (Appendix 4.2). The time lag for the completion of a comprehensive distribution map is not likely to be influenced by the data sampling. The distribution maps for most species were completed in 2014 because A) the entire sample of specimens, and thus sample of locations, were only collected by the end of the twentieth century. And B) the specimens were all correctly determined during the comprehensive revision of *Aframomum*, completed in 2014.

One intriguing result from the data is that the time lags, both the 'discovery lag' and the 'knowledge lag', differ widely between species which are restricted and widespread in distribution. Widespread *Aframomum* species were discovered (time lag 1) quicker than restricted species, as in other groups of organisms (Gaston and Blackburn, 1994; Blackburn and Gaston, 1995; Gaston *et al.*, 1995). The novel finding here is that widespread species can be considered to be 'known' much slower than restricted species. This can be attributed to simply requiring more specimens to complete the greater number of degree squares occupied by a widespread species. However, this means that while widespread species are 'discovered' earlier than the average species, they also take considerably longer to 'know' properly.

4.4 CONCLUSIONS

Taxonomy is the process of discovering, classifying, and naming the natural world. These names underpin all we know about the natural world and allow us to utilise and conserve it. Our ability to name and understand the natural world is particularly important and urgent at a time of the 6th mass extinction (Barnosky *et al.*, 2011) and rapid human-induced climate change (IPCC, 2014). However it is clear that we know surprisingly little about the natural world (Heywood, 2001). Even in ‘well known’ groups such as the vascular plants only 80 – 90% (Joppa *et al.*, 2010) of the estimated 380,000 species in existence (Lughadha *et al.*, 2016) are thought to have been discovered and it is estimated that 74% of tropical species have been collected so infrequently that they are effectively invisible to climate modelling (Feeley, 2015).

Within this context the first two targets of the Global Strategy for Plant Conservation (GSPC, Sharrock, 2012) to complete “an online Flora...” and “an assessment of the conservation status of all known plant species...” by 2020 seems ambitious. If we are to assume that “all known plants” includes all published species then the time lags found here indicate that this target may be unobtainable within this time frame. The data presented here indicates that it takes more than 100 years from the collection of the first specimen to the production of an accurate IUCN Red List conservation assessment or a comprehensive distribution map. An accurate preliminary IUCN Red List conservation assessment based a species’ geographic range (Criteria B) requires only a basic understanding of the species’ range, yet currently less than 20,000 species of flowering plant have had an IUCN Red List conservation assessment (IUCN, 2016). The lack of preliminary IUCN Red List conservation assessments is probably due to the assessment and submission process rather than lack of correctly determined specimens for many species (Brummitt *et al*., 2015). These time lags may shorten in the twenty first century as a result to the massive acceleration in the collection of specimens in the second half of the twentieth century (documented in Chapters 2 and 3). However the time lags within each event, between the collection and correct determination may lengthen further due to the lack of taxonomic capacity (Paknia *et al.*, 2015; Villaseñor, 2015) to determine specimens correctly. Expertise and focus can greatly improve the quality of names on specimens (Chapter 2), and this will be needed if we are to produce an accurate IUCN Red List conservation assessment, and thus a basic understanding of a species’ distribution, for an accurate account of all published species in a world Flora.

4.5 BIBLIOGRAPHY

Barnosky, A. D., *et al*. (2011). "Has the Earth's sixth mass extinction already arrived?" *Nature* 471: 51–57.

Bebber, D. P., *et al*. (2010). "Herbaria are a major frontier for species discovery." *PNAS* 107: 22169–22171.

Blackburn, T. M. and K. J. Gaston (1995). "What determines the probability of discovering species?: A study of South American oscine passerine birds." *Journal of Biogeography* 22: 7–14.

Brummitt, N. A. *et al*. (2015). "Green plants in the red: A baseline global assessment for the IUCN Sampled Red List Index for plants" *PLoS ONE* 10: e0135152.

Dial, K. P. and J. M. Marzluff (1989). "Nonrandom diversification with in taxonomic assemblages." *Systematic Biology* 38: 26–37.

Feeley, K. J. (2015). "Are we filling the data void? an assessment of the amount and extent of plant collection records and census data available for tropical South America." *PLoS ONE* 10: e0125629.

Feeley, K. J. and M. R. Silman (2011). "The data void in modeling current and future distributions of tropical species." *Global Change Biology* 17: 626–630.

Fontaine, B., *et al*. (2012). "21 years of shelf life between discovery and description of new species." *Current Biology* 22: R943–R944.

Gaston, K. J. and T. M. Blackburn (1994). "Are newly described bird species small-bodied?" *Biodiversity Letters* 2: 16–20.

Gaston, K. J., *et al*. (1995). "Which species are described first?: The case of North American butterflies." *Biodiversity and Conservation* 4: 119–127.

Harris, D. J. and A. H. Wortley (in press). "Monograph of *Aframomum* (Zingiberaceae)." *Systematic Botany Monographs*.

Hawthorne, W. D. and C. A. M. Marshall (2016). A manual for Rapid Botanic Survey (RBS) and measurement of vegetation bioquality. Published online, Department of Plant Sciences, University of Oxford, U.K. 56.

Heywood, V. (2001). "Floristics and monography-an uncertain future?" *Taxon* 50: 361–380.

IPCC (2014). Climate change 2014: synthesis report. Contribution of working groups I, II and III to the fifth assessment report of the Intergovernmental Panel on Climate Change. Core Writing Team, R. K. Pachauri and L. A. Meyer. Geneva, Switzerland, IPCC: 151.

IUCN. (2016). "IUCN Red List of Threatened Species. Version 2016.3." Retrieved April 2017, from http://www.iucnredlist.org.

Joppa, L. N., *et al*. (2010). "How many species of flowering plants are there?" *Proceedings of the Royal Society B: Biological Sciences* 278: 554–559.

Lughadha, E. M. N., *et al*. (2016). "Counting counts: revised estimates of numbers of accepted species of flowering plants, seed plants, vascular plants and land plants with a review of other recent estimates." *Phytotaxa* 272: 082–088.

McNeill *et al*. (2012). International Code of Nomenclature for algae, fungi, and plants (Melbourne Code) adopted by the Eighteenth International Botanical Congress Melbourne, Australia, July 2011. In *Regnum Vegetabile*. A.R.G. Gantner Verlag KG 154.

Paknia, O., *et al*. (2015). "Lack of well-maintained natural history collections and taxonomists in megadiverse developing countries hampers global biodiversity exploration." *Organisms Diversity & Evolution* 15: 1–11.

Prance, G. T. (1994). "A comparison of the efficacy of higher taxa and species numbers in the assessment of biodiversity in the neotropics." *Philosophical Transactions of the Royal Society of London. Series B: Biological Sciences* 345: 89–99.

Rivers, M. C., *et al*. (2010). "Subpopulations, locations and fragmentation: applying IUCN Red List criteria to herbarium specimen data." *Biodiversity and Conservation* 19: 2071–2085.
Rivers, M. C., *et al*. (2011). "How many herbarium specimens are needed to detect threatened species?" *Biological Conservation* 144: 2541–2547.
Sharrock, S. (2012). Global Strategy for Plant Conservation: a guide to the GSPC - All the targets, objectives and facts. Richmond, Botanic Gardens Conservation International: 36.
ter Steege, H., *et al*. (2013). "Hyperdominance in the Amazonian tree flora." *Science* 342: 1243092.
Villaseñor, J. L. (2015). "¿La crisis de la biodiversidad es la crisis de la taxonomía?" *Botanical Sciences* 93: 1–12.
Willis, J. C. (1922). *Age and area; a study in geographical distribution and origin of species*. London, Cambridge University Press. 284.

5 Narratives of species discovery and distribution

CONTENTS

5.1 INTRODUCTION

The process of species discovery is poorly known. There is a well-documented time lag between the first collection of a seed plant and the publication of a new species name (Bebber *et al.*, 2010; Fontaine *et al.*, 2012). Publication of a species is considered to be the time when the species is considered as 'known'. However, in this thesis this simple narrative has been questioned because of two observations. Firstly, in Chapter 2, at any given time during the process of discovery more than half the specimens in an unrevised group do not have the correct name. Secondly, in Chapter 4, there are long lags in the species discovery process which prolong the time between the first collection and the time when the species is considered to be fully 'known'. These two results have implications for measuring and accurately assessing the current state of knowledge of the world flora which I shall examine in this chapter.

While investigating the time lags inherent within the species discovery process, discussed in Chapter 4, it became clear that the histories of species discovery in *Aframomum* are variable. This result confirms previous work that has shown that species discovery time lags vary between taxa (Fontaine *et al.*, 2012) and that date of species publication can be influenced by a variety of factors: Widespread species are discovered earlier than restricted species (Gaston *et al.*, 1995; Allsopp, 1997; Roberts *et al.*, 2016) and large bodied species are discovered before smaller bodied species (Gaston, 1991; Blackburn and Gaston, 1994; Gaston and Blackburn, 1994; Blackburn and Gaston, 1995; Gaston *et al.*, 1995; Reed and Boback, 2002). Differences in the process of species discovery in Chapter 4 were caused by a combination of spatial and temporal variables including geographical distribution, date of first specimen collection, publication date, and levels and influence of incorrect determinations. For example, the time lags documented in Chapter 4 indicated that while widespread species tended to be 'discovered' more quickly than restricted species, it took longer to properly 'know' a widespread species than a restricted species. The variation in the process of species discovery between species of *Aframomum* has implications for our understanding of the 'known' world flora and the species that remain to be described. For example, species which await discovery are likely to be restricted in distribution and have a high risk of extinction (Roberts *et al.*, 2016).

In this chapter, I document the various generalised narratives of species discovery. Secondly, I document the effect of the process of species discovery (investigated in Chapter 4) on the understanding of the geographical distribution of two species over time; one widespread and one restricted.

5.2 Generalised Narratives Of Species Discovery

In this section I describe five general patterns of species discovery that can be distinguished for groups of species of *Aframomum*. These generalised narratives form part of a continuum, but five more or less distinct patterns can be distinguished. I provide a short detailed description of an example species which is typical for each narrative.

5.2.1 Materials and methods

Key variables were assembled for all 61 species of *Aframomum* accepted by Harris and Wortley (in press) including:

- Geographic range (Table 5.1A)
- Year of the first specimen collection (Table 5.1B)
- Year of publication (Table 5.1C)
- Proportion and effect of the incorrect determinations (Table 5.1D)

Each variable was subdivided into discrete categories for descriptive and interpretative purposes. The species were then allocated to groups of species with similar scores for all four variables (Appendix 5.1.1).

Firstly, species were categorised by size of geographic range based upon the number of degree squares occupied (Table 5.1A), the three categories were derived from the Star system (Hawthorne and Marshall, 2016) which is designed to rank a species' global rarity based upon herbarium specimen derived geographic distribution data. Green Star species were 'Widespread' (>24 degree squares occupied), Blue Star species were 'Medium' (24 – 9 degree squares occupied), and the most globally rare species, Black and Gold Star species, were 'Restricted' (9> degree squares occupied).

Secondly, species were categorised by the year in which the species' first specimen was collected (Table 5.1B) based upon the historical collecting patterns observed in *Aframomum* specimens discussed in Chapter 2. Species first collected prior to 1900 were classed as 'Early', prior to 1900 relatively low numbers of *Aframomum* specimens were collected yet almost all new specimens collected were new species. Species first collected between 1900 and 1949 were classed as 'Medium', rates of *Aframomum* specimen collecting started to increase during this period but were apparently disrupted by the two World Wars. Species first collected since 1950 were classed as 'Recent', during this period specimen collecting in *Aframomum* was characterised by a dramatic increase in the number of specimens with a doubling in the number of specimens between 1966 and 2000.

Thirdly, species were categorised by year in which the species' name was published (Table 5.1C) based upon the historical patterns observed in *Aframomum* specimens collection and name publication discussed in Chapter 2. Species published prior to 1900 were classed as 'Early', prior to 1900 nearly a third of currently accepted species and an equal number of non-accepted names were published based upon a small number of *Aframomum* specimens, almost all new specimens collected were described as new species during this period. Species published between 1900 and 1949 were classed as 'Medium', rates of *Aframomum* specimen collecting started to increase during this period but were apparently disrupted by the two World Wars. Species published since 1950 were classed as 'Recent', during this period nearly half of currently accepted *Aframomum* names were published, very few synonyms were published and the number of *Aframomum* specimens increased dramatically.

Finally, species were categorised by proportion and influence of incorrect determinations (Table 5.1D). This was primarily an indicator of the proportion of incorrectly determined specimens relative to correctly determined specimens. Was the proportion of incorrect determinations of this name among all determinations high (>10%), low (<10%) or where there no incorrect determinations at all. And secondly an indicator of the influence of those incorrectly determined specimens on the. When the proportion of incorrectly determined specimens was low (<10%) did the incorrectly determined specimens have a large or small effect on the understanding of a species' geographical range.

Table 5.1 Variables influencing the narratives of species discovery. Variables by category of key variables of species discovery: (A) Geographic range, 'widespread', 'medium' and 'restricted'; (B) year of the first specimen collection, 'early', 'medium', and 'recent'; (C) year of publication, 'early', 'medium', and 'recent'; (D) incorrect determinations, 'high', 'low but effective', 'low', and 'none'.

A

Geographic Range	**Number of degree square cells occupied**
Widespread	>24
Medium	9 – 24
Restricted	<9

B

Collected	**Year first specimen was collected**
Early	< 1900
Medium	1900 – 1949
Recent	1950 – 2015

C

Publication	**Year species name was published**
Early	< 1900
Medium	1900 – 1949
Recent	1950 – 2015

D

Incorrect Determinations	**Proportion of incorrectly determined specimens and their influence on geographical range**
High	Large proportion (>10%)
Low But Effective	Small proportion (<10%) but has greatly influenced incorrect geographical range
Low	Small proportion (<10%) but has not greatly influenced incorrect geographical range
None	None

For each of the five generalised narratives recognised, a single species was chosen for discussion purposes which most typified each narrative. For each of these five species the accumulation of specimens where the complete determination history was available (full methods in Chapter 2) were plotted by collection, determination and correct determination. The full geographical distribution was visualised in two ways, firstly showing the species' distribution based upon countries occupied, secondly a more detailed distribution map showing degree squares occupied based upon correct and incorrect determinations of specimens. The Kew GeoCAT online tool (Bachman *et al.*, 2011) was used to calculate the extent of occupancy (EOO) for each species based upon all determined and correctly determined specimens.

5.2.2 GENERALISED NARRATIVES OF SPECIES DISCOVERY

Here I present the five general narratives of the temporal and spatial dynamics of species discovery:

5.2.2.1 Widespread species

Aframomum alboviolaceum, *A. angustifolium*, *A. daniellii*, *A. luteoalbum*, *A. melegueta*, *A. polyanthum*, *A. sceptrum*, *A. zambesiacum*.

These species are characterised by an early first collection (1700s – 1800s), early publication (1700s – 1800s), and are geographically widespread (>24 degree squares occupied). These species take many years for the complete species range to be discovered and for most of their history many incorrectly determined specimens have added incorrect locations to the geographical range of these species. However, these incorrect locations usually either overlap with correct locations or are within the boundaries of the species range (EOO), thus the overall understanding of the species' geographical ranges and conservation assessments are not greatly affected by incorrect determinations.

Example: *Aframomum angustifolium*

The first specimen of *Aframomum angustifolium* (Sonn.) K.Schum. was collected by Sonnerat in Madagascar around the year 1781, Sonnerat published the new species name in 1782. *Aframomum angustifolium* is a widespread species found in 23 countries (Figure 5.2.1B) and 112 degree squares (Figure 5.2.1C) across tropical Africa from Ivory Coast to Mozambique and including Madagascar, Mauritius and the Seychelles. The large number of specimens of this species (261) (Figure 5.2.1A) collected over ~230 years and the large proportion of incorrectly determined specimens at any given time in the past (up to 30%) have meant that it took until the current monograph (Harris and Wortley, in press) to understand the complete geographical distribution of *A. angustifolium* correctly (Appendix 5.1.2).

5.2.2.2 Recently published, restricted species

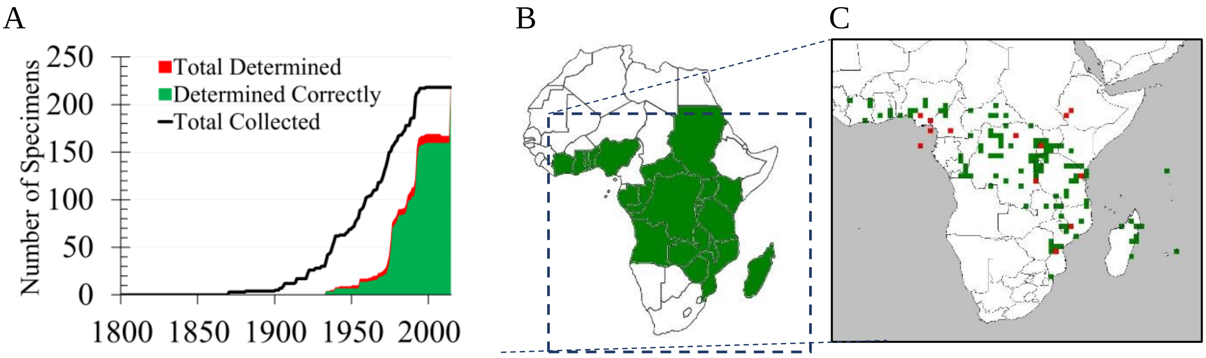
Aframomum atewae, *A. chrysanthum*, *A. cordifolium*, *A. dhetchuvi*, *A. elegans*, *A. fragrans*, *A. hirsutum*, *A. kamerunica*, *A. kodmin*, *A. laxiflorum*, *A. longiligulatum*, *A. longipetiolatum*, *A. lutarium*, *A. makandensis*, *A. orientale*, *A. parvulum*, *A. plicatum*, *A. rotundum*, *A. scalaris*, *A. sericeum*, *A. singulariflorum*, *A. spiroligulatum*, *A. submontanum*, *A. tchoutoui*, *A. uniflorum*, *A. verrucosum*, *A. wuerthii*.

These species are published relatively recently (1970 – 2010s), and generally the first collection was made fewer than 50 years before publication although a few have been collected over 100 years before publication. All of these species are apparently rare and range restricted (<24 degree squares occupied, usually <5). Only correct determinations of these species have been made and all of these determinations have been made exclusively by the species' authors or Harris and Wortley (In Press).

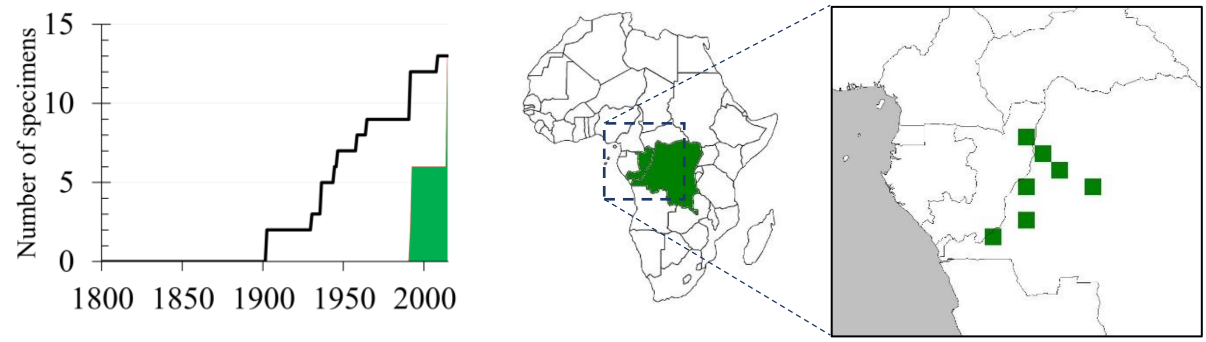
Example: *Aframomum singulariflorum*

The first specimen of *Aframomum singulariflorum* Dhetchuvi was collected in 1902, however the species was published 91 years later in 1993. *Aframomum singulariflorum* is a restricted species found in seven degree squares (Figure 5.2.2C) across two countries (Figure 5.2.2B); the Democratic Republic of Congo (DRC) and the Republic of Congo (Congo). This species name has only been applied to specimens by two sets of the authors; the author of the name, Dhetchuvi, and Harris and Wortley. There are two consequences of this: firstly that there has only been one incorrect determination of this species (the specimen was not included in this analysis, Figure 5.2.2A). Secondly, the complete geographical distribution of *A.*

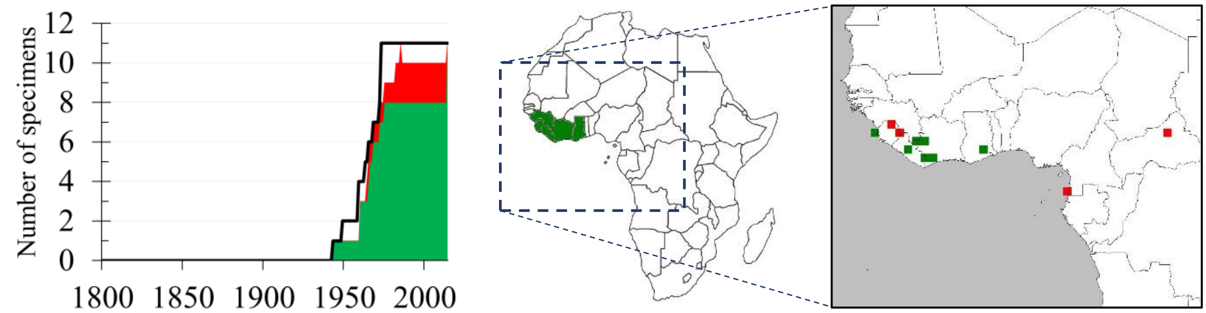
singulariflorum was not understood prior to the recent monograph by Harris and Wortley (in press) (Appendix 5.1.2).



5.1.1 *Aframomum angustifolium*



5.1.2 *Aframomum singulariflorum*



5.1.3 *Aframomum longiscapum*

Figure 5.1 Specimen accumulation (A), geographical distribution by country (B), and distribution by degree square cells (C) of *Aframomum angustifolium*, *A. singulariflorum* and *A. longiscapum*. (A) Accumulation of specimens collected over time (black line) plotted against the accumulation of correct determinations (solid green) and incorrect determinations (solid red). (B) Complete geographical distribution per country (green). (C) Complete historical geographical distribution per degree square cell with correct (green) and incorrect (red) locations.

5.2.2.3 Old, restricted, and misunderstood species

These species were first collected and described early (1700s or 1800s). These species are generally (but not exclusively) geographically restricted species (<24 degree squares occupied) however their ranges have only become fully understood in recent times with the work of Harris and Wortley (in press). These species fall into two main subtypes:

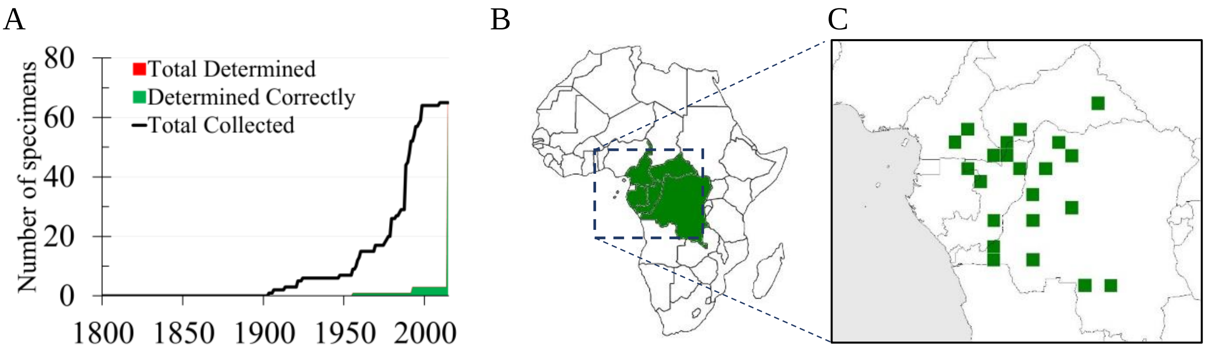
5.2.2.3.1 Type 1

Aframomum arundinaceum, *A. citratum*, *A. elliotii*, *A. exscapum*, *A. giganteum*, *A. kayserianum*, *A. leptolepis*, *A. longiscapum*, *A. mala*, *A. pilosum*, *A. strobilaceum*, *A. subsericeum*, *A. sulcatum*.

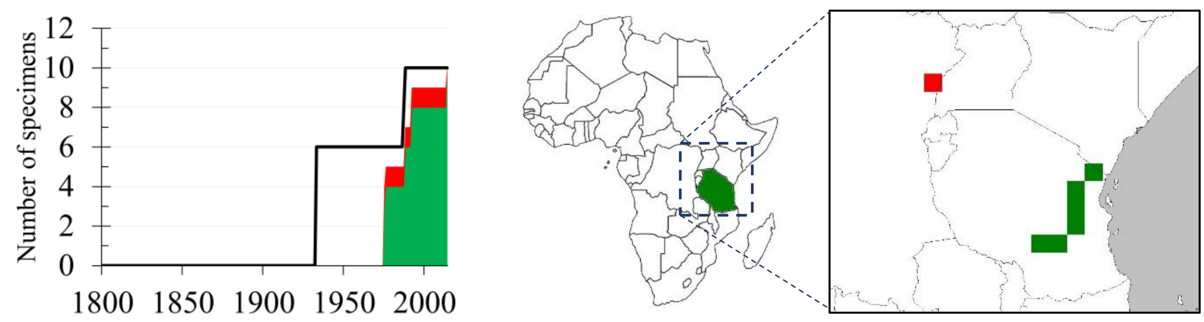
The incorrect use of these names on specimens of other species have added incorrect locations to the geographical distribution of these species. These false positives greatly expanded the known range of the species in the absence of a comprehensive taxonomic revision.

Example: *Aframomum longiscapum*

The first specimen of *Aframomum longiscapum* (Hook.f.) K.Schum. was collected in 1853 and the species was published in 1854 by Joseph Hooker. *Aframomum longiscapum* is a restricted species found in six degree squares (Figure 5.2.3.C) and five countries in West Africa (Figure 5.2.3B). Historically there have been significant numbers of incorrect determinations of this species (Figure 5.2.3A). These incorrect determinations have greatly influenced the historical understanding of the distribution of *A. longiscapum*; prior to Harris and Wortley (in press) the geographical distribution of *A. longiscapum* included Cameroon and the Central African Republic in Central Africa (Figure 5.2.3C, Appendix 5.1.2) giving the species an EOO of >800,000 km^2 (instead of the correct EOO of ~113,000 km^2).



5.2.1 *Aframomum thonneri*



5.2.2 *Aframomum alpinum*

Figure 5.2 Specimen accumulation (A), geographical distribution by country (B), and distribution by degree square cells (C) of *Aframomum thonneri* and *A. alpinum*. (A) Accumulation of specimens collected over time (black line) plotted against the accumulation of correct determinations (solid green) and incorrect determinations (solid red). (B) Complete geographical distribution per country (green). (C) Complete historical geographical distribution per degree square cell with correct (green) and incorrect (red) locations.

5.2.2.3.2 Type 2

Aframomum corrorima, *A. glaucophyllum*, *A. letestuanum*, *A. limbatum*, *A. mannii*, *A. rostratum*, *A. thonneri*.
Many specimens of these species were not determined correctly until very recently either due to synonymy (for example *A. glaucophyllum*) or because the name was not being used (for example *A. thonneri*). These false negatives greatly reduced the known range of these species in the absence of a comprehensive taxonomic revision.

Example: *Aframomum thonneri*
The first specimen of *Aframomum thonneri* De Wild. was collected in 1903 and the species was published in 1911 by De Wildeman. *Aframomum thonneri* is a widespread species found in 38 degree square cells across six countries in Central Africa (Figure 5.2.1B) and an EOO of >1,485,000 km^2. However, prior to 2014 very low numbers of specimens were determined as this species; only three collections were determined as *A. thonneri* (Figure 5.2.1A) prior to the work of Harris and Wortley (in press). Thus the species was incorrectly thought to be an extremely rare species, with an EOO of 14,000 km^2, restricted to a small area of western DRC (Figure 5.2.1C, Appendix 5.1.2).

5.2.2.4 Recently published, restricted, and misunderstood species

Aframomum albiflorum, *A. alpinum*, *A. aulacocarpos*, *A. mildbraedii*, *A. pseudostipularis*, *A. stanfieldii*.
These species were all published in the twentieth century, mostly in the second half of it and have small ranges (<24 degree squares occupied). However proportionally large numbers of incorrect determinations of specimens has mistakenly increased the geographical distribution of these species.

Example: *Aframomum alpinum*
The first specimen of *Aframomum alpinum* (Gagnep.) K.Schum. was collected in 1889 and the species was published in 1902 by Gagnepain. *Aframomum alpinum* is a restricted species found in six degree square cells across one country, Tanzania, in East Africa (Figure 5.2.2B). Historically very low numbers of specimens (one or two) have been determined incorrectly as this species (Figure 5.2.2A, Appendix 5.1.2); however as there are only fifteen specimens determined as *A. alpinum* by Harris and Wortley (in press) these incorrect determinations disproportionately influenced the historical interpretation of *A. alpinum*'s geographical distribution. The incorrectly determined specimens implied that the species occurred in the east of the DRC and extended the species' range (extent of occupancy) by 1,000% (Figure 5.2.2C).

5.2.3 DISCUSSION

The results I present here reflect the variation in the narratives of species discovery between species in the same genus. The 61 species of *Aframomum* each have a unique narrative of species discovery which fall along a continuum. The five types of narrative described here are an attempt to understand the underlying variation and interaction between four measured variables; date of first specimen collection, publication date, proportions of accurate determinations and size of geographic range.
The first general narrative, 5.2.2.1 'widespread species', is primarily defined by the widespread geographical distribution (occupying >24 degree squares) of the species. The remaining narratives represent species which are generally restricted in geographical distribution (occupying <24 degree squares). The second general narrative, 5.2.2.2 'recently published, restricted species', is defined by very recent publication (since the 1970s) and the more or less straight forward accumulation of understanding. This narrative includes the 12

new species to be published in Harris and Wortley (in press). The third and fourth narratives, two variations of 'old restricted, and misunderstood species', are defined by high levels of misunderstanding of the species in the past, either because of incorrect determinations (5.2.2.3.1 type 1) or because of long time lags to the correct determination on specimens (5.2.2.3.2 type 2). The fifth narrative, 5.2.2.4 'recently published, restricted, and misunderstood species', includes restricted species which are affected by both incorrect determinations and long time lags until the correct determination.

The temporal variables investigated here, the dates of the first specimen collection and species publication, were the first and second key events in the process of species discovery documented in Chapter 4. Both of these two variables show a wide range of variation between different species of *Aframomum*. The collection date of the first specimen ranged from 1700 to 2003, more than 300 years, and the date of species publication ranged from 1802 to 2017, more than 200 years. It is clear how these two dates can impact the narrative of species discovery; a new species cannot be discovered until the first specimen has been collected, and a species cannot be known until the species has been published.

The spatial variable, size of geographical range, was also an important influence on the narrative of species discovery. As has been found in other taxa (Gaston *et al.*, 1995; Allsopp, 1997; Roberts *et al.*, 2016) widespread species of *Aframomum* were generally discovered (both first collected and published) earlier than restricted species (Chapter 4). However the narratives I present here indicate that there is more variation in the process of species discovery between species than is explained by just size of geographical range alone.

For example, the species discovery narratives are affected by the relationship between the extent of a species' geographic range and the level of impact on the species' distribution by incorrectly determined specimens. Widely distributed species, as exemplified by *A. angustifolium*, can have large numbers of incorrectly determined specimens. These incorrect determinations in these widespread species have limited impact on the understanding of these species' distributions because the correctly determined specimens of the species occur in the same locations as the incorrectly determined specimens. However they do greatly lengthen time lag 3, from the collection of the first specimen to the completion of a comprehensive distribution map. In contrast, the understanding of species with restricted distributions are much more vulnerable to the misinformation caused by incorrectly determined specimens; the understanding of a restricted species' geographical distribution is disproportionately affected by just a few incorrectly determined specimens, for example *A. longiscapum*. Species with restricted distributions are also more vulnerable to long time lags in the use of the correct name on a specimen, for example *A. thonneri*; missing specimens are more likely to mean missing geographical locations in a restricted species. This means that while it takes longer to obtain the complete geographical distribution correct for a widespread species the understanding of a species' geographical distribution in the absence of a recent revision is worse for species with restricted geographical range than for widespread species.

In Chapter 2 I found that more than half of specimens in an unrevised group of tropical plants did not have the correct name. In Chapter 4 I found that it takes on average >100 years to properly 'know' a species, whether we consider that to be a preliminary IUCN Red List conservation assessment or the complete geographical distribution. Here I have shown that these two facts produce different responses in different species based on a complex interaction of four temporal and spatial variables. Widespread species can have accurate preliminary IUCN Red List conservation assessments relatively soon after publication, but have a long time lag to the fourth key event, the completion of a comprehensive distribution map. Some restricted species such as the 'recently published, restricted species' (5.2.2.2) were collected and published recently, and were well understood relatively quickly. However many restricted species are vulnerable to incomplete understanding caused by incorrect determinations (‘old, restricted, and misunderstood species, type 1’ 5.2.2.3.1), long time lags to the correct determinations on specimens (‘old, restricted, and misunderstood species, type 2’ 5.2.2.3.2), or a combination of both (‘recently published, restricted, and misunderstood species’ 5.2.2.4).

In this study the influence of specimens misidentified as synonyms on the understanding of a species was not explored. In species, such as *A. glaucophyllum*, where large numbers of specimens have been determined as a synonym there are two possible caveats to the results presented here. The best case scenario is that if the majority of specimens were determined as the same synonym then the correct distribution, and thus correct their IUCN threat category, would have been known but under a different name. Alternatively, the worst case scenario, if the specimens’ determinations are equally split between the correct name and a synonym, or several different synonyms, then the IUCN threat category will have been over exaggerated and split over several different names for the same species (Kirschner and Kaplan, 2002).

The implication of this result is that differences in the narrative of species discovery can result in restricted species having their IUCN threat categories incorrectly exaggerated (e.g. *A. thonneri*) or downplayed (e.g. *A. longiscapum*). In the absence of a comprehensive taxonomic revision non-experts cannot differentiate between species with correct or incorrect IUCN Red List conservation categories. This confirms the importance of taxonomic revision to conservation (Mace, 2004), in particular our ability to produce accurate IUCN Red List conservation assessments (Kirschner and Kaplan, 2002; Meier and Dikow, 2004; Hjarding *et al.*, 2014). This also confirms the importance of comprehensive taxonomic revision in the discovery of new species (Wayt Thomas, 1999) which are more likely to be geographically restricted, data deficient, and at risk from extinction (Good *et al.*, 2006; Roberts *et al.*, 2016).

The lack of recent taxonomic revisions in tropical plants (Paton *et al.*, 2008) and resulting uncertainty in specimen names (Chapters 2 and 3) negatively affects our ability to complete IUCN Red List conservation assessments needed for the completion of the online world Flora (Sharrock, 2012) and to update our estimates for the number of threatened plants in the world (22 – 47% Pitman and Jørgensen, 2002; >20% Brummitt *et al.*, 2015).

5.3 THE EFFECT OF SPECIES DISCOVERY ON DISTRIBUTION MAPS

Here I present two worked examples of species to explore in detail the implications of the time lags of species discovery (documented in Chapter 4) on our historical understanding of the geographical distribution of these species. The first example is a widespread species, *A. angustifolium*, the second example is a restricted species, *A. singulariflorum*. Each example will have four elements:

1. A brief introduction to dates of the four key events in the process of species discovery for each species; the collection of the first specimen, publication of the species, collection, determination and correct determination of the first 15 specimens and of the complete distribution map. In addition a brief description of the species known geographic range and preliminary IUCN Red List conservation status.
2. A detailed description of the collection and determination history of the species' specimens.
3. A description of the historical accumulation of the species' geographical distribution by the collection and determination of specimens in degree squares and IUCN Red List conservation assessments.
4. A brief analysis of the effects of the determination lag on the historical geographical distribution for each species.

5.3.1 MATERIALS AND METHODS

5.3.1.1 Key events in the process of species discovery and distribution maps

The date of the collection of the first specimen, publication of the species, the collection, determination and correct determination of the first 15 specimens (10 for *A. singulariflorum*) and of the complete distribution map were recorded for each species.

The determination data were recorded for specimens from each species, including species name, date and name of the author of the determination on each specimen (full methods as per Chapter 2). The scientific names given in all determinations were then classified as either 'correct', 'synonym', 'indeterminate' or 'other' relative to the determination in the current monograph (Harris and Wortley, in press). Basionyms of accepted *Aframomum* names were classified as 'correct'. The specimen and determination data were filtered to include only specimens for which both A) the year of collection and B) the year of every determination are recorded.

The accumulation of collections were plotted over time for all of the specimens for which the entire determination history is known for each species.

The Kew GeoCAT online tool (Bachman *et al.*, 2011) was used to calculate the extent of occupancy (EOO), area of occupancy (AOO, using a 2 x 2 km^2 grid) and preliminary IUCN Red List conservation assessment. The EOO and AOO polygons generated using GeoCAT for each species were visualised in Google Earth.

5.3.1.2 Historical patterns of specimen collection and determination

For the subset of specimens with entire known determination history the accumulation of specimens as they were collected, determined and determined correctly were plotted over time. The key events in the discovery of the species; the years in which the first specimen was collected, the species name was published, the collection, determination and correct determination of the first 15 specimens (10 for *A. singulariflorum*) and of the complete distribution map were plotted. The three time lags in the process of species discovery were calculated for each species:

- Time lag 1 – From the collection of the first specimen to the publication of the species name.
- Time lag 2 – From the collection of the first specimen to the correct determination of the first 15 specimens.
- Time lag 3 – From the collection of the first specimen to the correct determination of the first specimen in the last degree square of the comprehensive distribution map.

5.3.1.3 The effect of species discovery on completing a distribution map

The earliest date the first specimen was collected, determined and determined correctly in each degree square were calculated. Based upon these dates geographical distribution maps were drawn for each year from the date of the first collection to 2014. The AOO, EOO and IUCN Red List conservation status for each species for each year were calculated using the Kew GeoCAT online tool (as described in 5.3.1.1).

The time lags for the appearance of each species in each degree square cell as specimens were collected, determined and correctly determined were calculated. The consequences for the understanding of each species' IUCN Red List conservation status were briefly explored.

5.3.2 *AFRAMOMUM ANGUSTIFOLIUM*

5.3.2.1 Key events in the process of species discovery and distribution maps

Here I introduce the dates of the key events in the process of species discovery in *A. angustifolium*. The type specimen, Sonnerat *s.n.*, thought to be the first known specimen of *A. angustifolium*, was collected in Madagascar with no recorded collection date. It remains unclear when exactly Sonnerat travelled to Madagascar or if he even collected this specimen himself. He definitely travelled to Madagascar in 1789 (Dorr, 1997) seven years after the publication of the name. However, Sonnerat did voyage to Africa between 1774 and 1781 (Sonnerat, 1782) so I have assigned the collection date as 1781 as it is the latest possible year the specimen is likely to have been collected.

The basionym, *Amomum angustifolium* Sonn., was published in 1782, and the currently accepted combination, *Aframomum angustifolium* (Sonn.) K.Schum., was published in 1904. The first 15 specimens of *A. angustifolium* were collected by 1914, determined by 1955, and correctly determined by 1961. The specimens allowing the completion of the distribution map of *A. angustifolium* were collected by 1998, determined by 2014, and correctly determined by 2014.

For this study 218 specimens were analysed, the first specimen in the data set was collected in 1870. These specimens represent 150 independent mappable points and are from 20 countries and 72 degree square cells across tropical Africa (Figure 5.3A). This gives an EOO of >12,700,000 km^2 and an AOO of 476 km^2 which would give *A. angustifolium* an IUCN Red List conservation assessment category of Least Concern and Endangered, respectively.

5.3.2.2 Historical patterns of specimen collection and determination

Here I describe the patterns of collection, determination and correct determination of *A. angustifolium* specimens over time. In addition I document the resulting collection, determination and correct determination of key events 3 and 4 (the first 15 specimens and the completion of a comprehensive distribution map).

Accumulation of the *A. angustifolium* specimens as they are collected over time shows a pattern typical of the specimen accumulation documented in Chapter 2. The first specimen for which we can allocate a degree square was collected in 1870 and accumulation of specimens was initially slow. However, collecting accelerated rapidly into the twentieth century (Figure 5.3B, green line); the first ten specimens were collected by 1906, the first 15 specimens collected eight years later in 1914 (Figure 5.3C), and the first 20 specimens collected seven years later in 1921. The rate of specimen collection further accelerated in the second half of the twentieth century when the vast majority of the specimens were collected (~200). The last specimen in this study was collected in 1998.

The basionym *Amomum angustifolium* Sonn. was published in 1782, however the first specimen to be correctly determined in this analysis, Schlieben 3195, was determined in 1933. The correct determination rate remained low through to the mid-twentieth century (Figure 5.3B, blue line); the first ten specimens were determined correctly as *A. angustifolium* in 1955, the first 15 specimens determined correctly in 1961, and the first 20 specimens determined correctly in 1969 (Figure 5.3C). However the number of incorrect determinations increased at a faster rate from 1936 onwards (Figure 5.3B). The first ten specimens were determined (including both incorrectly and correctly) as *A. angustifolium* by 1950, the first 15 specimens determined by 1955, and the first 20 specimens determined by 1964. There were rapid increases in the number of correctly determined specimens in the mid-1970s, 1990s, and in the 2010s (Figure 5.3B).

Time lag 1 for *A. angustifolium* was very short, as little as one year (Figure 5.3C), however time lags 2 and 3 were much longer than average (time lag 2, 180 years; time lag 3, 233 years).

5.3.2.3 The effect of the species discovery on completing a distribution map

5.3.2.3.1 Effect of determination lag on completing a distribution map

Here I describe and discuss the effects of the specimen determination lag (the average time taken from collection to the correct determination of a specimen, M = 37.8 years, Chapter 2) on the discovery of *A. angustifolium*'s geographical distribution. This has two elements; temporal and spatial, and although I focus on degree squares as a standardised unit, I also briefly discuss the temporal and spatial patterns found in the species' IUCN Red List conservation assessments.

5.3.2.3.1.1 Temporal patterns

In this section I explore the general patterns in the accumulation of knowledge of the geographical distribution of *A. angustifolium* as specimens were collected and determined over time. In particular, I shall address the questions: Firstly, does the time lag from collection to the correct determination of a specimen have an effect on the discovery lag for each degree square? Secondly, are there any notable patterns or trends in these data?

The specimens analysed here occur across 72 different degree square cells. There was a mean lag of 29.4 years (SD = 32.5) between the first collection in a degree square cell and the first correct determination in a degree square cell. This is shorter than the mean time lag between the collection and correct determination of a specimen, 37.8 years. The mean year a degree square cell was first collected in was 1955.6 (Appendix 5.3.1, SD = 29.7), the mean year that the first specimen was determined correctly in a degree square cell was 1985.1 (SD = 17.4).

There were two distinct phases in the understanding of the range of *A. angustifolium* as specimens were collected over time. In the first phase (1870 – 1950) the increase in the known geographical distribution (Figure 5.3D, green line) was slow because of the low rate of specimen collection; even though each new specimen usually added a new degree square cell to the known distribution. In the second phase, in the mid- to late-twentieth century the sheer volume of specimens being collected across Africa maintained a regular supply of new degree squares to the distribution. An apparent plateau in the discovery of new degree square cells in the 1990s may have been due to the plateau in new collections (the last specimen seen in this study was collected in 1998).

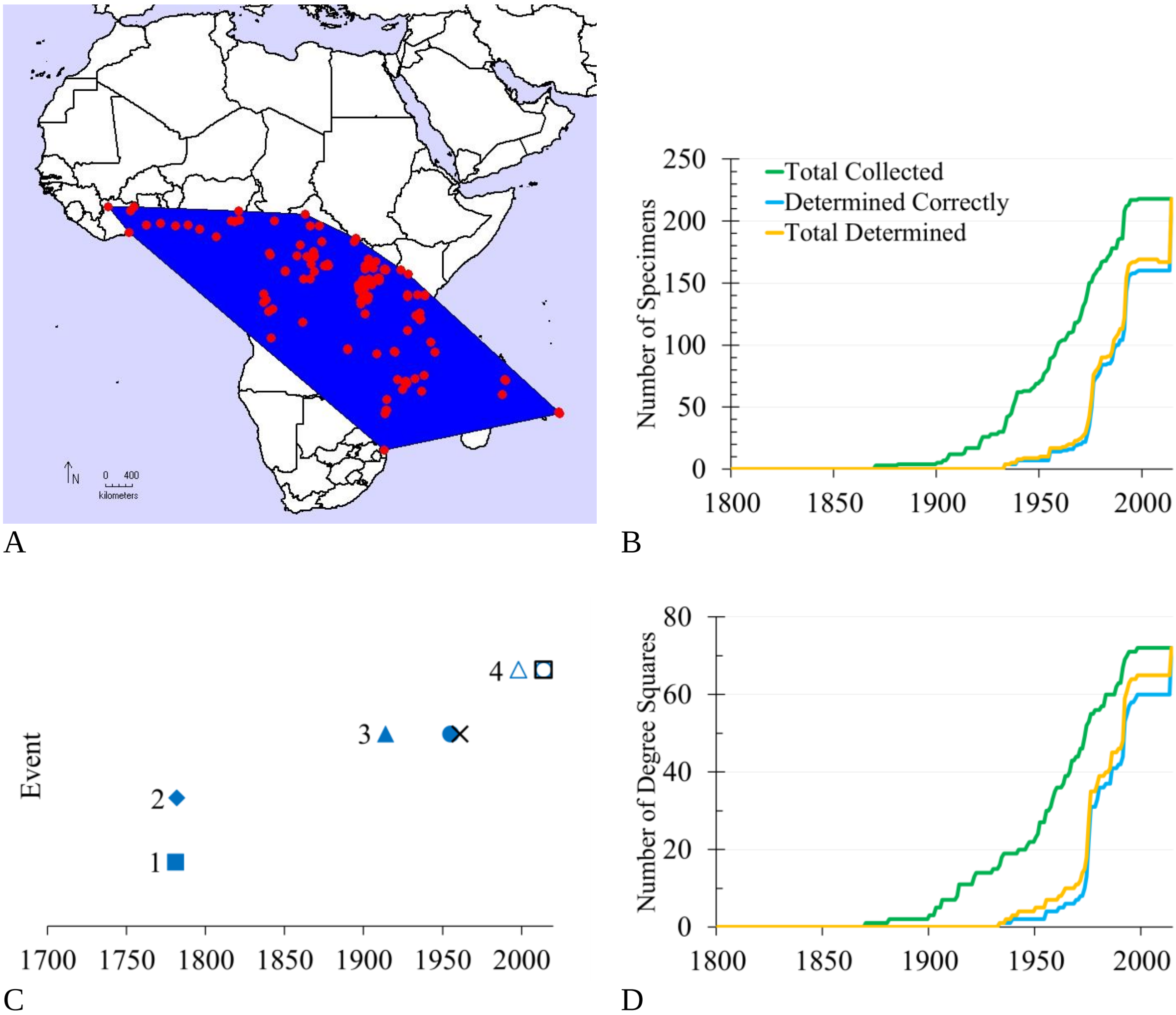


Figure 5.3 The geographical distribution (A), collection and determination history (B) of *Aframomum angustifolium* specimens, the four key events in the history of the discovery of *A. angustifolium* (C) and the discovery of the distribution of *A. angustifolium* (D) over time. (A) The geographical distribution (individual points = yellow markers and extent of occupancy = blue polygon) of the subset of *A. angustifolium* specimens available for use in this study. (B) The accumulation of *A. angustifolium* specimens as they are collected (green), determined correctly (blue) and all determinations for that name (orange) between 1800 and 2015. (C) Key events in the history of *A. angustifolium* between 1700 and 2020: Key event 1 – the first specimen was collected (■); key event 2 – the name was published (♦); key event 3 – the first 15 specimens were collected (▲), determined (●) and determined correctly (X) as *A. angustifolium*; key event 4 – the comprehensive distribution map was completed as specimens were collected (Δ), determined (○) and determined correctly (□) as *A. angustifolium.* The determination (●/○) and correct determination (X/□) partially overlap (key event 3) and fully overlap (key event 4). (D) The accumulation of degree squares in the distribution of *A. angustifolium* as specimens were collected (green), determined correctly (blue) and all determinations for that name (orange) between 1800 and 2015.

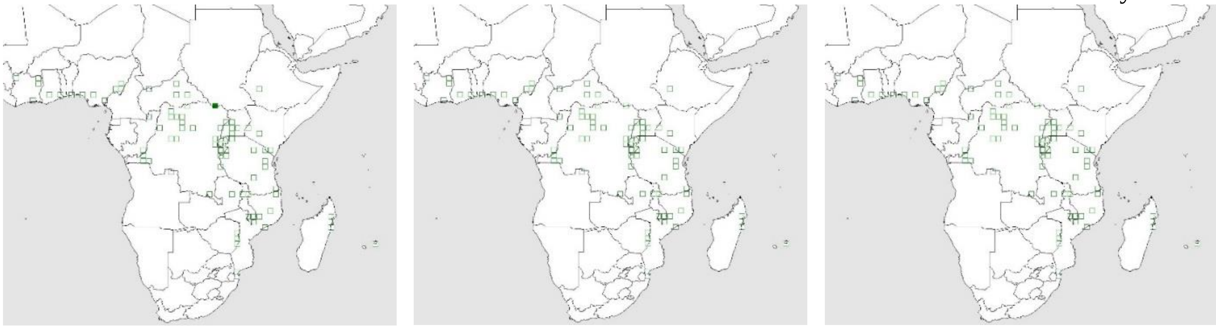
The 37.8 year time lag between the collection and correct determination of specimens produced a different pattern in the accumulation of degree square records as specimens were determined correctly (Figure 5.3D, blue line). The first degree square cells were discovered as the first specimens were determined correctly in the 1930s (Figure 5.3B, blue line). Later in the twentieth century the number of degree square cells increased substantially when the efforts were made to revise the genus; the number of known degree square cells tripled (from 10 to 30) during the mid-1970s and jumped again in the mid-1990s from the low 40s to the

high 50s. The complete geographic distribution was realised with the determinations made by Harris and Wortley (in press).
The range of determination lags of *A. angustifolium* specimens in degree squares was variable over time (Appendix 5.3.1). The time lag between the first collection of a specimen in a degree square and the first correct determination of a specimen in degree square decreased over time. A large proportion (N = 20, 26%) of degree square cells were first determined correctly in the mid-1970s, all of these specimens were collected in the twentieth century. The 26 degree square cells with the shortest time lag (<10 years) between first collection and first correct determination were all collected in the second half of the twentieth century (1955 - 1998). Half of these specimens (13) had a time lag of zero years between collection and correct determination. However there were some exceptions, the 11 degree square cells first determined correctly in 2014 include some of the earliest collected specimens: the specimens collected in 1870, 1881, and 1903, as well as a range of specimens collected throughout the twentieth century up to 1993.

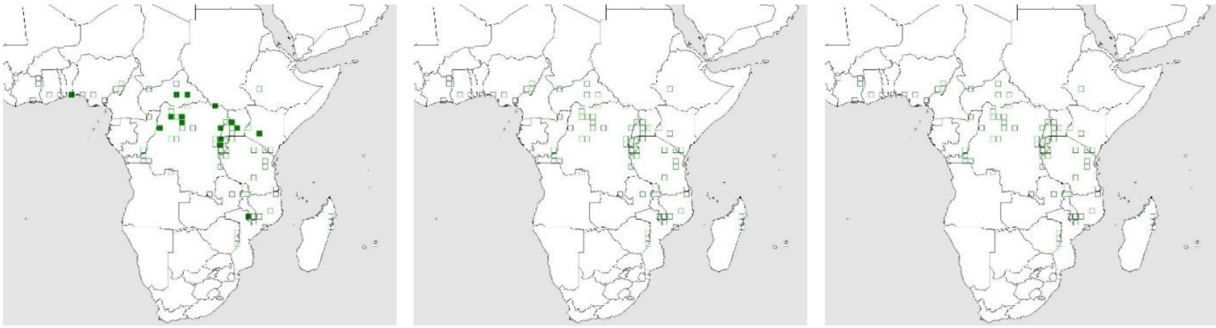
5.3.2.3.1.2 Spatial patterns

Here I explore the effects of the 37.8 year time lag between the collection and correct determination of *Aframomum* specimens on the historical understanding of *A. angustifolium*'s geographical distribution. By comparing the geographical distribution of *A. angustifolium* over time based upon the collection and correct determination of specimens.
The historical understanding of the geographical distribution of *A. angustifolium* based upon the collection of specimens (Figure 5.4, 'Collected') showed a variable accumulation of degree squares over 145 years. The first specimen for which we can allocate a degree square was collected on the border of the DRC and South Sudan in 1870. Over the next sixty years (until 1932) a scattering of specimens were collected across tropical Africa; from Benin in West Africa to Mozambique in Southeast Africa. As the rate of specimen collections accelerated in the second half of the twentieth century the degree squares continued to be accumulated; filling out a thick band of distribution across tropical Africa from West Africa to East Africa (1932 – 1998). The first specimens were collected from the Indian Ocean Islands of Mauritius in 1972 and Madagascar in 1992.
In contrast the historical understanding of the geographical distribution of *A. angustifolium* based upon the correct determination of specimens (Figure 5.4, 'Determined Correctly') showed no known geographical distribution for the species until 1933, when the first specimens were determined from northern East Africa (Tanzania and Uganda). This geographical distribution remained constant until 1942. A scattering of degree squares were added to the geographical distribution in southern East Africa (Zambia and Zimbabwe) in the 1950s and across East Africa (Tanzania and Zimbabwe) in the 1960s (Figure 5.4, 1972). In the 1970s an acceleration in the number of correct determinations produced a sudden expansion of the geographical distribution to encompass the whole of Central and East Africa and Mauritius. The known geographical distribution expanded to West Africa in the 1980s. In the 1990s (Figure 5.4, 1998) and 2000s the distribution across tropical Africa continued to fill out and Madagascar was added to the distribution (Figure 5.4, 2014).
The contrasting accumulation patterns of specimens as they were collected and determined correctly was reflected in the IUCN Red List status over time. The EOO (Appendix 5.3.3, green line, and Appendix 5.3.4) and AOO (Appendix 5.3.2, green line) provided an accurate IUCN Red List category of Least Concern and Endangered for *A. angustifolium* by 1881 as specimens were collected. However the correctly determined specimens did not produce the correct IUCN Red List category until 1955 (EOO >780,000 km^2, AOO = 16 km^2). The correct values for the EOO and AOO produced by the correct determination of specimens were mainly achieved in a short period during the 1970s. Two smaller bursts of correct

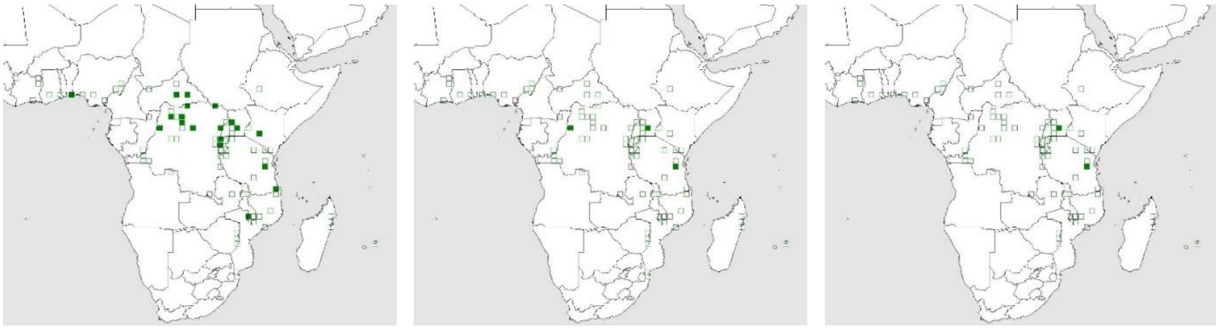
Collected | Determined | Determined Correctly



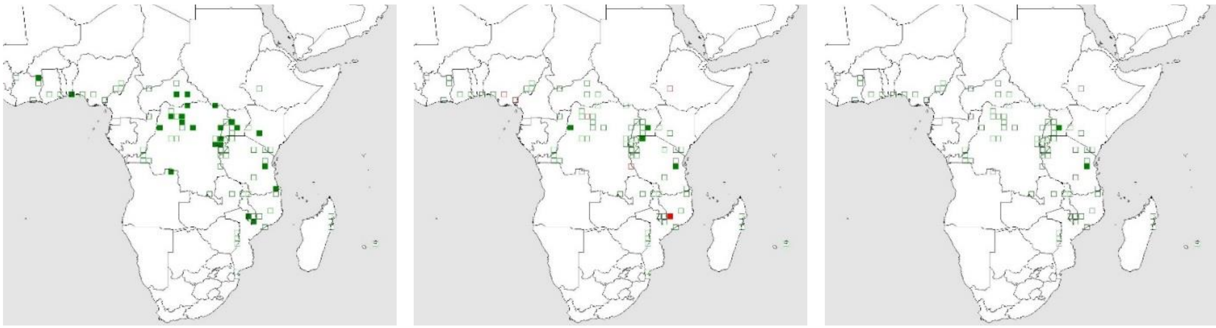
1870



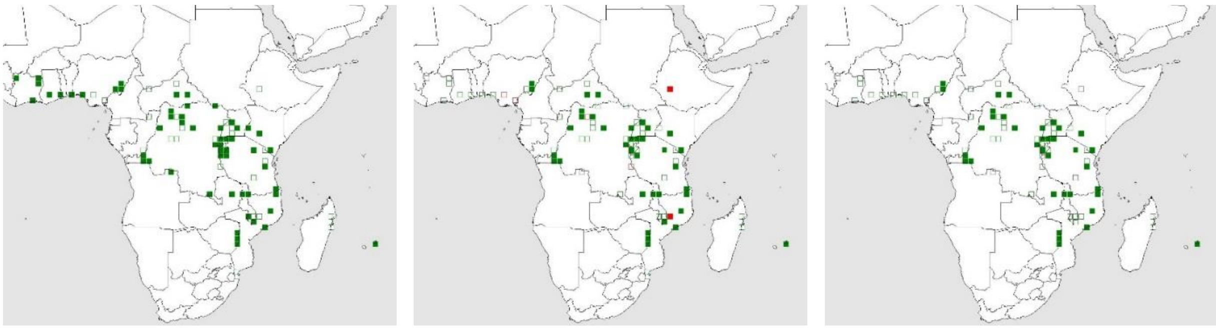
1932



1933



1942



1972

Figure 5.3

Continued on next page,,,

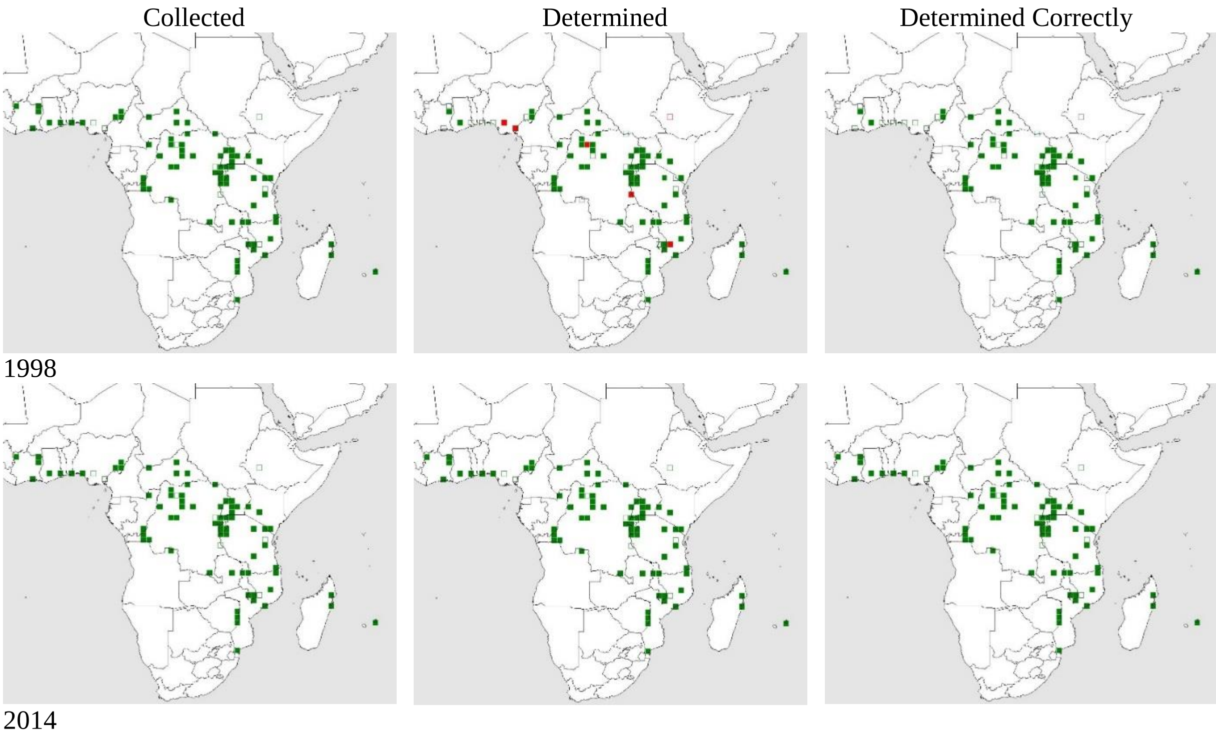


Figure 5.4 *Aframomum angustifolium* distribution maps over time. Presence of the species in degree squares based upon the collection of specimens (left), determinations on specimens (centre), and correct determinations on specimens (right) for a selection of dates between the collection of the first specimen in 1870 and 2014. Degree square cells currently considered to be within *A. angustifolium*'s distribution are green, degree square cells due to incorrect determinations are red.

determinations topped up the EOO and AOO in the 1990s and in 2014 (Appendix 5.3.3 and 5.3.2, blue line). The gap between that of the collected specimens and correctly determined specimens narrowed during the 1970s.

5.3.2.3.2 Effect of incorrect determinations on completing a distribution map

Here I explore the effects of specimens being incorrectly determined as *A. angustifolium* upon the historical understanding of the *A. angustifolium*'s geographical distribution. In particular two questions: Firstly, what effect is there on the time lag for discovery of a degree cell? Secondly, what effect has this time lag had on the understanding of *A. angustifolium*'s geographical distribution?

The mean time lag for the determination of the first specimen in a degree square was reduced slightly, from 29.4 years to 28.0 years (*SD* = 32.9), by the inclusion of incorrect determinations (Appendix 5.3.1).

The apparent geographical distribution of *A. angustifolium* based upon all determined specimens (Figure 5.4, 'Determined') compared to just correctly determined specimens (Figure 5.4, 'Determined Correctly') indicates that the inclusion of incorrectly determined specimens inflated the historical understanding of the species' geographical distribution (Figure 5.4, 1933 – 1972).

The geographical distribution maps based upon all determinations (Figure 5.4, 'Determined') showed larger geographical distribution than that of correctly determined specimens (Figure 5.4, 'Determined Correctly') because of a mixture of degree square cells which are incorrectly thought to contain *A. angustifolium* (six, Figure 5.4 red) and degree squares where a specimen is incorrectly determined as *A. angustifolium* prior to a specimen being correctly determined (four, Figure 5.4 green) (Appendix 5.3.1). For example, the geographical

distribution based upon all determined specimens included west DRC by 1933 and Mozambique by 1942.
The four degree squares which are determined early were responsible for the historical understanding of *A. angustifolium*'s distribution between 1933 and 1970 being that of a widespread species across Central and East Africa (Figure 5.4, 'Determined') much earlier than that of the maps based upon correctly determined specimens alone (Figure 5.4, 'Determined Correctly').
Only one of the incorrect degree squares caused by an incorrectly determined specimen, NE736 in Ethiopia, is outside of the currently understood species geographic range. The remaining locations are well within the tropical African distribution, often in cells adjacent to cells which contain correctly determined specimens of this species. Thus most of the degree squares due to incorrectly determined specimens have not made a significant nor negative difference to the historical understanding of the species' distribution.
A few incorrect determinations did however have a large effect on the EOO and AOO of *A. angustifolium* over time. By 1942, the EOO appeared to be >1,700,000 km^2 (Least Concern) based upon all determined specimens, this was much lower than that of the collected specimens (>4,696,000 km^2, Least Concern) and much higher than that of the correctly determined specimens (0 km^2) (Appendices 5.3.3 and 5.3.4). By 1972 the AOO of the correctly determined specimens (>949,000 km^2) would have given the correct Red List assessment status, Least Concern, but was still lagging far behind the AOO of the determined specimens (>3,850,000 km^2). The Red List assessment of all determined specimens remains 'ahead' of correctly determined specimens until 2014 (Appendices 5.3.2 and 5.3.3).

5.3.3 *AFRAMOMUM SINGULARIFLORUM*

5.3.3.1 Key events in the process of species discovery and distribution maps

Here I introduce the dates of the key events in the process of species discovery in *A. singulariflorum*. The first known specimen of *A. singulariflorum* was collected in 1902. The name, *Aframomum singulariflorum* Dhetchuvi, was published in 1993. The first 10 specimens of *A. singulariflorum* were collected by 1991, determined by 2014, and correctly determined by 2014. The specimens allowing the completion of the distribution map of *A. singulariflorum* were collected by 2008, determined by 2014, and correctly determined by 2014.
For this study, 11 specimens were analysed of which the first specimen was collected in 1902. These specimens represent 11 independent mappable points and are from five degree square cells across the DRC and Congo (Figure 5.5A). This gives an EOO of >186,700 km^2 and an AOO of 28 km^2, which would give *A. singulariflorum* an IUCN Red List conservation assessment category of Least Concern and Endangered, respectively.

5.3.3.2 Historical patterns of specimen collection and determination

Here I describe the patterns of collection, determination and correct determination of *A. singulariflorum* specimens over time. In addition I document the resulting collection, determination and correct determination of key events 3 and 4 (the first 15 specimens and the completion of a comprehensive distribution map).
The accumulation of specimens as they were collected was slow but constant at 1 – 3 specimens per decade throughout the twentieth century (Figure 5.5B, green line) except for a flurry of specimens in 1991. The first ten specimens were collected in 1991 (Figure 5.5C), the last specimen was collected in 2008.

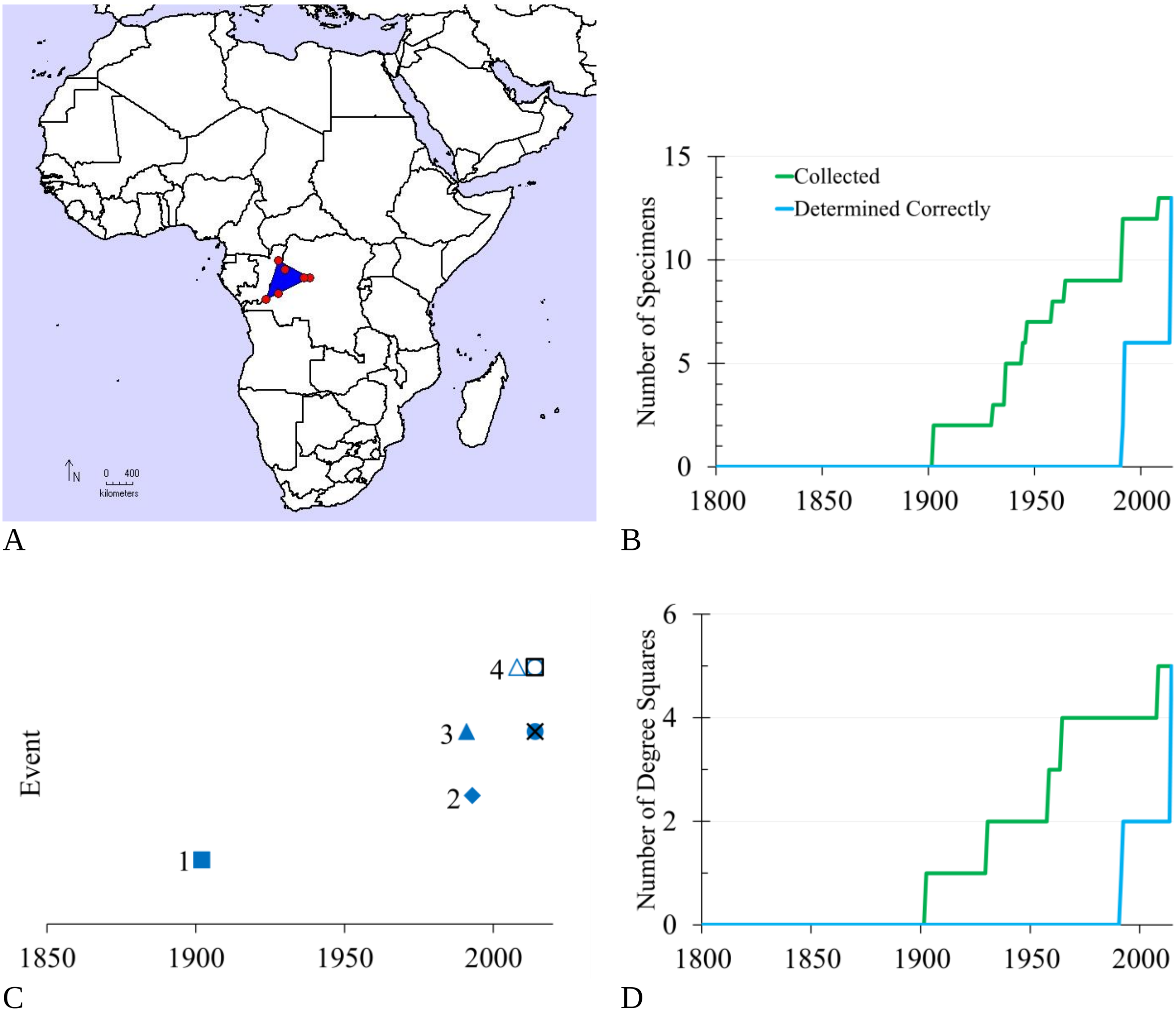


Figure 5.5 The geographical distribution (A), collection and determination history (B) of *Aframomum singulariflorum* specimens, the four key events in the history of the discovery of *A. singulariflorum* (C) and the discovery of the distribution of *A. singulariflorum* (D) over time. (A) The geographical distribution (individual points = yellow markers and extent of occupancy = blue polygon) of the subset of *A. singulariflorum* specimens available for use in this study. (B) The accumulation of *A. singulariflorum* specimens as they are collected (green), determined correctly (blue) and all determinations for that name (orange) between 1800 and 2015. (C) Key events in the history of *A. singulariflorum* between 1850 and 2014: Key event 1 – the first specimen was collected (■); key event 2 – the name was published (♦); key event 3 – the first 10 specimens were collected (▲), determined (●) and determined correctly (X) as *A. singulariflorum*; key event 4 – the comprehensive distribution map was completed as specimens were collected (∆), determined (○) and determined correctly (□) as *A. singulariflorum*. The determination (●/○) and correct determination (X/□) fully overlap (key events 3 and 4). (D) The accumulation of degree squares in the distribution of *A. singulariflorum* as specimens were collected (green), determined correctly (blue) and all determinations for that name (orange) between 1800 and 2015.

The first specimens in this analysis to be correctly determined were two duplicates of Dhetchuvi 924 in 1991 (Figure 5.5B, blue line). A further four specimens were determined by Dhetchuvi in 1992 and the name was published in 1993; the remaining specimens were determined as *A. singulariflorum* in 2014 by Harris and Wortley. Thus the first ten specimens were correctly determined in 2014 (Figure 5.5C).

There were no incorrect determinations on the subset of specimens studied here. The name *A. singulariflorum* was only applied correctly to specimens by Dhetchuvi (the author of the species) and by Harris and Wortley (the authors of the recent monograph).

Time lag 1 in *A. singulariflorum* was longer than average for *Aframomum*, 91 years, however time lags 2 and 3 were only slightly longer; both were 112 years.

5.3.3.3 The effect of species discovery on completing a distribution map

5.3.3.3.1 Effect of determination lag on completing a distribution map

Here I describe and discuss the effects of the specimen determination lag (the average time taken from collection to the correct determination of a specimen, *M* = 37.8 years, Chapter 2) on the discovery of *A. singulariflorum*'s geographical distribution. This has two elements; temporal and spatial, and although I focus on degree squares as a standardised unit, I also discuss the temporal and spatial patterns found in the species' IUCN Red List conservation assessments.

5.3.3.3.1.1 Temporal patterns

In this section I shall explore the general patterns in the accumulation of knowledge of the geographical distribution of *A. singulariflorum* as specimens were collected and determined over time. In particular, I shall address the questions: Firstly, does the time lag from collection to the correct determination of a specimen have an effect on the discovery lag for each degree square? Secondly, are there any notable patterns or trends?

Despite the small number of specimens involved, as *A. singulariflorum* specimens were collected the increase in the known geographical range was remarkably consistent over time (Figure 5.5D, green line) with a specimen being collected in a new degree square cell approximately every 30 years.

The late publication of *A. singulariflorum* (relative to the collection of the first specimen) dramatically delayed the actual discovery of the species' distribution; the geographical distribution was discovered in two rapid bursts (Figure 5.5F, blue line) as the specimens were determined in the 1990s and in the 2010s.

The specimens analysed here occur across five different degree square cells. The first specimen in a degree square were collected on average in 1952.4 (Appendix 5.4.1, *SD* = 35.5) and determined in 2005 (*SD* = 11.0). The mean lag between the first collection in a degree square cell and the first correct determination in a degree square cell was 52.6 years (*SD* = 35.2). This is longer than the mean time lag between the collection and correct determination of a specimen, 37.8 years and may be due to the late publication date (1993, 91 years after the first collected specimen).

5.3.3.3.1.2 Spatial patterns

Here I explore the effects of the 37.8 year time lag between the collection and correct determination of *Aframomum* specimens on the historical understanding of *A. singulariflorum*'s geographical distribution. By comparing the geographical distribution of *A. singulariflorum* over time based upon the collection and correct determination of specimens.

The accumulation of degree squares increased gradually as specimens of *A. singulariflorum* were collected (Figure 5.5D, green line) over time, this is reflected in the distribution maps (Figure 5.6, 'Collected'). From 1902 *A. singulariflorum* was known from western DRC, this range expanded marginally north, east, and then west over the following decades, the last locality to be collected was the specimen from the Congo in the late 1990s.

The distribution of *A. singulariflorum* became known in two distinct phases. *Aframomum singulariflorum* was first known from the northwest DRC in the early 1990s as Dhetchuvi determined his own specimens as a new species. Then, the remainder of the species' distribution, further east and south in western DRC and Congo become apparent in 2014 with the full revision of the genus (Harris and Wortley, in press).

The contrasting accumulation patterns of specimens as they were collected and determined correctly is reflected in the IUCN Red List status of *A. singulariflorum* over time. The EOO (Appendices 5.4.3, green line, and 5.4.4) and AOO (Appendix 5.4.2, green line) provided an

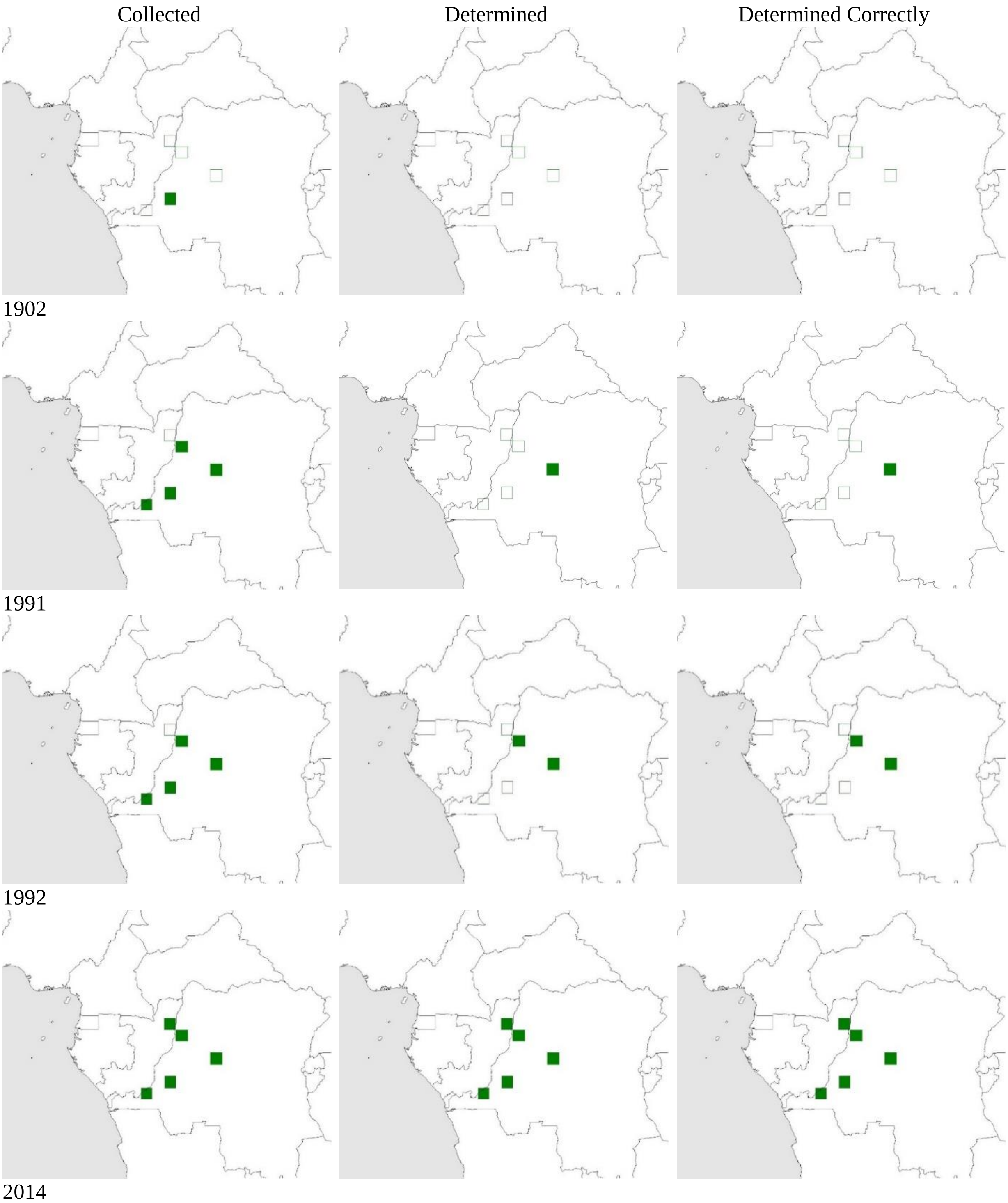


Figure 5.6 *Aframomum singulariflorum* distribution maps over time. Presence of the species in degree squares based upon the collection of specimens (left), determinations on specimens (centre), and correct determinations on specimens (right) for a selection of dates between the collection of the first specimen in 1902 and 2014. Degree square cells currently considered to be within *A. singulariflorum*'s distribution are green, degree square cells due to incorrect determinations are red.

accurate conservation assessment of Least Concern and Endangered for *A. angustifolium* by 1958 as specimens were collected. However the correctly determined specimens did not produce the correct EOO and AOO values until 2014 (EOO > 186,000 km^2, AOO = 28 km^2). The correct values for the EOO and AOO produced by the correct determination of specimens were only achieved during two short periods; in 1991 – 1992 and 2014 for the EOO (Appendix 5.4.2, blue line), and in 2014 only for the AOO (Appendix 5.4.3, blue line).

5.3.3.3.2 Effect of incorrect determinations on completing a distribution map

There are no incorrectly determined specimens of *A. singulariflorum* (Figure 5.5D) in this subset of specimens; thus there is no misinformation in the historical understanding of the species distribution, whether examining the distribution by degree square cell (Figure 5.5F) or IUCN Red List conservation assessment (Appendices 5.4.2, 5.4.3 and 5.4.4).

5.3.4 Discussion

The exploration of two species, *A. angustifolium* and *A. singulariflorum*, presented here demonstrates two starkly different narratives of discovery but also presents some common themes.

Aframomum angustifolium is a widespread species that was collected and published early, and is represented by >250 specimens from across tropical Africa and the Indian Ocean Islands. Although sufficient specimens to produce an accurate conservation assessment (15) were collected and determined correctly in the early twentieth century the vast majority of specimens (>200) were collected after 1950. This matches the general pattern seen in *Aframomum* (Chapter 2) and across most seed plants (Chapter 3). Similar to the results for the whole of *Aframomum*, *A. angustifolium* shows substantial increases in the numbers of correctly determined specimens only during periods of revision of the group, in the 1970s, 1990s and 2010s. This means that the time lag between the first collection and the first correct determination in a degree square that has been collected recently (since 1970) is generally shorter than that of degree squares collected earlier. However, the importance of a completed comprehensive taxonomic revision can be shown by the fact that three degree squares were correctly determined and thus added to the geographic distribution of *A. angustifolium* from old (>100 years prior to Harris and Wortley, in press) specimens only during the most recent taxonomic effort in 2014.

The date of the collection of the first *A. angustifolium* specimen is uncertain (see 5.3.1.1), however if it was collected by Sonnerat himself then it is likely that *A. angustifolium* was collected and published very quickly (Lag 1 may be as short as one year). However the slow collection rate of specimens and slow rate of correct determinations pre-1950 mean that the time lags 2 and 3 were much longer in *A. angustifolium* than average for *Aframomum* (time lag 2 = 180 and time lag 3 = 233 years, the average for *Aframomum* were 101 and 115 years respectively, Chapter 4).

The distribution maps based upon the collection, determination and correct determination of *A. angustifolium* specimens over time presented here show clearly how the time lag in specimen determinations and species discovery time lag 3 slows down the understanding of the species' distribution. The maps illustrating the distribution of collected specimens show a more complete distribution earlier than those for determined and correctly determined specimens. Until the focused taxonomic efforts in the 1970s, 1990s and 2010s (Figure 2.6G and Figure 5.3D) the distribution maps of *A. angustifolium* based upon the correctly determined specimens were incomplete and misleading, apparently indicating the species to be restricted to East Africa (Figure 5.4).

This misinformation is also reflected in the IUCN Red List conservation assessments of the species. The correct preliminary IUCN Red List conservation status of *A. angustifolium* and areas calculated using the AOO and EOO were achieved much later when calculated using the correctly determined specimens than with the collection of specimens (Appendices 5.3.2 and 5.3.3).

As noted in section 5.2.3 the incorrect determination of *A. angustifolium* specimens rarely adversely affect the understanding of the species' geographical distribution, instead the incorrect locations tended to be 'hidden' within the correct distribution. The species distribution maps based upon all determined specimens instead achieve the 'correct' distributions and IUCN Red List conservation assessments earlier than the distribution maps based upon correct determinations alone (Figure 5.4).

In contrast *A. singulariflorum* is a restricted species that was collected relatively early but published very recently and is represented by very few specimens (11). The relatively late publication date of *A. singulariflorum* strongly influenced the past understanding of the species' distribution maps. These distribution maps could not be produced until the species name was published in 1993 (Figure 5.6).

However, similar to *A. angustifolium*, the distribution maps and IUCN Red List conservation assessments were only completed as a result of focused taxonomic effort in 2014. The original species publication missed a number of extant specimens which would have enlarged the known geographical distribution at the time. Only a complete revision of the genus was able to find and correctly determine those specimens and consequently complete the understanding of the species' geographical distribution.

In contrast to *A. angustifolium*, time lag 1 for *A. singulariflorum* (between the first collection and publication) was longer than average for *Aframomum* (91 years). However, the lags to key events 3 and 4 were only slightly longer (both 122 years). This is due to the timing of the publication of *A. singulariflorum*; during the 1970 – 2000 doubling of specimens and coinciding with two successive periods of focused taxonomic revisions of *Aframomum*, in the 1990s and 2010s (Chapter 2).

As discussed in Chapter 4 the results I present here are based upon a subset (approximately 50%) of specimens; only 1,779 specimens had a complete set of dates for every determination. A comparison of the full dataset and the subset examined here is provided in Appendix 5.2. The results I present here represent the latest possible dates for the understanding of a species' geographical distribution. The understanding of geographical distribution based on all available specimens would have occurred earlier, in particular, because specimens collected pre-1900 were more likely to not have a complete determination history. However, the date for the completion of a comprehensive distribution map is not likely to be influenced by the data sampling. The distribution maps were completed in 2014 because A) the full set of the specimens, and thus locations, were only collected by the end of the twentieth century. And B) the specimens were all correctly determined during the comprehensive revision of *Aframomum*, completed in 2014.

The implications of the spatial and temporal complexity of variations in species discovery are important: widespread species take much longer to be 'known' completely than restricted species. Differences in the date of publication between widespread and restricted species are well documented (Gaston *et al.*, 1995; Allsopp, 1997; Roberts *et al.*, 2016). However the results I present here show that the process of species discovery is more complex than previous work has suggested, particularly for restricted species which demonstrate substantial variation. The timing of the first two key events, the collection of the first specimen and the publication of the name, relative to the exponential increase in the number of specimens post-1950 and relative to the periods of focused taxonomic effort strongly influence species discovery time lags and the understanding of a species' geographical distribution. This bodes well for the recently discovered species and species yet to be discovered. The collections of specimens exist (Bebber *et al.*, 2010), only the focused effort of experts (Bebber *et al.*, 2012) is required. The majority of remaining species are probably restricted (Roberts *et al.*, 2016) so maybe the 2020 target for a completed online world Flora and conservation assessments for all known species (Sharrock, 2012) is viable if the required taxonomic revisions are completed.

The differences in understanding of widespread compared with restricted species documented here have further implications for the unquestioning use of data from online aggregators such as GBIF. The large number of specimens filed under just a few widespread species of *Ipomoea* (Chapter 3) showed the importance of widespread species in herbaria and online data aggregators. The dominance of specimens of widespread species in herbaria combined with the tendency for specimens of restricted species to be determined as widespread species documented in this chapter this should lead to extra caution.

5.4 CONCLUSIONS

There are two main conclusions from this chapter: Firstly, that the time lags documented in Chapter 4 have important implications for the understanding of species distributions in the absence of comprehensive taxonomic revisions. This has been shown by the presence of species in degree squares and by the accumulation of calculated EOO and AOO over time. Secondly, that different species have different narratives of species discovery. These narratives are defined by a complex interplay between temporal (the dates of key events) and spatial (the size of the species' geographical range) variables and the quality of the determinations on the specimens.

This is important because different species are not understood fully in the absence of comprehensive taxonomic revisions for different reasons.

Firstly, widespread species are quick to 'discover' (time lag 1) but take a long time to 'know' completely (time lag 3). Two different processes seem to influence time lag 3. 1) The long time lags in the correct determination of specimens in different locations and 2) specimens of other species are incorrectly determined as the widespread species prevent the correct understanding of the species' geographical distribution in the absence of a comprehensive taxonomic revision.

Secondly, the process of species discovery, especially in restricted species is strongly influenced by the date of the key events (particularly the collection of the first specimen and species publication) relative to the post-1950 doubling of specimens and periods of focused taxonomic effort in the 1970s, 1990s and 2010s. This is important in restricted species because they are more vulnerable to misinformation cause by incorrect determinations and long determination lags than widespread species.

These results mean that if we are to complete an online world Flora and conservation assessments for all known species (Sharrock, 2012) by 2020 then: 1) there is a need to tackle widespread species. They may all have been 'discovered' but they are not completely understood and contain incorrectly determined specimens. 2) Focused taxonomic effort rapidly helps understand recently discovered and new species which are yet to be discovered. These species are likely to be restricted in distribution and at a high risk of extinction so they are important to understand, in particular for conservation.

5.5 BIBLIOGRAPHY

Allsopp, P. G. (1997). "Probability of describing an Australian scarab beetle: influence of body size and distribution." *Journal of Biogeography* 24: 717–724.

Bachman, S., *et al*. (2011). "Supporting Red List threat assessments with GeoCAT: Geospatial Conservation Assessment Tool." *ZooKeys*: 117–126.

Bebber, D. P., *et al*. (2012). "Big hitting collectors make massive and disproportionate contribution to the discovery of plant species." *Proceedings of the Royal Society B: Biological Sciences* 279: 2269–2274.

Bebber, D. P., *et al*. (2010). "Herbaria are a major frontier for species discovery." *PNAS* 107: 22169–22171.

Blackburn, T. M. and K. J. Gaston (1994). "Animal body size distributions change as more species are described." *Proceedings of the Royal Society B: Biological Sciences* 257: 293–297.

Blackburn, T. M. and K. J. Gaston (1995). "What determines the probability of discovering species?: A study of South American oscine passerine birds." *Journal of Biogeography* 22: 7–14.

Brummitt, N. A., *et al*. (2015). "Green plants in the red: a baseline global assessment for the IUCN Sampled Red List Index for Plants." *PLoS ONE* 10: e0135152.

Dorr, L. J. (1997). *Plant collectors in Madagascar and the Comoro Islands: a biographical and bibliographical guide to individuals and groups who have collected herbarium material of algae, bryophytes, fungi, lichens, and vascular plants in Madagascar and the Comoro Islands*. Washington, D.C. : Dept. of Botany, MRC-166, National Museum of Natural History, Smithsonian Institution, , Royal Botanic Gardens, Kew. xlvi + 524.

Fontaine, B., *et al*. (2012). "21 years of shelf life between discovery and description of new species." *Current Biology* 22: R943–R944.

Gaston, K. J. (1991). "Body size and probability of description: the beetle fauna of Britain." *Ecological Entomology* 16: 505–508.

Gaston, K. J. and T. M. Blackburn (1994). "Are newly described bird species small-bodied?" *Biodiversity Letters* 2: 16–20.

Gaston, K. J., *et al*. (1995). "Which species are described first?: The case of North American butterflies." *Biodiversity and Conservation* 4: 119–127.

Good, T. C., *et al*. (2006). "Addressing data deficiency in classifying extinction risk: a case study of a radiation of Bignoniaceae from Madagascar." *Conservation Biology* 20: 1099–1110.

Harris, D. J. and A. H. Wortley (in press). "Monograph of *Aframomum* (Zingiberaceae)." *Systematic Botany Monographs*.

Hjarding, A., *et al*. (2014). "Red List assessments of East African chameleons: a case study of why we need experts." *Oryx* 48: 1–7.

Kirschner, J. and Ž. Kaplan (2002). "Taxonomic monographs in relation to global Red Lists." *Taxon* 51: 155–158.

Mace, G. M. (2004). "The role of taxonomy in species conservation." *Philosophical Transactions of the Royal Society B: Biological Sciences* 359: 711–719.

Meier, R. and T. Dikow (2004). "Significance of specimen databases from taxonomic revisions for estimating and mapping the global species diversity of invertebrates and repatriating reliable specimen data." *Conservation Biology* 18: 478–488.

Paton, A. J., *et al*. (2008). "Towards Target 1 of the Global Strategy for Plant Conservation: a working list of all known plant species - progress and prospects." *Taxon* 57: 602–611.

Pitman, N. C. A. and P. M. Jørgensen (2002). "Estimating the size of the world’s threatened flora." *Science* 298: 989.

Reed, R. N. and S. M. Boback (2002). "Does body size predict dates of species description among North American and Australian reptiles and amphibians?" *Global Ecology & Biogeography* 11: 41–47.
Roberts, D. L., *et al*. (2016). "Threatened or data deficient: assessing the conservation status of poorly known species." *Biodiversity Research* 22: 1–8.
Sharrock, S. (2012). Global Strategy for Plant Conservation: a guide to the GSPC - All the targets, objectives and facts. Richmond, Botanic Gardens Conservation International: 36.
Sonnerat, P. (1782). *Voyages aux Indes Orientales et à la Chine*. Paris, Dentu xxviii + 372.
Wayt Thomas, W. (1999). "Conservation and monographic research on the flora of Tropical America." *Biodiversity and Conservation* 8: 1007–1015.

6 Summary, discussion and conclusions

CONTENTS

6.1 KEY RESULTS AND THEMES

6.1.1 WIDESPREAD UNCERTAINTY IN NAMES AND A DOUBLING IN THE NUMBER OF COLLECTIONS

Aframomum (Zingiberaceae) is a moderately sized genus of tropical plants recently revised by Harris and Wortley (in press). By examining the determination history of *Aframomum* specimens in Chapter 2 I found that that firstly, in the absence of a recent taxonomic revision more than half of specimens of *Aframomum* specimens do not have the correct name. Similar results were found for other seed plants. Secondly, I found that the numbers of specimens of seed plants in herbaria, found in *Aframomum* and in other taxa and floras, doubled between 1970 and 2000.

What are the implications of these results? Firstly, that the current system for putting names on specimens is failing to keep up with the influx of specimens even for ‘well known’ and recently revised groups, such as the Dipterocarpaceae. A combination of more active expert taxonomists, proactive curation and integrated databases of specimens and names is required to keep on top of the names on specimens. Secondly, that groups of seed plants that have not been ‘recently’ revised (since 1970) are so poorly known that getting a correct determination on a specimen is problematic. The benefits for further species discovery by revisiting recently revised taxa has already been shown (Prance, 1977; Dexter *et al.*, 2010), but these two results show the continuing need for expertise to improve the quality of names on specimens.

The results in Chapter 4 indicate why there may be large amounts of uncertainty in the quality of names on plant specimens. Put simply, it takes a long time to understand something as that might appear to be straight forward as a plant species’ geographical distribution. The time lag to 'discover' a species of seed plant is well established (Bebber *et al.*, 2010; Fontaine *et al.*, 2012). However here I have shown that most seed plants are not well 'known' at the time of publication because 93.8% of seed plant species protologues cited less than 15 specimens. This already suggests that 32-39 years (the 'discovery lag' Bebber *et al.*, 2010; Fontaine *et al.*, 2012) is shorter than the 'knowledge lag', the time taken from the collection of the first specimen to the complete understanding of a species' geographical distribution. The time lags calculated for *Aframomum* show that it is almost certainly true, for *Aframomum* both lag 2 and lag 3 are longer than 100 years. Chapter 5 then showed the importance of partial taxonomic revisions in improving our general understanding of a species' distribution both to produce accurate conservation assessments. However, a complete and comprehensive taxonomic revision is required to completely understand a species' geographical distribution. The final implication of the results found here is that, through focused taxonomic effort it is possible to clean up names on specimens and in literature (Chapter 2). This dramatically improves our understanding of species' geographical distribution (Chapter 5) and shortens the species discovery time lags (Chapter 4). Because an author's experience of taxa and specimens increases an author's ability to determine correctly specimens (Chapter 2) we can clear up uncertainty in plant names and specimens through investment in training and expertise (Ahrends *et al.*, 2011; Bebber *et al.*, 2012).

6.1.2 THE IMPORTANCE OF WIDESPREAD SPECIES

Widespread species are known to be discovered, collected and published early (Gaston *et al.*, 1995; Allsopp, 1997; Roberts *et al.*, 2016) and the results in this thesis show that to be true for *Aframomum* (Chapter 4). However, the results I present here also indicate that the process of species discovery in widespread species of *Aframomum* is complex: Widespread species names contain the majority of incorrectly determined specimens and mixed species concepts in past taxonomic accounts (Chapter 2). The uncertainty in specimen names negatively affects the complete understanding of the geographical distribution of widespread species (Chapter 5), and lengthens the 'knowledge lag' (time lag 3) for widespread species (Chapter 4).

This means that although we have probably already 'discovered' most widespread species (Roberts *et al.*, 2016), we do not necessarily understand their distribution. This is important for two reasons: Firstly, the incorrect determinations and long correct determination lags on specimens of widespread species cause incomplete understanding of the geographical distribution of those widespread species. Secondly, the time lags to the correct determinations of specimens in other species lengthen when these specimens are incorrectly determined as widespread species. Thus the incorrect determinations in widespread species need to be corrected if we are to understand both the widespread species and other species better.

The misinformation contained on the specimens of widespread species has particular resonance for the unquestioning use of data aggregators such as GBIF. Specimens identified as widespread species inevitably dominate the records held in these aggregators (Chapter 3). Yet in the absence of a revision these same widespread species names may incorrectly contain many specimens from other species, implying that this data is of little value for the study of restricted species.

6.1.3 THE IMPORTANCE OF RESTRICTED SPECIES

Geographically-restricted species are known, to be on average, discovered later than widespread species (Gaston *et al.*, 1995; Allsopp, 1997; Roberts *et al.*, 2016) and the results in this thesis show that to be true for *Aframomum* (Chapter 4). However, the results I present here also indicate that the process of species discovery in restricted species of *Aframomum* is complex and very different to that of widespread species.

Firstly, restricted species have widely variable narratives of species discovery (Chapter 5), four main narratives of species discovery were identified for restricted species. These narratives varied by the quantity and type of misinformation in the determinations on specimens and how this influenced the understanding of the species' geographical distribution. This appeared to be determined by the dates of the first two key events of the species, the collection of the first specimen and the publication of the species name, relative to the second half of the twentieth century. In particular, relative to the two defining events in the history of *Aframomum*: the doubling of the number of *Aframomum* specimens between 1966 and 2000 and the three periods of focused taxonomic effort in the 1970s, 1990s and 2010s. Collection of the first specimen during or after the doubling in the number of *Aframomum* specimens meant that more specimens of the species were likely to have been collected immediately after the initial specimen collection, thus allowing complete understanding of the species to quickly follow. The publication of the species name during or after periods of focused taxonomic effort meant that specimens of the species were correctly determined more quickly than those of species published prior to the periods of focused taxonomic effort.

Differences in the date of publication between widespread and restricted species are well documented (Gaston *et al.*, 1995; Allsopp, 1997; Roberts *et al.*, 2016). However the results I present here (Chapter 5) show that the process of species discovery for restricted species is more complex than previous work has suggested. The incorrect determinations of restricted species (usually as widespread species, Chapters 2 and 5) has implication for the unquestioning use of data aggregators such as GBIF, implying that this data is of little value for the study of restricted species.

The species of seed plant still to be described are likely to be restricted species and thus threatened (Roberts *et al*., 2016); the search for these new species needs to have two parts, firstly focused taxonomic revision using existing herbarium collections (Bebber *et al*., 2010) and secondly targeted specimen collecting from under-collected locations in the Tropics (Prance *et al*., 2000).

The first part, the discovery of new species found amongst existing collections requires effort and resources as seen in the Harris and Wortley (in press) monograph of *Aframomum* examined here, but can be highly effective (Wayt Thomas, 1999). The traditional concept of single botanist dedicating a life-time of work to a single group, as typified by *Hypericum* (Carine and Christenhusz, 2010), appears to be dying out (Bebber *et al*., 2012). This is potentially problematic because the results shown here for *Aframomum* indicate that only focussed expertise makes significant positive contributions to specimen determinations. However, species-rich groups considered to be too large for single individuals to tackle are increasingly being targeted by international collaborations (Wayt Thomas *et al*., 2012) exemplified by the PBI Solanum Project (2012). This bodes well because it has become clear in this thesis that the specimens of widespread species need determined correctly in order to discover the mis-identified specimens of restricted species which may be hidden among those of the widespread species. Such are the large numbers of specimens available now and the domination of widespread species in herbarium collection indicated here, that this may represent too much work for a single expert. The trends towards large international taxonomic collaborations and increasing digitisation of herbarium specimens (JSTOR, 2017; Chagnoux and Michiels, 2011) and literature (Wayt Thomas and Tulig, 2015) promises an opportunity to solve this conundrum.

The second part, new collection of specimens from under-collected regions may be best achieved by focusing resources on collectors with training (Ahrends *et al*., 2011) and experience (Bebber *et al.*, 2012). To build up the necessary capacity and knowledge there is clearly a need for the use of parataxonomists (Basset *et al*., 2000; Janzen, 2004; Webb *et al*., 2010) made possible by rapid training in the principles of family-level tropical plant identification (Harris *et al.*, 2015) and use of high-quality identification literature (Hawthorne *et al.*, 2014). Collecting needs to be guided by up-to-date and accurate mapping (Prance, 2001) of hotspots (for example Marshall *et al*., 2016) and existing collections (for example Feeley, 2015; Stropp *et al*., 2016). The results from the study of *Aframomum* indicate that newly collected specimens of restricted species will be more likely to be recognised as such if a complete taxonomic revision of existing collections has already occurred, as was demonstrated for Neotropical Chrysobalanaceae (Prance, 1977).

Understanding restricted species is important because many of them are likely to be threatened (Roberts *et al.*, 2016) or extinct (Pimm *et al.*, 2014), yet the results I present here show that a few incorrectly determined or indeterminate specimens can mean that extinction risk of restricted species is either over exaggerated or underestimated. This highlights the importance of comprehensive taxonomic revisions and expert aggregated datasets to IUCN Red List conservation assessments (Kirschner and Kaplan, 2002; Mesibov, 2013; Hjarding *et al.*, 2014). If we are to recognise threatened species then we need to understand the restricted species.

6.2 SUMMARY CONCLUSIONS

For the first time ever the complex process of species discovery in seed plants has been investigated in detail. Two key results have profound implications for documenting the known species of seed plants: in the absence of a recent taxonomic revision, more than half of specimens do not have the correct name, secondly there was a doubling in the number of specimens collected between 1970 and 2000. These results have several implications: Firstly, that the current system for updating names on the influx of specimens is not working efficiently. Secondly, that even if it were working effectively, the taxonomy of many groups is so poorly known that existing knowledge of many groups does not allow for accurate identification of specimens. Thus groups not revised 'recently' need to be comprehensively revised. However the increase in the number of specimens provides an opportunity for new species to be discovered, for known species to be understood better and focused taxonomic effort can rapidly improve understanding of recently discovered species. This bodes well for ambitious targets to complete an online Flora for all known plants (Sharrock, 2012).

There is a need to tackle both geographically widespread species and geographically restricted species. Widespread species may all have been 'discovered' but they are not completely understood and contain incorrectly determined specimens. Newly discovered species are likely to be restricted in distribution and at a high risk of extinction, so they are important for conservation. The understanding of these species is likely to be poor without taxonomic effort. However, the understanding of restricted species can be rapidly improved by focused taxonomic effort by experts.

6.3 Bibliography

Ahrends, A., *et al*. (2011). "Conservation and the botanist effect." *Biological Conservation* 144: 131–140.

Allsopp, P. G. (1997). "Probability of describing an Australian scarab beetle: influence of body size and distribution." *Journal of Biogeography* 24: 717–724.

Basset, Y., *et al*. (2000). "Quantifying biodiversity: experience with parataxonomists and digital photography in Papua New Guinea and Guyana." *BioScience* 50: 899–908.

Bebber, D. P., *et al*. (2010). "Herbaria are a major frontier for species discovery." *PNAS* 107: 22169–22171.

Bebber, D. P., *et al*. (2012). "Big hitting collectors make massive and disproportionate contribution to the discovery of plant species." *Proceedings of the Royal Society B: Biological Sciences* 279: 2269–2274.

Carine, M. A. and M. J. M. Christenhusz (2010). "About this volume: the monograph of *Hypericum* by Norman Robson." *Phytotaxa* 4: 1–4.

Chagnoux, S. and H. Michiels (2011). Switching to the fast track: rapid digitization of the world's largest herbarium. TDWG 2011- New Orleans.

Dexter, K. G., *et al*. (2010). "Using DNA to assess errors in tropical tree identifications: How often are ecologists wrong and when does it matter?" *Ecological Monographs* 80: 267–286.

Feeley, K. J. (2015). "Are we filling the data void? an assessment of the amount and extent of plant collection records and census data available for tropical South America." *PLoS ONE* 10: e0125629.

Fontaine, B., *et al*. (2012). "21 years of shelf life between discovery and description of new species." *Current Biology* 22: R943–R944.

Gaston, K. J., *et al*. (1995). "Which species are described first?: The case of North American butterflies." *Biodiversity and Conservation* 4: 119–127.

Harris, D. J., *et al*. (2015). Training in tropical plant identification. In *Descriptive taxonomy: the foundation of biodiversity research*. M. F. Watson, C. H. C. Lyal and C. A. Pendry. Cambridge Cambridge University Press. 84: 160–170.

Harris, D. J. and A. H. Wortley (in press). "Monograph of *Aframomum* (Zingiberaceae)." *Systematic Botany Monographs*.

Hawthorne, W. D., *et al*. (2014). "Empirical trials of plant field guides." *Conservation Biology* 28: 654–662.

Hjarding, A., *et al*. (2014). "Red List assessments of East African chameleons: a case study of why we need experts." *Oryx* 48: 1–7.

Janzen, D. H. (2004). "Setting up tropical biodiversity for conservation through non-damaging use: participation by parataxonomists." *Journal of Applied Ecology* 41: 181–187.

JSTOR. (2017). "JSTOR Global Plants."   Retrieved April 2017, from http://plants.jstor.org/.

Kirschner, J. and Ž. Kaplan (2002). "Taxonomic monographs in relation to global Red Lists." *Taxon* 51: 155–158.

Kress, W. J., *et al*. (2002). "The phylogeny and a new classification of the gingers (Zingiberaceae): evidence from molecular data." *American Journal of Botany* 89: 1682–1696

Marshall, C. A. M., *et al*. (2016). "Bioquality hotspots in the tropical African flora." *Current Biology* 26: 3214–3219.

Mesibov, R. (2013). "A specialist's audit of aggregated occurrence records." *ZooKeys* 293: 1–18.

PBI Solanum Project. (2012). "Solanaceae Source." Retrieved from http://www.nhm.ac.uk/research-curation/research/projects/solanaceaesource/
Pedersen, L. B. (2004). "Phylogenetic analysis of the subfamily Alpinioideae (Zingiberaceae), particularly *Etlingera* Giseke, based on nuclear and plastid DNA." *Plant Systematics and Evolution* 245: 239–258.
Pimm, S. L., *et al*. (2014). "The biodiversity of species and their rates of extinction, distribution, and protection." *Science* 344: 1246752.
Prance, G. T. (1977). "Floristic inventory of the tropics: where do we stand?" *Annals of the Missouri Botanical Garden* 64: 659–684.
Prance, G. T. (2001). "Discovering the plant world." *Taxon* 50: 345–358.
Prance, G. T., *et al*. (2000). "The tropical flora remains undercollected." *Annals of the Missouri Botanical Garden* 87: 67–71.
Roberts, D. L., *et al*. (2016). "Threatened or data deficient: assessing the conservation status of poorly known species." *Biodiversity Research* 22: 1–8.
Särkinen, T. E., *et al*. (2007). "Recent oceanic long-distance dispersal and divergence in the amphi-Atlantic rain forest genus *Renealmia* L.f. (Zingiberaceae)." *Molecular Phylogenetics and Evolution* 44: 968–980.
Sharrock, S. (2012). Global Strategy for Plant Conservation: a guide to the GSPC - All the targets, objectives and facts. Richmond, Botanic Gardens Conservation International: 36.
Stropp, J., *et al*. (2016). "Mapping ignorance: 300 years of collecting flowering plants in Africa." *Global Ecology and Biogeography* 25: 1085–1096.
Wayt Thomas, W. (1999). "Conservation and monographic research on the flora of Tropical America." *Biodiversity and Conservation* 8: 1007–1015.
Wayt Thomas, W., *et al*. (2012). "Large-scale monographs and floras: the sum of local floristic research." *Plant Ecology & Diversity* 5: 217–223.
Wayt Thomas, W. and M. Tulig (2015). "Hard copy to digital: Flora Neotropica and the World Flora Online." *Rodriguésia* 66: 983–987.
Webb, C. O., *et al*. (2010). "Biodiversity inventory and informatics in Southeast Asia." *Biodiversity and Conservation* 19: 955–997.

Appendices

CONTENTS

1 APPENDICES – INTRODUCTION

1.1 CURRENTLY ACCEPTED SPECIES OF *AFRAMOMUM* AND THEIR GEOGRAPHIC RANGE

The 61 *Aframomum* species accepted by Harris and Wortley (In Press) with the year of publication (*Aframomum* combination in parentheses), extent of geographical range (number of degree square cells occupied), and Star rating following protocol in Hawthorne and Marshall (2016).
The publication dates of the 12 new species to be published in Harris and Wortley (In Press) is given as 2017, as this is the most likely year of publication and a year is required for calculation of mean dates.
Stars are designed to indicate the global rarity of a species. Black Stars are the rarest category and have extremely restricted geographical distributions, at the other extreme, Green Stars are geographically widespread and are of no special conservation concern in terms of their rarity. The sequence from high to low rarity is: Black, Gold, Blue and Green (Hawthorne and Marshall, 2016). I have used Stars to indicate whether a species is widespread or restricted.

Species	**Year**	**Range**	**Star**
Aframomum albiflorum Lock	1984	19	Blue
Aframomum alboviolaceum (Ridl.) K.Schum.	1887 (1904)	28	Green
Aframomum alpinum (Gagnep.) K.Schum.	1902 (1904)	6	Gold
Aframomum angustifolium (Sonn.) K.Schum.	1782 (1904)	105	Green
Aframomum arundinaceum (Oliv. & D.Hanb.) K.Schum.	1864 (1904)	7	Gold
Aframomum atewae Lock & J.B.Hall	1974	1	Black
Aframomum aulacocarpos Pellegr. ex Koechlin	1964	2	Black
Aframomum chrysanthum Lock	1978	15	Blue
Aframomum citratum (J.Pereira) K.Schum.	1850 (1904)	12	Blue
Aframomum cordifolium Lock & J.B. Hall	1974	6	Gold
Aframomum corrorima (A.Braun) P.C.M.Jansen	1848 (1981)	13	Blue
Aframomum daniellii (Hook.f.) K.Schum.	1854 (1904)	54	Green
Aframomum dhetchuvi D.J.Harris & Wortley In Press	2017	1	Black
Aframomum elegans Lock	1980	3	Gold
Aframomum elliotii (Baker) K.Schum.	1898 (1904)	4	Gold
Aframomum exscapum (Sims) Hepper	1805 (1967)	12	Blue
Aframomum fragrans D.J.Harris & Wortley In Press	2017	7	Gold
Aframomum giganteum (Oliv. & D.Hanb.) K.Schum.	1864 (1904)	23	Blue
Aframomum glaucophyllum (K.Schum.) K.Schum.	1893 (1904)	19	Blue
Aframomum hirsutum D.J.Harris & Wortley	2017	7	Gold

Continued on next page,,,

Appendix 1

Appendix 1.1

Species	Year	Range	Star
Aframomum kamerunica D.J.Harris & Wortley In Press	2017	3	Gold
Aframomum kayserianum (K.Schum.) K.Schum.	1893 (1904)	5	Gold
Aframomum kodmin D.J.Harris & Wortley	2017	2	Black
Aframomum laxiflorum Loes. ex Lock	1976	3	Gold
Aframomum leptolepis (K.Schum.) K.Schum.	1893 (1904)	8	Gold
Aframomum letestuanum Gagnep.	1908	37	Green
Aframomum limbatum (Oliv. & D.Hanb.) K.Schum.	1864 (1904)	54	Green
Aframomum longiligulatum Koechlin	1965	8	Gold
Aframomum longipetiolatum Koechlin	1964	4	Gold
Aframomum longiscapum (Hook.f.) K.Schum.	1854 (1904)	6	Gold
Aframomum lutarium D.J.Harris & Wortley In Press	2017	4	Gold
Aframomum luteoalbum (K.Schum.) K.Schum.	1892 (1904)	24	Blue
Aframomum makandensis Dhetchuvi	1995	4	Gold
Aframomum mala (K.Schum. ex Engl.) K.Schum.	1895 (1904)	8	Gold
Aframomum mannii (Oliv. & D.Hanb.) K.Schum.	1864 (1904)	3	Gold
Aframomum melegueta (Roscoe) K.Schum.	1827 (1904)	56	Green
Aframomum mildbraedii Loes.	1910	10	Blue
Aframomum orientale Lock	1984	3	Gold
Aframomum parvulum D.J.Harris & Wortley In Press	2017	3	Gold
Aframomum pilosum (Oliv. & D.Hanb.) K.Schum.	1864 (1904)	8	Gold
Aframomum plicatum D.J.Harris & Wortley In Press	2017	5	Gold
Aframomum polyanthum (K.Schum.) K.Schum.	1893 (1904)	36	Green
Aframomum pseudostipulare Loes. & Mildbr. ex Koechlin	1964	8	Gold
Aframomum rostratum K.Schum.	1904	10	Blue
Aframomum rotundum D.J.Harris & Wortley In Press	2017	1	Black
Aframomum scalaris D.J.Harris & Wortley In Press	2017	7	Gold
Aframomum sceptrum (Oliv. & D.Hanb.) K.Schum.	1864 (1904)	55	Green
Aframomum sericeum Dhetchuvi & D.J.Harris	2011	13	Blue
Aframomum singulariflorum Dhetchuvi	1993	7	Gold
Aframomum spiroligulatum A.D.Poulsen & Lock	1997	2	Black
Aframomum stanfieldii Hepper	1968	9	Blue
Aframomum strobilaceum (Sm.) Hepper	1802 (1967)	14	Blue
Aframomum submontanum D.J.Harris & Wortley In Press	2017	4	Gold
Aframomum subsericeum (Oliv. & D.Hanb.) K.Schum.	1864 (1904)	17	Blue

Continued on next page,,,

Appendix 1

Appendix 1.1

Species	**Year**	**Range**	**Star**
Aframomum sulcatum (Oliv. & D.Hanb. ex Baker) K.Schum.	1898 (1904)	13	Blue
Aframomum tchoutoui D.J.Harris & Wortley In Press	2017	4	Gold
Aframomum thonneri De Wild.	1911	38	Green
Aframomum uniflorum Lock & A.D.Poulsen	1997	3	Gold
Aframomum verrucosum Lock	1984	15	Blue
Aframomum wuerthii Dhetchuvi & Eb.Fisch.	2006	1	Black
Aframomum zambesiacum (Baker) K.Schum.	1898 (1904)	28	Green

2 APPENDICES – *AFRAMOMUM*, THE HISTORY OF A TAXON

2.1 HISTORY OF SPECIMENS, NAMES AND DETERMINATIONS IN *AFRAMOMUM*

2.1.1 *Aframomum* nomenclature

Full *Aframomum* nomenclature including 173 names from *Aframomum*, *Amomum*, *Cardamomum*, and *Alexis* treated by Harris and Wortley (In Press), indicating taxonomic status (Accepted, Autonym, Basionym, Excluded, Heterotypic synonym, or Homotypic synonym) and the accepted name where appropriate.

Name	Status	Accepted
Aframomum albiflorum Lock	Accepted	
Aframomum alboviolaceum (Ridl.) K.Schum.	Accepted	
Aframomum alpinum (Gagnep.) K.Schum.	Accepted	
Aframomum amaniense Loes.	Heterotypic	*Aframomum limbatum* (Oliv. & D.Hanb.) K.Schum.
Aframomum angustifolium (Sonn.) K.Schum.	Accepted	
Aframomum arundinaceum (Oliv. & D.Hanb.) K.Schum.	Accepted	
Aframomum atewae Lock & J.B.Hall	Accepted	
Aframomum aulacocarpos Pellegr. ex Koechlin	Accepted	
Aframomum baumannii K.Schum.	Heterotypic	*Aframomum angustifolium* (Sonn.) K.Schum.
Aframomum biauriculatum K.Schum.	Heterotypic	*Aframomum alboviolaceum* (Ridl.) K.Schum.
Aframomum candidum Gagnep.	Heterotypic	*Aframomum alboviolaceum* (Ridl.) K.Schum.
Aframomum cereum (Hook.f.) K.Schum.	Excluded	
Aframomum chlamydanthum Loes. & Mildbr.	Heterotypic	*Aframomum zambesiacum* (Baker) K.Schum.
Aframomum chrysanthum Lock	Accepted	
Aframomum citratum (J.Pereira) K.Schum.	Accepted	
Aframomum colosseum K.Schum.	Excluded	
Aframomum cordifolium Lock & J.B.Hall	Accepted	
Aframomum corrorima (A.Braun) P.C.M.Jansen	Accepted	
Aframomum crassilabium (K.Schum. ex Engl.) K.Schum.	Excluded	
Aframomum cuspidatum (Gagnep.) K.Schum.	Heterotypic	*Aframomum exscapum* (Sims) Hepper
Aframomum dalzielii Hutch.	Heterotypic	*Aframomum leptolepis* (K.Schum.) K.Schum.
Aframomum daniellii (Hook.f.) K.Schum.	Accepted	
Aframomum dhetchuvii D.J.Harris & Wortley	Accepted	
Aframomum elegans Lock	Accepted	
Aframomum elliotii (Baker) K.Schum.	Accepted	
Aframomum erythrostachyum Gagnep.	Heterotypic	*Aframomum strobilaceum* (Sm.) Hepper
Aframomum exscapum (Sims) Hepper	Accepted	
Aframomum flavum Lock	Heterotypic	*Aframomum daniellii* (Hook.f.) K.Schum.
Aframomum fragrans D.J.Harris & Wortley	Accepted	

Continued on next page,,,

Appendix 2

Appendix 2.1.1

Name	Status	Accepted
Aframomum geocarpum Lock & J.B.Hall	Heterotypic	*Aframomum limbatum* (Oliv. & D.Hanb.) K.Schum.
Aframomum giganteum (Oliv. & D.Hanb.) K.Schum.	Accepted	
Aframomum giganteum (Oliv. & D.Hanb.) K.Schum. var. *puberulifolium* Koechlin	Heterotypic	*Aframomum hirsutum* D.J.Harris & Wortley
Aframomum glaucophyllum (K.Schum.) K.Schum.	Accepted	
Aframomum granum-paradisi (L.) K.Schum.	Excluded	
Aframomum hanburyi K.Schum.	Heterotypic	*Aframomum daniellii* (Hook.f.) K.Schum.
Aframomum hirsutum D.J.Harris & Wortley	Accepted	
Aframomum kamerunica D.J.Harris & Wortley	Accepted	
Aframomum kayserianum (K.Schum.) K.Schum.	Accepted	
Aframomum keniense R.E.Fr.	Heterotypic	*Aframomum zambesiacum* (Baker) K.Schum.
Aframomum kodmin D.J.Harris & Wortley	Accepted	
Aframomum korarima (J.Pereira) Engl.	Heterotypic	*Aframomum corrorima* (A.Braun) P.C.M.Jansen
Aframomum latifolium (Afzel.) K.Schum.	Heterotypic	*Aframomum alboviolaceum* (Ridl.) K.Schum.
Aframomum laurentii (De Wild. & T.Durand) K.Schum.	Heterotypic	*Aframomum giganteum* (Oliv. & D.Hanb.) K.Schum.
Aframomum laxiflorum Loes. ex Lock	Accepted	
Aframomum leonense K.Schum.	Heterotypic	*Aframomum exscapum* (Sims) Hepper
Aframomum leptolepis (K.Schum.) K.Schum.	Accepted	
Aframomum letestuanum Gagnep.	Accepted	
Aframomum limbatum (Oliv. & D.Hanb.) K.Schum.	Accepted	
Aframomum longiligulatum Koechlin	Accepted	
Aframomum longipetiolatum Koechlin	Accepted	
Aframomum longiscapum (Hook.f.) K.Schum.	Accepted	
Aframomum lutarium D.J.Harris & Wortley	Accepted	
Aframomum luteoalbum (K.Schum.) K.Schum.	Accepted	
Aframomum lycobasis K.Schum.	Heterotypic	*Aframomum limbatum* (Oliv. & D.Hanb.) K.Schum.
Aframomum macrospermum (Sm.) Burkill	Excluded	
Aframomum makandensis Dhetchuvi	Accepted	
Aframomum mala (K.Schum. ex Engl.) K.Schum.	Accepted	
Aframomum mannii (Oliv. & D.Hanb.) K.Schum.	Accepted	
Aframomum masuianum (De Wild. & T.Durand) K.Schum.	Heterotypic	*Aframomum sceptrum* (Oliv. & D.Hanb.) K.Schum.
Aframomum melegueta (Roscoe) K.Schum.	Accepted	
Aframomum melegueta (Roscoe) K.Schum. var. *violacea* (Ridl.) K.Schum.	Heterotypic	*Aframomum melegueta* (Roscoe) K.Schum.
Aframomum meleguetella K.Schum.	Heterotypic	*Aframomum melegueta* (Roscoe) K.Schum.
Aframomum mildbraedii Loes.	Accepted	
Aframomum oleraceum A.Chev.	Excluded	
Aframomum orientale Lock	Accepted	

Continued on next page,,,

Appendix 2

Appendix 2.1.1

Name	**Status**	**Accepted**
Aframomum parvulum D.J.Harris & Wortley	Accepted	
Aframomum pilosum (Oliv. & D.Hanb.) K.Schum.	Accepted	
Aframomum plicatum D.J.Harris & Wortley	Accepted	
Aframomum polyanthum (K.Schum.) K.Schum.	Accepted	
Aframomum pruinosum Gagnep.	Heterotypic	*Aframomum letestuanum* Gagnep.
Aframomum pseudostipulare Loes. & Mildbr. ex Koechlin	Accepted	
Aframomum rostratum K.Schum.	Accepted	
Aframomum rotundum D.J.Harris & Wortley	Accepted	
Aframomum sanguineum (K.Schum.) K.Schum.	Heterotypic	*Aframomum angustifolium* (Sonn.) K.Schum.
Aframomum scalaris D.J.Harris & Wortley	Accepted	
Aframomum sceleratum A.Chev.	Heterotypic	*Aframomum angustifolium* (Sonn.) K.Schum.
Aframomum sceptrum (Oliv. & D.Hanb.) K.Schum.	Accepted	
Aframomum sericeum Dhetchuvi & D.J.Harris	Accepted	
Aframomum simiarum A.Chev.	Heterotypic	*Aframomum strobilaceum* (Sm.) Hepper
Aframomum singulariflorum Dhetchuvi	Accepted	
Aframomum spiroligulatum A.D.Poulsen & Lock	Accepted	
Aframomum stanfieldii Hepper	Accepted	
Aframomum stipulatum (Gagnep.) K.Schum.	Heterotypic	*Aframomum alboviolaceum* (Ridl.) K.Schum.
Aframomum strobilaceum (Sm.) Hepper	Accepted	
Aframomum submontanum D.J.Harris & Wortley	Accepted	
Aframomum subsericeum (Oliv. & D.Hanb.) K.Schum.	Accepted	
Aframomum subsericeum (Oliv. & D.Hanb.) K.Schum. subsp. *glaucophyllum* (K.Schum.) Lock	Homotypic	*Aframomum glaucophyllum* (K.Schum.) K.Schum.
Aframomum subsericeum (Oliv. & D.Hanb.) K.Schum. subsp. *subsericeum*	Autonym	*Aframomum subsericeum* (Oliv. & D.Hanb.) K.Schum.
Aframomum sulcatum (Oliv. & D.Hanb. ex Baker) K.Schum.	Accepted	
Aframomum tchoutoui D.J.Harris & Wortley	Accepted	
Aframomum tectorum K.Schum.	Heterotypic	*Aframomum giganteum* (Oliv. & D.Hanb.) K.Schum.
Aframomum thonneri De Wild.	Accepted	
Aframomum uniflorum Lock & A.D.Poulsen	Accepted	
Aframomum usambarense Lock	Heterotypic	*Aframomum corrorima* (A.Braun) P.C.M.Jansen
Aframomum verrucosum Lock	Accepted	
Aframomum wuerthii Dhetchuvi & Eb.Fisch.	Accepted	
Aframomum zambesiacum (Baker) K.Schum.	Accepted	
Aframomum zambesiacum (Baker) K.Schum. subsp. *puberulum* Lock	Heterotypic	*Aframomum zambesiacum* (Baker) K.Schum.
Aframomum zimmermannii K.Schum.	Heterotypic	*Aframomum alpinum* (Gagnep.) K.Schum.
Alexis bifurca Salisb.	Excluded	
Alexis grandiflora (Sm.) Salisb.	Excluded	

Continued on next page,,,

Appendix 2

Appendix 2.1.1

Name	Status	Accepted
Amomum afzelii Roscoe	Heterotypic	*Aframomum exscapum* (Sims) Hepper
Amomum alboviolaceum Ridl.	Basionym	*Aframomum alboviolaceum* (Ridl.) K.Schum.
Amomum alpinum Gagnep.	Basionym	*Aframomum alpinum* (Gagnep.) K.Schum.
Amomum angustifolium Salisb.	Excluded	
Amomum angustifolium Sonn.	Basionym	*Aframomum angustifolium* (Sonn.) K.Schum.
Amomum arundinaceum Oliv. & D.Hanb.	Basionym	*Aframomum arundinaceum* (Oliv. & D.Hanb.) K.Schum.
Amomum bitacoum Gagnep.	Heterotypic	*Aframomum alboviolaceum* (Ridl.) K.Schum.
Amomum cereum Hook.f.	Excluded	
Amomum citratum J.Pereira	Basionym	*Aframomum citratum* (J.Pereira) K.Schum.
Amomum clusii Sm.	Heterotypic	*Aframomum angustifolium* (Sonn.) K.Schum.
Amomum corrorima A.Braun	Basionym	*Aframomum corrorima* (A.Braun) P.C.M.Jansen
Amomum crassilabium K.Schum. ex Engl.	Excluded	
Amomum cuspidatum Gagnep.	Heterotypic	*Aframomum exscapum* (Sims) Hepper
Amomum daniellii Hook.f.	Basionym	*Aframomum daniellii* (Hook.f.) K.Schum.
Amomum elatum Salisb.	Excluded	
Amomum elliotii Baker	Basionym	*Aframomum elliotii* (Baker) K.Schum.
Amomum erythrocarpum Ridl.	Heterotypic	*Aframomum daniellii* (Hook.f.) K.Schum.
Amomum exscapum Sims	Basionym	*Aframomum exscapum* (Sims) Hepper
Amomum giganteum Oliv. & D.Hanb.	Basionym	*Aframomum giganteum* (Oliv. & D.Hanb.) K.Schum.
Amomum glaucophyllum K.Schum.	Basionym	*Aframomum glaucophyllum* (K.Schum.) K.Schum.
Amomum grandiflorum Sm.	Heterotypic	*Aframomum exscapum* (Sims) Hepper
Amomum granum-paradisi L.	Excluded	
Amomum kayserianum K.Schum.	Basionym	*Aframomum kayserianum* (K.Schum.) K.Schum.
Amomum korarima J.Pereira	Heterotypic	*Aframomum corrorima* (A.Braun) P.C.M.Jansen
Amomum latifolium Afzel.	Heterotypic	*Aframomum alboviolaceum* (Ridl.) K.Schum.
Amomum latifolium Lam.	?	
Amomum latifolium Salisb.	Excluded	
Amomum latifolium Sessé & Moc.	?	
Amomum laurentii De Wild. & T.Durand	Heterotypic	*Aframomum giganteum* (Oliv. & D.Hanb.) K.Schum.

Continued on next page,,,

Appendix 2.1.1

Name	Status	Accepted
Amomum leptolepis K.Schum.	Basionym	*Aframomum leptolepis* (K.Schum.) K.Schum.
Amomum limbatum Oliv. & D.Hanb.	Basionym	*Aframomum limbatum* (Oliv. & D.Hanb.) K.Schum.
Amomum longiscapum Hook.f.	Basionym	*Aframomum longiscapum* (Hook.f.) K.Schum.
Amomum luteoalbum K.Schum.	Basionym	*Aframomum luteoalbum* (K.Schum.) K.Schum.
Amomum macrolepis K.Schum.	Heterotypic	*Aframomum citratum* (J.Pereira) K.Schum.
Amomum macrospermum Sm.	Excluded	
Amomum madagascariense Lam.	Heterotypic	*Aframomum angustifolium* (Sonn.) K.Schum.
Amomum mala K.Schum. ex Engl.	Basionym	*Aframomum mala* (K.Schum. ex Engl.) K.Schum.
Amomum mannii Oliv. & D.Hanb.	Basionym	*Aframomum mannii* (Oliv. & D.Hanb.) K.Schum.
Amomum masuianum De Wild. & T.Durand	Heterotypic	*Aframomum sceptrum* (Oliv. & D.Hanb.) K.Schum.
Amomum melegueta Roscoe	Basionym	*Aframomum melegueta* (Roscoe) K.Schum.
Amomum melegueta Roscoe var. *violacea* Ridl.	Heterotypic	*Aframomum melegueta* (Roscoe) K.Schum.
Amomum nemorosum Bojer	Excluded	
Amomum palustre Afzel.	Heterotypic	*Aframomum strobilaceum* (Sm.) Hepper
Amomum pilosum Oliv. & D.Hanb.	Basionym	*Aframomum pilosum* (Oliv. & D.Hanb.) K.Schum.
Amomum polyanthum K.Schum.	Basionym	*Aframomum polyanthum* (K.Schum.) K.Schum.
Amomum sanguineum K.Schum.	Heterotypic	*Aframomum angustifolium* (Sonn.) K.Schum.
Amomum sansibaricum Werth	Heterotypic	*Aframomum angustifolium* (Sonn.) K.Schum.
Amomum sceptrum Oliv. & D.Hanb.	Basionym	*Aframomum sceptrum* (Oliv. & D.Hanb.) K.Schum.
Amomum stipulatum Gagnep.	Heterotypic	*Aframomum alboviolaceum* (Ridl.) K.Schum.
Amomum strobilaceum Sm.	Basionym	*Aframomum strobilaceum* (Sm.) Hepper
Amomum subsericeum Oliv. & D.Hanb.	Basionym	*Aframomum subsericeum* (Oliv. & D.Hanb.) K.Schum.
Amomum sulcatum Oliv. & D.Hanb. ex Baker	Basionym	*Aframomum sulcatum* (Oliv. & D.Hanb. ex Baker) K.Schum.
Amomum zambesiacum Baker	Basionym	*Aframomum zambesiacum* (Baker) K.Schum.
Cardamomum afzelii (Roscoe) Kuntze	Heterotypic	*Aframomum exscapum* (Sims) Hepper
Cardamomum angustifolium (Sonn.) Kuntze	Homotypic	*Aframomum angustifolium* (Sonn.) K.Schum.

Continued on next page,,,

Appendix 2.1.1

Name	**Status**	**Accepted**
Cardamomum arundinaceum (Oliv. & D.Hanb.) Kuntze	Homotypic	*Aframomum arundinaceum* (Oliv. & D.Hanb.) K.Schum.
Cardamomum cereum (Hook.f.) Kuntze	Excluded	
Cardamomum citratum (J.Pereira) Kuntze	Homotypic	*Aframomum citratum* (J.Pereira) K.Schum.
Cardamomum clusii (Sm.) Kuntze	Heterotypic	*Aframomum angustifolium* (Sonn.) K.Schum.
Cardamomum daniellii (Hook.f.) Kuntze	Homotypic	*Aframomum daniellii* (Hook.f.) K.Schum.
Cardamomum giganteum (Oliv.D.Hanb.) Kuntze	Homotypic	*Aframomum giganteum* (Oliv. & D.Hanb.) K.Schum.
Cardamomum grandiflorum (Sm.) Kuntze	Heterotypic	*Aframomum exscapum* (Sims) Hepper
Cardamomum granum-paradisi (L.) Kuntze	Excluded	
Cardamomum latifolium (Afzel.) Kuntze	Heterotypic	*Aframomum alboviolaceum* (Ridl.) K.Schum.
Cardamomum limbatum (Oliv. & D.Hanb.) Kuntze	Homotypic	*Aframomum limbatum* (Oliv. & D.Hanb.) K.Schum.
Cardamomum longiscapum (Hook.f.) Kuntze	Homotypic	*Aframomum longiscapum* (Hook.f.) K.Schum.
Cardamomum mannii (Oliv.D.Hanb.) Kuntze	Homotypic	*Aframomum mannii* (Oliv. & D.Hanb.) K.Schum.
Cardamomum melegueta (Roscoe) Kuntze	Homotypic	*Aframomum melegueta* (Roscoe) K.Schum.
Cardamomum palustre (Afzel.) Kuntze	Heterotypic	*Aframomum strobilaceum* (Sm.) Hepper
Cardamomum pilosum (Oliv. & D.Hanb.) Kuntze	Homotypic	*Aframomum pilosum* (Oliv. & D.Hanb.) K.Schum.
Cardamomum sceptrum (Oliv. & D.Hanb.) Kuntze	Homotypic	*Aframomum sceptrum* (Oliv. & D.Hanb.) K.Schum.
Cardamomum subsericeum (Oliv. & D.Hanb.) Kuntze	Homotypic	*Aframomum subsericeum* (Oliv. & D.Hanb.) K.Schum.

2.1.2 Determination accuracy on *Aframomum* specimens

Determination accuracy (percentage) of *Aframomum* specimens for which all determinations were available. Where the determinations were 'Correct', 'Synonym', 'Other', or 'Indeterminate' and the number (N) of extant specimens for a selection of years between 1900 and 2014.

	Percentage				
Year	**Correct**	**Synonym**	**Other**	**Indeterminate**	**N**
1900	11%	7%	78%	4%	27
1910	15%	13%	64%	8%	104
1920	11%	10%	67%	12%	156
1930	9%	11%	64%	16%	191
1940	13%	9%	52%	27%	293
1950	11%	9%	51%	29%	399
1960	11%	14%	41%	34%	604
1970	15%	15%	34%	36%	757
1980	37%	8%	24%	30%	1038
1990	38%	8%	22%	32%	1293
2000	42%	8%	18%	32%	1774
2010	44%	8%	17%	31%	1779
2014	100%	0%	0%	0%	1779

2.2 AUTHORS OF DETERMINATIONS

2.2.1 Variables defining different categories of authors

The variables defining four categories of the 29 most prolific authors of determinations on *Aframomum* specimens showing values for individual authors and the mean per author category. Indicating (A) numbers of determinations, (B) number of specimens determined, (C) number of countries where the specimens were collected from, (D) number of herbaria where the specimens are housed, (E) percentage of determinations made on specimens collected by the author, (F) percentage of determinations made on specimens not collected by the author, percentage of determinations which are either (G) 'Correct', (H) 'Synonym', (I) 'Other' or (J) 'Indeterminate' relative to Harris and Wortley (In Press), and (K) number of species determined by each author.

'General Collectors'	**A**	**B**	**C**	**D**	**E**	**F**	**G**	**H**	**I**	**J**	**K**
Cable, S.	27	27	1	1	100.0	0.0	0.0	0.0	0.0	100.0	0
Chapman, J.D.	21	17	2	4	100.0	0.0	0.0	0.0	19.0	81.0	1
De Koning, J.	29	17	2	3	100.0	0.0	20.7	10.3	41.4	27.6	5
De Witte, G.F.	21	19	1	3	100.0	0.0	0.0	0.0	81.0	19.0	1
Devred	22	18	1	2	100.0	0.0	0.0	0.0	0.0	100.0	0
Etuge, M.	20	20	1	1	100.0	0.0	0.0	0.0	9.5	90.5	0
Evrard, C.M.	21	17	1	3	95.2	4.8	4.8	4.8	23.8	66.7	5
Fay, J.M.	23	18	1	2	95.7	4.3	21.7	4.3	21.7	52.2	5
Germain, R.	23	20	1	2	100.0	0.0	4.3	0.0	13.0	82.6	2
Gossweiler, J.	58	29	1	6	100.0	0.0	0.0	6.7	40.0	53.3	1
Le Testu, G.	66	30	4	8	100.0	0.0	13.6	1.5	51.5	33.3	4
Leeuwenberg, A.J.M.	23	13	3	8	100.0	0.0	0.0	0.0	43.5	56.5	0
Louis, J.	40	28	1	6	100.0	0.0	0.0	0.0	12.5	87.5	1
Mann, G.	26	11	3	6	100.0	0.0	0.0	0.0	100.0	0.0	0
Schlieben, H.J.	25	7	1	8	100.0	0.0	40.0	0.0	60.0	0.0	4
Thomas, D.W.	63	44	3	7	98.4	1.6	11.1	3.2	12.7	73.0	8
Vanden Berghen, C.	32	28	1	1	100.0	0.0	18.8	0.0	78.1	3.1	5
Westphal, E.	63	42	2	5	100.0	0.0	15.6	7.8	50.0	26.6	7
Mean	**33.5**	**22.5**	**1.7**	**4.2**	**99.4**	**0.6**	**8.4**	**2.1**	**36.5**	**52.9**	**2.7**

Continued on next page,,,

Appendix 2.2.1

'General Taxonomists'	**A**	**B**	**C**	**D**	**E**	**F**	**G**	**H**	**I**	**J**	**K**
Aké Assi, L.	29	26	3	5	93.1	6.9	51.7	13.8	27.6	6.9	12
Breteler, F.J.	41	24	4	7	73.2	26.8	7.0	9.3	32.6	51.2	9
Hall, J.B.	25	20	4	6	48.0	52.0	40.0	28.0	16.0	16.0	11
Léonard, J.	49	31	5	3	8.2	91.8	0.0	78.3	10.9	10.9	8
Mullenders, W.	45	37	1	5	82.2	17.8	0.0	32.6	63.0	4.3	8
Poulsen, A.D.	96	68	3	4	90.6	9.4	50.0	1.1	40.2	8.7	16
Mean	**47.5**	**34.3**	**3.3**	**5.0**	**65.9**	**34.1**	**24.8**	**27.2**	**31.7**	**16.3**	**10.7**
'Flora Writers'											
Hepper, F.N.	72	66	14	10	19.4	80.6	36.8	5.9	33.8	23.5	18
Koechlin, J.	41	24	3	5	0.0	100.0	56.1	31.7	12.2	0.0	13
Mean	**56.5**	**45.0**	**8.5**	**7.5**	**9.7**	**90.3**	**46.4**	**18.8**	**23.0**	**11.8**	**15.5**
'Revision Writers'											
Dhetchuvi, M.M.	291	248	13	10	32.3	67.7	60.0	9.3	18.6	12.1	23
Harris, D.J.	2895	2089	39	40	15.8	84.2	92.4	0.7	0.8	6.1	79
Lock, J.M.	637	516	34	19	3.5	96.5	70.7	8.2	10.6	10.5	49
Mean	**1274.3**	**951.0**	**28.7**	**23.0**	**17.2**	**82.8**	**74.4**	**6.1**	**10.0**	**9.6**	**50.3**

2.3 PAST TAXONOMIC ACCOUNTS

2.3.1 Mixed species concepts

Here I present a detailed analysis of the determinations of specimens cited in each taxonomic account. The determinations of specimens cited in the past taxonomic accounts are compared with the determinations on those specimens in Harris and Wortley (In Press). To understand the species concepts in each taxonomic account the results are presented by the species name in the past taxonomic account and colour coded relative to their treatment in Harris and Wortley (In Press).

2.3.1.1 *Flora of Tropical Africa*, 1898

The *Flora of Tropical Africa* account treated twenty five species and one variety as accepted and described another six "imperfectly known" species; of the latter "imperfectly known" species only two species accounts provided sufficient details regarding the cited specimens to allow analysis of the determinations. Varieties are treated as a separate taxon name in this analysis.

The *Flora of Tropical Africa* account cited 77 specimens in 28 taxa (27 species and one variety, Figure 2.5.1A).

One specimen cited in the *Flora of Tropical Africa* is now recognised as a mixed collection (Appendix 2.3.3). This specimen was not recognised as a mixed collection by the *Flora of Tropical Africa*, the specimen was cited under a correct name for one of the two species in the collection.

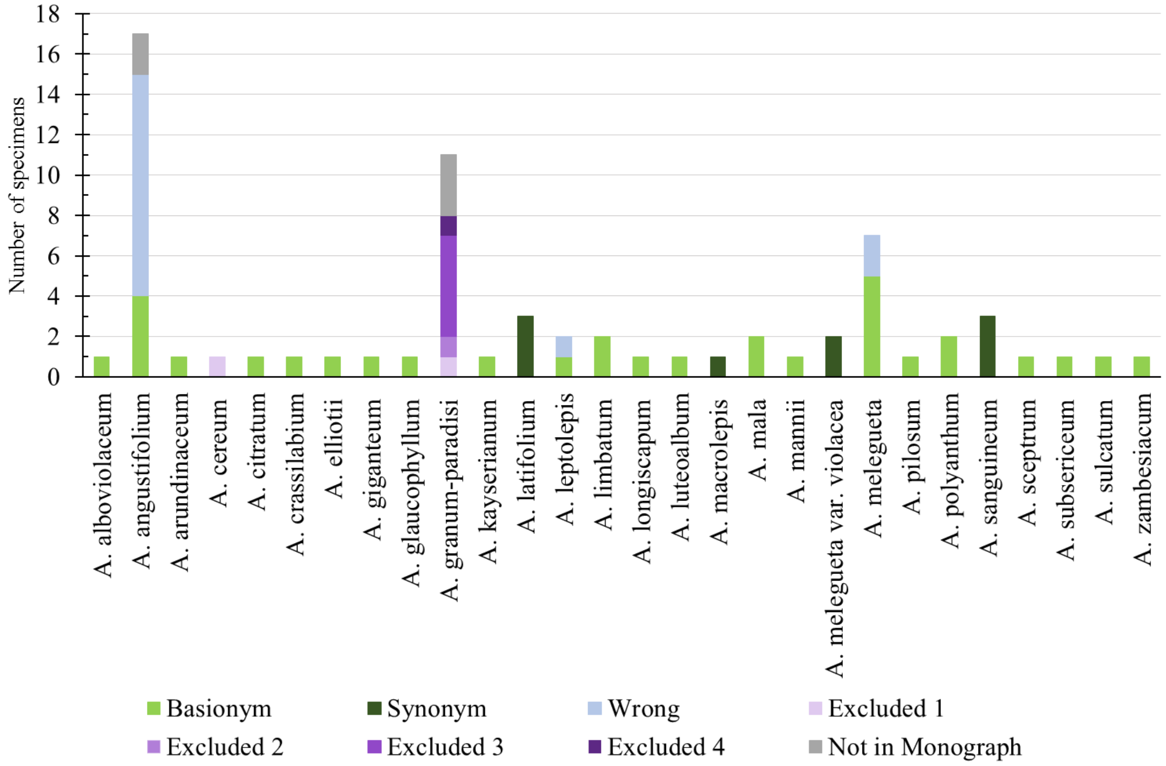


Figure 1 Species circumscription in the *Flora of Tropical Africa* vs Harris and Wortley (In Press). *Amomum* species names treated as accepted by *Flora of Tropical Africa*, and the determinations of the specimens cited as those names relative to the determinations of those specimens by Harris and Wortley.

Of the 77 specimens, 32 (42%) had the correct determination, nine (12%) were cited under a heterotypic synonym of the correct determination for the specimen. 14 (18%) specimens were determined incorrectly, nine (12%) specimens were determined as doubtful or excluded names and 13 (17%) of the specimens cited were not seen by Harris and Wortley (In Press) (Figure 2.6B).

In the *Flora of Tropical Africa* account the majority of species (18, 67%) cited one specimen, six species cited two or three specimens each, and three species cited between 9 and 15 specimens (Figure 1).

The specimens in the singleton species were predominantly determined correctly (16); one singleton species each cited a name which is now considered to be excluded (*Amomum cereum* Hook.f.) and a heterotypic synonym (*Amomum macrolepis* K.Schum.) in Harris and Wortley (In Press).

Six species with two or more specimens cited had a consistent species concept, three of these species were the correct name for the specimens (*Amomum limbatum* Oliv. & D.Hanb., *Amomum mala* K.Schum. ex Engl. and *Amomum polyanthum* K.Schum.) and three were the heterotypic synonym of the correct name for the specimens (*Amomum melegueta* Roscoe var. *violacea* Ridl., *Amomum latifolium* Afzel. and *Amomum sanguineum* K.Schum.). The four other species with two or more specimens cited specimens had a mixed species concept; three species had a mixture of correctly and incorrectly determined specimens (*Amomum angustifolium* Sonn., *Amomum leptolepis* K.Schum. and *Amomum melegueta* Roscoe). The final name, *Amomum granum-paradisi* L., is considered to be an excluded name by Harris and Wortley (In Press) and cited specimens from four different species accepted in Harris and Wortley (In Press).

2.3.1.2 *Das Pflanzenreich*, 1904

The *Das Pflanzenreich* account cited 107 specimens in 44 different species and one variety (Figure 2.5.2A), of these specimens 36 (34%) had the correct determination, 22 (21%) were cited under the heterotypic synonym of the correct determination for the specimen. Four (3.7%) specimens were determined incorrectly, ten (9%) specimens were cited as excluded names and 35 (33%) of the specimens cited were not seen by Harris and Wortley (In Press) (Figure 2.6B).

Two specimens cited are considered to be mixed species collections by Harris and Wortley (Appendix 2.3.3). One specimen was recognised as a mixed collection by the *Das Pflanzenreich* account, being cited twice under a correct name and an incorrect name. The second specimen was not recognised as a mixed collection, however the name it is cited under is a correct determination.

Nearly half, 23 (52%), of the species cited only one specimen, and 21 species (48%) cited two or more specimens (Figure 2).

Eleven (48%) singleton species had the correct determination, six singleton species (26%) were determined as a heterotypic synonym of the correct determination in Harris and Wortley (In Press) and five (22%) singleton species were specimens which had not been seen by the Harris and Wortley (In Press) (Figure 2). One specimen was cited as a name (*Aframomum cereum* Gagnep.) which is considered to be excluded by Harris and Wortley (In Press).

Of the 21 species with two or more specimens cited, five species exhibited mixed species concepts (Figure 2). Four of these species cited a mixture of specimens with the correct and incorrect determinations (*Aframomum citratum* (J.Pereira) K.Schum., *Aframomum glaucophyllum* (K.Schum.) K.Schum., *A. sceptrum* and *Aframomum sulcatum* (Oliv. & D.Hanb. ex Baker) K.Schum.), and the fifth species, *Aframomum granum-paradisi* (L.) K.Schum., considered to be an excluded name by Harris and Wortley (In Press) cited specimens from two different currently accepted species (Figure 2).

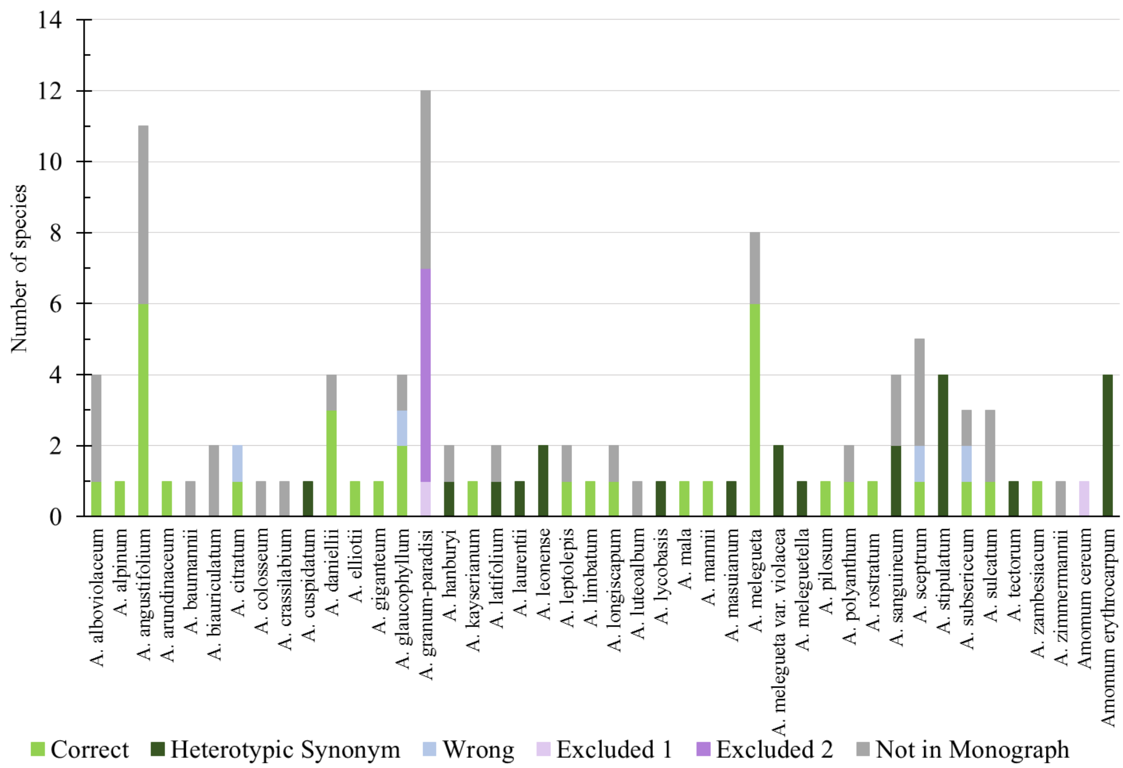


Figure 2 Species circumscription in *Das Pflanzenreich* vs Harris and Wortley (In Press). Species names treated as accepted by *Das Pflanzenreich*, and the determinations of the specimens cited as those names relative to the determinations of those specimens by Harris and Wortley.

Seven species (*Aframomum hanburyi* K.Schum., *Aframomum latifolium* (Afzel.) K.Schum., *Aframomum leonense* K.Schum., *Aframomum melegueta* (Roscoe) K.Schum. var. *violacea* (Ridl.) K.Schum., *Aframomum sanguineum* (K.Schum.) K.Schum., *Aframomum stipulatum* (Gagnep.) K.Schum. and *Aframomum erythrocarpum* Gagnep.) cited specimens under a species names which is considered to be a heterotypic synonym of the correct determination for these specimens. 75% (16) of the species with two or more specimens cited have one or more specimen cited which has not been seen by Harris and Wortley (In Press).

2.3.1.3 *Flora of West Tropical Africa* 1st ed., 1936

The *Flora of West Tropical Africa* 1st ed. account cited 74 specimens in 18 different accepted species (Figure 2.5.3A). Of these specimens 24 (32%) had the correct determination, 10 (14%) were cited under the heterotypic synonym of the correct determination for the specimen. 26 (35%) specimens were determined incorrectly and 14 (19%) of the specimens cited were not seen by Harris and Wortley (In Press) (Figure 2.6B).

Six specimens cited in the *Flora of West Tropical Africa* 1st ed. have since been determined as mixed collection. One of those specimens, Chevalier, A. 20943, was recognised as a mixed collection in the *Flora of West Tropical Africa* 1st ed. (Appendix 2.3.3). The determinations for this specimen are both incorrect. The other five specimens have been cited under a mixture determinations which are correct, incorrect, and synonyms.

Four species (22% of the 18 species) cited only one specimen and 14 species (78%) cited two or more specimens (Figure 3).

Two of the singleton species were determined as a species name which is considered to be a heterotypic synonym (*Aframomum chlamydanthum* Loes. & Mildbr. and *Aframomum simiarum* A.Chev.) by Harris and Wortley (In Press), the other two singleton specimens were incorrectly determined (*Aframomum baumannii* K.Schum. and *Aframomum subsericeum* (Oliv. & D.Hanb.) K.Schum.) (Figure 3).

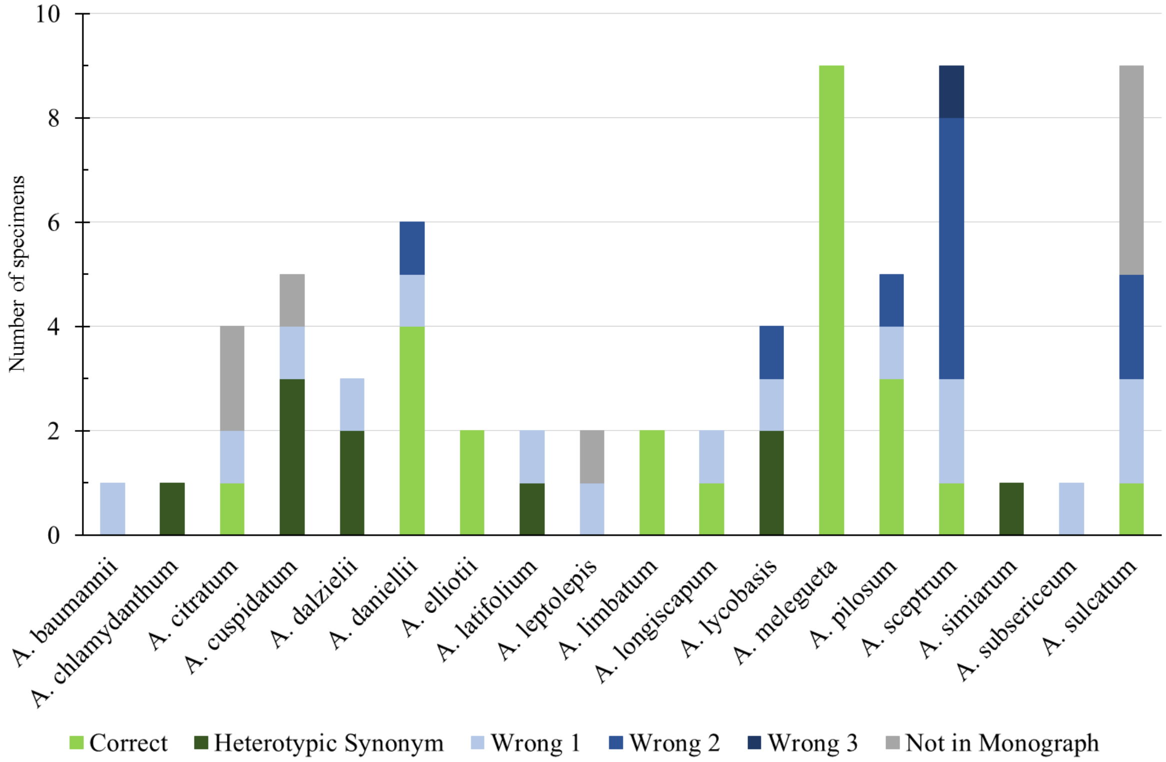


Figure 3 Species circumscription in the *Flora of West Tropical Africa 1st ed.* vs Harris and Wortley (In Press). Species names treated as accepted by *Flora of West Tropical Africa 1st ed.*, and the determinations of the specimens cited as those names relative to the determinations of those specimens by Harris and Wortley.

The majority of species (ten) which cited two or more specimens cited specimens which are now considered to belong to two or more different species (Figure 3). All of these species names cited at least one specimen which is correctly determined or the heterotypic synonym of the correct determination. The remaining specimens in each species were incorrectly determined and belong to one (*A. citratum*, *Aframomum cuspidatum* (Gagnep.) K.Schum., *Aframomum dalzielii*, *A. latifolium* and *Aframomum longiscapum* (Hook.f.) K.Schum.), two (*Aframomum daniellii* (Hook.f.) K.Schum., *A. lycobasis*, *Aframomum pilosum* (Oliv. & D.Hanb.) K.Schum. and *A. sulcatum*) or three (*A. sceptrum*) other different species. Only three species (*Aframomum elliotii* (Baker) K.Schum., *A. limbatum* and *Aframomum melegueta* (Roscoe) K.Schum.) had multiple specimens which were all cited as the same correct species.

2.3.1.4 *Flora of West Tropical Africa* 2nd ed., 1968

The *Flora of West Tropical Africa* 2nd ed. account cited 173 specimens in 20 different species (Figure 2.5.4A); of these specimens 88 (49%) had the correct determination, 19 (11%) were cited under the heterotypic synonym of the correct determination for the specimen (Figure 2.6B). 49 (28%) specimens were determined incorrectly and 22 (12%) of the specimens cited were not seen by Harris and Wortley (In Press).
Eight collections cited in *Flora of West Tropical Africa* 2nd ed. are now recognised as mixed collections (Appendix 2.3.3), one of these, Chevalier 19839, was recognised as a mixed collection in the *Flora of West Tropical Africa* 2nd ed. account. The mixed collections are

cited under a mixture of determinations which are correct, incorrect, and synonyms. One specimen, Harley 1553, is recognised as a mixed collection and both determinations are considered to be correct. Two specimens, Chevalier 19639 and Jones 17338, were cited twice in the *Flora of West Tropical Africa* 2nd ed. account although neither is recognised as a mixed collection by Harris and Wortley (In Press).

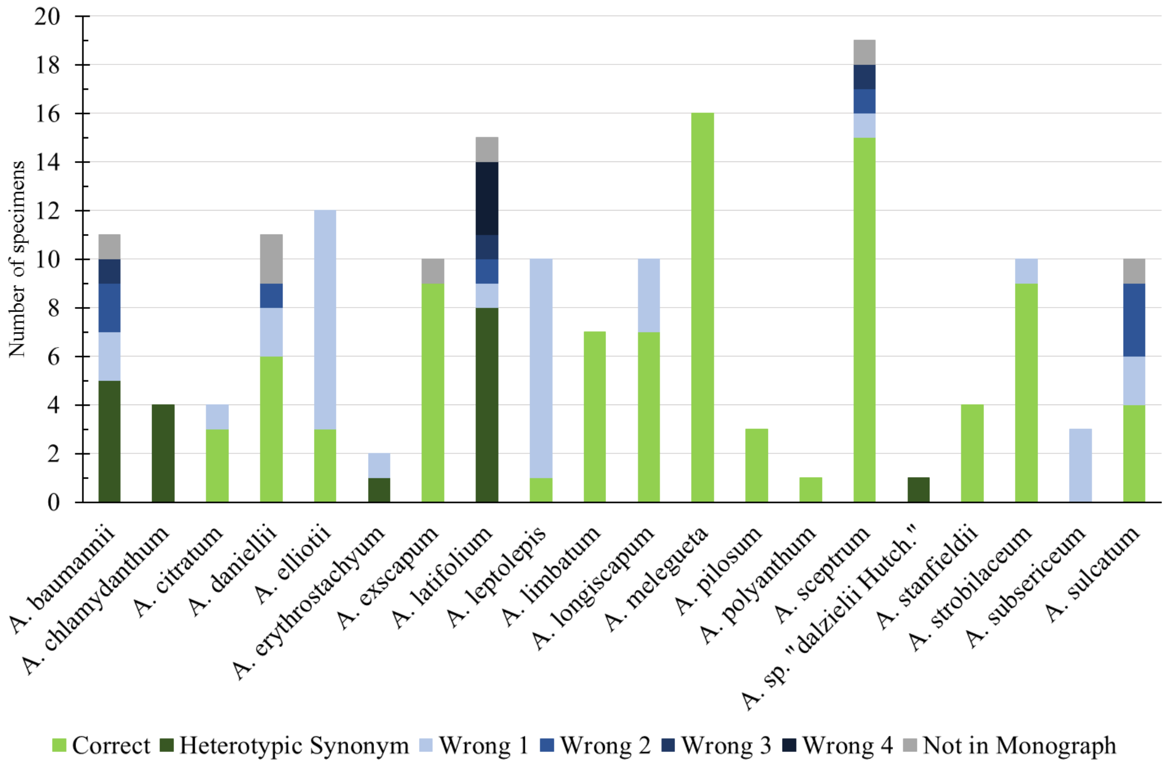


Figure 4 Species circumscription in the *Flora of West Tropical Africa 2nd ed.* vs Harris and Wortley (In Press). Species names treated as accepted by *Flora of West Tropical Africa 2nd ed.*, and the determinations of the specimens cited as those names relative to the determinations of those specimens by Harris and Wortley.

Two species (10%) cited only one specimen and 18 species (80%) cited two or more specimens (Figure 4).
Of the two singleton species one name was correct and the other species name is now considered to be a heterotypic synonym by Harris and Wortley (In Press).
The majority of species (eleven) which cited multiple specimens had mixed species concepts, seven species had specimens cited from the correct name or heterotypic synonym of the correct name and one (*A. citratum*, *A. elliotii*, *A. erythrostachyum*, *Aframomum leptolepis* (K.Schum.) K.Schum., *A. longiscapum* and *Aframomum strobilaceum* (Sm.) Hepper), two (*A. daniellii* and *A. sulcatum*), three (*A. baumannii* and *A. sceptrum*) or four (*A. latifolium*) incorrect names. Four species (*A. limbatum*, *A. melegueta*, *A. pilosum* and *Aframomum stanfieldii* Hepper) had multiple specimens which were determined correctly. Two species also had consistent specimen determinations, however one species name (*A. chlamydanthum*) is a heterotypic synonym, and the other species' specimens were incorrectly determined (*A. subsericeum*). Six of the species with two or more specimens cited have one or more specimen cited which has not been seen by Harris and Wortley (In Press).

2.3.1.5 *Flora of Tropical East Africa*, 1985

The *Flora of Tropical East Africa* account cited 89 specimens (Figure 2.5.5A) in 16 different species (Figure 2.5.5C), of these specimens 65 (73%) had the correct determination, seven (7.9%) were cited under the heterotypic synonym of the correct determination for that specimen. Two (2.2%) specimens were determined incorrectly and 15 (17%) of the specimens cited were not seen by Harris and Wortley (In Press) (Figure 2.6B).
Three specimens cited in *Flora of Tropical East Africa* are now recognised as mixed collections by Harris and Wortley (In Press) (Appendix 2.3.3). None of these specimens are recognised as mixed collections in the *Flora of Tropical East Africa*, however two of the specimens were determined correctly, only one specimen was determined incorrectly.
One species, *Aframomum* sp. A, cited only one specimen, this specimen has not been seen by Harris and Wortley (In Press).

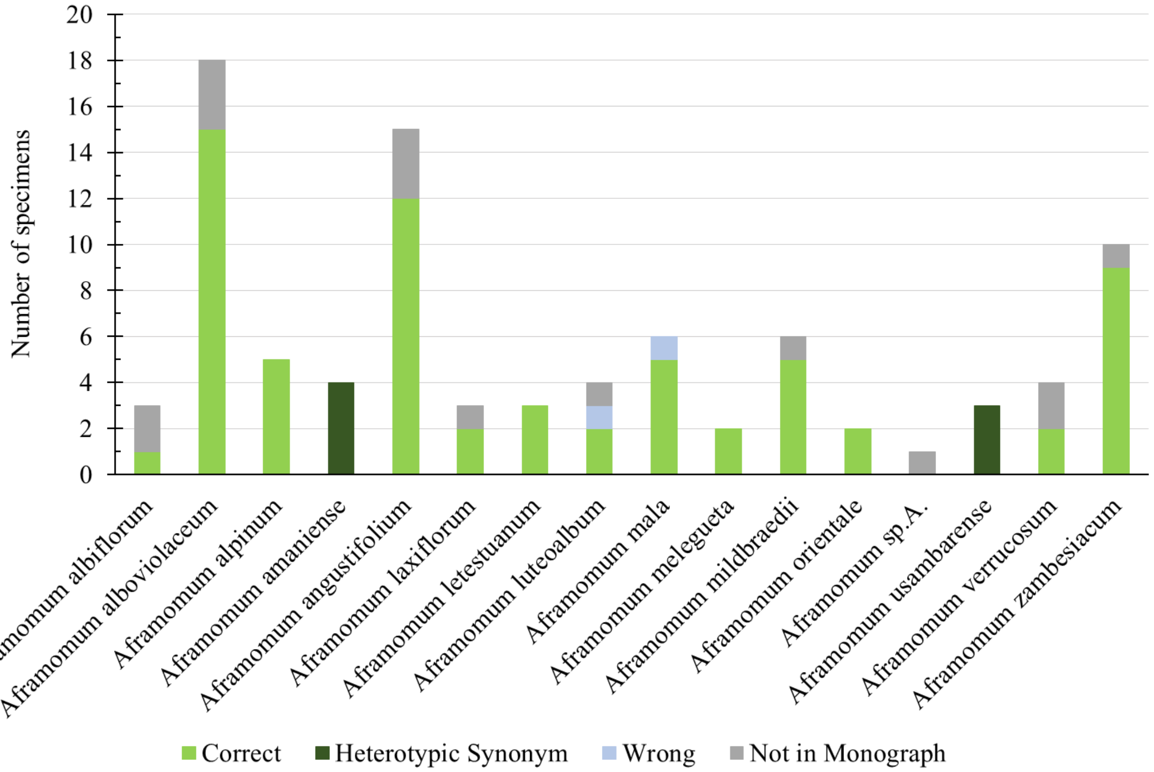


Figure 5 Species circumscription in the *Flora of Tropical East Africa* vs Harris and Wortley (In Press). Species names treated as accepted by *Flora of Tropical East Africa*, and the determinations of the specimens cited as those names relative to the determinations of those specimens by Harris and Wortley.

The remaining 15 species (94%) cited two or more specimens, the majority of species cited correctly all their specimens which have been seen by Harris and Wortley. Only two species (*Aframomum luteoalbum* (K.Schum.) K.Schum. and *Aframomum mala* (K.Schum. ex Engl.) K.Schum.) cited a single specimens which is now considered to be incorrectly determined (Figure 5). Nine species with two or more specimens cited have one to three specimens cited which have not been seen by Harris and Wortley (In Press).

2.3.2 Incorrect determinations

Here I present a detailed analysis of the species which contain the most incorrect determinations in past taxonomic accounts. The determinations of specimens in Harris and

Wortley (In Press) are compared with the determinations on those specimens in the past taxonomic accounts. To understand which species contain the most incorrect determinations the results are presented by the species name in Harris and Wortley (In Press) and colour coded relative to their treatment in Harris and Wortley (In Press).

2.3.2.1 *Flora of Tropical Africa*, 1898

A total of 62 specimens seen by Harris and Wortley (In Press) were cited by the *Flora of Tropical Africa* account, these specimens represent 25 species in Harris and Wortley (In Press) (Figure 6). 17 (68%) of the species accepted by Harris and Wortley (In Press) were represented by just one specimen in the *Flora of Tropical Africa* treatment, the remaining species were represented by two to 13 specimens.

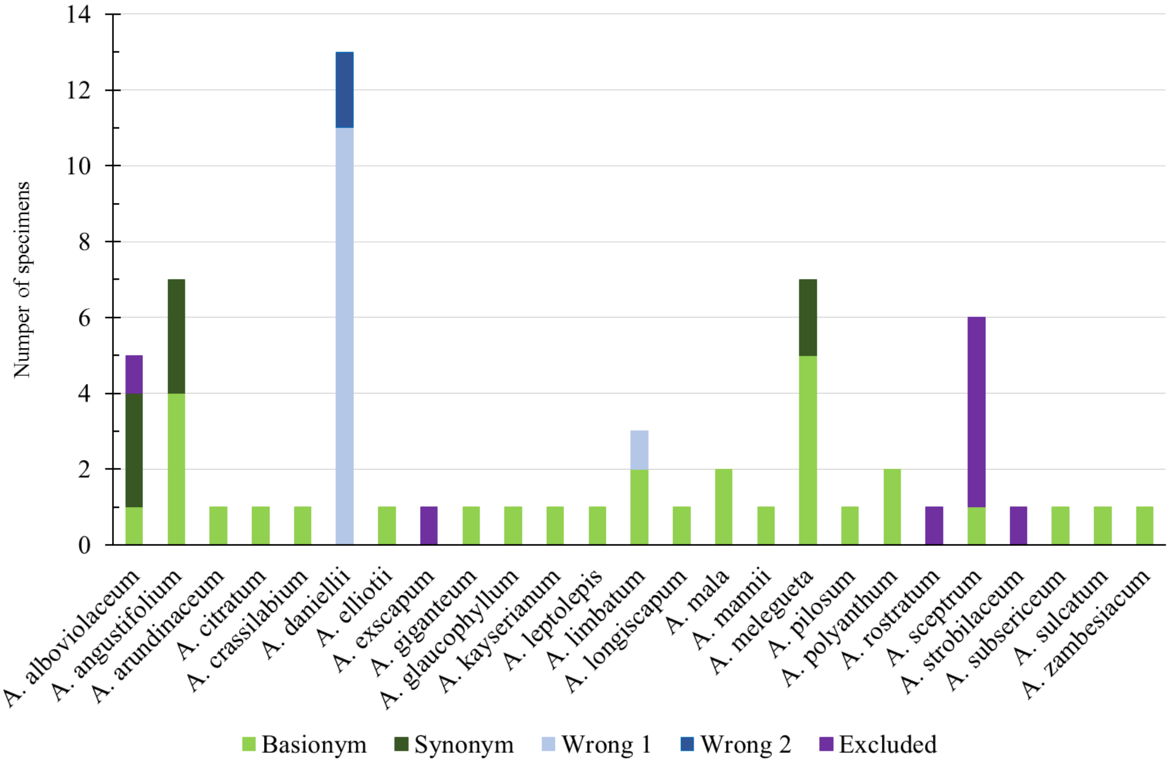


Figure 6 Species circumscription in Harris and Wortley (In Press) vs the *Flora of Tropical Africa*. Species names treated as accepted by Harris and Wortley (In Press) and the specimens which belong to each of those species which have been cited in the *Flora of Tropical Africa* indicating the relative determinations of the specimens cited in the *Flora of Tropical Africa*.

Of the 17 species which were represented by just one specimen in the *Flora of Tropical Africa* account, 14 of these specimens were correctly determined and three specimens (from *A. exscapum*, *Aframomum rostratum* K.Schum. and *A. strobilaceum*) were determined as a name which is currently considered to be excluded (Figure 6).
Of the species with multiple specimens cited in the *Flora of Tropical Africa* account only two species were represented by specimens which were consistently correctly determined in the *Flora of Tropical Africa* (*A. mala* and *Aframomum polyanthum* (K.Schum.) K.Schum.). Four species had specimens cited in *Flora of Tropical Africa* under the correct name and either a heterotypic synonym (*A. angustifolium* and *A. melegueta*), incorrect (*A. limbatum*) or excluded name (*A. sceptrum*). One species, *A. alboviolaceum*, had specimens determined as three different species in the *Flora of Tropical Africa*; the correct name, a heterotypic synonym and an excluded name. One species, *A. daniellii*, was represented by thirteen

specimens in the *Flora of Tropical Africa* all of which were determined as one of two different incorrect names.

2.3.2.2 *Das Pflanzenreich*, 1904

A total of 70 specimens seen by Harris and Wortley (In Press) were cited in the *Das Pflanzenreich* account, these specimens represented 24 species in Harris and Wortley (In Press). 13 (54%) of these species accepted by Harris and Wortley (In Press) were represented by just one specimen in the *Das Pflanzenreich* treatment, the remaining species were represented by two to nine specimens (Figure 7).

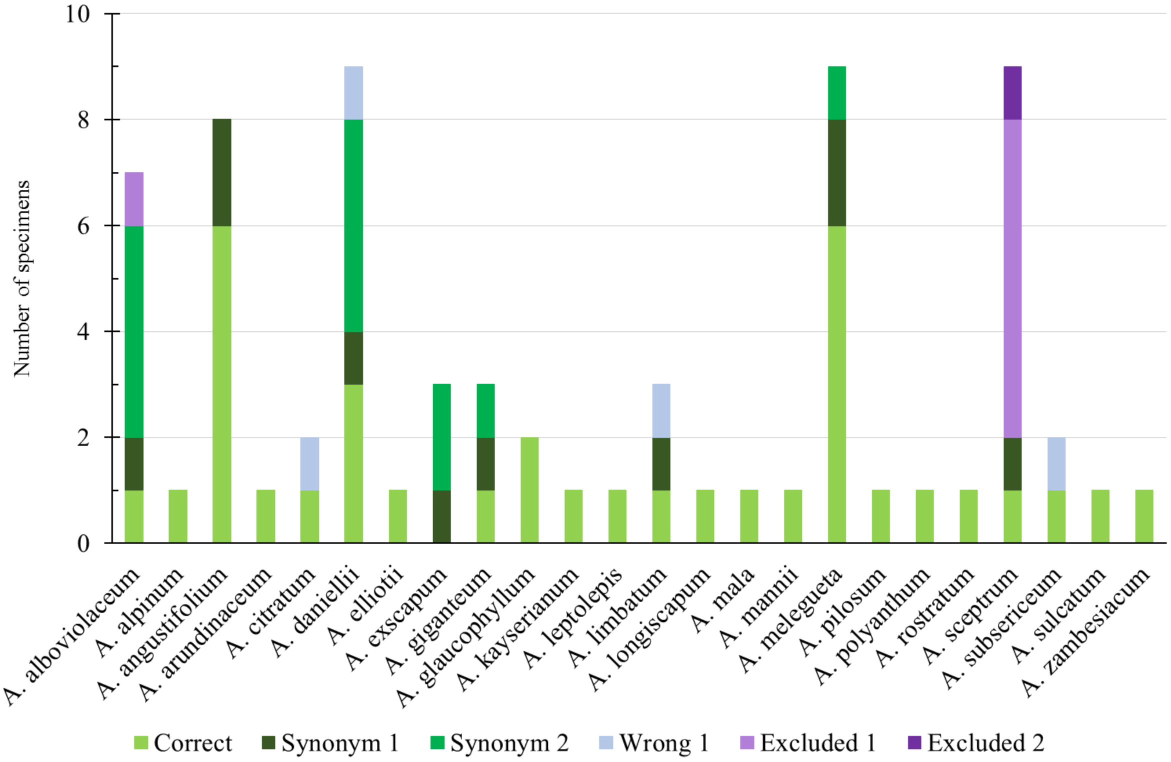


Figure 7 Species circumscription in Harris and Wortley (In Press) vs *Das Pflanzenreich*. Species names treated as accepted by Harris and Wortley (In Press) and the relative determinations of the specimens cited in each those names in *Das Pflanzenreich 1904*.

All of the species with just one specimen (13) cited in the *Das Pflanzenreich* account were correctly determined in that account. Of the 11 species represented by two or more specimens in *Das Pflanzenreich*, only one species, *A. glaucophyllum*, has both of the cited specimens determined correctly in the *Das Pflanzenreich* account. The other ten species which were represented by two or more specimens in the *Das Pflanzenreich* account have mixed species concepts; specimens from the same species were cited as a mixture of correct, heterotypic synonyms, incorrect and excluded names. Three species were determined as the correct name and one (*A. angustifolium*) or two (*Aframomum giganteum* (Oliv. & D.Hanb.) K.Schum. and *A. melegueta*) heterotypic synonyms. Four species were determined as a mixture of correct, heterotypic synonyms and either excluded (*A. alboviolaceum* and *A. sceptrum*) or incorrect (*A. daniellii* and *A. limbatum*) names. Two species (*A. citratum* and *Aframomum subsercerium*) were determined as a mixture of correct and incorrect names. Just one species, *A. exscapum*, had no specimens correctly determined with the specimens determined under two different heterotypic synonyms.

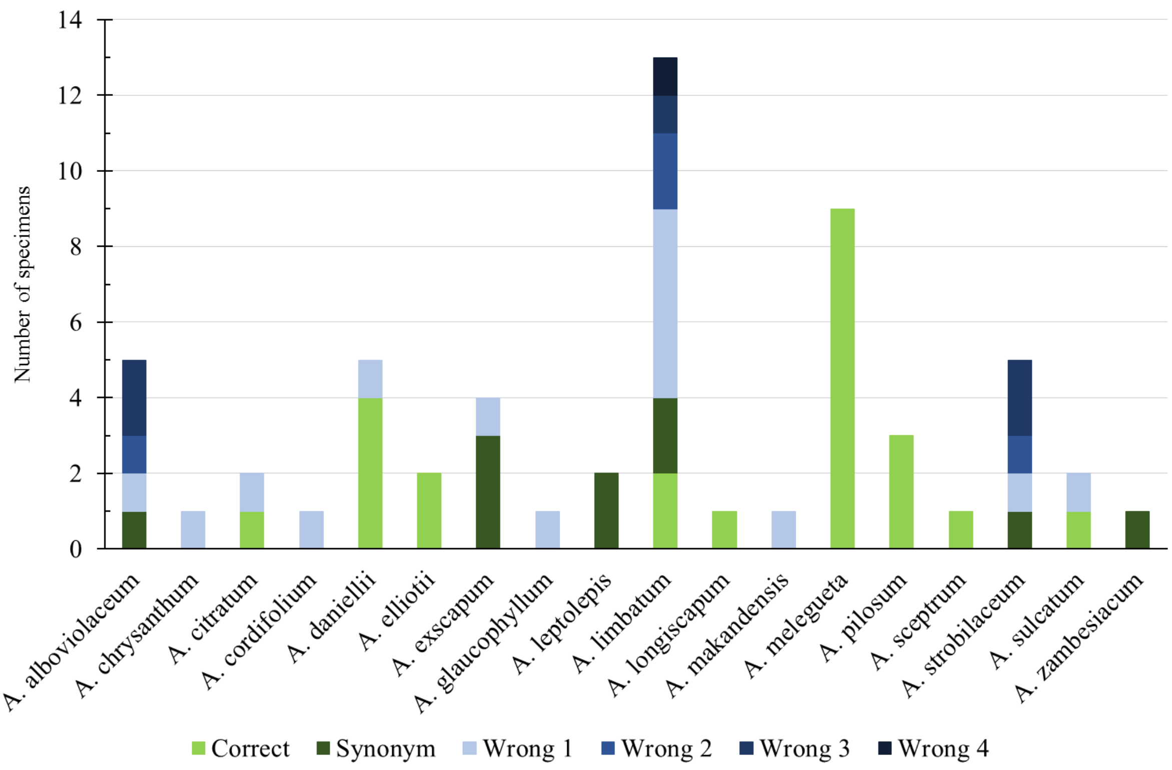


Figure 8 Species circumscription in Harris and Wortley (In Press) vs the *Flora of West Tropical Africa 1st ed.*. Species names treated as accepted by Harris and Wortley (In Press) and the relative determinations of the specimens cited in each those names in the *Flora of West Tropical Africa 1st ed.*.

2.3.2.3 *Flora of West Tropical Africa* 1st ed., 1936

A total of 59 specimens seen by Harris and Wortley (In Press) were cited by the *Flora of West Tropical Africa* 1st ed. account, these specimens represented 18 species in Harris and Wortley (In Press) (Figure 8). Seven (39%) of the species accepted by Harris and Wortley (In Press) were represented by just one specimen in the *Flora of West Tropical Africa* 1st ed. treatment, the remaining 11 species were represented by two to 13 specimens (Figure 8).
Of the seven species which were represented in the *Flora of West Tropical Africa* 1st ed. account by just one specimen two specimens were correctly determined (*A. longiscapum* and *A. sulcatum*), one specimen was determined as a heterotypic synonym (*Aframomum zambesiacum* (Baker) K.Schum.), and four specimens were incorrectly determined (*Aframomum chrysanthum* Lock, *Aframomum cordifolium* Lock & J.B.Hall, *A.glaucophyllum* and *Aframomum makandensis* Dhetchuvi).
Of the species represented by two or more specimens in the *Flora of West Tropical Africa* 1st ed. account four species were consistently determined, three species (*A. elliotii*, *A. melegueta* and *A. pilosum*) determined correctly and one (*A. leptolepis*) as a heterotypic synonym. The other seven species which were represented by two or more specimens in the treatment had mixed species concepts; specimens from the same species were cited as a mixture of correct, heterotypic synonyms, and one to four different incorrect names, with specimens from individual species determined as up to six different names. Four species (*A. citratum*, *A. daniellii*, *A. exscapum* and *A. sulcatum*) had specimens cited incorrectly and correctly or as a heterotypic synonym. Three species had specimens under three or four different incorrect names, a heterotypic synonym (*A. alboviolaceum* and *A. strobilaceum*) and the correct name (*A. limbatum*).

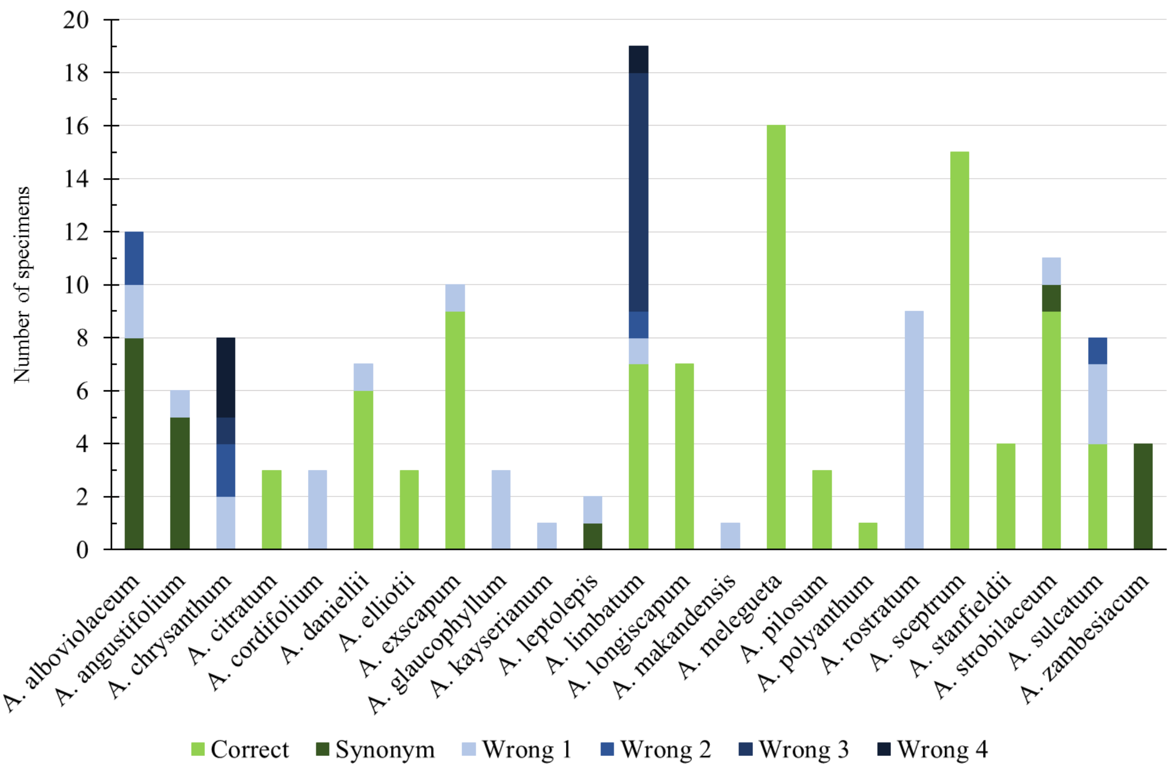


Figure 9 Species circumscription in Harris and Wortley (In Press) vs the *Flora of West Tropical Africa 2nd ed.*. Species names treated as accepted by Harris and Wortley (In Press) and the relative determinations of the specimens cited in each those names in the *Flora of West Tropical Africa 2nd ed.*.

2.3.2.4 *Flora of West Tropical Africa* 2nd ed., 1968

A total of 156 specimens seen by Harris and Wortley (In Press) were cited by *Flora of West Tropical Africa* 2nd ed. account, these specimens represent 23 species in Harris and Wortley (In Press). Three (13%) of the species accepted by Harris and Wortley (In Press) were represented by just one specimen in the *Flora of West Tropical Africa* 2nd ed. treatment, the remaining species were represented by two to 19 specimens (Figure 9).

Only three of the species in Harris and Wortley (In Press) which were represented by specimens in the *Flora of West Tropical Africa* 2nd ed. account were represented by just one specimen, two of these were incorrectly determined (*Aframomum kayserianum* (K.Schum.) K.Schum. and *A. makandensis*) and one was correctly determined (*A. polyanthum*).

Seven species (*A. citratum*, *A. elliotii*, *A. longiscapum*, *A. melegueta*, *A. pilosum*, *A. sceptrum* and *A. stanfieldii*) were represented by multiple specimens which were all correctly determined in the *Flora of West Tropical Africa* 2nd ed. account. One species (*A. zambesiacum*) had all specimens determined under one heterotypic synonym in the *Flora of West Tropical Africa* 2nd ed. account. The remaining twelve species which were represented by two or more specimens in the treatment were either completely incorrectly determined (*A. cordifolium*, *A.glaucophyllum* and *A. rostratum*) or have mixed species concepts; specimens from the same species were cited as a mixture of correct names, heterotypic synonyms, and one to four different incorrect names. Four species were represented by specimens cited as correct and one (*A. daniellii* and *A. exscapum*), two (*A. sulcatum*) or four (*A. limbatum*) incorrect names. Three species were represented by specimens cited as a heterotypic synonym and one (*A. angustifolium* and *A. leptolepis*) or two (*A. alboviolaceum*) incorrect names. One species was represented by the correct name, a heterotypic synonym and an incorrect determination (*A. strobilaceum*) and one species (*A. chrysanthum*) was just represented under four different incorrect determinations.

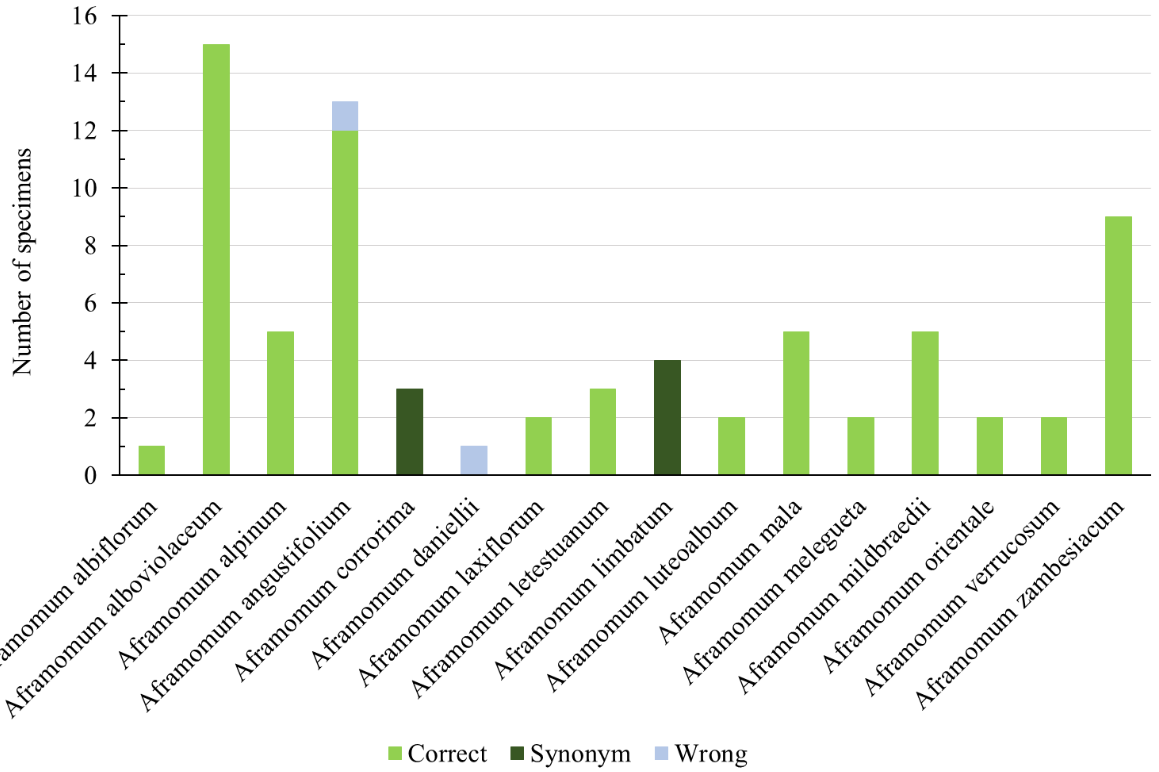


Figure 10 Species circumscription in Harris and Wortley (In Press) vs the *Flora of Tropical East Africa*. Species names treated as accepted by Harris and Wortley (In Press) and the relative determinations of the specimens cited in each those names in the *Flora of Tropical East Africa*.

2.3.2.5 *Flora of Tropical East Africa*, 1985

A total of 74 specimens seen by Harris and Wortley were cited in the *Flora of Tropical East Africa* account (Figure 10), these specimens represented 16 species in Harris and Wortley (In Press).

Two species were represented by just one specimen, one was correctly determined (*Aframomum albiflorum* Lock) and the other was incorrectly determined (*A. daniellii*) (Figure 10).

The majority of species, eleven, (*A. alboviolaceum*, *Aframomum alpinum* (Gagnep.) K.Schum., *Aframomum laxiflorum* Loes. ex Lock, *Aframomum letestuanum* Gagnep., *A. luteoalbum*, *A. mala*, *A. melegueta*, *Aframomum mildbraedii* Loes., *Aframomum orientale* Lock, *Aframomum verrucosum* Lock and *A. zambesiacum*) had all of their specimens determined correctly in the *Flora of Tropical East Africa* account. Two species (*Aframomum corrorima* (A.Braun) P.C.M.Jansen and *A. limbatum*) had all of their specimens determined as a heterotypic synonym in the *Flora of Tropical East Africa* account. Only one species, *A. angustifolium*, had a mixed species concept with a single incorrectly determined specimen.

In the following sections (2.3.2-2.3.7) the six taxonomic accounts are abbreviated as follows:

Flora of Tropical Africa – FTA
Das Pflanzenreich – Pflanzenreich
Flora of West Tropical Africa 1st ed. – FWTA1
Flora of West Tropical Africa 2nd ed. – FWTA2
Flora of Tropical East Africa – FTEA
Harris & Wortley (In Press) – H & W

2.3.3 Mixed collections

17 specimens which are considered to be mixed collections in either Harris & Wortley (In Press) (15) or in at least one of the five past taxonomic accounts (2). Showing the determination(s) in Harris and Wortley (In Press) and (in parenthesis) whether the determination(s) in the past taxonomic account were 'C' = correct, 'I' = incorrect, 'S' = synonym or 'N' = not cited in Harris and Wortley. Where "Y" indicates the specimen has been cited in the taxonomic account, and "M" indicates that the taxonomic account determined the specimen as multiple species.
* Two specimens, Chevalier 19639 and Jones, A.P.D. 17338, are not considered to be mixed collections by Harris and Wortley (In Press).

	Name in Harris and Wortley (In Press)							
Specimen	**Specimen A**	**Specimen B**	**Specimen C**	**FTA**	**Pflanzenreich**	**FWTA 1**	**FWTA 2**	**FTEA**
Chevalier, A. 17384	*Aframomum limbatum* (Oliv. & D.Hanb.) K.Schum.	*Aframomum* sp.					Y (I/N)	
Chevalier, A. 19639*	*Aframomum chrysanthum* Lock						M (I/I)	
Chevalier, A. 19839	*Aframomum strobilaceum* (Sm.) Hepper	*Aframomum sceptrum* (Oliv. & D.Hanb.) K.Schum.					Y (C/I)	
Chevalier, A. 20943	*Aframomum strobilaceum* (Sm.) Hepper	*Aframomum* sp.				Y/M (I/N)		
Daniel, P.M. 16	*Aframomum sulcatum* (Oliv. & D.Hanb. ex Baker) K.Schum.	*Aframomum limbatum* (Oliv. & D.Hanb.) K.Schum.					Y (I/I)	
Deistel, H. 455	*Aframomum leptolepis* (K.Schum.) K.Schum.	*Aframomum daniellii* (Hook.f.) K.Schum.				Y (S/I)		
Gillman, H. 448	*Aframomum angustifolium* (Sonn.) K.Schum.	*Aframomum* sp.						Y (I/N)
Harley, W.J. 1526	*Aframomum chrysanthum* Lock	*Aframomum sulcatum* (Oliv. & D.Hanb. ex Baker) K.Schum.					Y (I/I)	
Harley, W.J. 1553	*Aframomum sulcatum* (Oliv. & D.Hanb. ex Baker) K.Schum.	*Aframomum exscapum* (Sims) Hepper					Y/M (C/C)	

Continued on next page,,,

Appendix 2.3.3

Specimen	Name in Harris and Wortley (In Press) Specimen A	Specimen B	Specimen C	FTA	Pflanzenreich	FWTA 1	FWTA 2	FTEA
Jones, A.P.D. 17338*	*Aframomum daniellii* (Hook.f.) K.Schum.						M (C/I)	
Le Testu, G. 707	*Aframomum alboviolaceum* (Ridl.) K.Schum.	*Aframomum alboviolaceum* (Ridl.) K.Schum.						Y (C/C)
Leeuwenberg, A.J.M. 2457	*Aframomum longiscapum* (Hook.f.) K.Schum.	*Aframomum* sp.					Y (C/N)	
Pobéguin, H. 941	*Aframomum strobilaceum* (Sm.) Hepper	*Aframomum limbatum* (Oliv. & D.Hanb.) K.Schum.				Y (I/I)	Y (S/I)	
Preuss, P.R. 555	*Aframomum pilosum* (Oliv. & D.Hanb.) K.Schum.	*Aframomum limbatum* (Oliv. & D.Hanb.) K.Schum.		Y (C/I)	Y/M (C/I)	Y (I/N)	Y (C/I)	
Sonnerat, P. *s.n.*	*Aframomum angustifolium* (Sonn.) K.Schum.	*Aframomum* sp.			Y (C/N)			Y (C/N)
Talbot, P.A. 83	*Aframomum exscapum* (Sims) Hepper	*Aframomum limbatum* (Oliv. & D.Hanb.) K.Schum.	*Renealmia* sp.			Y (C/I/N)		
Thomas, N.W. 2137	*Aframomum* sp.	*Aframomum limbatum* (Oliv. & D.Hanb.) K.Schum.				Y (I/I)		

2.3.4 Coverage by species name in the past taxonomic accounts and Harris & Wortley

The 90 *Aframomum* and *Amomum* names accepted by the five past taxonomic accounts (presence indicated by "Y") with the nomenclatural status in Harris and Wortley (In Press) and the total number of times that the name occurs in the five past taxonomic accounts.

Name	Status	FTA	H & W	Pflanzenreich	H & W	FWTA 1	H & W	FWTA 2	H & W	FTEA	H & W	Total
Aframomum albiflorum Lock	accepted	-	-	-	-	-	-	-	-	Y	Y	1
Aframomum alboviolaceum (Ridl.) K.Schum.	accepted	-	Y	Y	Y	-	Y	-	Y	Y	Y	2
Aframomum alpinum (Gagnep.) K.Schum.	accepted	-	-	Y	Y	-	-	-	-	Y	Y	2
Aframomum amaniense Loes.	heterotypic synonym	-	-	-	-	-	-	-	-	Y	-	1
Aframomum angustifolium (Sonn.) K.Schum.	accepted	-	Y	Y	Y	-	-	-	Y	Y	Y	2
Aframomum arundinaceum (Oliv. & D.Hanb.) K.Schum.	accepted	-	Y	Y	Y	-	-	-	-	-	-	1
Aframomum baumannii K.Schum.	heterotypic synonym	-	-	Y	-	Y	-	Y	-	-	-	3
Aframomum biauriculatum K.Schum.	heterotypic synonym	-	-	Y	-	-	-	-	-	-	-	1
Aframomum chlamydanthum Loes. & Mildbr.	heterotypic synonym	-	-	-	-	Y	-	Y	-	-	-	2
Aframomum chrysanthum Lock	accepted	-	-	-	-	-	Y	-	Y	-	-	0
Aframomum citratum (J.Pereira) K.Schum.	accepted	-	Y	Y	Y	Y	Y	Y	Y	-	-	3
Aframomum colosseum K.Schum.	excluded	-	-	Y	-	-	-	-	-	-	-	1
Aframomum cordifolium Lock & J.B.Hall	accepted	-	-	-	-	-	Y	-	Y	-	-	0
Aframomum corrorima (A.Braun) P.C.M.Jansen	accepted	-	-	-	-	-	-	-	-	-	Y	0
Aframomum crassilabium (K.Schum. ex Engl.) K.Schum.	excluded	-	Y	Y	-	-	-	-	-	-	-	1
Aframomum cuspidatum (Gagnep.) K.Schum.	heterotypic synonym	-	-	Y	-	Y	-	-	-	-	-	2
Aframomum dalzielii Hutch.	heterotypic synonym	-	-	-	-	Y	-	Y	-	-	-	2
Aframomum daniellii (Hook.f.) K.Schum.	accepted	-	Y	Y	Y	Y	Y	Y	Y	-	Y	3
Aframomum elliotii (Baker) K.Schum.	accepted	-	Y	Y	Y	Y	Y	Y	Y	-	-	3
Aframomum erythrostachyum Gagnep.	heterotypic synonym	-	-	-	-	-	-	Y	-	-	-	1
Aframomum exscapum (Sims) Hepper	accepted	-	Y	-	Y	-	Y	Y	Y	-	-	1
Aframomum giganteum (Oliv. & D.Hanb.) K.Schum.	accepted	-	Y	Y	Y	-	-	-	-	-	-	1
Aframomum glaucophyllum (K.Schum.) K.Schum.	accepted	-	Y	Y	Y	-	Y	-	Y	-	-	1

Continued on next page,,,

Appendix 2.3.4

Name	Status	FTA	H & W	Pflanzenreich	H & W	FWTA 1	H & W	FWTA 2	H & W	FTEA	H & W	Total
Aframomum granum-paradisi (L.) K.Schum.	excluded	-	-	Y	-	-	-	-	-	-	-	1
Aframomum hanburyi K.Schum.	heterotypic synonym	-	-	Y	-	-	-	-	-	-	-	1
Aframomum kayserianum (K.Schum.) K.Schum.	accepted	-	Y	Y	Y	-	-	-	Y	-	-	1
Aframomum latifolium (Afzel.) K.Schum.	heterotypic synonym	-	-	Y	-	Y	-	Y	-	-	-	3
Aframomum laurentii (De Wild. & T.Durand) K.Schum.	heterotypic synonym	-	-	Y	-	-	-	-	-	-	-	1
Aframomum laxiflorum Loes. ex Lock	accepted	-	-	-	-	-	-	-	-	Y	Y	1
Aframomum leonense K.Schum.	heterotypic synonym	-	-	Y	-	-	-	-	-	-	-	1
Aframomum leptolepis (K.Schum.) K.Schum.	accepted	-	Y	Y	Y	Y	Y	Y	Y	-	-	3
Aframomum letestuanum Gagnep.	accepted	-	-	-	-	-	-	-	-	Y	Y	1
Aframomum limbatum (Oliv. & D.Hanb.) K.Schum.	accepted	-	Y	Y	Y	Y	Y	Y	Y	-	Y	3
Aframomum longiscapum (Hook.f.) K.Schum.	accepted	-	Y	Y	Y	Y	Y	Y	Y	-	-	3
Aframomum luteoalbum (K.Schum.) K.Schum.	accepted	-	-	Y	-	-	-	-	-	Y	Y	2
Aframomum lycobasis K.Schum.	heterotypic synonym	-	-	Y	-	Y	-	-	-	-	-	2
Aframomum makandensis Dhetchuvi	accepted	-	-	-	-	-	Y	-	Y	-	-	0
Aframomum mala (K.Schum. ex Engl.) K.Schum.	accepted	-	Y	Y	Y	-	-	-	-	Y	Y	2
Aframomum mannii (Oliv. & D.Hanb.) K.Schum.	accepted	-	Y	Y	Y	-	-	-	-	-	-	1
Aframomum masuianum (De Wild. & T.Durand) K.Schum.	heterotypic synonym	-	-	Y	-	-	-	-	-	-	-	1
Aframomum melegueta (Roscoe) K.Schum.	accepted	-	Y	Y	Y	Y	Y	Y	Y	Y	Y	4
Aframomum melegueta (Roscoe) K.Schum. var. *violacea* (Ridl.) K.Schum.	heterotypic synonym	-	-	Y	-	-	-	-	-	-	-	1
Aframomum meleguetella K.Schum.	heterotypic synonym	-	-	Y	-	-	-	-	-	-	-	1
Aframomum mildbraedii Loes.	accepted	-	-	-	-	-	-	-	-	Y	Y	1
Aframomum orientale Lock	accepted	-	-	-	-	-	-	-	-	Y	Y	1
Aframomum pilosum (Oliv. & D.Hanb.) K.Schum.	accepted	-	Y	Y	Y	Y	Y	Y	Y	-	-	3
Aframomum polyanthum (K.Schum.) K.Schum.	accepted	-	Y	Y	Y	-	-	Y	Y	-	-	2
Aframomum rostratum K.Schum.	accepted	-	Y	Y	Y	-	-	-	Y	-	-	1

Continued on next page,,,

Appendix 2.3.4

Name	Status	FTA	H & W	Pflanzenreich	H & W	FWTA 1	H & W	FWTA 2	H & W	FTEA	H & W	Total
Aframomum sanguineum (K.Schum.) K.Schum.	heterotypic synonym	-	-	Y	-	-	-	-	-	-	-	1
Aframomum sceptrum (Oliv. & D.Hanb.) K.Schum.	accepted	-	Y	Y	Y	Y	Y	Y	Y	-	-	3
Aframomum simiarum A.Chev.	heterotypic synonym	-	-	-	-	Y	-	-	-	-	-	1
Aframomum sp.A.		-	-	-	-	-	-	-	-	Y	-	1
Aframomum stanfieldii Hepper	accepted	-	-	-	-	-	-	Y	Y	-	-	1
Aframomum stipulatum (Gagnep.) K.Schum.	heterotypic synonym	-	-	Y	-	-	-	-	-	-	-	1
Aframomum strobilaceum (Sm.) Hepper	accepted	-	Y	-	-	-	Y	Y	Y	-	-	1
Aframomum subsericeum (Oliv. & D.Hanb.) K.Schum.	accepted	-	Y	Y	Y	Y	-	Y	-	-	-	3
Aframomum sulcatum (Oliv. & D.Hanb. ex Baker) K.Schum.	accepted	-	Y	Y	Y	Y	Y	Y	Y	-	-	3
Aframomum tectorum K.Schum.	heterotypic synonym	-	-	Y	-	-	-	-	-	-	-	1
Aframomum usambarense Lock	heterotypic synonym	-	-	-	-	-	-	-	-	Y	-	1
Aframomum verrucosum Lock	accepted	-	-	-	-	-	-	-	-	Y	Y	1
Aframomum zambesiacum (Baker) K.Schum.	accepted	-	Y	Y	Y	-	Y	-	Y	Y	Y	2
Aframomum zimmermannii K.Schum.	heterotypic synonym	-	-	Y	-	-	-	-	-	-	-	1
Amomum alboviolaceum Ridl.	basionym	Y	-	-	-	-	-	-	-	-	-	1
Amomum angustifolium Sonn.	basionym	Y	-	-	-	-	-	-	-	-	-	1
Amomum arundinaceum Oliv. & D.Hanb.	basionym	Y	-	-	-	-	-	-	-	-	-	1
Amomum cereum Hook.f.	excluded	Y	-	Y	-	-	-	-	-	-	-	2
Amomum citratum J.Pereira	basionym	Y	-	-	-	-	-	-	-	-	-	1
Amomum crassilabium K.Schum. ex Engl.	excluded	Y	-	-	-	-	-	-	-	-	-	1
Amomum elliotii Baker	basionym	Y	-	-	-	-	-	-	-	-	-	1
Amomum erythrocarpum Ridl.	heterotypic synonym	-	-	Y	-	-	-	-	-	-	-	1
Amomum giganteum Oliv. & D.Hanb.	basionym	Y	-	-	-	-	-	-	-	-	-	1
Amomum glaucophyllum K.Schum.	basionym	Y	-	-	-	-	-	-	-	-	-	1
Amomum granum-paradisi L.	excluded	Y	-	-	-	-	-	-	-	-	-	1
Amomum kayserianum K.Schum.	basionym	Y	-	-	-	-	-	-	-	-	-	1

Continued on next page,,,

Appendix 2.3.4

Name	**Status**	**FTA**	**H & W**	**Pflanzenreich**	**H & W**	**FWTA 1**	**H & W**	**FWTA 2**	**H & W**	**FTEA**	**H & W**	**Total**
Amomum latifolium Afzel.	heterotypic synonym	Y	-	-	-	-	-	-	-	-	-	1
Amomum leptolepis K.Schum.	basionym	Y	-	-	-	-	-	-	-	-	-	1
Amomum limbatum Oliv. & D.Hanb.	basionym	Y	-	-	-	-	-	-	-	-	-	1
Amomum longiscapum Hook.f.	basionym	Y	-	-	-	-	-	-	-	-	-	1
Amomum luteoalbum K.Schum.	basionym	Y	-	-	-	-	-	-	-	-	-	1
Amomum macrolepis K.Schum.	heterotypic synonym	Y	-	-	-	-	-	-	-	-	-	1
Amomum mala K.Schum. ex Engl.	basionym	Y	-	-	-	-	-	-	-	-	-	1
Amomum mannii Oliv. & D.Hanb.	basionym	Y	-	-	-	-	-	-	-	-	-	1
Amomum melegueta Roscoe	basionym	Y	-	-	-	-	-	-	-	-	-	1
Amomum pilosum Oliv. & D.Hanb.	basionym	Y	-	-	-	-	-	-	-	-	-	1
Amomum polyanthum K.Schum.	basionym	Y	-	-	-	-	-	-	-	-	-	1
Amomum sanguineum K.Schum.	heterotypic synonym	Y	-	-	-	-	-	-	-	-	-	1
Amomum sceptrum Oliv. & D.Hanb.	basionym	Y	-	-	-	-	-	-	-	-	-	1
Amomum subsericeum Oliv. & D.Hanb.	basionym	Y	-	-	-	-	-	-	-	-	-	1
Amomum sulcatum Oliv. & D.Hanb. ex Baker	basionym	Y	-	-	-	-	-	-	-	-	-	1
Amomum zambesiacum Baker	basionym	Y	-	-	-	-	-	-	-	-	-	1

2.3.5 Mixed species concepts in the past taxonomic accounts and Harris & Wortley

The 31 *Aframomum* and *Amomum* names which were either accepted by the five past taxonomic accounts which cited specimens from two or more different species *fide* Harris and Wortley, and/or accepted in Harris and Wortley (H & W) and are represented in one or more past taxonomic account under two or more different names. The total number of times that each name occurs in the past taxonomic accounts is provided.

Name	**FTA**	**H & W**	**Pflanzenreich**	**H & W**	**FWTA 1**	**H & W**	**FWTA 2**	**H & W**	**FTEA**	**H & W**	**Total**
Aframomum alboviolaceum (Ridl.) K.Schum.	-	3	-	4	-	4	-	3	-	-	0
Aframomum angustifolium (Sonn.) K.Schum.	-	2	-	2	-	-	-	2	-	2	0
Aframomum baumannii K.Schum.	-	-	-	-	-	-	4	-	-	-	1
Aframomum chrysanthum Lock	-	-	-	-	-	-	-	4	-	-	0
Aframomum citratum (J.Pereira) K.Schum.	-	-	2	2	2	2	2	-	-	-	3
Aframomum cuspidatum (Gagnep.) K.Schum.	-	-	-	-	2	-	-	-	-	-	1
Aframomum dalzielii Hutch.	-	-	-	-	2	-	-	-	-	-	1
Aframomum daniellii (Hook.f.) K.Schum.	-	2	-	4	3	2	3	2	-	-	2
Aframomum elliotii (Baker) K.Schum.	-	-	-	-	-	-	2	-	-	-	1
Aframomum erythrostachyum Gagnep.	-	-	-	-	-	-	2	-	-	-	1
Aframomum exscapum (Sims) Hepper	-	-	-	2	-	2	-	2	-	-	0
Aframomum giganteum (Oliv. & D.Hanb.) K.Schum.	-	-	-	3	-	-	-	-	-	-	0
Aframomum glaucophyllum (K.Schum.) K.Schum.	-	-	2	-	-	-	-	-	-	-	1
Aframomum granum-paradisi (L.) K.Schum.	-	-	2	-	-	-	-	-	-	-	1
Aframomum latifolium (Afzel.) K.Schum.	-	-	-	-	2	-	5	-	-	-	2
Aframomum leptolepis (K.Schum.) K.Schum.	-	-	-	-	-	-	2	2	-	-	1
Aframomum limbatum (Oliv. & D.Hanb.) K.Schum.	-	2	-	3	-	6	-	5	-	-	0
Aframomum longiscapum (Hook.f.) K.Schum.	-	-	-	-	2	-	2	-	-	-	2
Aframomum luteoalbum (K.Schum.) K.Schum.	-	-	-	-	-	-	-	-	2	-	1
Aframomum lycobasis K.Schum.	-	-	-	-	3	-	-	-	-	-	1
Aframomum mala (K.Schum. ex Engl.) K.Schum.	-	-	-	-	-	-	-	-	2	-	1

Continued on next page,,,

Appendix 2.3.5

Name	**FTA**	**H & W**	**Pflanzenreich**	**H & W**	**FWTA 1**	**H & W**	**FWTA 2**	**H & W**	**FTEA**	**H & W**	**Total**
Aframomum melegueta (Roscoe) K.Schum.	-	2	-	3	-	-	-	-	-	-	0
Aframomum pilosum (Oliv. & D.Hanb.) K.Schum.	-	-	-	-	3	-	-	-	-	-	1
Aframomum sceptrum (Oliv. & D.Hanb.) K.Schum.	-	2	2	4	4	-	4	-	-	-	3
Aframomum strobilaceum (Sm.) Hepper	-	-	-	-	-	4	2	3	-	-	1
Aframomum subsericeum (Oliv. & D.Hanb.) K.Schum.	-	-	2	2	-	-	-	-	-	-	1
Aframomum sulcatum (Oliv. & D.Hanb. ex Baker) K.Schum.	-	-	-	-	3	2	3	3	-	-	2
Amomum angustifolium Sonn.	2	-	-	-	-	-	-	-	-	-	1
Amomum granum-paradisi L.	4	-	-	-	-	-	-	-	-	-	1
Amomum leptolepis K.Schum.	2	-	-	-	-	-	-	-	-	-	1
Amomum melegueta Roscoe	2	-	-	-	-	-	-	-	-	-	1

2.3.6 Incorrect determinations, synonyms and excluded names in the past taxonomic accounts compared to Harris & Wortley

The 21 *Aframomum* names accepted by Harris and Wortley (In Press) which have specimens which have been determined incorrectly in the past taxonomic accounts, as heterotypic synonyms or as excluded names and the number of each type of name which has been applied. The incorrect determinations do not include specimens determined as names currently considered to be excluded.

	Incorrect Determination					Heterotypic Synonym					Excluded				
Name	**FTA**	**Pflanzenreich**	**FWTA 1**	**FWTA 2**	**FTEA**	**FTA**	**Pflanzenreich**	**FWTA 1**	**FWTA 2**	**FTEA**	**FTA**	**Pflanzenreich**	**FWTA 1**	**FWTA 2**	**FTEA**
Aframomum alboviolaceum (Ridl.) K.Schum.	-	-	3	2	-	1	2	1	1	-	1	1	-	-	-
Aframomum angustifolium (Sonn.) K.Schum.	-	-	-	1	1	1	1	-	1	-	-	-	-	-	-
Aframomum chrysanthum Lock	-	-	1	4	-	-	-	-	-	-	-	-	-	-	-
Aframomum citratum (J.Pereira) K.Schum.	-	1	1	-	-	-	-	-	-	-	-	-	-	-	-
Aframomum cordifolium Lock & J.B.Hall	-	-	1	1	-	-	-	-	-	-	-	-	-	-	-
Aframomum corrorima (A.Braun) P.C.M.Jansen	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-
Aframomum daniellii (Hook.f.) K.Schum.	2	1	1	1	1	-	2	-	-	-	-	-	-	-	-
Aframomum exscapum (Sims) Hepper	-	-	1	1	-	-	2	1	-	-	1	-	-	-	-
Aframomum giganteum (Oliv. & D.Hanb.) K.Schum.	-	-	-	-	-	-	2	-	-	-	-	-	-	-	-
Aframomum glaucophyllum (K.Schum.) K.Schum.	-	-	1	1	-	-	-	-	-	-	-	-	-	-	-
Aframomum kayserianum (K.Schum.) K.Schum.	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-
Aframomum leptolepis (K.Schum.) K.Schum.	-	-	-	1	-	-	-	1	1	-	-	-	-	-	-
Aframomum limbatum (Oliv. & D.Hanb.) K.Schum.	1	1	4	4	-	-	1	1	-	1	-	-	-	-	-
Aframomum makandensis Dhetchuvi	-	-	1	1	-	-	-	-	-	-	-	-	-	-	-
Aframomum melegueta (Roscoe) K.Schum.	-	-	-	-	-	1	2	-	-	-	-	-	-	-	-
Aframomum rostratum K.Schum.	-	-	-	1	-	-	-	-	-	-	1	-	-	-	-
Aframomum sceptrum (Oliv. & D.Hanb.) K.Schum.	-	-	-	-	-	-	1	-	-	-	1	2	-	-	-
Aframomum strobilaceum (Sm.) Hepper	-	-	3	1	-	-	-	1	1	-	1	-	-	-	-
Aframomum subsericeum (Oliv. & D.Hanb.) K.Schum.	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-
Aframomum sulcatum (Oliv. & D.Hanb. ex Baker) K.Schum.	-	-	1	2	-	-	-	-	-	-	-	-	-	-	-
Aframomum zambesiacum (Baker) K.Schum.	-	-	-	-	-	-	-	1	1	-	-	-	-	-	-

2.3.7 Incorrect determinations in the past taxonomic accounts

The 22 *Aframomum* names accepted by the past taxonomic accounts which cite specimens which are now considered to have been determined incorrectly, compared to Harris and Wortley (In Press). The total number of species those specimens are now considered to belong to is provided in addition to a total for the occurrences of incorrect determinations for that name in the past taxonomic accounts.

Name	**FTA**	**Pflanzenreich**	**FWTA 1**	**FWTA 2**	**FTEA**	**Total**
Aframomum baumannii K.Schum.	-	-	1	3	-	2
Aframomum citratum (J.Pereira) K.Schum.	-	1	1	1	-	3
Aframomum cuspidatum (Gagnep.) K.Schum.	-	-	1	-	-	1
Aframomum dalzielii Hutch.	-	-	1	-	-	1
Aframomum daniellii (Hook.f.) K.Schum.	-	-	2	2	-	2
Aframomum elliotii (Baker) K.Schum.	-	-	-	1	-	1
Aframomum erythrostachyum Gagnep.	-	-	-	1	-	1
Aframomum glaucophyllum (K.Schum.) K.Schum.	-	1	-	-	-	1
Aframomum latifolium (Afzel.) K.Schum.	-	-	1	4	-	2
Aframomum leptolepis (K.Schum.) K.Schum.	-	-	1	1	-	2
Aframomum longiscapum (Hook.f.) K.Schum.	-	-	1	1	-	2
Aframomum luteoalbum (K.Schum.) K.Schum.	-	-	-	-	1	1
Aframomum lycobasis K.Schum.	-	-	2	-	-	1
Aframomum mala (K.Schum. ex Engl.) K.Schum.	-	-	-	-	1	1
Aframomum pilosum (Oliv. & D.Hanb.) K.Schum.	-	-	2	-	-	1
Aframomum sceptrum (Oliv. & D.Hanb.) K.Schum.	-	1	3	3	-	3
Aframomum strobilaceum (Sm.) Hepper	-	-	-	1	-	1
Aframomum subsericeum (Oliv. & D.Hanb.) K.Schum.	-	-	1	1	-	2
Aframomum sulcatum (Oliv. & D.Hanb. ex Baker) K.Schum.	-	1	2	2	-	3
Amomum angustifolium Sonn.	1	-	-	-	-	1
Amomum leptolepis K.Schum.	1	-	-	-	-	1
Amomum melegueta Roscoe	1	-	-	-	-	1

3 APPENDICES – WIDESPREAD MISTAKEN IDENTITY IN TROPICAL PLANT COLLECTIONS

3.1 DOCUMENTING UNCERTAINTY IN NATURAL HISTORY COLLECTIONS

3.1.1 Species and numbers of specimens of *Inga* surveyed at MO

The 44 *Inga* species surveyed at MO. Indicating the range of each species, the number of specimens surveyed per species (and the estimated total number of specimens present in the herbarium), range in number of degree square cells and number of countries (parentheses) occupied by each species *sensu* Pennington (1997) and Star rating for each species *fide* Hawthorne and Marshall (2016). *Range of the genus.

Species	Specimens Sampled	Range (Countries)	Star
Inga acrocephala Steud.	91 (148)	17 (8)	Blue
Inga acuminata Benth.	8 (78)	22 (8)	Blue
Inga alba (Sw.) Willd.	5 (373)	84 (12)	Green
Inga aliena J.F. Macbride	4 (5)	1 (1)	Black
Inga allenii J. León	1 (13)	3 (2)	Gold
Inga approximata T.D. Penn.	6 (12)	3 (1)	Gold
Inga barbata Benth.	4 (45)	14 (3)	Blue
Inga barbourii Standl.	15 (26)	8 (3)	Gold
Inga belizensis Standl.	7 (21)	4 (3)	Gold
Inga bella M. Sousa	9 (17)	2 (1)	Black
Inga bicoloriflora Ducke	1 (3)	2 (1)	Black
Inga blanchetiana Benth.	1 (10)	4 (1)	Gold
Inga bollandii Sprague & Sandwith	1 (11)	3 (1)	Gold
Inga bracteifera N. Zamora & T.D. Penn.	3 (3)	1 (1)	Black
Inga brevipes Benth.	6 (17)	3 (2)	Gold
Inga bullatorugosa Ducke	3 (10)	2 (1)	Black
Inga cabrerae M. Sousa	1 (2)	2 (2)	Black
Inga calcicola M. Sousa	5 (6)	2 (1)	Black
Inga canonegrensis N. Zamora & T.D. Penn.	3 (3)	1 (1)	Black
Inga chiapensis Miranda ex M. Sousa	1 (2)	2 (1)	Black
Inga chrysantha Ducke	2 (22)	9 (3)	Blue
Inga cookii Pittier	8 (16)	5 (2)	Gold
Inga cordistipula Mart.	1 (20)	3 (1)	Gold
Inga cuspidata M. Sousa	5 (8)	2 (1)	Black
Inga dasycarpa M. Sousa	5 (23)	4 (4)	Gold
Inga davidsei M. Sousa	6 (20)	7 (3)	Gold
Inga dwyeri M. Sousa	5 (7)	1 (1)	Black
Inga edwallii (Harms) T.D. Penn.	8 (29)	5 (1)	Gold
Inga exalata T.S. Elias	15 (28)	6 (2)	Gold
Inga expansa Rusby	7 (9)	2 (1)	Black
Inga extra-nodis T.D. Penn.	10 (16)	2 (1)	Black
Inga fanchoniana Poncy	1 (5)	3 (2)	Gold
Inga flexuosa Schltdl.	13 (20)	4 (1)	Gold
Inga gereauana (Pipoly & R. Vásquez) T.D. Penn.	5 (5)	1 (1)	Black
Inga glomeriflora Ducke	1 (8)	5 (3)	Gold
Inga golfodulcensis N. Zamora	5 (9)	1 (1)	Black
Inga herrerae N. Zamora	4 (9)	3 (1)	Gold

Continued on next page,,,

Appendix 3

Appendix 3.1.1

Species	**Specimens Sampled**	**Range (Countries)**	**Star**
Inga involucrata R.S. Cowan	1 (8)	2 (2)	Black
Inga lallensis Spruce ex Benth.	3 (15)	6 (2)	Gold
Inga latipes Pittier	6 (7)	2 (1)	Black
Inga macrophylla Humb. & Bonpl. ex Willd.	7 (75)	21 (7)	Blue
Inga ruiziana G. Don	2 (153)	40 (8)	Green
Inga umbratica Poepp. & Endl.	4 (77)	34 (6)	Green
Inga vera Kunth	231 (>1,500)	>150* (>25)	Green

3.1.2 Species and numbers of specimens of *Hypericum* surveyed at MO

The 40 *Hypericum* species surveyed at MO. Indicating the number of specimens sampled (and the estimated total number of specimens present in the herbarium), geographic range (continent) and reference.

Filing Name (Accepted Name)	Specimens Sampled	Continent	Reference
Hypericum aciculare Kunth	28 (48)	Southern America	Robson NKB (1987) Studies in the genus *Hypericum* L. (Guttiferae). 7. Section 29. *Brathys* (part 1). Bull.br.Mus.nat.Hist.Bot. 16(1):1–106.
Hypericum andinum Gleason	20 (37)	Southern America	Robson NKB (1987) Studies in the genus *Hypericum* L. (Guttiferae). 7. Section 29. *Brathys* (part 1). Bull.br.Mus.nat.Hist.Bot. 16(1):1–106.
Hypericum androsaemum L.	1 (3)	Europe, Africa, Asia Temperate	Robson NKB (1985) Studies in the genus *Hypericum* L. (Guttiferae). 3. Sections 1. *Campylosporus* to 6a. *Umbraculoides*. Bull.br.Mus.nat.Hist.Bot. 12:163–325.
Hypericum angulosum Michx. ex Willd. (*Hypericum denticulatum* Walter)	2 (2)	Northern America	Robson NKB (1990) Studies in the genus *Hypericum* L. (Guttiferae). 8. Sections 29. *Brathys* (part 2) and 30. *Trigynobrathys*. Bull.br.Mus.nat.Hist.Bot. 20(1):1–151.
Hypericum apocynifolium Small	5 (6)	Northern America	Robson NKB (1996) Studies in the genus *Hypericum* L. (Guttiferae): 6. Sections 20. *Myriandra* to 28. *Elodes*. Bull.br.Mus.nat.Hist.Bot. 26(2):110–112.
Hypericum arbuscula Standl. & Steyerm.	1 (1)	Northern America, Southern America	Robson NKB (1990) Studies in the genus *Hypericum* L. (Guttiferae). 8. Sections 29. *Brathys* (part 2) and 30. *Trigynobrathys*. Bull.br.Mus.nat.Hist.Bot. 20(1):1–151.
Hypericum ascyron L.	32 (48)	Asia Temperate, Asia Tropical, Northern America	Robson NKB (2001) Studies in the genus *Hypericum* L. (Guttiferae). 4(1). Sections 7. *Roscyna* to 9. *Hypericum* sensu lato (part 1). Bull.br.Mus.nat.Hist.Bot. 31:37–88.
Hypericum boreale (Britton) E.P. Bicknell	37 (57)	Northern America	Robson NKB (1990) Studies in the genus *Hypericum* L. (Guttiferae). 8. Sections 29. *Brathys* (part 2) and 30. *Trigynobrathys*. Bull.br.Mus.nat.Hist.Bot. 20(1):1–151.
Hypericum boreale x *canadense*	1 (1)	Northern America	
Hypericum callacallanum N. Robson	2 (3)	Southern America	Robson NKB (1990) Studies in the genus *Hypericum* L. (Guttiferae). 8. Sections 29. *Brathys* (part 2) and 30. *Trigynobrathys*. Bull.br.Mus.nat.Hist.Bot. 20(1):1–151.
Hypericum callithyrsum Coss.	1 (1)	Europe, Africa	Robson NKB (2010) Studies in the genus *Hypericum* L. (Hypericaceae) 5(2). Sections 17. *Hirtella* to 19. *Coridium*. Phytotaxa 4:127–258.

Continued on next page,,,

Appendix 3.1.2

Filing Name (Accepted Name)	**Specimens Sampled**	**Continent**	**Reference**
Hypericum campestre Cham. & Schltdl.	19 (33)	Southern America	Robson NKB (1990) Studies in the genus *Hypericum* L. (Guttiferae). 8. Sections 29. *Brathys* (part 2) and 30. *Trigynobrathys*. Bull.br.Mus.nat.Hist.Bot. 20(1):1–151.
Hypericum campestre Cham. & Schltdl. subsp. *tenue* N. Robson	3 (5)	Southern America	Robson NKB (1990) Studies in the genus *Hypericum* L. (Guttiferae). 8. Sections 29. *Brathys* (part 2) and 30. *Trigynobrathys*. Bull.br.Mus.nat.Hist.Bot. 20(1):1–151.
Hypericum canariense L.	10 (14)	Africa	Robson NKB (1996) Studies in the genus *Hypericum* L. (Guttiferae): 6. Sections 20. *Myriandra* to 28. *Elodes*. Bull.br.Mus.nat.Hist.Bot. 26(2):110–112.
Hypericum caracasanum Willd.	4 (8)	Southern America	Robson NKB (1987) Studies in the genus *Hypericum* L. (Guttiferae). 7. Section 29. *Brathys* (part 1). Bull.br.Mus.nat.Hist.Bot. 16(1):1–106.
	15 (21)		
Hypericum cardonae Cuatrec.	1 (4)	Southern America	Robson NKB (1987) Studies in the genus *Hypericum* L. (Guttiferae). 7. Section 29. *Brathys* (part 1). Bull.br.Mus.nat.Hist.Bot. 16(1):1–106.
Hypericum collinum Schltdl. & Cham.	1 (2)	Southern America	Robson NKB (2006) Studies in the genus *Hypericum* L. (Clusiaceae). 4(3). Section 9. *Hypericum* sensu lato (part 3): subsection 1. *Hypericum* series 2. *Senanensia*, subsection 2. *Erecta* and section 9b. *Graveolentia*. Syst Biodivers 4:19–98.
Hypericum confusum Rose (*Hypericum bithynicum* Boiss.)	1 (3)	Asia Temperate	Robson NKB (1990) Studies in the genus *Hypericum* L. (Guttiferae). 8. Sections 29. *Brathys* (part 2) and 30. *Trigynobrathys*. Bull.br.Mus.nat.Hist.Bot. 20(1):1–151.
Hypericum conjungens N. Robson	1 (4)	Africa	Robson NKB (1996) Studies in the genus *Hypericum* L. (Guttiferae): 6. Sections 20. *Myriandra* to 28. *Elodes*. Bull.br.Mus.nat.Hist.Bot. 26(2):110–112.
Hypericum constanzae Urb. (*Hypericum diosmoides* Griseb.)	41 (91)	Northern America	Robson NKB (1987) Studies in the genus *Hypericum* L. (Guttiferae). 7. Section 29. *Brathys* (part 1). Bull.br.Mus.nat.Hist.Bot. 16(1):1–106.
Hypericum costaricense N. Robson	1 (1)	Southern America	Robson NKB (1987) Studies in the genus *Hypericum* L. (Guttiferae). 7. Section 29. *Brathys* (part 1). Bull.br.Mus.nat.Hist.Bot. 16(1):1–106.
Hypericum cubense Turcz. (*Hypericum nitidum* subsp. *cubense* (Turcz.) N. Robson)	19 (33)	Southern America	Robson NKB (1993) Studies in *Hypericum*: validation of new names. Bull.br.Mus.nat.Hist.Bot. 23(2):67–70.

Continued on next page,,,

Appendix 3.1.2

Filing Name (Accepted Name)	Specimens Sampled	Continent	Reference
Hypericum denticulatum Walter	1 (5)	Northern America	Robson NKB (1990) Studies in the genus *Hypericum* L. (Guttiferae). 8. Sections 29. *Brathys* (part 2) and 30. *Trigynobrathys*. Bull.br.Mus.nat.Hist.Bot. 20(1):1–151.
Hypericum dichotomum Lam.	4 (6)	Southern America	Robson NKB (1987) Studies in the genus *Hypericum* L. (Guttiferae). 7. Section 29. *Brathys* (part 1). Bull.br.Mus.nat.Hist.Bot. 16(1):1–106.
Hypericum diffusum Rose (*Hypericum pumillum* subsp. *diffusum* (Rose) N. Robson)	1 (2)	Northern America	Robson NKB (1990) Studies in the genus *Hypericum* L. (Guttiferae). 8. Sections 29. *Brathys* (part 2) and 30. *Trigynobrathys*. Bull.br.Mus.nat.Hist.Bot. 20(1):1–151.
Hypericum diosmoides Griseb.	12 (19)	Southern America	Robson NKB (1987) Studies in the genus *Hypericum* L. (Guttiferae). 7. Section 29. *Brathys* (part 1). Bull.br.Mus.nat.Hist.Bot. 16(1):1–106.
Hypericum ekmanii Alain	2 (2)	Southern America	Robson NKB (1987) Studies in the genus *Hypericum* L. (Guttiferae). 7. Section 29. *Brathys* (part 1). Bull.br.Mus.nat.Hist.Bot. 16(1):1–106.
Hypericum epigeium R. Keller	2 (3)	Northern America, Southern America	Robson NKB (2006) Studies in the genus *Hypericum* L. (Clusiaceae). 4(3). Section 9. *Hypericum* sensu lato (part 3): subsection 1. *Hypericum* series 2. *Senanensia*, subsection 2. *Erecta* and section 9b. *Graveolentia*. Syst Biodivers 4:19–98.
Hypericum fasciculatum Lam.	3 (28)	Northern America, Southern America	Robson NKB (1996) Studies in the genus *Hypericum* L. (Guttiferae): 6. Sections 20. *Myriandra* to 28. *Elodes*. Bull.br.Mus.nat.Hist.Bot. 26(2):110–112.
Hypericum fastigiatum Elliott (*Hypericum adpressum* W.P.C.Barton)	6 (5)	Northern America, Southern America	Robson NKB (1996) Studies in the genus *Hypericum* L. (Guttiferae): 6. Sections 20. *Myriandra* to 28. *Elodes*. Bull.br.Mus.nat.Hist.Bot. 26(2):110–112.
Hypericum formosum Kunth	12 (24)	Northern America, Southern America	Robson NKB (2006) Studies in the genus *Hypericum* L. (Clusiaceae). 4(3). Section 9. *Hypericum* sensu lato (part 3): subsection 1. *Hypericum* series 2. *Senanensia*, subsection 2. *Erecta* and section 9b. *Graveolentia*. Syst Biodivers 4:19–98.
Hypericum fuertesii Urb.	2 (3)	Southern America	Robson NKB (1987) Studies in the genus *Hypericum* L. (Guttiferae). 7. Section 29. *Brathys* (part 1). Bull.br.Mus.nat.Hist.Bot. 16(1):1–106.
Hypericum galinum S.F. Blake	2 (1)	Northern America	Robson NKB (1987) Studies in the genus *Hypericum* L. (Guttiferae). 7. Section 29. *Brathys* (part 1). Bull.br.Mus.nat.Hist.Bot. 16(1):1–106.

Continued on next page,,,

Appendix 3.1.2

Filing Name (Accepted Name)	Specimens Sampled	Continent	Reference
Hypericum limosum Griseb.	2 (2)	Southern America	Robson NKB (1996) Studies in the genus *Hypericum* L. (Guttiferae): 6. Sections 20. *Myriandra* to 28. *Elodes*. Bull.br.Mus.nat.Hist.Bot. 26(2):110–112.
Hypericum millefolium Urb. & Ekman	2 (2)	Southern America	Robson NKB (1987) Studies in the genus *Hypericum* L. (Guttiferae). 7. Section 29. *Brathys* (part 1). Bull.br.Mus.nat.Hist.Bot. 16(1):1–106.
Hypericum mutilum L.	1 (171)	Northern America	Robson NKB (1990) Studies in the genus *Hypericum* L. (Guttiferae). 8. Sections 29. *Brathys* (part 2) and 30. *Trigynobrathys*. Bull.br.Mus.nat.Hist.Bot. 20(1):1–151.
Hypericum nakamurai (Masam.) N.Robson	2 (2)	Asia Temperate	Robson NKB (1985) Studies in the genus *Hypericum* L. (Guttiferae). 3. Sections 1. *Campylosporus* to 6a. *Umbraculoides*. Bull.br.Mus.nat.Hist.Bot. 12:163–325.
Hypericum nitidum Lam. subsp. *cubense* (Turcz.) N. Robson	18 (16)	Southern America	Robson NKB (1993) Studies in *Hypericum*: validation of new names. Bull.br.Mus.nat.Hist.Bot. 23(2):67–70.
Hypericum perfoliatum L.	2 (2)	Europe, Africa, Asia Temperate	Robson NKB (2010) Studies in the genus *Hypericum* L. (Hypericaceae) 5(1). Sections 10. *Olympia* to 15/16. *Crossophyllum*. Phytotaxa 4:5–126.
Hypericum perforatum L.	17 (196)	Europe, Africa, Asia Temperate	Robson NKB (2002) Studies in the genus *Hypericum* L. (Guttiferae). 4(2). Section 9. *Hypericum* sensu lato (part 2): subsection 1. *Hypericum* series 1. *Hypericum*. Bull.br.Mus.nat.Hist.Bot. 32:61–123.
Hypericum petiolatum L.	1 (1)	Southern America	www.tropicos.org/
Hypericum petiolulatum Hook. f. & Thomson ex Dyer	7 (8)	Asia Temperate, Asia Tropical	Robson NKB (2001) Studies in the genus *Hypericum* L. (Guttiferae). 4(1). Sections 7. *Roscyna* to 9. *Hypericum* sensu lato (part 1). Bull.br.Mus.nat.Hist.Bot. 31:37–88.
Hypericum polycladum Urb. (*Hypericum dichotomum* Lam.)	2 (2)	Southern America	Robson NKB (1987) Studies in the genus *Hypericum* L. (Guttiferae). 7. Section 29. *Brathys* (part 1). Bull.br.Mus.nat.Hist.Bot. 16(1):1–106.
Hypericum polygonifolium Rupr. (*Hypericum linarioides* Bosse)	3 (3)	Asia Temperate, Europe	Robson NKB (2010) Studies in the genus *Hypericum* L. (Hypericaceae) 5(2). Sections 17. *Hirtella* to 19. *Coridium*. Phytotaxa 4:127–258.
Hypericum ponticum Lipsky (*Hypericum lydium* Boiss.)	1 (1)	Asia Temperate	Robson NKB (2010) Studies in the genus *Hypericum* L. (Hypericaceae) 5(2). Sections 17. *Hirtella* to 19. *Coridium*. Phytotaxa 4:127–258.
Hypericum prattii Hemsl.	1 (1)	Asia Temperate	Robson NKB (1985) Studies in the genus *Hypericum* L. (Guttiferae). 3. Sections 1. *Campylosporus* to 6a. *Umbraculoides*. Bull.br.Mus.nat.Hist.Bot. 12:163–325.

Continued on next page,,,

Appendix 3.1.2

Filing Name (Accepted Name)	**Specimens Sampled**	**Continent**	**Reference**
Hypericum przewalskii Maxim.	15 (15)	Asia Temperate	Robson NKB (2001) Studies in the genus *Hypericum* L. (Guttiferae). 4(1). Sections 7. *Roscyna* to 9. *Hypericum* sensu lato (part 1). Bull.br.Mus.nat.Hist.Bot. 31:37–88.
Hypericum pycnophyllum Urb.	5 (6)	Southern America	Robson NKB (1987) Studies in the genus *Hypericum* L. (Guttiferae). 7. Section 29. *Brathys* (part 1). Bull.br.Mus.nat.Hist.Bot. 16(1):1–106.
Hypericum sprucei N. Robson	2 (61)	Southern America	Robson NKB (1987) Studies in the genus *Hypericum* L. (Guttiferae). 7. Section 29. *Brathys* (part 1). Bull.br.Mus.nat.Hist.Bot. 16(1):1–106.
Hypericum stragulum W.P. Adams & N. Robson (*Hypericum hypericoides* subsp. *multicaule* (Michx. ex Willd.) N. Robson)	12 (22)	Northern America	Robson NKB (1996) Studies in the genus *Hypericum* L. (Guttiferae): 6. Sections 20. *Myriandra* to 28. *Elodes*. Bull.br.Mus.nat.Hist.Bot. 26(2):110–112.
Hypericum styphelioides A. Rich.	6 (29)	Southern America	Robson NKB (1987) Studies in the genus *Hypericum* L. (Guttiferae). 7. Section 29. *Brathys* (part 1). Bull.br.Mus.nat.Hist.Bot. 16(1):1–106.

3.1.3 Determination accuracy in *Inga* and *Hypericum*

Determination accuracy (percentage) of (A) *Inga* and (B) *Hypericum* specimens sampled at MO for which all determinations were available. Where the determinations were 'Correct', 'Synonym', 'Other', or 'Indeterminate' (Indet) and the number (N) of extant specimens for a selection of years between 1900 and 2015.

A	**Percentage**				
Year	**Correct**	**Synonym**	**Other**	**Indet**	**N**
1900	25.0	0.0	37.5	37.5	8
1910	25.0	0.0	37.5	37.5	8
1920	21.4	28.6	28.6	21.4	14
1930	22.2	27.8	22.2	27.8	18
1940	22.9	17.1	40.0	20.0	35
1950	27.8	16.7	41.7	13.9	36
1960	36.6	0.0	46.3	17.1	41
1970	24.4	11.0	37.8	26.8	82
1980	21.2	14.7	35.9	28.2	156
1990	44.8	13.2	25.7	16.3	319
2000	71.5	8.3	15.5	4.7	445
2010	95.3	0.0	4.1	0.6	512
2015	95.3	0.0	4.1	0.6	514

B	**Percentage**				
Year	**Correct**	**Synonym**	**Other**	**Indet**	**N**
1900	78.9	0.0	2.6	18.4	38
1910	82.8	0.0	0.0	17.2	58
1920	81.7	0.0	0.0	18.3	71
1930	78.9	2.2	0.0	18.9	90
1940	75.7	3.7	0.0	20.6	107
1950	72.8	3.2	0.0	24.0	125
1960	64.2	7.3	0.0	28.5	151
1970	58.2	7.7	0.0	34.0	194
1980	62.1	8.2	0.0	29.6	243
1990	73.6	5.9	0.0	20.5	303
2000	78.4	2.2	0.0	19.4	356
2010	99.2	0.5	0.0	0.3	371
2015	99.5	0.5	0.0	0.0	372

3.1.4 Comparing names on specimen records of *Aframomum* and *Ipomoea* in GBIF

Numbers and percentage of (A) *Aframomum* and (B) *Ipomoea* names and specimen records in GBIF which are 'Accepted', 'Synonym', 'Excluded' and 'Indeterminate' (specimens only).

	Names		**Specimens**	
A	**N**	**%**	**N**	**%**
Accepted	49	53.8	3,029	67.8
Synonym	39	42.8	580	12.9
Excluded	3	3.3	37	0.8
Indeterminate	-	-	821	18.4
Total	91	-	4,467	-

	Names		**Specimens**	
B	**N**	**%**	**N**	**%**
Accepted	245	43.8	38,004	86.2
Synonym	223	39.8	2,954	6.7
Unknown	5	0.9	40	0.1
Invalid or Error	87	15.5	3,109	7.0
Indeterminate	-	-	5,401	10.9
Total	560	100.0	49,508	-

3.1.5 Comparing determinations on duplicate specimen records of Dipterocarpaceae

Numbers of Dipterocarpaceae specimen records and specimen collections matched with number (and percentage) of specimen collections which had the same or different determination between specimen records from different herbaria.

	N (%)
Total number of Dipterocarpaceae specimens records	58,860
Total number of specimen records matched	21,075

Number of specimen collections	9,222
Number of specimen collections with same determinations	6,542 (70.9%)
Number of specimen collections with different determinations	2,680 (29.1%)

3.2 ACCUMULATION OF SPECIMENS AND HERBARIA OVER TIME

3.2.1 Online data sources

Name, number of records, origin, URL and contact details for databases used to generate Figure 3.3 *A-L*. *dataset ends in 1994; **dataset ends in 1996.

	Number of records				
Database Name	**In total**	**With dates**	**Between 1700 - 2000**	**URL**	**Contact**
3.3A *Aframomum*	3,213	2,961	2,910	Harris & Wortley (In Press)	David.Harris(at)rbge(dot)org(dot)uk
3.3B *Aglaia*	6,363	5,113	5,027	http://herbaria.plants.ox.ac.uk/bol/aglaia Accessed 2015/04/14	Caroline Pannell c(dot)pannell(at)plants(dot)ox(dot)ac(dot)uk
3.3C Conifers of the World	37,000	19,486	19,011	http://herbaria.plants.ox.ac.uk/bol/conifers Accessed 2015/04/14	Aljos Farjon A(dot)Farjon(at)kew(dot)org
3.3D Dipterocarpaceae	43,252	39,521	30,367	N/A	E, KEP, L, MO, SING, SAN, SAR, U, WAG
3.3E *Inga**	9,847	6,393	6,393	http://herbaria.plants.ox.ac.uk/bol/brahms/Samples/Inga Accessed 2015/04/07	Terence Pennington t(dot)pennington(at)kew(dot)org
3.3F *Ipomoea*	108,781	72,765	63,996	http://www.gbif.org/occurrence/search?TAXON_KEY=2928509 Accessed 2014/12/09	See Data CD
3.3G *Leucaena***	2,807	2,724	2,724	http://herbaria.plants.ox.ac.uk/bol/leucaena Accessed 2014/07/21	Colin Hughes colin(dot)hughes(at)systbot(dot)uzh(dot)ch
3.3H Belize	40,248	38,456	31,034	N/A	Zoë Goodwin zoe(dot)goodwin(at)plants(dot)ox(dot)ac(dot)uk
3.3I Gabon	74,400	73,701	57,334	http://herbaria.plants.ox.ac.uk/bol/gabon Accessed 2015/04/14	Jan Wieringa jan(dot)wieringa(at)wur(dot)nl
3.3J Rocky Mountain Herbarium (RM)	820,361	464,804	291,167	http://www.rmh.uwyo.edu Accessed 2015/04/07	Ronald L. Hartman rhartman(at)uwyo(dot)edu

Continued on next page,,,

Appendix 3.2.1

Database Name	Number of records			URL	Contact
	In total	With dates	Between 1700 - 2000		
3.3K SING	169,027	159,510	139,398	http://herbaria.plants.ox.ac.uk/bol/sing Accessed 2015/06/04	Serena Lee Serena_lee(at)nparks(dot)gov(dot)sg
3.3L All plant specimens in GBIF	48,525,291	35,223,949	31,068,510	http://www.gbif.org/occurrence/search?TAXON_KEY=6 Accessed 2015/02/10	See online data

3.2.2 Growth of herbaria across the world

Herbaria foundation dates per continent. Indicating number of herbaria, mean foundation date, standard deviation, percentage of herbaria in each region founded since 1970, percentage of herbaria in each region which are inactive, and percentage of all inactive herbaria in each region (where *N* = 733).

Continent	**Number of herbaria**	**Mean foundation date**	**Standard deviation**	**% of herbaria in each region founded since 1970**	**% of herbaria in each region which are inactive**	**% of inactive herbaria in each region**
Africa	153	1957.1	28.9	33.9%	16.0%	4.2%
Asia	686	1964.5	27.8	47.8%	5.1%	5.3%
Europe	726	1916.2	70.2	24.1%	30.3%	56.9%
North America	829	1943.2	39.2	27.5%	19.4%	27.4%
Oceania	64	1945.6	36.9	26.6%	15.2%	1.6%
South America	288	1967.5	32.1	58.7%	10.2%	4.5%

4 APPENDICES – HOW LONG DOES IT TAKE TO 'KNOW' A SPECIES

4.1 KEY EVENTS IN THE PROCESS OF SPECIES DISCOVERY

The 61 species of *Aframomum* accepted by Harris and Wortley (In Press) (Appendix 2.1). Indicating range size (number of degree squares occupied), range type (widespread, medium or restricted) and Star rating (following Hawthorne and Marshall, 2016), and the years in which the first specimen was collected (1st C), species name published (P), first ten (10), fifteen (15), and twenty (20) specimens and last degree square (Last DS) were collected (C), determined (D) and determined correctly (DC). Total number (N), mean (M), standard deviation (SD) and range are provided.

					10		
Species	**Range size**	**Range (Star)**	**1st C**	**P**	**C**	**D**	**DC**
A. albiflorum	19	Medium (Blue)	1904	1984	1957	1997	1997
A. alboviolaceum	28	Widespread (Green)	1700	1887 (1904)	1905	1937	1975
A. alpinum	6	Restricted (Gold)	1889	1902 (1904)	1988	2014	2014
A. angustifolium	105	Widespread (Green)	N/A	1782 (1904)	1906	1950	1955
A. arundinaceum	7	Restricted (Gold)	1862	1864 (1904)			
A. atewae	1	Restricted (Black)	1968	1974			
A. aulacocarpos	2	Restricted (Black)	1914	1964			
A. chrysanthum	15	Medium (Blue)	1853	1978	1967	1983	1983
A. citratum	12	Medium (Blue)	N/A	1850 (1904)	1987	1973	1994
A. cordifolium	6	Restricted (Gold)	1907	1974			
A. corrorima	13	Medium (Blue)	1847	1848 (1981)	1965	1986	1986
A. daniellii	54	Widespread (Green)	1800	1854 (1904)	1908	1909	1975
A. dhetchuvi	1	Restricted (Black)	1991	2017			
A. elegans	3	Restricted (Gold)	1964	1980			
A. elliotii	4	Restricted (Gold)	1892	1898 (1904)			
A. exscapum	12	Medium (Blue)	1794	1805 (1967)	1965	2014	2014
A. fragrans	7	Restricted (Gold)	1966	2017	1993	2014	2014
A. giganteum	23	Medium (Blue)	1800	1864 (1904)	1912	1976	1979
A. glaucophyllum	19	Medium (Blue)	1889	1893 (1904)	1973	2014	2014

Continued on next page,,,

Appendix 4

Appendix 4.1

					10		
Species	**Range size**	**Range (Star)**	**1^{st} C**	**P**	**C**	**D**	**DC**
A. hirsutum	7	Restricted (Gold)	1919	2017	1985	2014	2014
A. kamerunica	3	Restricted (Gold)	1976	2017	1996	2014	2014
A. kayserianum	5	Restricted (Gold)	1891	1893 (1904)			
A. kodmin	2	Restricted (Black)	1972	2017	1998	2014	2014
A. laxiflorum	3	Restricted (Gold)	1932	1976			
A. leptolepis	8	Restricted (Gold)	1890	1893 (1904)	1976	2014	2014
A. letestuanum	37	Widespread (Green)	1900	1908	1946	1978	1978
A. limbatum	54	Widespread (Green)	1861	1864 (1904)	1951	1988	1988
A. longiligulatum	8	Restricted (Gold)	1900	1965	1995	2014	2014
A. longipetiolatum	4	Restricted (Gold)	1963	1964			
A. longiscapum	6	Restricted (Gold)	1853	1854 (1904)			
A. lutarium	4	Restricted (Gold)	1913	2017	1977	2014	2014
A. luteoalbum	24	Medium (Blue)	1870	1892 (1904)	1939	1995	1995
A. makandensis	4	Restricted (Gold)	1911	1995	1994	2014	2014
A. mala	8	Restricted (Gold)	1893	1895 (1904)			
A. mannii	3	Restricted (Gold)	1862	1864 (1904)			
A. melegueta	56	Widespread (Green)	1792	1827 (1904)	1939	1945	1974
A. mildbraedii	10	Medium (Blue)	1908	1910	1952	1974	1974
A. orientale	3	Restricted (Gold)	1955	1984			
A. parvulum	3	Restricted (Gold)	1909	2017			
A. pilosum	8	Restricted (Gold)	1862	1864 (1904)	1993	1989	1989
A. plicatum	5	Restricted (Gold)	1984	2017	1993	2014	2014
A. polyanthum	36	Widespread (Green)	1870	1893 (1904)	1951	1974	1996
A. pseudostipulare	8	Restricted (Gold)	1910	1964			
A. rostratum	10	Medium (Blue)	1826	1904	1951	2014	2014
A. rotundum	1	Restricted (Black)	1994	2017			
A. scalaris	7	Restricted (Gold)	1952	2017	1995	2014	2014

Continued on next page,,,

Appendix 4

Appendix 4.1

					10		
Species	**Range size**	**Range (Star)**	**1st C**	**P**	**C**	**D**	**DC**
A. sceptrum	55	Widespread (Green)	1863	1864 (1904)	1919	1964	1965
A. sericeum	13	Medium (Blue)	1960	2011	1985	2014	2014
A. singulariflorum	7	Restricted (Gold)	1902	1993	1991	2014	2014
A. spiroligulatum	2	Restricted (Black)	1980	1997			
A. stanfieldii	9	Restricted (Blue)	1902	1968			
A. strobilaceum	14	Medium (Blue)	1700	1802 (1967)	1973	1975	1975
A. submontanum	4	Restricted (Gold)	1914	2017			
A. subsericeum	17	Medium (Blue)	1862	1864 (1904)	1952	1963	1977
A. sulcatum	13	Medium (Blue)	1873	1898 (1904)	1959	1972	1972
A. tchoutoui	4	Restricted (Gold)	1987	2017	1999	2014	2014
A. thonneri	38	Widespread (Green)	1903	1911	1957	2014	2014
A. uniflorum	3	Restricted (Gold)	1914	1997			
A. verrucosum	15	Medium (Blue)	1905	1984	1949	1998	1998
A. wuerthii	1	Restricted (Black)	2003	2006			
A. zambesiacum	28	Widespread (Green)	1887	1898 (1904)	1953	1975	1975
N	**61**		**59**	**61**	**39**	**39**	**39**
M	**14.5**		**1897.7**	**1934.5**	**1963.9**	**1991.1**	**1996.2**
SD	**18.4**		**63.2**	**67.8**	**27.5**	**26.2**	**18.4**
Range	**1 - 105**		**1700 - 2003**	**1782 - 2017**	**1905 - 1999**	**1909 - 2014**	**1955 - 2014**

Continued on next page,,,

Appendix 4

Appendix 4.1

	15			20			Last DS		
Species	**C**	**D**	**DC**	**C**	**D**	**DC**	**C**	**D**	**DC**
A. albiflorum	1964	2008	2008	1973	2008	2008	1975	2010	2010
A. alboviolaceum	1908	1945	1975	1914	1945	1975	1998	2014	2014
A. alpinum							1988	1988	1988
A. angustifolium	1914	1955	1961	1921	1964	1969	1998	2014	2014
A. arundinaceum							1999	2014	2014
A. atewae							1972	1972	1972
A. aulacocarpos							1990	2014	2014
A. chrysanthum	1974	2014	2014	1976	2014	2014	1975	2014	2014
A. citratum	1994	1987	2014	1999	1999	2014	1999	2014	2014
A. cordifolium							1976	2014	2014
A. corrorima	1968	1995	1995	1975	1995	1995	1995	2014	2014
A. daniellii	1921	1950	1979	1946	1956	1980	1999	2014	2014
A. dhetchuvi							1991	2014	2014
A. elegans							1975	2014	2014
A. elliotii							1909	1979	1909
A. exscapum	1992	2014	2014				1992	2014	2014
A. fragrans	1996	2014	2014	1999	2014	2014	1999	2014	2014
A. giganteum	1920	1989	1993	1967	1993	2014	1993	2014	2014
A. glaucophyllum	1979	2014	2014	1985	2014	2014	1993	2014	2014
A. hirsutum							1988	2014	2014
A. kamerunica							1995	2014	2014
A. kayserianum							1988	2014	2014
A. kodmin							1975	2014	2014
A. laxiflorum							1987	1992	1992
A. leptolepis	1984	2014	2014	1986	2014	2014	1993	2014	2014
A. letestuanum	1948	1979	1979	1953	1989	1992	1995	2014	2014
A. limbatum	1965	1989	1991	1974	1991	1996	1998	2014	2014

Continued on next page,,,

Appendix 4

Appendix 4.1

	15			20			Last DS		
Species	**C**	**D**	**DC**	**C**	**D**	**DC**	**C**	**D**	**DC**
A. longiligulatum							1998	2014	2014
A. longipetiolatum							1985	1985	1985
A. longiscapum							1972	1983	1972
A. lutarium	1998	2014	2014				1989	2014	2014
A. luteoalbum	1959	1995	1995	1977	1996	1998	1995	2014	2014
A. makandensis							1994	2014	2014
A. mala									
A. mannii							1990	2009	2009
A. melegueta	1949	1951	1981	1974	1966	1992	1995	2014	2014
A. mildbraedii	1955	1986	1986	1974	1992	1992	1995	1995	1995
A. orientale									
A. parvulum							1948	2014	2014
A. pilosum							1998	2014	2014
A. plicatum	1993	2014	2014	1995	2014	2014	1993	2014	2014
A. polyanthum	1955	1996	2014	1978	2014	2014	1996	2014	2014
A. pseudostipulare							1988	1992	1989
A. rostratum	1959	2014	2014	1975	2014	2014	1977	2014	2014
A. rotundum							1994	2014	2014
A. scalaris							1995	2014	2014
A. sceptrum	1940	1965	1972	1952	1972	1975	1998	2014	2014
A. sericeum	1991	2014	2014	1994	2014	2014	1993	2014	2014
A. singulariflorum							2008	2014	2014
A. spiroligulatum							1994	2010	2010
A. stanfieldii							1973	2014	2014
A. strobilaceum	1974	1995	1995	1989	2010	2010	1974	2010	2010
A. submontanum							1958	2014	2014
A. subsericeum	1968	1975	1997	1977	1977	2014	1996	2014	2014

Continued on next page,,,

Appendix 4.1

	15			20			Last DS		
Species	**C**	**D**	**DC**	**C**	**D**	**DC**	**C**	**D**	**DC**
A. sulcatum	1972	1975	2014	1975	1988	2014	1984	2014	2014
A. tchoutoui							1996	2014	2014
A. thonneri	1960	2014	2014	1977	2014	2014	2009	2014	2014
A. uniflorum							1996	1996	1996
A. verrucosum	1982	2014	2014	1994	2014	2014	1996	2014	2014
A. wuerthii									
A. zambesiacum	1959	1976	1976	1964	1976	1976	1994	2014	2014
N	**29**	**29**	**29**	**27**	**27**	**27**	**58**	**58**	**58**
M	**1963.5**	**1991.9**	**1999.3**	**1972.7**	**1994.7**	**2002.0**	**1988.0**	**2009.5**	**2008.1**
SD	**24.5**	**22.3**	**16.6**	**20.4**	**20.3**	**15.2**	**15.3**	**10.2**	**16.5**
Range	**1908 - 1998**	**1945 - 2014**	**1961 - 2014**	**1914 - 1999**	**1945 - 2014**	**1969 - 2014**	**1909 - 2009**	**1972 - 2014**	**1909 - 2014**

The mean year of publication for all *Aframomum* species excluding *A. angustifolium* and *A. citratum* is 1938.5 (*N* = 59, *SD* = 64.95, range 1802 – 2017). Three species (*A. mala*, *A. orientale* and *A. wuerthii*) had no specimens with a complete determination history and accurate geographic location, thus time lag 3 could not be calculated for these species.
The following tables show the mean dates of the four key events; collection of the first specimen, publication, an accurate conservation assessment and the completion of a comprehensive distribution map. For all species, species with at least 10, 15 or 20 specimens, restricted, medium and widespread species. Key events 3 and 4 occur as specimens are collected (C), determined (D) and determined correctly (DC).

Key Event 1 – First collection

	N	M	SD	Range
All	59	1897.7	63.2	1700 - 2003
10	37	1910.0	44.2	1800 - 1987
15	27	1899.9	43.7	1800 - 1984
20	25	1899.4	45.2	1800 - 1984
Restricted	33	1925.6	41.4	1853 - 1994
Medium	14	1856.5	61.0	1700 - 1960
Widespread	9	1841.8	62.5	1700 - 1903

Key Event 2 – Publication

	N	M	SD	Range
All	61	1934.5	67.8	1782 - 2017
10	39	1920.5	70.6	1782 - 2014
15	29	1900.4	65.1	1782 - 2014
20	27	1899.7	61.1	1782 - 2014
Restricted	33	1968.0	54.6	1854 - 2017
Medium	14	1902.7	63.7	1802 - 2011
Widespread	9	1878.4	26.4	1827 - 1911

Appendix 4.1

Key Event 3 – Accurate conservation assessment

		N	M	SD	Range
10	C	39	1963.9	27.5	1905 - 1999
10	D	39	1991.1	26.2	1909 - 2014
10	**DC**	**39**	**1996.2**	**18.4**	**1955 - 2014**
15	C	29	1963.5	24.5	1908 - 1998
15	D	29	1991.9	22.3	1945 - 2014
15	**DC**	**29**	**1999.3**	**16.6**	**1961 - 2014**
20	C	27	1972.7	20.4	1914 - 1999
20	D	27	1994.7	20.3	1945 - 2014
20	**DC**	**27**	**2002.0**	**15.2**	**1969 - 2014**

Key Event 4 – Comprehensive distribution map

		N	M	SD	Range
All	C	58	1988.0	15.3	1909 - 2009
All	D	58	2009.5	10.2	1972 - 2014
All	**DC**	**58**	**2008.1**	**16.5**	**1909 - 2014**
10	C	39	1992.8	8.1	1974 - 2009
10	D	39	2012.6	5.1	1988 - 2014
10	**DC**	**39**	**2012.6**	**5.1**	**1988 - 2014**
15	C	29	1992.6	8.0	1974 - 2009
15	D	29	2013.1	3.6	1995 - 2014
15	**DC**	**29**	**2013.1**	**3.6**	**1995 - 2014**
20	C	27	1992.8	8.3	1974 - 2009
20	D	27	2013.0	3.7	1995 - 2014
20	**DC**	**27**	**2013.0**	**3.7**	**1995 - 2014**
Restricted	C	33	1984.7	18.1	1909 - 2008
Restricted	D	33	2004.4	20.9	1909 - 2014
Restricted	**DC**	**33**	**2006.9**	**12.5**	**1972 - 2014**
Medium	C	14	1988.1	8.6	1974 - 1996
Medium	D	14	2012.1	4.9	1995 - 2014
Medium	**DC**	**14**	**2012.1**	**4.9**	**1995 - 2014**
Widespread	C	9	1998.0	4.2	1994 - 2009
Widespread	D	9	2014.0	0.0	2014 - 2014
Widespread	**DC**	**9**	**2014.0**	**0.0**	**2014 - 2014**

4.2 TIME LAGS IN THE PROCESS OF SPECIES DISCOVERY

Time Lag 1 between the collection of the first specimen and the publication of the species name for all species, species with at least 10, 15 or 20 specimens, restricted, medium and widespread species.

	N	M	SD	Range
All	59	40.8	40.1	1 - 187
10	37	46.0	42.6	1 - 187
15	27	43.3	45.8	1 - 187
20	25	42.1	45.6	1 - 187
Restricted	33	42. 4	35.1	1 - 108
Medium	14	46.2	40.5	1 - 125
Widespread	9	36. 7	55.6	1 - 187

Time Lag 2 between the collection of the first specimen and the collection (C), determination (D), and correct determination (DC) of the first 10, 15 or 20 specimens. The time lags between the collection and correct determination of 10, 15 and 20 specimens are 32.3, 35.8 and 29.3 years.

		N	M	SD	Range
10	C	39	55.5	31.9	9 - 127
10	D	39	82.6	35.9	27 - 180
10	**DC**	**39**	**87.7**	**38.6**	**27 - 180**
15	C	29	65.0	33.8	9 - 128
15	D	29	93.4	38.6	30 - 189
15	**DC**	**29**	**100.8**	**38.8**	**30 - 193**
20	C	27	74.8	40.8	11 - 167
20	D	27	96.8	40.4	30 - 193
20	**DC**	**27**	**104.1**	**42.8**	**30 - 214**

Appendix 4.2

Time Lag 3 between the collection of the first specimen and the completion of the distribution map for all species, species with at least 10, 15 or 20 specimens, restricted, medium and widespread species as specimens are collected (C), determined (D), and determined correctly (DC).

		N	M	SD	Range
All	C	56	92.8	65.1	0 - 298
All	D	56	113.0	66.1	4 - 314
All	**DC**	**56**	**114.5**	**65.0**	**4 - 314**
10	C	39	81.2	43.3	3 - 199
10	D	39	101.0	41.4	27 - 214
10	**DC**	**39**	**101.0**	**41.4**	**27 - 214**
15	C	29	89.8	42.0	9 - 199
15	D	29	110.2	39.9	30 - 214
15	**DC**	**29**	**110.2**	**39.9**	**30 - 214**
20	C	27	90.2	43.3	9 - 199
20	D	27	110.4	41.2	30 - 214
20	**DC**	**27**	**110.4**	**41.2**	**30 - 214**
Restricted	C	33	35.3	39.6	0 - 137
Restricted	D	33	57.5	39.7	0 - 152
Restricted	**DC**	**33**	**55.0**	**41.1**	**0 - 152**
Medium	C	14	82.5	40.5	33 - 193
Medium	D	14	106.5	38.2	54 - 214
Medium	**DC**	**14**	**106.5**	**38.2**	**54 - 214**
Widespread	C	9	112.7	34.5	80 - 199
Widespread	D	9	128.7	34.3	100 - 214
Widespread	**DC**	**9**	**128.7**	**34.3**	**100 - 214**

5 APPENDICES – NARRATIVES OF SPECIES DISCOVERY AND GEOGRAPHY

5.1 GENERALISED NARRATIVES OF SPECIES DISCOVERY

5.1.1 Variables in the narratives of species discovery

The 61 species of *Aframomum* accepted by Harris & Wortley (In Press) by category of narrative of species discovery. Indicating the values and range for each variable of species discovery and a brief description narrative of the species discovery for the species: Number of degree squares occupied (DS), first specimen collection date (Coll), publication date (Pub), proportion of incorrect determinations (Incorr dets). Variables and categories defined in Table 5.1.

Appendix 5.1.1.1 Widespread species

Species	**DS**	**Range**	**Coll**	**Range**	**Pub**	**Range**	**Incorr dets**	**General narrative**
A. alboviolaceum	143	Widespread	1700	Early	1887	Early	Low but effective	Early widespread, incorrect determinations more of a problem pre-1970, most correct determinations 1970+, incorrect determinations add incorrect locations.
A. angustifolium	105	Widespread	1800	Early	1782	Early	Low but effective	Early widespread, always a few incorrect determinations adding extra locations.
A. daniellii	54	Widespread	1800	Early	1854	Early	Low but effective	Early widespread, but most specimens only determined recently, small number of incorrect determinations cause huge incorrect geographical range.
A. luteoalbum	24	Medium	1870	Early	1892	Early	Low but effective	Early widespread, few incorrect determinations massively increases geographical range incorrectly
A. melegueta	56	Widespread	1792	Early	1827	Early	High	Early widespread, huge numbers of incorrect determinations, large incorrect geographical range
A. polyanthum	36	Widespread	1870	Early	1893	Early	Low but effective	Early widespread, few incorrect determinations cause some incorrect geography, most specimens not correctly Determined until Harris & Wortley.
A. sceptrum	55	Widespread	1863	Early	1864	Early	High	Early widespread, large numbers of incorrect determinations through all time cause large incorrect geography (degree squares only)

Continued on next page,,,

Appendix 5.1.1.1 Widespread species

Species	DS	Range	Coll	Range	Pub	Range	Incorr dets	General narrative
A. zambesiacum	28	Widespread	1887	Early	1898	Early	Low but effective	Early widespread, most specimens not recognised, but only small level of incorrect determinations (incorrect geography)

Appendix 5.1.1.2 Recently published, restricted species

Species	DS	Range	Coll	Range	Pub	Range	Incorr dets	General narrative
A. atewae	1	Restricted	1968	Recent	1972	Recent	None	Rare species discovered only recently - probably genuinely rare, no incorrect determinations, very few specimens
A. chrysanthum	15	Medium	1853	Early	1978	Recent	None	Recently discovered but common and first collected early (discovery lag > mean), long lag to disc geography
A. cordifolium	6	Restricted	1907	Medium	1974	Recent	None	Rare species discovered only recently - probably genuinely rare, most of range only discovered recently
A. dhetchuvi	1	Restricted	1991	Recent	2017	Recent	None	Rare species discovered only recently - probably genuinely rare collected during recent ramp up of collecting
A. elegans	3	Restricted	1964	Recent	1980	Recent	None	Rare species discovered only recently - probably genuinely rare collected during recent ramp up of collecting
A. fragrans	7	Restricted	1966	Recent	2017	Recent	None	Recently discovered but common and first collected early (discovery lag > mean)
A. hirsutum	7	Restricted	1919	Medium	2017	Recent	None	Rare species discovered only recently - probably genuinely rare but first collected long ago
A. kamerunica	3	Restricted	1976	Recent	2017	Recent	None	Rare species discovered only recently - probably genuinely rare collected during recent ramp up of collecting
A. kodmin	2	Restricted	1972	Recent	2017	Recent	None	Rare species discovered only recently - probably genuinely rare collected during recent ramp up of collecting
A. laxiflorum	3	Restricted	1932	Medium	1976	Recent	None	Rare species discovered only recently - probably genuinely rare, specimens determined quickly
A. longiligulatum	8	Restricted	1900	Medium	1965	Recent	Low	Recently discovered but common and first collected early (discovery lag > mean), few incorrect determinations, only really detted recently
A. longipetiolatum	4	Restricted	1963	Recent	1964	Recent	None	Rare species discovered only recently - probably genuinely rare, quick idents, no incorrect determinations

Continued on next page,,,

Appendix 5.1.1.2 Recently published, restricted species

Species	**DS**	**Range**	**Coll**	**Range**	**Pub**	**Range**	**Incorr dets**	**General narrative**
A. lutarium	4	Restricted	1913	Medium	2017	Recent	None	Rare species discovered only recently - probably genuinely rare but first collected long ago
A. makandensis	4	Restricted	1911	Medium	1995	Recent	None	Rare species discovered only recently - probably genuinely rare, gradual disc, no incorrect determinations
A. orientale	3	Restricted	1955	Recent	1984	Recent	None	Rare species discovered only recently - probably genuinely rare but first collected long ago
A. parvulum	3	Restricted	1909	Medium	2017	Recent	None	Rare species discovered only recently - probably genuinely rare but first collected long ago
A. plicatum	5	Restricted	1984	Recent	2017	Recent	None	Rare species discovered only recently - probably genuinely rare collected during recent ramp up of collecting
A. rotundum	1	Restricted	1994	Recent	2017	Recent	None	Rare species discovered only recently - probably genuinely rare collected during recent ramp up of collecting
A. scalaris	7	Restricted	1952	Recent	2017	Recent	None	Rare species discovered only recently - probably genuinely rare but first collected long ago
A. sericeum	13	Medium	1960	Recent	2011	Recent	None	Rare species discovered only recently - probably genuinely rare but first collected long ago
A. singulariflorum	7	Restricted	1902	Medium	1993	Recent	None	Rare species discovered only recently - probably genuinely rare but first collected long ago, only Determined by authors and Harris & Wortley.
A. spiroligulatum	2	Restricted	1980	Recent	1997	Recent	None	Rare species discovered only recently - probably genuinely rare collected during recent ramp up of collecting, only Determined by authors and Harris & Wortley.
A. submontanum	4	Restricted	1914	Medium	2017	Recent	None	Rare species discovered only recently - probably genuinely rare but first collected long ago
A. tchoutoui	4	Restricted	1987	Recent	2017	Recent	None	Rare species discovered only recently - probably genuinely rare collected during recent ramp up of collecting
A. uniflorum	3	Restricted	1914	Medium	1997	Recent	None	Rare species discovered only recently - probably genuinely rare but first collected long ago
A. verrucosum	15	Medium	1905	Medium	1984	Recent	None	Recently discovered but common and first collected early (discovery lag > mean)

Continued on next page,,,

Appendix 5.1.1.2 Recently published, restricted species

Species	DS	Range	Coll	Range	Pub	Range	Incorr dets	General narrative
A. wuerthii	0	Restricted	2003	Recent	2006	Recent	None	Rare species discovered only recently - probably genuinely rare but first collected long ago, only Determined by authors and Harris & Wortley.

Appendix 5.1.1.3 Old, restricted, and misunderstood species – Type 1

Species	DS	Range	Coll	Range	Pub	Range	Incorr dets	General narrative
A. arundinaceum	7	Restricted	1862	Early	1864	Early	High	Medium Range, discovered early & quickly, large proportion of incorrect determinations adds many countries & degree squares incorrectly
A. citratum	12	Medium	1890	Early	1850	Early	High	Medium Range, discovered early, large proportion of incorrect determinations greatly increase geographical range incorrectly
A. elliotii	4	Restricted	1892	Early	1898	Early	High	Restricted but discovered early & recognised quickly after collection (discovery lag << mean), lots of incorrect determinations later cause huge false range
A. exscapum	12	Medium	1794	Early	1805	Early	Low but effective	Medium Range, discovered early & quickly, small incorrect determinations, small incorrect geographical range
A. giganteum	23	Medium	1800	Early	1864	Early	Low	Medium Range, discovered early & but slowly, small incorrect determinations
A. kayserianum	5	Restricted	1891	Early	1892	Early	None	Restricted but discovered early & recognised quickly after collection (discovery lag << mean), small number of incorrect determinations
A. leptolepis	8	Restricted	1890	Medium	1893	Early	Low but effective	Medium Range, discovered early, few early incorrect determinations massively increases geographical range incorrectly
A. longiscapum	6	Restricted	1853	Early	1854	Early	High	Restricted but discovered early & recognised quickly after collection (discovery lag << mean), high proportion of incorrect determinations causes massive incorrect geographical range
A. mala	8	Restricted	1893	Early	1895	Early	None	Restricted but discovered early & recognised quickly after collection (discovery lag << mean)

Continued on next page,,,

Appendix 5.1.1.3 Old, restricted, and misunderstood species – Type 1

Species	DS	Range	Coll	Range	Pub	Range	Incorr dets	General narrative
A. pilosum	8	Restricted	1862	Early	1864	Early	Low but effective	Medium Range, discovered early & quickly, few incorrect determinations cause sig incorrect geography
A. strobilaceum	14	Medium	1700	Early	1802	Early	Low but effective	Medium Range, discovered early & but slowly, few incorrect determinations cause incorrect geography
A. subsericeum	17	Medium	1862	Early	1864	Early	High	Medium Range, discovered early & quickly, large proportion of incorrect determinations adds many countries & degree squares incorrectly
A. sulcatum	13	Medium	1873	Early	1898	Early	High	Medium Range, discovered early & quickly, large proportion of incorrect determinations adds many countries & degree squares incorrectly

Appendix 5.1.1.4 Old, restricted, and misunderstood species – Type 2

Species	DS	Range	Coll	Range	Pub	Range	Incorr dets	General narrative
A. corrorima	13	Medium	1847	Early	1848	Early	None	Medium Range, discovered early & quickly, but most of geography only discovered very recently
A. glaucophyllum	19	Medium	1889	Early	1893	Early	None	Medium Range, discovered early & quickly, however all specimens in subset incorrectly determined until Harris & Wortley so specimens & geographical range not known before. (subsericeum & leptolepis (both incorrectly determined) or subser species glauco (syn))
A. letestuanum	37	Widespread	1900	Medium	1908	Medium	Low	Early widespread? Gradually Determined, few incorrect determinations.
A. limbatum	54	Widespread	1861	Early	1864	Early	Low	Early widespread Gradually Determined, few incorrect determinations.
A. mannii	3	Restricted	1862	Early	1864	Early	None	Restricted but discovered early & recognised quickly after collection (discovery lag << mean), but specimens Determined late
A. rostratum	10	Medium	1826	Early	1904	Medium	None	Recently discovered but common and first collected early (discovery lag > mean), no incorrect determinations, good determinations only by Harris & Wortley.

Continued on next page,,,

Appendix 5.1.1.4 Old, restricted, and misunderstood species – Type 2

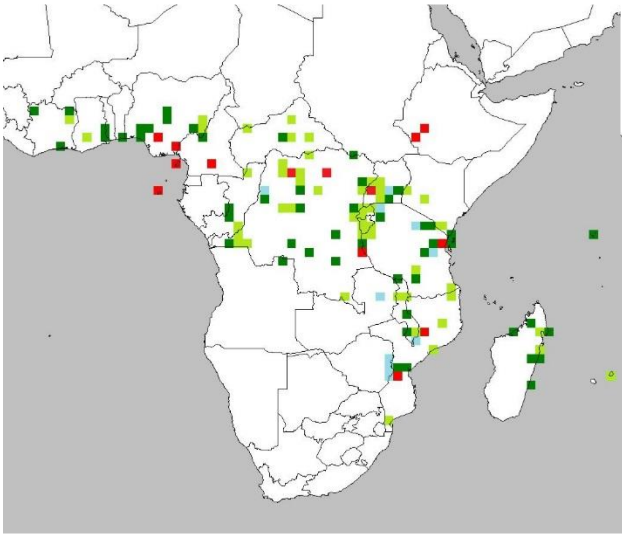
Species	**DS**	**Range**	**Coll**	**Range**	**Pub**	**Range**	**Incorr dets**	**General narrative**
A. thonneri	38	Widespread	1903	Medium	1911	Medium	None	Described early but only recently recognised as widespread (name rarely used until Harris & Wortley!)

Appendix 5.1.1.5 Recently published, restricted, and misunderstood species

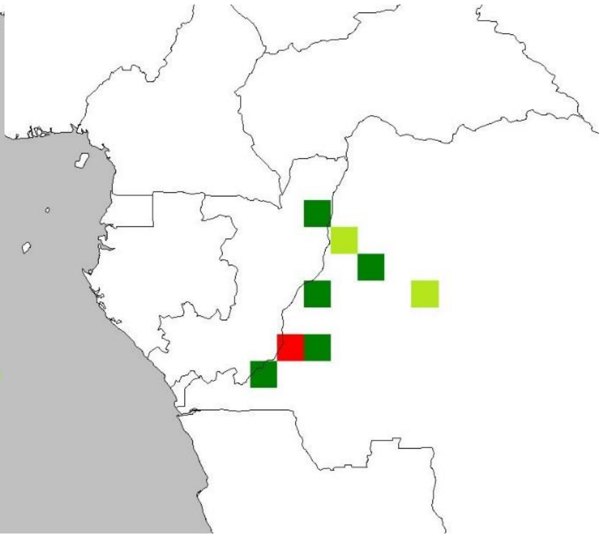
Species	**DS**	**Range**	**Coll**	**Range**	**Pub**	**Range**	**Incorr dets**	**General narrative**
A. albiflorum	19	Medium	1904	Medium	1985	Recent	Low but effective	Recently discovered but common and first collected early (discovery lag > mean), low levels of incorrect determinations add extra specimens & 2 extra degree squares, lag in publication of species causes large lag in discovery of geography
A. alpinum	6	Restricted	1889	Early	1902	Medium	Low but effective	Restricted but discovered early & recognised quickly after collection (discovery lag << mean), small number of incorrect determinations greatly increased geography incorrectly.
A. aulacocarpos	2	Restricted	1914	Medium	1964	Recent	Low but effective	Rare species discovered only recently - probably genuinely rare, incorrect determinations incorrectly increase geographical range
A. mildbraedii	10	Medium	1908	Medium	1910	Medium	Low but effective	Medium Range, discovered early & quickly, small incorrect determinations, small incorrect geographical range
A. pseudostipulare	8	Restricted	1910	Medium	1964	Recent	Low but effective	Rare species discovered only recently - probably genuinely rare but first collected long ago, small incorrect determinations cause proportion large incorrect geography
A. stanfieldii	9	Restricted	1902	Medium	1968	Recent	Low but effective	Recently discovered but common and first collected early (discovery lag > mean), few incorrect determinations cause proportion large incorrect geography

5.1.2 Discovery of degree squares over time

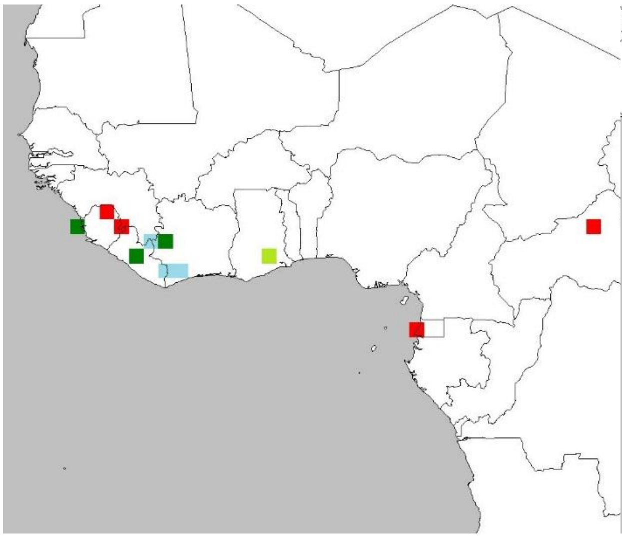
Degree squares determined correctly pre-1970 (pale blue), degree squares determined correctly between 1970 and 2013 (pale green), degree squares determined correctly in 2014 (dark green), and incorrectly determined degree squares (red). For the examples of each category of species discovery narrative: (A) *A. angustifolium*, (B) *A. singulariflorum*, (C) *A. longiscapum*, (D) *A. thonneri* and (E) *A. alpinum*.



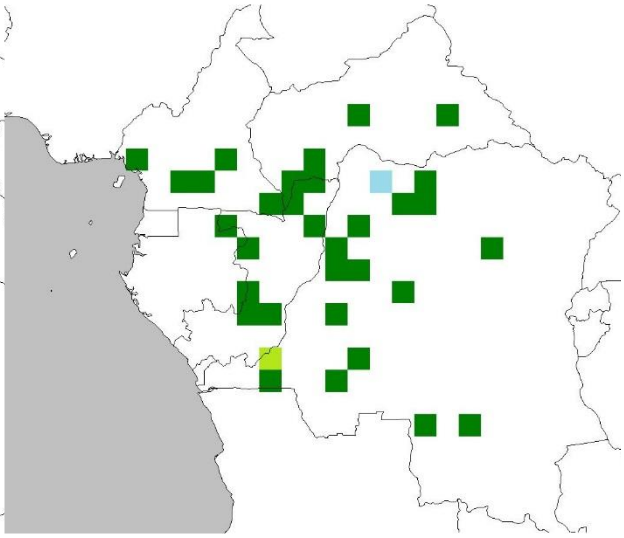
A



B



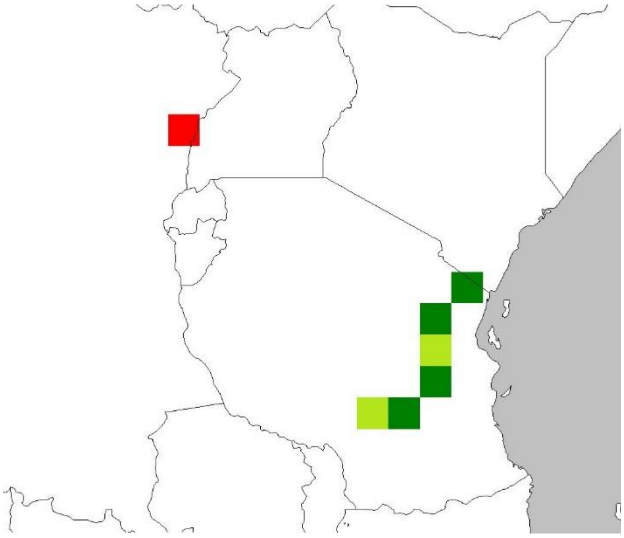
C



D

Continued on next page,,,

Appendix 5.1.2



E

5.2 REPRESENTATIVE SAMPLING

5.2.1 Methods and materials

Here I present a comparison of the complete set of specimens with the subset of specimens for which there is a complete determination history.
The determination data were recorded for specimens from each species, including species name, date and name of the author of the determination on each specimen. The scientific names given in all determinations were then classified as either 'correct', 'synonym', 'indeterminate' or 'other' relative to the determination in the current monograph (Harris and Wortley, In Press). Basionyms of accepted *Aframomum* names were classified as 'correct'.
The specimen and determination data were filtered to include only specimens for which both A) the year of collection and B) the year of every determination are recorded.
The accumulation of collections were plotted over time for all of the specimens cited in Harris and Wortley (In Press) and for the subset of those specimens for which the entire determination history is known for each species. For both sets of specimens the Kew GeoCAT online tool was used to calculate the Extent of Occupancy (EOO), Area of Occupancy (AOO, using a 2 x 2 km^2 grid) and preliminary IUCN Red List assessments. Distribution maps for each species were drawn in Google Earth, from the EOO and AOO polygons generated using GeoCAT.

5.2.2 *Aframomum angustifolium*

The geographical ranges of each set of specimens are similar but not identical.
Harris and Wortley (In Press) obtained 261 collections of *A. angustifolium*, these collections result in 246 mappable points (5.2.4, 1.A) and are from 23 countries and 112 degree square cells across tropical Africa from Ivory Coast to Mozambique and including Madagascar, Mauritius and the Seychelles. These collections provide an EOO of >15,300,000 km^2 and an AOO of 788 km^2, which gives the species an IUCN Red List conservation assessment category of Least Concern and Vulnerable respectively.
For this study, 218 specimens were included (i.e. specimens of which the full determination history was available), the first specimen in the data set studied here was collected in 1870.

These specimens include 150 mappable points and are from 20 countries and 72 degree square cells across tropical Africa (Gabon, Seychelles and Togo are missing) (5.2.4, 1.B). This subset of specimens gives *A. angustifolium* an EOO of >12,700,000 km^2 and an AOO of 476 km^2; this gives *A. angustifolium* an IUCN Red List conservation assessment category of Least Concern and Endangered respectively.
The subset of specimens analysed here is mainly missing specimens from within the extent of the known geographical range, hence the EOO of the subset still far exceeds 10,000,000 km^2. Most of the loss in EOO, ~1,600,000 km^2, is over ocean due to the absence of the Seychelles in the subset. This loss in EOO does not affect the least concern status of the species. The AOO in the subset does not exceed 500km^2 hence an IUCN Red List conservation assessment of Endangered instead of Vulnerable, this should not matter too much as this is measure is more of a reflection of sample size. However it should be noted that most otherwise widespread species do not achieve Vulnerable status in AOO because this requires a minimum of 125 collections in different grid cells.
The history of specimen collection in the full data set and the subset analysed here are very similar (5.2.4, 1.C); both data sets include very few specimens prior to 1900, an increase in the number of specimens into the twentieth century and which escalates in the second half of the century. Both sets of specimens show the same historical plateaus and sudden surges in specimen collection.
In summary, the subset of specimens with complete determination history is comparable to the complete set of specimens. Although the subset is missing a number of specimens and thus some geographical range, this does not overly change our understanding of the species; a widespread species which shows a gradual accumulation of specimens over time.

5.2.3 *Aframomum singulariflorum*

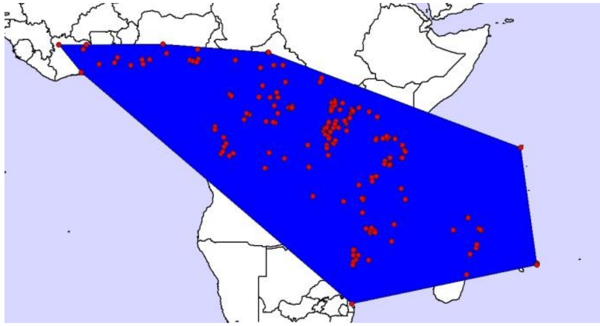
Harris and Wortley (In Press) obtained 19 specimens of *A. singulariflorum*, these specimens give 19 mappable points (5.2.4, 2.A) and are from seven degree square cells and two countries in central Africa; Democratic Republic of Congo and Congo (Brazzaville). The species has an EOO of >186,700 km^2 and an AOO of 44 km^2, which would give the species an IUCN Red List assessment category of Least Concern and Endangered respectively.
For this study, 11 specimens were included (i.e. specimens of which the full determination history was available), the first specimen in the data set studied here was collected in 1902. These specimens include 11 mappable points and are from five degree square cells across the Democratic Republic of Congo and Congo (5.2.4, 2.B). This subset of specimens gives an EOO of >186,700 km2 and an AOO of 28 km2 which would give *A. singulariflorum* an IUCN Red List assessment category of Least Concern and Endangered respectively.

5.2.4 Comparison of the full set and the subset of specimen distributions and collection history.

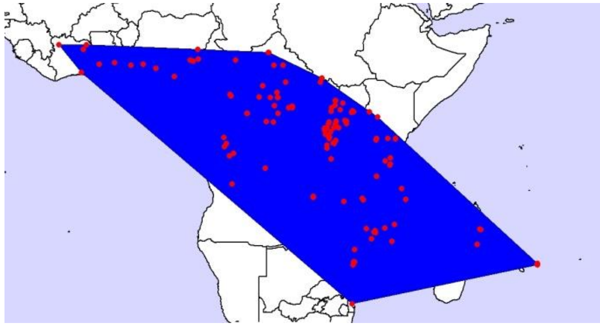
Comparison of the full set (A) and the subset (B) of *A. angustifolium* (1) and *A. singulariflorum* (2) specimen distributions and collection history (C). (A) The complete geographical distribution (individual specimen locations = yellow markers and extent of occupancy = blue polygon) of all known specimens and (B) the subset of specimens available for use in this study. (C) The accumulation of all known specimens (black) and the subset of specimens available for use in this study (green) from 1800 to 2015.

Continued on next page,,,

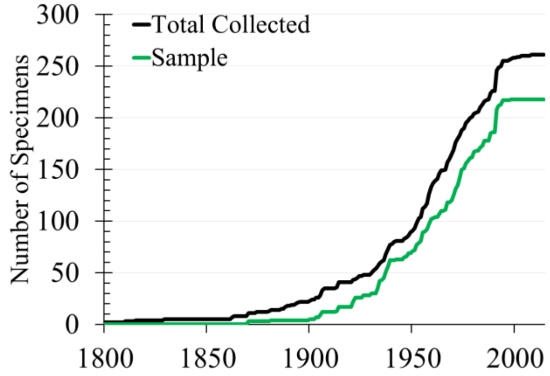
Appendix 5.2.4



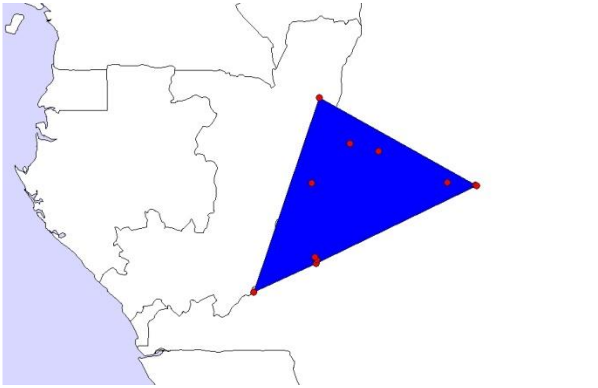
1.A



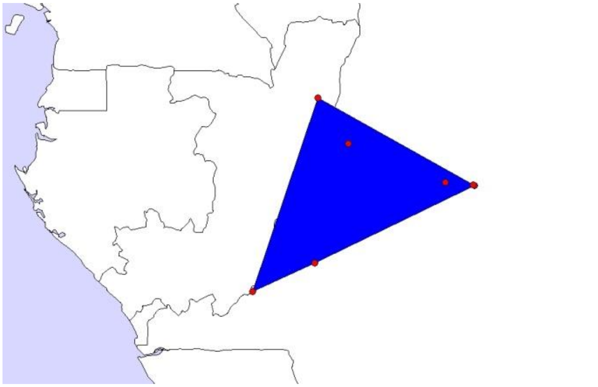
1.B



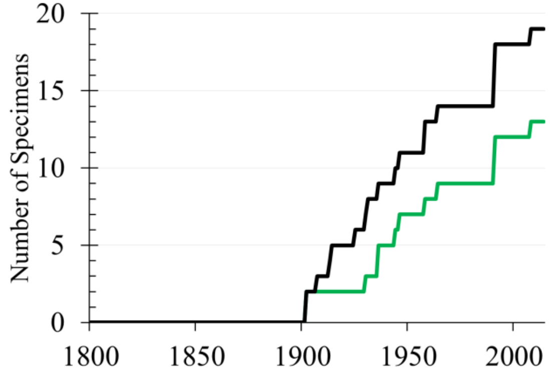
1.C



2.A



2.B



2.C

5.3 *AFRAMOMUM ANGUSTIFOLIUM*

5.3.1 When a degree square cell is discovered for *A. angustifolium*.

The year that the first specimen is collected (C), determined (D), and determined correctly (DC) in each degree square cell, and the time lags between the collection and determination (C-D) or correct determination (C-DC) in each degree square cell. The number of records, mean range are also presented.

	Year			Lag	
	Collected (C)	**Determined (D)**	**Determined Correctly (DC)**	**C-D**	**C-DC**
NE018	1930	1936	1976	6	46
NE022	1988	2014	2014	26	26
NE024	1934	1976	1976	42	42
NE029	1914	1975	1975	61	61
NE031	1994	1995	1995	1	1
NE032	1914	1939	1939	25	25
NE034	1974	1994	1994	20	20
NE122	1906	1992	1992	86	86
NE130	1991	1993	1993	2	2
NE131	1906	1974	1974	68	68
NE216	1988	1989	1989	1	1
NE220	1903	1976	1976	73	73
NE221	-	1992	-	-	-
NE222	1913	1975	1975	62	62
NE320	1955	1974	1974	19	19
ne423	1935	1992	1992	57	57
NE428	1870	2014	2014	144	144
NE58	-	1992	-	-	-
NE60	1958	2014	2014	56	56
NE62	1903	2014	2014	111	111
NE621	1921	1979	1979	58	58
NE623	1921	1979	1979	58	58
NE64	1963	2014	2014	51	51
NE66	-	1986	-	-	-
NE710	1978	2014	2014	36	36
NE711	1971	1980	1980	9	9
NE716	1983	1986	1986	3	3
NE736	-	1972	-	-	-
NE811	1976	1980	1980	4	4
NE821	1983	1986	1986	3	3
NW54	1975	2014	2014	39	39
NW61	1974	1986	1986	12	12
NW83	1967	1986	1986	19	19
NW93	1947	2014	2014	67	67
NW97	1973	2014	2014	41	41
SE031	1998	1998	1998	0	0
SE036	1922	1975	1975	53	53

Continued on next page,,,

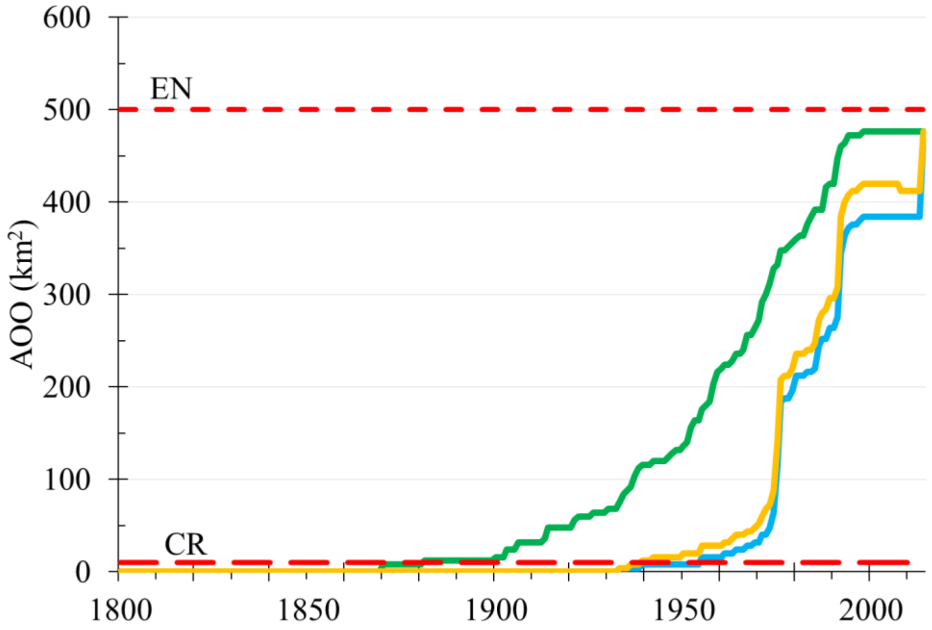
Appendix 5

Appendix 5.3.1

	Year			Lag	
	Collected (C)	**Determined (D)**	**Determined Correctly (DC)**	**C-D**	**C-DC**
SE1039	1934	1974	1974	40	40
SE1127	1959	1992	1992	33	33
SE1131	1955	1955	1955	0	0
SE1133	1973	1972	1973	-1	0
SE1134	1976	1976	1976	0	0
SE1139	1964	1975	1975	11	11
SE120	1991	1991	1991	0	0
SE121	1991	1991	1991	0	0
SE129	1914	1975	1975	61	61
SE130	1952	1975	1975	23	23
SE131	1974	1950	1980	-24	6
SE1438	1967	1975	1975	8	8
SE1534	1881	2014	2014	133	133
SE1535	1983	1983	1983	0	0
SE1536	-	1942	-	-	-
SE1549	1992	1992	1992	0	0
SE1635	1942	1963	1997	21	55
SE1737	1967	1975	1975	8	8
SE1749	1992	1992	1992	0	0
SE1832	1969	1969	1969	0	0
SE1932	1964	1964	1964	0	0
SE2032	1955	1955	1955	0	0
SE2057	1973	1973	1973	0	0
SE228	1950	1976	1976	26	26
SE229	1900	1987	1987	87	87
SE2532	1981	1994	1994	13	13
SE315	1991	1992	1992	1	1
SE329	1966	1975	1975	9	9
SE330	1952	1992	1992	40	40
SE335	1960	1961	1961	1	1
SE337	1993	2014	2014	21	21
N	**72**	**78**	**72**	**72**	**72**
Mean	**1955.6**	**1983.2**	**1985.1**	**28.0**	**29.4**
SD	**29.7**	**18.8**	**17.4**	**32.9**	**32.5**
Range	**1870 - 1998**	**1933 - 2014**	**1933 - 2014**	**-24 - 144**	**0 - 144**

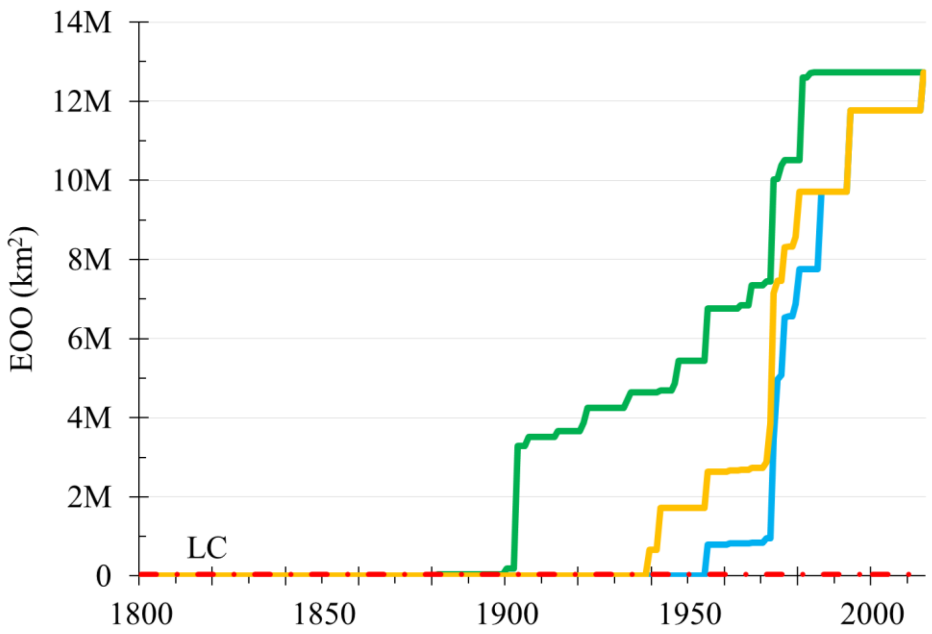
5.3.2 The discovery of AOO for *A. angustifolium*

The accumulation of area of occupancy (AOO, km^2) for *A. angustifolium* as specimens were collected (green), determined (orange) or determined correctly (blue) between 1800 and 2014, *N* = 476 km^2 in 2014. Red dash lines indicate IUCN Red List threshholds for EN & CR.



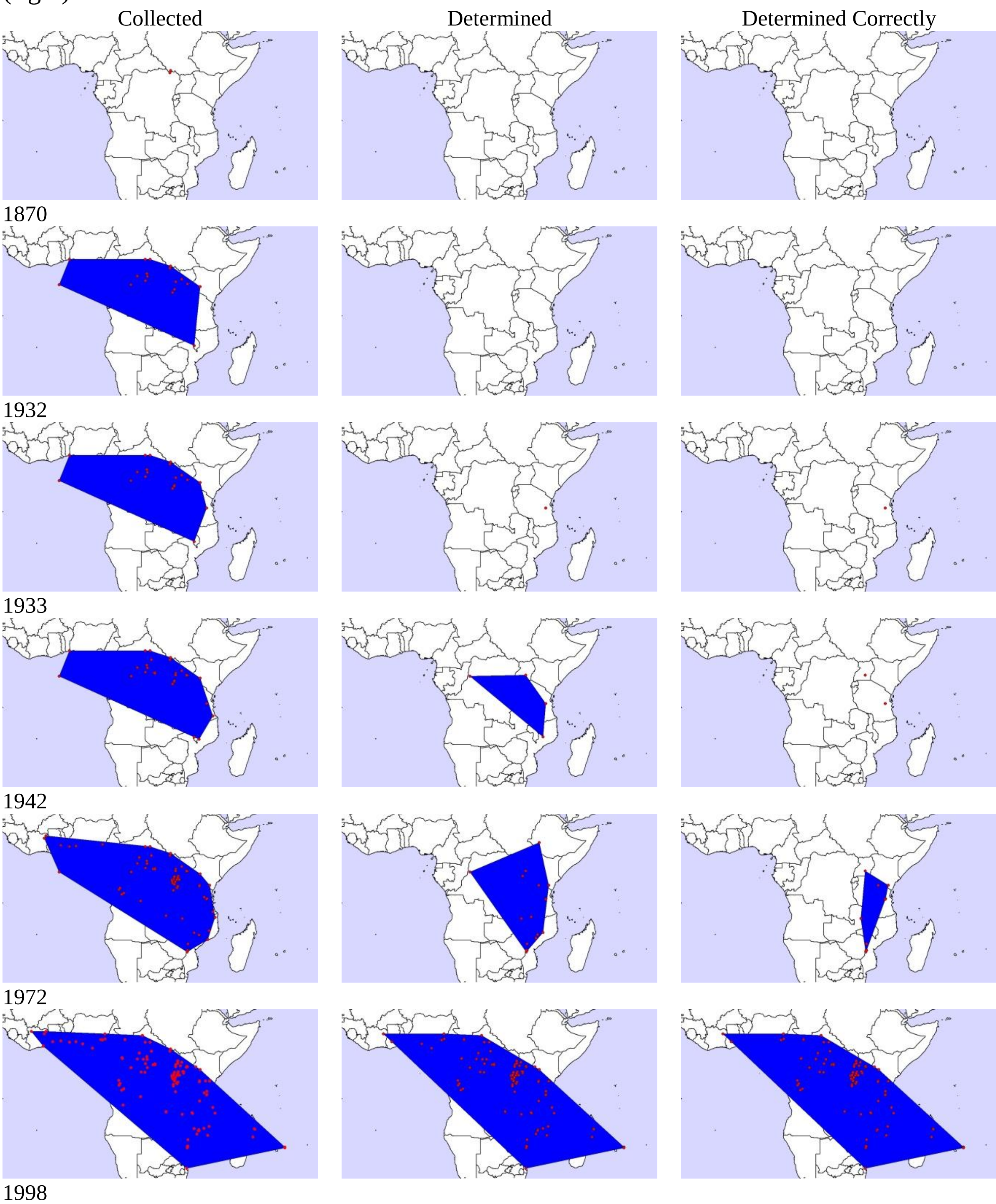
5.3.3 The discovery of EOO for *A. angustifolium*

The accumulation of extent of occupancy (EOO, km^2) for *A. angustifolium* as specimens were collected (green), determined (orange) or determined correctly (blue) between 1800 and 2014, *N* = 12,722,864 km^2 in 2014. Red dash line indicates IUCN Red List threshhold for LC.



5.3.4 *Aframomum angustifolium* EOO maps and localities over time

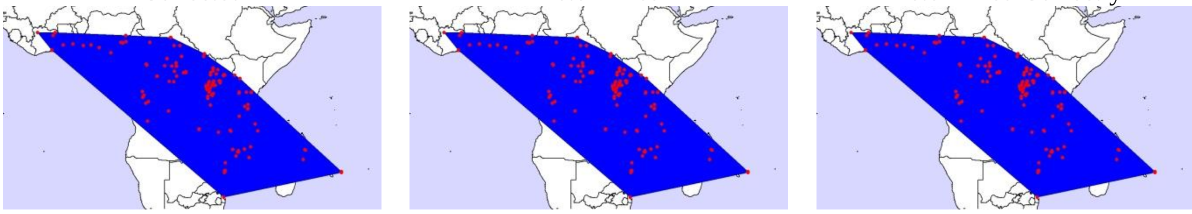
Extent of occupancy (blue polygon) and individual data points (yellow markers) for *A. angustifolium* across a selection of dates between the collection of the first specimen in 1870 and 2014 as specimens were collected (left), determined (centre), and determined correctly (right).



Continued on next page,,,

Appendix 5.3.4

Collected Determined Determined Correctly



2014

5.4 *AFRAMOMUM SINGULARIFLORUM*

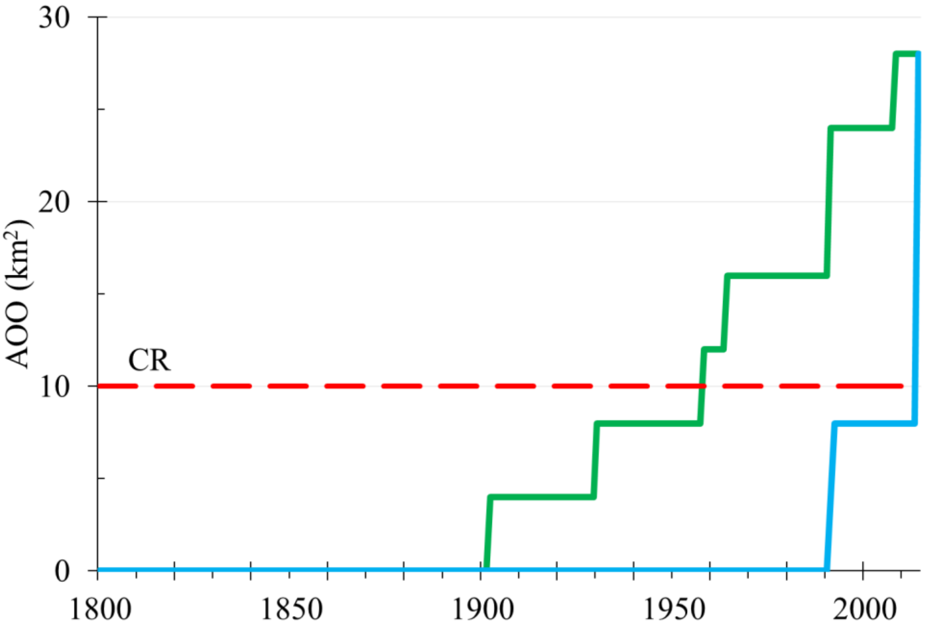
5.4.1 When a degree square cell is discovered for *A. singulariflorum*.

The year that the first specimen is collected (C), determined (D), and determined correctly (DC) in each degree square cell, and the time lags between the collection and determination (C-D) or correct determination (C-DC) in each degree square cell. The number of records, mean range are also presented.

	Year			Lag	
	Collected (C)	**Determined (D)**	**Determined Correctly (DC)**	**C-D**	**C-DC**
NE018	1930	1992	1992	62	62
NE117	2008	2014	2014	6	6
SE121	1958	1991	1991	33	33
SE317	1902	2014	2014	112	112
SE415	1964	2014	2014	50	50
N	**5**	**5**	**5**	**5**	**5**
Mean	**1952.4**	**2005**	**2005**	**52.6**	**52.6**
SD	**35.5**	**11.0**	**11.0**	**35.2**	**35.2**
Range	**1902 - 2008**	**1991 - 2014**	**1991 - 2014**	**6 - 112**	**6 - 112**

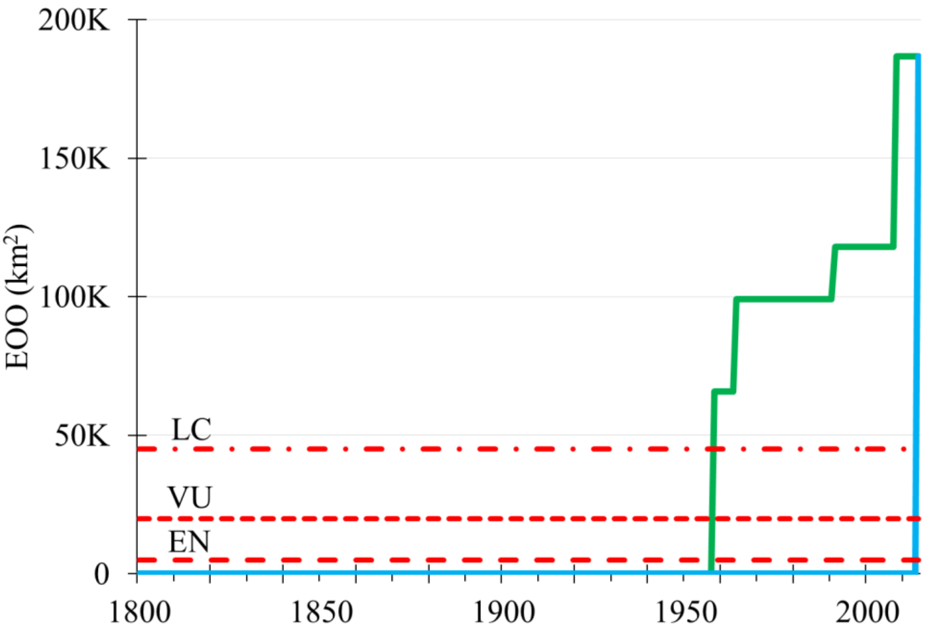
5.4.2 The discovery of AOO for *A. singulariflorum*

The accumulation of area of occupancy (AOO, km^2) for *A. singulariflorum* as specimens were collected (green), determined (orange) or determined correctly (blue) between 1800 and 2014, N = 28 km^2 in 2014. Red dash line indicates IUCN Red List threshhold for CR.



5.4.3 The discovery of EOO for *A. singulariflorum*

The accumulation of extent of occupancy (EOO, km^2) for *A. singulariflorum* as specimens were collected (green), determined (orange) or determined correctly (blue) between 1800 and 2014, N = 186,744 km^2 in 2014. Red dash lines indicate IUCN Red List threshholds for LC, VU & EN.



5.4.4 *Aframomum singulariflorum* EOO maps and localities over time

Extent of occupancy (blue polygon) and individual data points (yellow markers) for *A. singulariflorum* across a selection of dates between the collection of the first specimen in 1902 and 2014. As specimens are collected (left), determined (centre), and determined correctly (right).