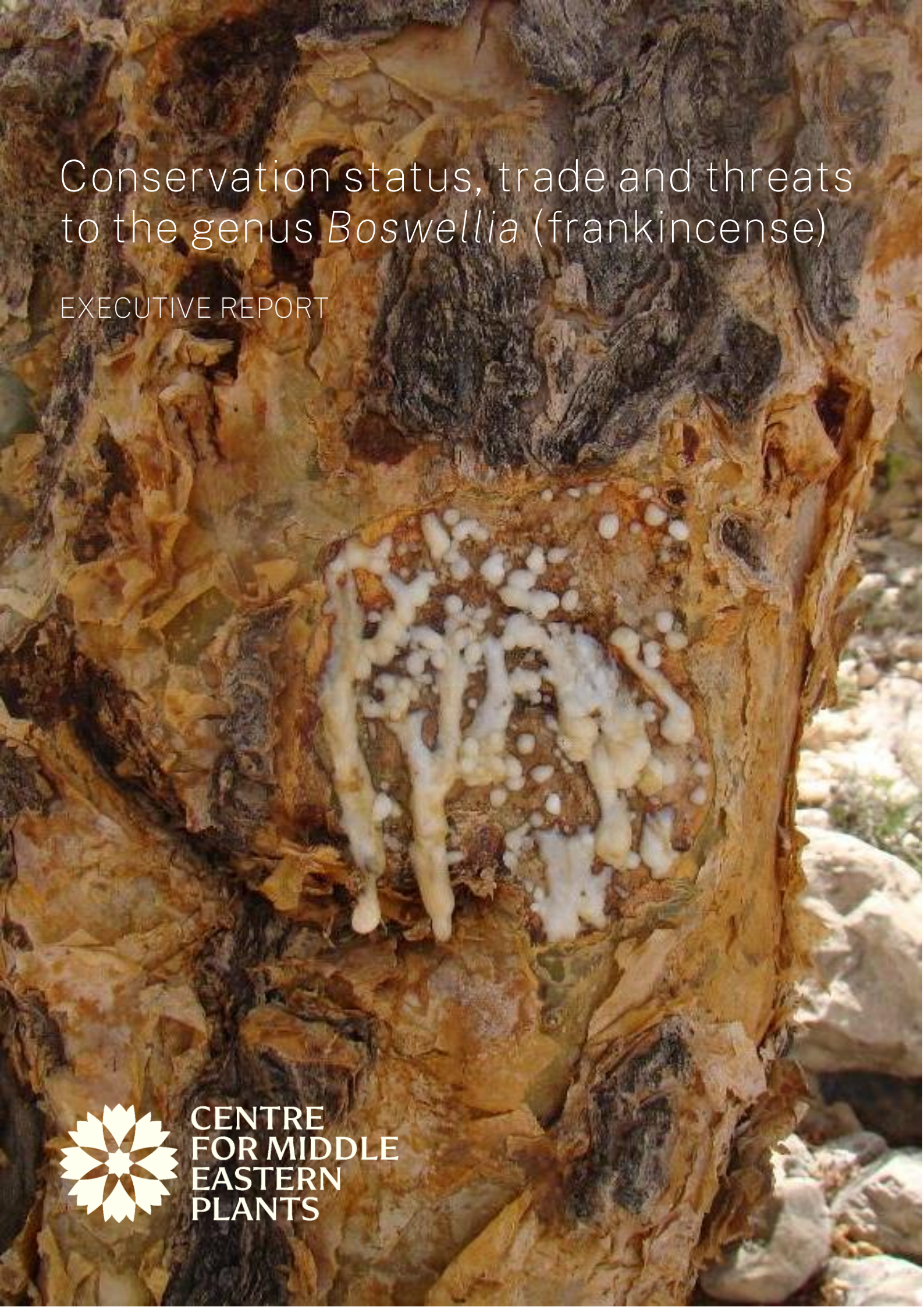
Conservation status, trade and threats to the genus *Boswellia* (frankincense)

EXECUTIVE REPORT



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Cover image: *Boswellia sacra* resin in Hadramout, Yemen. Photo credit: Omer Baeshan, Environment Protection Authority, Yemen.

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Federal Department of Home Affairs FDHA
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International Affairs

Species Conservation in international Trade

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Introduction

Due to increasing concerns in the international and sustainable trade community, a report into potential over-harvesting of frankincense (*Boswellia* spp., Burseraceae) was commissioned in 2016. This report, coupled with a series of subsequent academic publications, made it clear that concern about over-harvesting fuelled by the global trade in resins and essential oils was warranted, and that Listing *Boswellia* species on CITES Appendix II required consideration.

A review of available literature on *Boswellia* revealed a wide range and large number of difficult to navigate publications, many of which contained valuable information but did not address questions specifically related to relevant actions to ensure a sustainable future for frankincense. As a result, CITES Decisions 18.205 to 18.208 were adopted at the Conference of Parties in Geneva in 2018 resulting in PC25 Doc.25 that outlined information that was required for consideration and data gathered from Parties.

A series of critical questions remained unanswered, and actions undertaken and recommended for sustainable solutions were lacking. Therefore, in order to progress practical solutions the project "Sustainable use, trade and threats to the genus *Boswellia* (frankincense)" was funded by the Swiss Federation Food Safety and Veterinary Office and undertaken by the Centre for Middle Eastern Plants, Royal Botanic Garden Edinburgh.

This document represents the Executive Summary of that research, with links to more detailed results that can be downloaded freely from the newly established Frankincense Resource Portal.

https://padme.rbge.org.uk/boswellia/index.php

Section ONE

Boswellia taxonomy and nomenclature

Most global conventions and conservation practices deal with conservation and sustainable use at the species level, and most conservation assessments are made at this level also. As such, it is critically important that species can be distinguished from each other to ensure that like is being compared with like. To achieve this, an assessment of how robust species level taxonomy is for a particular group, and provision of tools to distinguish among species are recommended. Identification at the species level relies upon sound taxonomy constructed using characters that can distinguish among each species: as the description of each species is based upon a diagnosis accompanied by a "type" voucher specimen that displays those characters, it is not possible to describe species based upon chemical or molecular markers alone.

While the genus *Boswellia* benefits from a recently published taxonomic monograph (see Thulin 2020), it is not without controversial taxonomy. New species have been described recently alongside some lingering issues and opinions about the status of other species. These are considered directly below.

Boswellia sacra – one species or more?

There has long been controversy as to whether a single variable species occurs in northeast Africa and southern Arabia or whether these can be differentiated into more than one species. This issue has resulted in two different names being used – *Boswellia sacra* in Arabia and *Boswellia carteri* in northeast Africa. Both names are widely used in trade and industry.

In this study, more than 100 specimens were examined for 37 morphological characters and could not find any that reliably distinguished between African and Arabian populations (Gibson 2023). Both Thulin (2020) and this study noted that more variation in characters was seen within northeast Africa than was detected between northeast Africa and Arabia. While claims have been made that the resins collected from Africa and Arabia differ, these samples were not representative of the range of variation across the species distribution and no voucher specimens were collected to allow formal identification of the trees sampled. Further, resin and indeed molecular characters cannot be used to describe new species, nor can they be used in the field to undertake identifications.

Boswellia microphylla and *Boswellia neglecta*

Although the name *B. microphylla* was published more than 100 years ago, it has long been considered as the same species as *B. neglecta* and has been treated as such in multiple studies. This has implications for any assessment or study using the name *B. neglecta* as these may contain samples or distribution records that in fact represent *B. microphylla*.

A total of 43 characters were considered and measured. Several characters were located that either singly or in combination can be used to distinguish between specimens representing two distinct taxa, and plots of character pairs show a non-random distribution that can visually distinguish two clusters. As such it is considered that two species are represented, and that this is suggestive of a significant barrier to gene flow even though much of the range of these two species overlaps in eastern Africa.

The Soqotra Archipelago

There are currently eleven recognised taxa as well as unconfirmed reports of hybrids on the Soqotra Archipelago which represents the most dramatic example of speciation in *Boswellia*. These taxa appear to be part of a recently arrived and actively diversifying group (Forrest *et al*, unpub.) and are the best studied species of *Boswellia* globally. At present, as the island is small and each species is represented by less than 5000 mature individuals, there is little trade affecting Soqotra (although this could change very rapidly should trade in Soqotran frankincense be marketed and subsequently increase). Therefore, there is currently little concern that taxonomic changes will impact identification and trade significantly.

Boswellia papyrifera 'Kebtele'

It remains possible that additional taxa await discovery within *Boswellia*. The most obvious example of this is *B. papyriefra* "Kebtele" which has been highlighted as having a unique and distinct resin chemistry (Melese, 2007). While resin chemistry cannot be used to describe new species, it may reveal morphological differences previously overlooked, as was the case when *B. occulta* was described (Thulin *et al*, 2019).

Additional examples that require investigation include reports of *B. serrata* from both Iran and Pakistan, for which voucher specimens and associated resin samples require examination.

Nomenclature

As well as being able to distinguish between different species, it is also desirable to use their correct names. This ensures that in comparative studies, the identification and naming of individuals can be compared "like for like" and avoids confusion where than one name is used for the same species. Further, the International Code of Botanical Nomenclature requires that a species is described according to its unique morphological characters which are represented on a "type" specimen (or specimens) meaning that the name is linked directly to the identity of that species.

All recorded names in *Boswellia* have been checked against their original publications. Where any case of nomenclatural complexity was uncovered, this was checked with experts at the International Plant Names Index (IPNI) and changes incorporated where necessary. The majority of global databases take their cue from IPNI and as such these changes will eventually filter down to other global and thematic repositories.

In the case of *B. carteri* – a name which has been extensively used in the past and as such is widely used in commerce today to refer to plants and their resins occurring in or collected from Somalia - it has been demonstrated that the name *B. carteri* is superfluous and illegitimate. There is no valid precedent to adopt the name *B. carteri* based on commercial use and were such a name proposed for conservation under the International Code of Botanical Nomenclature such a proposal would very likely be rejected. The correct name for this species is *B. sacra* and all stakeholders should be encouraged to use the correct name, and eventually the name *B. carteri* should disappear from use. If the name is fundamental to commercial operations, an alternative solution will need to be found but should include the name *B. sacra* in the first instance as the scientifically correct name.

Recommendations

There are no formal recommendations for further taxonomic clarification in *Boswellia* other than examination of reports of potentially new species in several locations that require verification.

Section TWO

Identification of *Boswellia* trees, resins and essential oils

Frankincense trees can, in most cases, be accurately identified through examination of morphological characters of the trees themselves. This is useful for field surveys – the cornerstone of effective conservation prioritisation and management – and for the identification of species in trade. As such, the CITES Secretariat has placed great importance on understanding the taxonomy of species threatened by trade and has also focused on provision of identification guides (see, for example Rutherford, Groves & Sajeva 2018; Rutherford & Groves 2023).

In the case of *Boswellia*, this is slightly more complex as the traded parts are resins and their derivatives. While these resins may differ qualitatively between different species, chemical markers cannot used to describe and identify species in the field or on preserved specimens. Therefore, to identify species in trade via their resins or essential oils it is imperative that the species themselves can be unambiguously identified at source and that representative specimens are collected alongside resins making a direct link between species identity and traded products.

An interactive identification key to all species of *Boswellia* has been constructed, and a review of identification using resin chemistry undertaken to evaluate its utility in identifying traded products. The collection of resin samples from all species accompanied by voucher specimens has been initiated, and preliminary results via Direct Analysis in Real Time – Time of Flight Mass Spectrometry (DART-ToFMS) is presented.

Tree Identification Key

The *Boswellia* monograph by Thulin (2020) provides a key to 24 species in the genus *Boswellia*. This is an excellent resource but suffers from two practical impediments: firstly, it is a taxonomic key that uses technical terminology that trained and experienced taxonomists are familiar with, but which is less easy to use for local teams and communities, and secondly it is a fixed document that cannot be updated directly in the face of taxonomic or nomenclatural change. To address these issues, we have taken the key in Thulin (2020) and several other relevant publications and constructed an interactive key which is presented online in the Frankincense Resource Portal. In addition, each character and character state has been illustrated thus removing some of the issues associated with the use of technical taxonomic terminology (although such text is maintained so that individuals with such experience can use the key as they wish).

It is intended that a series of instruction manuals will be developed including information about the key characters of the species involved so that the key can be used as an educational tool in areas where more than one species of *Boswellia* co-exist. These can be translated into different languages and made available online as required. Further, the key will be developed as an app that can be incorporated into survey tools to enable accurate identification in areas.

Resin identification using chemical analyses

Since the first publication regarding the chemical constituents of frankincense (Stenhouse 1840) there has been a significant amount of interest and subsequent research into the chemical components of frankincense and its derived essential oils. While most of these publications have focused on the constituents directly, more recently interest has increased in the applications of resin chemistry to identification. This interest has been driven by the global frankincense trade and the necessity to identify resins in trade to ensure that adulteration and/or illegal import of both resins and essential oils can be better regulated.

Despite claims that it is possible to identify *Boswellia* resins to species based upon their chemical constituents and the use of chemistry to inform taxonomic status (eg. Smiech *et al* 2019, 2021; Woolley *et al* 2012) some doubts remain as to the application of resin chemistry in identification. A review of >150

articles on *Boswellia* resin chemistry was conducted, concluding that very few studies of the resin and essential oil chemistry of *Boswellia* taxa can be directly compared to judge inter-specific identification potential. This is due to incomparability of the methods used, the potential for extraction and distillation methods altering chemical structures, and the lack of tree vouchers collected to verify identification and allow updates to be made in the face of future taxonomic change.

Reference set of *Boswellia* resins

In order to unambiguously identify one species from another, all 24 taxa should be represented in any reference set and should contain significant representation of both geographical and ecological variation and resins that are co-produced following insect activity in some taxa. Although only a few species are currently recognised as being significant in trade, this picture is changing and as sources become depleted in some taxa harvesting may move to other areas, states and species. Further, rare and threatened species can be marketed as such and rapidly become threatened as has occurred with rare plants in the horticulture trade. Therefore, including all taxa is proof against future taxonomy, trade directions and changes in the geographical origin of samples in trade. The process of collating a representative sample of resins from all 24 currently recognised species has been started, with each sample accompanied by a voucher specimen and all samples exported under license from the appropriate authorities in all range States. This process will continue until the reference set is complete.

Direct Analysis in Real Time – Time of Flight Mass Spectrometry (DART-ToFMS)

Of the numerous techniques that could be used to analyse *Boswellia* resin chemistry for identification of products in trade, DART-ToFMS shows promise for several reasons. Preliminary tests (see Price *et al*, 2024) demonstrate the potential resolution of the method which gives an advantage over Thin Layer Chromatography. Both Gas Chromatography-Mass Spectrometry and DART-ToFMS require initial resources for hardware, but the latter is beneficial due to its quick analysis time and low consumables cost. It also benefits from minimal to zero extraction and pre-treatment allowing direct analyses, removing the requirement for variable and incomparable methodologies. DART-ToFMS has been successfully used for identification in the illegal timber trade, and it is proposed that as this method becomes more widely available and accessible it demonstrates advantages over other methods currently available.

The "proof of concept" investigation using DART-ToFMS on commercial resin samples (see Price *et al* 2024) demonstrated a high level of repeatability and a high degree of accuracy in identification, with the caveat that samples were not taxonomically verified. However, under the assumption that species can be distinguished in this way and that commercial samples may be incorrectly identified or contain mixed samples, the expectation would be that a fully verified and vouchered reference set of resins would demonstrate even greater ability to distinguish among those species. Testing wild collected, vouchered specimens is ongoing.

Recommendations

Continue gathering vouchered resin samples from all species across all range states for complete analysis of the ability to differentiate among resins and essential oils in trade using DART-ToFMS or other future technologies, with potential to expand to other gums and resins.

It is recommended that a similar proof of concept study using DART-ToFMS with commercial essential oils is undertaken before establishing whether a reference set of essential oils is also required for identification of essential oils in trade. This is methodologically more complex as purchased essential oils will have been distilled and extracted using different techniques and experimental procedures but may still give an indication as to the efficacy of DART-ToFMS to distinguish among species in traded products and to identify erroneous labelling and/or adulteration.

Section THREE

The distribution of *Boswellia* species

When considering the conservation and sustainable use of any species, knowing where it occurs is fundamental to a range of analyses and subsequent actions. These can include conservation assessments at global and regional scales, species modelling in cases where detailed fieldwork across wide ranges is impractical, and modelling distribution in both the contemporary and future senses against climate change predictions. It also allows comparisons of whether species are well represented in conservation programmes including Protected Areas, and how these might protect species and habitats in the future.

When considering a small genus of plants such as *Boswellia*, there is much data held in small institutions, published literature and unpublished matter that is not available in global databases. Further, stakeholders interested in *Boswellia* are of different types and may not have access to the skills required to sift through data held in global data repositories. In such cases, gathering and curating data in a single location that suits the varied users can be beneficial.

This process focused first on geo-referenced herbarium voucher specimens. These specimens are the only type of data that is robust in the face of taxonomic change as they can be examined and re-determined as necessary: >1600 specimens were recorded. Secondly, online databases and published literature was consulted to collate additional distribution records from field surveys and from literature records: >2000 records were recorded. All records are presented in the Frankincense Resource Portal.

Species Distribution Modelling (SDM)

The main purpose of SDM was to explore the potential range of nine *Boswellia* species outside of their current known extent of occurrence. This requires a minimum number of discrete location points – often cited as at least ten but a minimum of 20 is ideal. Of the *Boswellia* species currently described, SDM is currently inappropriate for several of them: these include species from Soqotra as the topography of Soqotra is extremely complex and variable over short distances and climate models do not represent orographic rain and fog that are critical in determining their distribution. Several other narrow endemics have very few verified distribution points available to build robust models from associated environmental data (*B. globosa*, *B. occulta*, *B. ogadensis*, *B. ovalifoliolata*.

The remaining nine species are amenable to robust modelling. The resulting maps of modelled distribution have multiple applications, e.g. calculation of predicted extent of occurrence for use in IUCN Red List assessments, guiding the direction of systematic field surveys to search for new populations in under-studied areas, examining potential habitat loss in conjunction with historical land use and land cover change data, or to explore potential range shifts under different climate change scenarios. Several range States have indicated they would be interested to see actual, potential and future distribution models for *Boswellia* species in relation to current and proposed Protected Areas.

The nine distribution models are presented in the Frankincense Resource Portal and will be formally published in more detail subsequently. They are directly comparable as they use identical methodologies.

Recommendations

Continue to gather additional distribution information on all species from all range States via the submission form on the Frankincense Resource Portal, for use in further modelling and conservation planning.

Finalise distribution models comparing vouchered and field records, model against future climate scenarios to enable conservation prioritization against future distribution changes and subsequently compare against World Database on Protected Areas to establish practical spatial conservation outcomes alongside range State stakeholders.

Section FOUR

The Conservation Status of *Boswellia* species

Global and National IUCN Red List Assessments are essential for identifying species at risk and understanding the factors driving their decline. These assessments inform conservation priorities, helping to direct resources and actions towards conserving biodiversity. Many *Boswellia* species, even those in trade, have not yet been assessed or their assessments are out-of-date.

Table 1 shows all previous, unpublished and current draft global assessments. All new assessments have been added to the IUCN Species Information Service database from which all assessments are submitted for review by the IUCN Threatened Species Unit. Information from range State experts is awaited before finalization, submission and publication, including finalization of National assessments for those species occurring in more than one State.

Of those species previously assessed, there is no evidence to suggest any should be upgraded to Threatened Status. Several species are assessed as Near Threatened as they meet some of the criteria for assessment as Threatened. Of those species not previously assessed formally, two narrow endemics are assessed as Threatened and the widespread *B. dalzielii* assessed as Near Threatened. International trade is by no means the only or most serious threat in many cases, whereas overharvesting is considered a major threat in some cases.

For those species not endemic to Soqotra, few of the assessments have changed. *B. dalzielii*, *B. rivae* and *B. serrata* have been upgraded from Least Concern to Near Threatened based upon gathered evidence of various threats leading to a decline that could potentially lead to a threatened status if not monitored and managed. *B. ogadensis* has been downgraded from Critically Endangered to Endangered based upon published survey work that identified additional sub-populations and numbers of mature individuals.

Species endemic to Soqotra have been universally upgraded since their last formal assessment in 2004 based upon extensive data collection and subsequent analyses (Madera *et al*, 2024). However, it should be noted that not all assessments are directly comparable with previous assessments as there have been some taxonomic rearrangements.

Recommendations

Complete gathering information from range State stakeholders and finalise assessments for submission to the IUCN Red List via SIS.

Prepare publication (open access) detailing all global and national assessments and circulate to all stakeholders. Highlight multiple threats, of which over-harvesting is one.

Species	Current RLA (date)	Draft RLA Thulin (2020)	Draft/New RLA 2024
B. dalzielii	LC Least Concern 2024	LC Least Concern	NT Near Threatened
B. frereana	Not Evaluated	VU C1	VU C1
B. globosa	Not Evaluated	VU D1	EN B1ab(iii)+2ab(iii)
B. microphylla	Not Evaluated	LC Least Concern	LC Least Concern
B. neglecta	Not Evaluated	LC Least Concern	LC Least Concern
B. occulta	Not Evaluated	EN B2a	EN B1ab(iii)+2ab(iii)
B. ogadensis	CR B1ab(iii) 2021	CR B1ab(iii)	EN B1ab(iii)+2ab(iii)
B. ovalifoliolata	VU A2cd; B1ab(I,ii,iii) 2015	VU A2cd; B1ab(I,ii,iii)	VU A2cd; B1ab(I,iii)+2ab(I,iii)
B. papyrifera	VU (not published)	VU A2cd+3cd	VU A2cd+3cd
B. pirottae	VU C1 2021	VU C1	VU C1
B. rivae	LC Least Concern 2021	LC Least Concern	NT Near Threatened
B. sacra	NT Near Threatened 1998	VU A2cd	NT Near Threatened
B. serrata	LC Least Concern (TBC)	LC Least Concern	NT Near Threatened
*B. ameero**	VU B2ab(ii,iii) 2004	EN B2ab(v)	EN B1ab(iii,iv,v)+2ab(iii,iv,v)
*B. aspleniifolia**	Not Evaluated	EN C1	EN B1ab(I,ii,iii,iv,v)+2ab(I,ii,iii,iv,v)
*B. bullata**	VU D2 2004	EN D	EN B1ab(iii,v)+2ab(iii,v); C2a(i)
*B. dioscoridis**	VU D2 2004	EN C1	EN B1ab(I,ii,iii,iv,v)+2ab(I,ii,iii,iv,v)
*B. elongata**	VU B2ab(iii) 2004	EN B2ab(v)	EN B1ab(I,ii,iii,iv,v)+2ab(I,ii,iii,iv,v)
*B. hesperia**	Not Evaluated	CR D	CR B1ab(iii)
*B. nana**	VU D2 2004	CR D	CR B1ab(v)
*B. popoviana**	VU D2 2004	EN D	EN B1ab(I,ii,iii,iv,v)+2ab(I,ii,iii,iv,v)
*B. samhaensis**	Not Evaluated	CR C2a	CR B1ab(v)+2ab(v); C2a(ii)
*B. scopulorum**	Not Evaluated	CR D	CR B1ab(iii,v); C2a(ii)
*B. socotrana**	VU D2 2004 *sensu lato*	EN C1	EN B1ab(I,ii,iii,iv,v)+2ab(I,ii,iii,iv,v)

Table 1. Comparison of current and new or draft IUCN Red List Assessments for all species of *Boswellia*. Assessments noted as "not published" means that a preliminary assessment has been conducted but has not been reviewed or published on the IUCN Red List by the IUCN Red List Unit. VU = Vulnerable. EN = Endangered. CR = Critically Endangered. *Assessments undertaken by Madera *et al* (2024) for Soqotran endemics are indicated and are currently under review. The assessment for *B. socotrana* conducted in 2004 was prior to that species being split into two taxa, both of which were assessed independently as sub-species by Madera *et al* (2024) noted here as *B. aspleniifolia* and *B. socotrana*. Not Evaluated indicates that no assessment had ever been attempted previously at the date indicated.

Section FIVE

Trade in frankincense

The key to understanding whether any taxon will benefit from a CITES listing is to determine whether international trade poses a significant threat to the continued existence of that taxon. Therefore, the amount of global trade is often cited as a measure of such a threat. This is clearly justifiable where individuals of the taxon in question are killed or significantly damaged during the harvesting process. In the case of timber, the volume of trade can be directly linked to the number of trees and areas felled; in the case of herbaceous plants this can be linked to the removal of plants from natural habitats and their disappearance or reduction at monitored sites (eg. orchids harvested to make salep, Ghorbani *et al* 2014, Kreziou *et al* 2016; jatamansi harvested in the Himalayas, Smith-Hall *et al* 2023).

Frankincense has been a valuable commodity for thousands of years. Used in religious rituals, traditional medicine, perfumery and personal care products, frankincense remains a significant product in global trade. The trade in frankincense is a complex interplay of ecological, economic, and cultural factors; while it provides livelihoods for many and supports important global markets, overharvesting, habitat loss, and inequitable supply chains threaten the long-term sustainability of *Boswellia* species. Addressing these challenges requires concerted efforts from producing, importing and re-exporting countries, international organisations, and the private sector to ensure that this trade continues to thrive in a sustainable and equitable manner.

While the harvesting of resins from frankincense trees does not directly kill the plants, if undertaken at unsustainable levels it can seriously damage individual plants directly as well as encouraging damaging insect activity. Over longer time periods, this can also reduce trees' ability to flower, fruit and reproduce leading to local declines and extinctions. Several publications have highlighted that communities have developed sustainable harvesting protocols, and that some species can only be harvested by collecting naturally exuding resins as cutting the stems does not induce additional resin production. However, there are many instances of unsustainable harvesting including observations of de-barking that produce both short term and long-term effects. It is for this reason that CITES has taken an increasing interest in the frankincense trade to ascertain whether a Listing in the CITES Appendices could be beneficial in ensuring frankincense is harvested and traded sustainably through regulation.

There are therefore several questions to be addressed when considering whether the global trade in gums and resins poses a threat to *Boswellia* species and whether that threat warrants a CITES Listing proposal - and whether such a listing would be beneficial in regulating trade to the benefit of the trees and the communities that depend upon them.

Is it possible to estimate trade in *Boswellia* globally?

The short answer to this question is no. Data sources are unreliable and tracking codes are not specific and are not applied consistently. Data sources are often incomplete and are expensive to access. The most accurate and detailed resource is the EU Wildlife Trade Regulations on which all species of *Boswellia* have been listed, and countries are required to report at the species level – however in some cases this is not applied consistently.

Is estimation of global trade in *Boswellia* reliable and relevant?

The short answers to these questions are no and no. It has been demonstrated that due to a variety of factors it is almost impossible to calculate with any degree of accuracy what the total amount of trade in *Boswellia* products is on a species-by-species basis. This includes lack of specificity, lack of consistency in reporting standards, and a low response from commercial entities as to revealing trade amounts and types.

It can easily be argued that even with the minimal data available it is possible to say that there is "significant" trade in *Boswellia* products globally, but little attempt has been made to quantify this. When assessing the tropical timber trade, it is more simplistic and realistic to be able to estimate the

volume of timber extracted based upon estimates of the number and size of trees of a given species in a given area, and that the existence of timber in trade equals trees that have been felled – at times illegally. However, the "standing crop" of resin that can be harvested from *Boswellia* trees is extremely difficult to calculate accurately and as such it is difficult to say what amount of trade globally – and locally – could be considered sustainable.

It is possible to gather data on the amount of resin harvested in a given area and upscale that across a species' range, and similarly it is possible to measure the quantity of resin required to produce a given amount of essential oil. All these measures would need to be averaged over huge areas, and the resulting estimates would have large statistical uncertainties. Little confidence can be placed in data extrapolated in this way. The inevitable conclusion is that knowing the amount of trade is extremely difficult to reconcile with whether that trade is a threat to the species in question.

How does the amount of global trade compare with the amount of local trade?

This is currently extremely difficult to estimate with any accuracy. The threat to any trees harvested for gums and resins is the act of harvesting itself rather than the amount of trade – whether local or international. While some States have reported local figures, these are for trade rather than harvesting. As such decision makers must rely on the opinions of "experts" rather than data gathered locally with incentives for sustainable practices.

Is it possible to tell which species are being traded?

The answer is both yes and no, but realistically not in enough detail to target conservation actions. *Boswellia* resins and products are very often sold with the species of *Boswellia* noted and used as a selling point, so it is relatively easy to demonstrate that all but a few very rare species can be purchased directly. However, the levels of trade differ considerably by volume, and while products are sold with the species names attached to them this is not the case in most trade tracking systems currently implemented. Adulteration, inaccuracy, misapplication and errors are also complicating factors.

Conclusions and recommendations

While trade data on its own has little conceptual value in assessing whether a specific volume of trade in gums and resins poses a threat to any species, except where that species is named and is known to be extremely limited in extent and in number (eg. endemic taxa on Soqotra), it can have additional value. For example, accurately estimated figures of national trade in terms of income can give a measure of importance to that State and the communities and businesses that trade supports.

Knowing how much global trade is exported from each state has value if there is an accurate estimate of total harvesting quantity, as then a measure of local vs global trade can be calculated. This would mean that individual States could assess whether threats to these species and the communities they support are better evaluated and regulated by addressing global trade through CITES Listing or by national regulations and incentives to better protect species that are frequently used locally and are threatened by over-harvesting.

A multi-faceted strategy is needed to address these challenges combining stakeholder collaboration, policy changes and technology. There are several recommendations to address this:

Introducing species specific HS Codes:

- Engaging with the World Customs Organization to create dedicated HS subcategories for frankincense oil, resin and other parts and derivatives is crucial. This change would require cooperation among producer and consumer countries to push for reclassification, with the caveat that this could also be applied to other gum and resin producing species as is already the case, for example, with gum Arabic – also sourced from diverse species.

Introduction and implementation of country-level HS codes:

- In the interim, individual countries could introduce national-level trade codes to better distinguish frankincense products and enable regulation of unsustainable trade.

Strengthening national, regional and international regulations:

- The development of species-specific legislation focussed on the frankincense trade would enable producer countries to accurately track quantities, support legal trade and enforce any necessary penalties for violations. This could act as a test case for regulation and conservation of other valuable gum and resin producing species.
- With such legislation in place, countries could list their populations on Appendix III of CITES, ensuring international support to monitor global trade in their native species.
- Producer countries could establish licensing systems for frankincense, requiring harvesters and exporters to document the source and volume of harvested resin. Certification could be tied to sustainability standards including field monitoring, ensuring compliance with legal and ecological requirements, and further allowing calculation of the relative importance of local versus international trade.
- Governments could mandate detailed reporting of frankincense exports, including information on species, volumes, and destination markets. Such data would improve transparency and aid in international tracking efforts

Technology-based tracking systems:

- Blockchain can provide transparent and tamper-proof records of frankincense transactions from harvest to sale. This technology ensures traceability and accountability, particularly in global supply chains, but should be operated by local regulators.
- Producers could tag frankincense batches with unique identifiers, such as barcodes or QR codes, containing information about the species, origin, harvest date, and trade route. These tags could be scanned along the supply chain, creating a digital trail.

Collaboration among stakeholders:

- Establish partnerships between producer and consumer countries to share data and enforce trade regulations.
- Companies involved in the frankincense trade can play a key role by adopting sustainable sourcing practices and sharing supply chain data. For instance, essential oil producers could provide detailed sourcing information to buyers and regulators.
- Research and data collection should be supported and field studies and market surveys conducted to improve understanding of frankincense trade dynamics using comparable methodologies.

Section SIX

Boswellia field survey and monitoring

Given the concept that tracking trade volumes and patterns only has limited value in either the identification of over-harvesting or any procedures to ameliorate that threat, it has become clear that monitoring trees and populations directly in the field is the only way in which the sustainable harvesting of *Boswellia* trees to support community livelihoods and biodiversity conservation can be achieved in the long term. As such, a rapid field survey protocol was developed and tested in ten localities encompassing five species.

The survey was designed with repeatability, comparability and the potential for expansion in mind. Further, it was designed to be straightforward to accomplish in the field by a variety of stakeholders, focusing entirely on local actors. It was NOT designed as a one-off, stand-alone scientific study during which detailed field assessments and subsequent analyses would be undertaken and published. Rather, it was designed as a methodology that gathered data relevant to assessing levels of harvesting and damage on individual trees and across populations that could demonstrate sustainable levels of harvesting in the short, medium and long term. Comparability was considered so that the same methods could be used in different areas, States and cultural backgrounds to enable judgements as to the levels of sustainability across the ranges of each species.

Surveys were designed so that critical factors were measured directly as opposed to being estimated on a scale or grade of intensity as the latter would be susceptible to differences in interpretation. This would make the data and surveys incomparable with each other spatially and temporally. Direct measurements also give greater statistical power for meta-analyses in the future should this be desirable.

Surveys were initially conducted in 50m x 50m plots with up to 50 trees surveyed where possible, and in some cases the Point Centred Quarter (PCQ) method was used to estimate population density. A standardised set of observations was recorded for each tree. Observations included diameter at breast height (measured at 1.3 m above the ground) for all stems, as well as tree height and crown spread estimates to allow for calculation of population level age structure. To allow for a comparison of harvesting intensity at different sites, survey teams recorded the number of cuts on each stem. Information was also gathered on presence/absence of flowers and fruits, damage from insects or animals, fire damage, and whether trees had been cut for wood.

Surveys were carried out in 2023 and 2024 by local teams in the following ten range states: *B. dalzielii* in Benin, Burkina Faso, Ghana, Niger and Nigeria, *B. frereana* in Puntland and Somaliland, *B. neglecta* in Kenya, *B. rivae* in Somalia and *B. sacra* in Somaliland and Yemen. A total of 879 trees were surveyed.

Boswellia dalzielii

A total of 470 trees were assessed across multiple locations in five range States. While there was clearly evidence of damage to trees in all locations, some damage was attributable to bark harvesting which has a predominantly local use. There was no evidence of over-mature stands indicative of long-term reproductive failure, but many trees were isolated in human influenced landscapes and in some cases most trees were either mature or young. Increased resin harvesting likely poses an additional threat as marketing of resin for trade increases, but conservation strategies focusing on a range of issues is warranted.

Boswellia frereana

A total of 109 trees were assessed in Somaliland and Puntland (additional surveys are currently under way). Cuts were recorded on most trees, and harvesting communities stated that there were no restrictions on the size of stems cut to harvest resin although a rest period of one year was implemented after 18 months of continuous cutting. All resin is harvested for trade as opposed to local use. Flowering

and fruiting were commonly observed, and most trees were of a small size class indicating that reproductive failure is not apparent. Some damage to trees from feeding troupes of baboons was noted.

Boswellia neglecta

A total of 156 trees were assessed at two sites in northern Kenya. Populations showed a normal distribution for tree age assessed via height and crown spread (DBH is difficult to measure in this species). Numerous trees were observed as flowering and fruiting. However, *B. neglecta* is not cut to harvest resin as this does not stimulate resin production, therefore no damage due to resin harvesting was expected. Some dead trees were recorded, via damage by grazing animals.

Boswellia rivae

A total of 50 trees were assessed in two locations in southwest Somalia. Results were similar to those for *B. neglecta* with trees of all ages and sizes recorded, with some damage to trees caused by grazing livestock. Flowering and fruiting were recorded less but this is season dependent.

Boswellia sacra

A total of 94 trees were assessed in several locations in both Somaliland and Yemen. The population density of trees was lower than other surveys, especially in Yemen. More than 60% of all trees were cut for resin harvesting, but again there were a good selection of age classes with more younger trees than older trees indicating that reproductive capacity is not being affected based upon a limited sample.

It was originally considered appropriate to develop a survey protocol that would be comparable across all species. This was quickly rejected as it is not possible to record the same characteristics for each species in the same way. For example, estimation of trunk diameter can be achieved in *B. dalzielii* using standard DBH measurements as it is predominantly a single stemmed species, but this is not appropriate for spreading bushes such as *B. neglecta* and *B. rivae* or for multi-stemmed trees that often branch low to the ground such as *B. sacra*. Variation within species also occurs and requires further research to establish robust and comparable methodologies.

Recommendations

Review and finalise monitoring protocols and secure funds to test across a wider selection of species and range states to demonstrate sustainable tree and population management, alongside engagement with harvesting communities and supply chain actors, as a long-term monitoring strategy.

Field monitoring should be based upon direct measurements of tree and population health rather than estimates of status based upon a scale that could be interpreted and scored differently by different surveys from different cultural and technical backgrounds. This will ensure that surveys are directly comparable in the long term.

Engage with line ministries in range states to introduce a licensing system so that harvesting is monitored and recorded and can be compared with export data to establish the relative importance of international versus national trade.

Section SEVEN

Frankincense Resource Portal

While there are many open access global databases for plant species distribution and associated information that lend themselves to meta-analyses, acquiring, combining, sorting and quality control of these data can be time consuming and beyond the technical capacity of potential users. It was therefore that a dedicated resource about *Boswellia* spp. would have value for stakeholders and interested parties given the widespread interest in and concern for frankincense. It was designed following feedback from a wide range of potential users and stakeholders.

The Frankincense Resource Portal is available online and can be viewed at:

https://padme.rbge.org.uk/boswellia/index.php

Each species page includes complete nomenclature, a brief description, a list of countries in which it occurs, a contemporary distribution map based upon data held in the database, a predicted distribution map based upon geo-referenced herbarium vouchers as data points, details on flowering, fruiting and altitude, and details about IUCN Red List status. As all these details are held in a database they can easily be updated and a record kept of those updates.

The Key Page features the interactive identification guide to all species of *Boswellia* as detailed in Section Two. This was constructed by using available and recent taxonomic literature and input with ideograms representing characters and character states with the intention that language and detailed knowledge of taxonomic terminology would not be a prerequisite for use.

Distribution data is input via a spreadsheet with fixed data fields, which is then auto checked for errors before upload. An additional page where these forms can be accessed and submitted will be added to the portal in the near future.

The functionality of the portal, how the data is stored, input and viewed, is complete. However, there are several developments and additional features to be implemented as well as accessing feedback from users on the functionality and utility of the website.

It is intended to make to contemporary maps “live” in that each data point will have information attached and different types of data will be colour coded (eg. herbarium vouchers vs field and literature records). New data will be added at routine intervals when received from collaborators, and over time comparisons between contemporary and modelled distributions can be made to elicit any difference that new data has contributed. Distributions modelled against future climate predictions will be published and added at a future date.

The identification key will develop by having images added of characters and character states from each species as and when these become available. This will assist in the ability to use the key without detailed knowledge of taxonomic descriptive language, and it can also be used without text with the addition of some simple training protocols.

Presenting parts of the portal in additional languages will be costed and scheduled for development.

The Frankincense Resource Portal was developed by and is currently hosted at the Royal Botanic Garden Edinburgh using an in-house database.

Section EIGHT

Boswellia and CITES

There has been much discussion at CITES meetings recently about the genus *Boswellia* with a view to deciding whether any listing proposal is warranted to ensure that international trade is not a significant threat to species survival. This has included the establishment of an Inter-Sessional Working Group on *Boswellia*. Integration with the CITES community is important as considerable expertise in regulating unsustainable trade as well as supporting the development of non-detriment findings and related protocols are very much within the remit of CITES.

From a position of considering whether CITES listing or the use of CITES protocols would be beneficial to the persistence of *Boswellia* species, there are several considerations to be made, and these are addressed below.

Genus level listing on CITES Appendix II

Genera or large groups of plants have been listed on CITES Appendix II in their entirety for a variety of reasons. In the case of *Boswellia*, due to the difficulty in species specific identification of the parts and derivatives in trade, a case would need to be made that one or more species were threatened in some way by international trade.

There is no doubt that resins and essential oils from nearly all species of *Boswellia* can be purchased outside their country of origin. Some of the more widespread species are clearly traded in large amounts, as evidenced by trade figures (such as they are) and import and export data. While these do not directly relate to the "standing crop" of trees on the ground as they might in the case of tropical timber species, over-harvesting and subsequent tree damage has been observed in many places with a documented link to international trade. A future reduction in harvesting capacity has been cited (Bongers *et al* 2019) and as such trade is likely to move to different locations and potentially to different species than those currently forming the bulk of trade. Given difficulties in identification of *Boswellia* resins and essential oils in trade, and a lack of detail and accuracy as to the source populations and species harvested, coupled with some documented examples of adulteration or mixed gatherings (eg. Ohja *et al* 2022) a case can be made for listing *Boswellia* on CITES Appendix II.

However, there is little evidence that more than a few species are traded in significant volumes that relates to tree and population health on the ground, and that some are either narrow range endemics that are highly unlikely to be deliberately traded or some that are not under threat from harvesting as the trees are not cut or damaged to induce resin production. Further, it is extremely difficult to relate actual harvesting amounts to whether those resins are traded internationally or locally, and as such it is almost impossible to conclude that international trade is the sole or most significant threat (eg. even in Ethiopia, cited as the major exporter of *B. papyrifera* resins globally, it has been suggested that a large proportion of that harvest is used internally (Stevens, pers. comm.). In addition, what evidence there is has often been estimated based upon assumptions that have not been empirically tested thoroughly or widely enough – in terms of amounts, locations and different species.

On this basis, it is considered that a genus level listing in CITES Appendix II would be inappropriate at this time.

Species level listing on CITES Appendix II

As a genus level listing is considered inappropriate at this time, each species should therefore be considered separately.

While there is clear evidence for many species of *Boswellia* that trees are being damaged through overharvesting, there is little hard evidence that directly links such damage to international trade even where this is known to be occurring. As such, at this stage it is difficult to recommend Listing on Appendix II for most species until better and further targeted data is gathered on the ground, as data on

the amount of trade is not a direct measure on whether any species is under threat from such trade across its' range.

This does not mean that international trade is NOT a threat to several *Boswellia* species, it is simply the case that there is not enough direct evidence to warrant a Listing. There are some exceptions to this.

B. ovalifoliolata, a narrow endemic species from India, has been noted to be suffering from overharvesting including substitution for *Commiphora wightii*. As such it meets the criteria for Listing on Appendix II.

B. papyrifera has been noted to be devastated by overharvesting linked to reproductive failure and over-mature populations where it has been studied in detail. While it occurs in several other States where it has not been assessed in such detail, most of the international trade is noted to be sourced in Ethiopia where very few populations remain unaffected. As such it meets the criteria for Listing on Appendix II, with the caveat that if this was not proposed then Listing on Appendix III would be highly beneficial to gather additional data on the positive effects of local initiatives.

A similar situation occurs with *B. sacra*, and while this species may meet the criteria for Listing on Appendix II further surveys currently being undertaken in Oman may reveal additional data on which decision making can be based. In Yemen, and in Somaliland and Puntland there are examples of overharvesting that are predominantly sources for international trade but data is sparse. A similar situation occurs with *B. frereana*. Neither species appears to exhibit population structure indicative of long-term decline and as such any Listing proposal would be precautionary.

Several species may benefit from Listing on Appendix III and these are highlighted in Table2.

Sustainable trade in gums and resins

It is plausible that the way in which international trade in gums and resins is regulated to benefit long-term persistence for community benefits and conservation purposes may require different approaches, of which *Boswellia* is a case study. Similar arguments apply to taxa such as myrrh (*Commiphora* spp.), gum Arabic (*Acacia, Senegalia* and *Vachellia* spp. *sensu lato*), Dragons Blood (*Dracaena* spp. and other taxa) and aloes (*Aloe* spp.). Aloes are mostly destructively sampled and hence listed in Appendix I and II but some of the issues are shared with frankincense such as identification in trade and a dearth of information on wild harvested populations. This could establish best practice in taxa where the harvest of NTFPs does not result in the immediate death of individuals but may cause long term harm to individuals and populations leading to CITES Listing due to declines brought about by harvesting for international trade.

All gums and resins have the potential to be harvested sustainably, but also over-harvesting has the potential – as has been demonstrated - to damage populations long term which eventually will lead to local extinction and a reduction in benefits to those communities that rely on them. Identification of gums and resins in trade is a complicating factor as current systems are not accurate and could not be used in legal proceedings where illegal export, import or adulteration are suspected.

This programme of work has taken the frankincense trade and demonstrated methods for identification of traded goods, identification and monitoring in the field, and stated which species meet the criteria for CITES listing to implement CITES protocols and methodologies in ensuring sustainably harvested and traded products. These methods should be examined in detail and discussed by the CITES Secretariat, CITES Plants Committee and the CITES community as it relates to trade in all gums and resins globally.

It is recommended that the CITES Plants Committee set up a Working Group on trade in gums and resins.

Additional recommendations

The CITES Secretariat should focus on working with those range States that are currently subject to CITES trade suspensions, in order to remove the impediment to trade in taxa that are important for local livelihoods in insecure and poverty-stricken states.

At the moment, there is not enough empirical evidence that all species of *Boswellia* are at significant and immediate threat of extinction due to international rather than local trade, even in those species and

states where evidence of over-harvesting and subsequent population decline is documented. However, additional data gathering could change this situation very quickly, and as such additional data gathering and regulation is recommended to address this data deficiency. Range States should be engaged through their CITES Authorities to support such data gathering and regulation in order to prevent future proposals to list species of *Boswellia* on CITES Appendices, which should be seen as a last resort when international trade is already having a devastating effect.

Species	Appendix II	Future Concern	Appendix III
B. dalzielii	No	Yes	Yes
B. frereana	Maybe	Yes	Yes
B. globosa	No	No	No
B. microphylla	No	No	No
B. neglecta	No	No	No
B. occulta	No	Yes	Yes
B. ogadensis	No	No	No
B. ovalifoliolata	Maybe	Yes	Yes (if not App.II)
B. papyrifera	Maybe	Yes	Yes (if not App.II)
B. pirottae	No	No	No
B. rivae	No	No	No
B. sacra	Maybe	Yes	Yes
B. serrata	No	No	No
Soqotra species	No	Maybe	Yes

Table 2. Assessment of which species of *Boswellia* meet the criteria for Listing on Appendix II, which are highlighted as being of future concern, and which could benefit from developing legislation to enable Listing on Appendix III.

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