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CONVENTION ON INTERNATIONAL TRADE IN ENDANGERED SPECIES
OF WILD FAUNA AND FLORA

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CONSERVATION STATUS, TRADE AND THREATS TO THE GENUS *BOSWELLIA* (FRANKINCENSE)

1. This document and its Annex have been submitted by Switzerland in relation with agenda item CoP19 Doc. 63 on *Boswellia trees (*Boswellia *spp.)*.*

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Annex

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

The long standing interest in frankincense – *Boswellia* spp. – in research and trade led to initial fact-finding regarding the potential threats of international trade summarized in CoP18 Doc.66. This document, submitted by Sri Lanka and the United States of America, outlined issues pertaining to international trade in *Boswellia* spp. and led to subsequent developments and requests for information to better inform decision making.

Decision 18.205 on *Boswellia* trees outlined knowledge gaps, as detailed below:

a) biological data on *Boswellia* species, including population size, distribution, status and population trends, identification information, and its role in the ecosystem in which it occurs;

b) available information about harvest and exploitation levels, trade names, stakeholders close to the harvest of the species and supply chain characteristics for domestic consumption and international trade;

c) information on threats to these species, especially as it pertains to the underlying causes of poor regeneration capability and the impact of harvest on these species;

d) information on any initiatives to artificially propagate these species or produce plantations of them;

e) existing regulations and ownership structures pertaining to the species, their habitat, drivers of habitat trends and management measures in place or under development, including sustainable harvest practices;

f) suggestions for meetings or other venues that might provide opportunities to collaborate or share information regarding harvest and management of these species.

Notification 2020-010 requested parties to complete a questionnaire about *Boswellia* species to address some of these knowledge gaps. Responses were received from 11 parties (representing 6 of the 21 Boswellia range States) and 20 additional submissions. Additional information has been presented in CoP19 Inf.10 (Doc.63).

The programme "Conservation status, trade and threats to *Boswellia* species (frankincense)", led by the Royal Botanic Garden, Edinburgh, was initiated in 2021 in order to focus on gathering new information, make practical assessments, and clarify relevant topics through active research and the provision of scientifically robust data to support decision making for the many and varied stakeholders with an interest in frankincense. A brief summary of activities and ongoing research is given below.

- **Taxonomy**

Taxonomy is not a fixed discipline and can change over time, leading to synonymy and new species being described – which has happened within *Boswellia* in the last two decades and is still ongoing. A full taxonomic treatment was published by Thulin (2020), again making the well-known point that the majority of *Boswellia* species are distinct and can be readily identified in the field and via preserved specimens that display the relevant morphological characters. However, most taxonomic publications are static and not routinely updated (although nomenclature is routinely updated via the International Plant Names Index (IPNI).

Output: to remedy this, full taxonomic details will be inserted into a taxonomic backbone underpinning a Frankincense Resource Portal that will allow associated data to be referenced against taxonomically accurate and geo-referenced records and that can be updated in the face of taxonomic change.

Thulin (2020) examined more than 750 herbarium specimens, with this knowledge backed up with field experience in some *Boswellia* range States. Prof Thulin is considered the most experienced taxonomic researcher who has worked on *Boswellia* and his publication is widely acknowledged as the most comprehensive study ever undertaken. However, additional herbarium specimens have been located and the vast majority subsequently fully geo-referenced leading to over 1,000 specimens, a number that is still growing. These

specimens are critical in terms of information associated with plant species names, as they are the only records that can be taxonomically verified: field records cannot be revisited or redetermined in the face of reinterpretation or taxonomic change. Any inaccuracy in identification leads to errors when using associated information relating to distribution, harvesting, condition and status and any downstream analyses using such unverified data points.

In addition, there is some uncertainty in the taxonomy of several species in *Boswellia*. These have been widely discussed in the literature for *B. sacra* and the illegitimate name *B. carteri*. They have been less discussed for *B. microphylla* and *B. neglecta* primarily due to the fact that trade in the latter species is not well documented or at as great a scale as the former species. The endemic *Boswellia* species of the Soqotra Archipelago appear to be an actively evolving group that is routinely re-assessed but has little contemporary relevance in international trade.

Thulin (2020) makes the taxonomic case for *B. sacra* as a single variable taxon, highlighting that *B. carteri* is an illegitimate name (despite the fact that it was validly published), and also the fact that those papers claiming support for two separate taxa are based upon (a) characters that cannot be verified in the field or on preserved specimens, and therefore not on any Type specimens, and (b) that the studies were based upon samples for which little provenance is available meaning the identity of the study samples cannot be verified taxonomically. In addition, some of the arguments for differentiation between the two taxa was shown to be inaccurate, and the sampling demonstrated to be extremely limited in terms of being representative of variation within the taxa studied. Nomenclatural clarification is an ongoing part of the current programme, which will lead to recommendations to clarify this situation.

In addition, publications stating the claim for two distinct taxa in this case are based upon chemical characteristics of different types. Without provenance information it is impossible to clarify whether these studies represent the spectrum of variation within each taxon, as would be expected in a systematic study of taxonomy. Secondly, in the vast majority of cases in which chemotaxonomy has been utilised historically, re-examination of preserved specimens has revealed morphological differentiation – therefore the chemical analyses did not identify new taxa but revealed a lack of systematic study in the underlying morphological character states. This approach is in fact exemplified by the recently published *B. occulta*, which resulted in redetermination of historical specimens highlighted by chemical analyses of contemporary collections.

Output: the current programme will address formal, systematic and statistical analyses of characters and character states in this species pair to examine whether any characters consistently differentiate between them. Previous publications by Prof Thulin suggest that this is not the case.

The use of the name *B. carteri* in trade cannot be taken as a taxonomic character, and neither is the differential location of specific taxa – as these characters could not be used to identify specimens by examining them in the absence of associated information. Following nomenclatural clarification, this will be addressed in nomenclatural terms to provide recommendations as to whether the name could be conserved and under what conditions in order to satisfy the International Code for Botanical Nomenclature. Conservation of validly published names can be proposed, but in this case it is the underlying taxonomy that is in question: nomenclature results from taxonomic study but is not driven by it.

The case of *B. microphylla* and *B. neglecta* is more complex, as these species have been clearly separated taxonomically but at different taxonomic ranks. Further, they have a largely overlapping distribution range. These taxonomic differences have often not been recognised in field collections and global databases: the fact that *B. microphylla* was for long periods recognised as a sub-species of *B. neglecta* means that many collections are recorded as *B. neglecta* only. As a result, downstream analyses based upon verified herbarium specimens is of critical importance: it is highly likely that some records annotated as *B. neglecta* are in fact *B. microphylla*. To our knowledge, *B. microphylla* has never been analysed for its chemical constituents so the current trend towards chemical identification in *Boswellia* cannot currently be applied to this species.

- **Identification**

Many conservation initiatives and actions are based upon the taxonomic rank of species – so to be able to conserve them you first must be able to identify them. CITES is no exception in terms of making Non-Detriment Findings (NDFs), trade and the monitoring of harvesting levels as well as potential adulteration and

misidentification of products and sources. Such identification is based upon the characters and character states in the species description and demonstrated on type specimens held in herbaria and can be subsequently used in the identification of field and preserved specimens. However, where trade is in plant products that do not display these characters, identification becomes a secondary issue. This can apply to plant parts, timber, and Non-Timber Forest Products (NTFPs) including gums and resins as well as downstream products that are developed from them.

There are many available methods and tools for plant identification. However, reviewing these tools and assessing their utility and cost is not relevant until the purpose of the identification is stated alongside the relationship between traded products and the identification process of the relevant plant species. In the case of *Boswellia*, there are a number of pertinent considerations.

Firstly, traditionally and still in a contemporary sense in the vast majority of cases, species are described and identified using morphological characters and character states. Such characters, and tools that utilise them, are applicable when identifying preserved specimens and also when examining plants in the field. This is important as the goal of all conservation and sustainable use programs relates to conservation of functioning populations *in situ*. Despite taxonomy being conducted using alternative tools and methods over the years – such as chemotaxonomy, DNA barcoding and related activities - these have little value in the field or herbarium without extensive resources and capacity and have rarely been used in the absence of differentiation of morphological characters and character states. There are many examples where new species have been described based upon both chemical characteristics or DNA sequences, but these are almost without exception subsequently re-examined and formal scientific descriptions and associated nomenclature are completed using previously overlooked morphological character descriptions. *Boswellia occulta* is a relevant sample from frankincense – while known as unique by local communities likely for millennia, chemical analyses identified unique characters compared to co-occurring taxa but the species *B. occulta* was based upon differentiating morphological characters with historical specimens re-identified as a result and without chemical analyses. Similar cases are known within additional species of *Boswellia* (see *B. papyrifera* “Kebtele” - Awoke *et al* 2021).

Taxonomy is not conducted on resins, gums and other exudates – these are secondary compounds produced in a variety of ways by plant species. However, as these are the traded products in *Boswellia*, in order to identify resins to a specific species it is imperative that resin samples are collected alongside morphological voucher specimens from the same tree – or potentially detailed anatomical photographs that capture the species-specific distinguishing characters (although these may not be adequate in the face of taxonomic change). Any claims that a particular resin, essential oil or associated product or derivative was sourced from a specific species of *Boswellia* in the absence of a voucher specimen cannot be treated as taxonomically verified. Population-level vouchers may be applicable in some cases but cannot be updated in the face of taxonomic change in terms of sample identification.

Such samples are extremely rare in the published literature on the chemical composition of *Boswellia* species. So far, in excess of 175 published works have been identified that examine the chemical composition of *Boswellia* taxa, and numerous additional papers are available and await translation for formal review. Of these, less than 40 papers examine multiple *Boswellia* taxa, and the majority examine fewer than five of the currently described 24 taxa. Only a single study cites individual resin samples against associated individual voucher specimens that can be identified taxonomically. In addition, in terms of representative sampling from range states, 11 states have never been studied, and several taxa are extremely poorly represented in sampling. *B. microphylla* – often considered as a sub-species of *B. neglecta* but currently recognised as a distinct taxon – has never been characterised chemically although it may be included erroneously in samples of *B. neglecta* which has been characterised in at least 11 studies.

As such, there is no evidence currently that chemical composition can accurately characterise frankincense to the species level as no comprehensive, systematic and adequately vouchered study exists covering all taxa. A formal review of the varying different chemical methods and procedures used in papers addressing multiple taxa – while likely to reveal that very few studies are directly comparable methodologically – would also lack verifiable specimens. The majority of papers published differ in the laboratory protocols used, and no comparative study has yet assessed whether such methodological differences contribute to observed differences in chemical profiles and the relative amounts of compounds detected.

Calls for a fully and individually vouchered reference collection to enable systematic identification of all *Boswellia* species – ongoing for at least twenty years - should be heeded. Further, the collection of reference samples should be undertaken from all range states, and any resultant data for identification made publicly available. Chemical analyses should be repeated in multiple labs and under different conditions to enable judgement of comparability and therefore accuracy and legal status of resultant identifications.

Output: the current programme is developing such a reference collection in collaboration with multiple stakeholders, with all required collection and export permits, that represents ALL currently described species with multiple examples incorporating geographical variation. The collection should include (a) herbarium vouchers inc. all characters (flowers, leaves, fruit etc) as well as detailed digital images deposited in range State and global herbaria, (b) resin samples collected from the same individual trees for chemical analyses with verified identification, and (c) essential oils distilled from the resin of individual trees. This will enable the following outputs:

- Reference samples stored in three locations: E, range state herbaria, one further duplicate collection set; digital images will be stored in the Frankincense Resource Portal;

- DART-ToFMS applied to all resin and essential oil samples to assess differentiation among taxa based upon taxonomically verified specimens. This will include a range of tests accounting for variation in laboratory protocols to address the comparability of procedures which will inform possibilities for routine testing globally;

- Identification key (both online/photographic and paper-based/published, in various languages) for field identification that is applicable on phones, tablets and on paper in areas where technology is not currently available;

Accessible identification keys are considered important to enable non-specialist and community stakeholders to collect taxonomically verifiable information rather than relying on external experts.

DART-ToFMS has been tested in a collaborating laboratory and has demonstrated that of the nine species tested, samples could be identified to species-level with over 95% probability in all cases. This is relevant as high probability identification can be used successfully in legal proceedings that require such evidence for prosecution. While this preliminary study awaits publication, it is noted that the samples used are NOT taxonomically verifiable but still achieve impressive identification results – which with taxonomically verified samples would be expected to improve by elimination of potential misidentifications, contaminants and adulterants.

The cost of DART-ToFMS is relevant to discuss. Initial costs for equipment and staff costs for analyses are large but running costs are insignificant. Therefore, any cost and availability estimates will require information on sample transport and verification and also replicability in multiple laboratories.

- **Identification Capacity**

Having established why identification is important, it should also be asked who will undertake identification, at what cost and for what purpose and benefit.

For field identification – critical if vouchers are to be collected and associated with resin or other product samples – identification tools to recognise individual trees in the field should be made available. Many such tools exist, ranging from a contemporary global monograph with a synoptic key to all *Boswellia* species (Thulin 2020) to a range of local floras that cover differentiation among species growing in that locality (available for the majority of range states). However, these keys are written by taxonomic experts, often using highly technical language, and are difficult to use for those who either (a) are not trained in technical identification skills or terminology, and (b) do not speak the language in which the keys are published. Visual guides are also available – for example to identify the endemic *Boswellia* taxa of Soqotra, or to distinguish among several species based upon leaf characters. Further, such keys cannot be used to identify resins or essential oils.

These are important considerations when assessing how to construct accurate and verifiable supply chains. The ability to distinguish among resins using chemical methods would by necessity occur after collection until such portable field techniques are developed and become widely affordable and available: this would require either

such methods and capacity to be available in range states, or that all testing was conducted outside range states in importing countries. While both are possible, significant investment in capacity and resources would be required to even implement random spot checks. The location of such checks requires assessment – while a broader and more detailed picture of frankincense trade is starting to emerge, the many trade routes and border crossings that currently occur are poorly documented and with current resource levels very difficult to monitor. The most efficient way would be to certify collections at source, which would require capacity development and a demonstration of added value to those performing it. Research into such transparent and implementable mechanisms would be valuable.

- **Distribution**

In order to undertake conservation status assessments, understand the locations of specific threats, and to plan for conservation actions taking into account future trends in development, climate and available land for restoration purposes, it is important to be able to map the distribution of individual taxa accurately both now and projected into the future under climate change scenarios. There is however a relationship between distribution and taxonomy and identification which requires assessment of different data types in order to ensure accuracy and to future proof against taxonomic change.

Plant species distribution is most often mapped based upon individual location points where a particular species has been observed. It is then possible to determine the exact distribution of a taxon using a number of related techniques: these include measures such as Extent of Occurrence (EOO, a minimum convex polygon encompassing all observations of a particular species, routinely used in IUCN Red List Assessments and dependent analyses and criteria to assess the spread and likelihood of threats), Area of Occupancy (AOO, used to summarize contemporary knowledge of where a species is observed to actually grow), inferred distributions (expert and field knowledge to estimate the extent of a species distribution range) and Species Distribution Modelling (SDM, using a range of environmental and climatic variables to predict where a species grows based upon data derived from the locations is it currently observed at). These distributions can then be modified based upon additional information, including the exclusion of unsuitable areas (for example water bodies) or the assumption that species grow in a particular mapped habitat or alongside other species which have also been mapped (for example exclusion of distribution ranges in particular vegetation types or from areas where associated species do not grow).

These methods are very reliant on each distribution point being accurately identified. If any distribution point included in modelling or inferred distributions is in fact an alternate species – due to misidentification or due to taxonomic change – then the distribution will be inaccurate, and any modelling algorithms applied will have lower statistical power and may lead to misleading assumptions on which conservation actions are based.

Identification associated with distribution points therefore has a hierarchical structure. Distribution points that are associated with physical specimens – ie. herbarium specimens – are the most robust and accurate information as identification can be verified and can also be updated in the face of future taxonomic change or re-interpretation. Field observations cannot be re-verified – although in the case of *Boswellia* there are many areas where only a single species is currently recognised and as such it is a fair assumption that identifications from those areas are accurate, although new records can of course change that situation. However, in *Boswellia* specific examples exist which make this an extremely important point in terms of accuracy of distribution records: these include the previously mentioned issues surrounding *B. sacra* and *B. carteri*, and *B. microphylla* and *B. neglecta*.

Output: the Frankincense Resource Portal will contain all collated distribution records for *Boswellia* species, annotated as to record type (preserved specimen, image, field record, literature record) to allow downstream analyses based upon taxonomically verified samples. Given the global interest in frankincense, not least from international trade stakeholders, this will provide a resource to enable decision making without repeatedly having to correct and interpret data held in global databases and that will – with the cooperation of data holders – include all available data on *Boswellia* species. Data access will be carefully considered with restrictions and obfuscations in place as necessary to protect taxa threatened or at risk from overexploitation.

Development of the Frankincense Resource Portal will be guided by a series of Use Case Scenarios and communication with a wide range of stakeholders.

Ascertaining exactly where each species of *Boswellia* would be expected to occur naturally will enable a range of analyses. Distribution data gathered as outlined above will form the basis of SDM. Comparison between models based upon verifiable herbarium specimens compared to data points that are potentially misidentifications or cannot be re-assessed following taxonomic revision, as well as model validity in areas of species overlap, potential hybridization and taxonomic complexity, will allow assessment of the best methods for accurate species distributions.

Distributions will also be modelled taking into account future climate scenarios so that any land use of conservation planning can be recommended in the face of future change.

Much SDM work is being undertaken in the research group of Prof Frans Bongers (Wageningen University). The results of these modelling exercises will be assessed and compared to additional modelled species, and discussion initiated as to how best make available this information for future analyses and implementations, and to identify further knowledge gaps.

Output: modelled distributions will be compared with land use change from remotely sensed imagery to ascertain how much actual and potential habitat has been lost – and for what reasons – in the last few decades. This will verify whether increased levels of harvesting are compounding habitat and species loss brought about by other activities thus concentrating reported over-harvesting in smaller and smaller areas to compound the problem.

- **Conservation Status**

Given the current interest globally in *Boswellia*, it is perhaps surprising that not all species have been assessed – either globally or nationally – using the IUCN Red List Criteria, and of those taxa that have been assessed some of those assessments are out of date. Many informal assessments do exist (see Bongers *et al* 2019; Thulin 2020).

Output: the collation of data on the distribution and threats to *Boswellia* species is ongoing and will lead to global and range State regional assessments for all taxa. Assessments will use known locations and modelled distributions for the spatial component of the assessments, alongside expert knowledge of the intensity and location of specific threats – including but not limited to harvesting and trade.

Range State assessments are considered important for two main reasons. Firstly, conservation activities are coordinated at range State levels rather than globally, therefore any species considered threatened nationally may have conservation activities implemented at that level. This is especially important when taking into account potentially different threat levels and threats in different range States. Secondly, it is clear that there are different levels of threat to Boswellia species in different range States due to the levels of harvesting, use and trade. Given that some predictions have been made on population and subsequent trade decline in certain areas, it is a distinct possibility that the focus of harvesting and subsequent trade will shift to alternate range States and alternate species. This is especially true for the trade in health and wellbeing products that are at least in part dependent of fashion and marketing – there is no fixed reason to keep trade focused on a single location or taxon in this case. As a result, Green Status Assessment – taking into account range State conservation activities and predictions of future trends – is considered important and will be addressed through research and assessment.

- **Threats**

Multiple reports of over-harvesting and claims that frankincense is undergoing decline, possible extinction and the collapse of the frankincense trade have been published with verifiable examples documented in different species and locations. Conversely, informal reports from multiple locations claim that there are large areas of untapped and infrequently tapped forests that are healthy. Other programmes report that claims that frankincense woodland is in a good condition are misguided. There is clearly a lack of comparative data on levels of harvesting and tree and woodland health, especially from difficult to access locations and also for species not widely traded but clearly under threat from future exploitation. Such data needs to be clearly comparable within a framework of targeted questions and subsequent conservation actions.

Several discussions have been initiated to increase the availability of comparable harvesting information including plans to develop a simple data gathering tool that can be widely implemented and input into the Frankincense

Resource Portal. This would be carefully designed to make use of existing detailed published information and to enable adding information from local communities and stakeholders to give a more comprehensive picture of harvesting intensity.

- **Trade**

Research to date has clearly shown that frankincense trade – whether local, regional or global – is extremely difficult to trace and quantify via formal mechanisms as in general these do not exist. Global Harmonised Customs codes are in the most part non-specific and trade volumes rely upon often informal estimates from a range of commercial and non-commercial entities.

It is important to understand the volumes of trade as these are directly related to the resource availability and whether trade amounts are sustainable given that resource. The issue is further complicated by (a) the varied products harvested, traded and sold and (b) while estimates have been made for international trade there are few accurate estimates of local harvesting, trade and use.

In order to demonstrate these difficulties, a focused study on the global fragrance industry was undertaken, concentrating almost entirely on globally traded products as opposed to local trade or use. Despite the lack of both species-specific information and geographic provenance, this data provides good information on the use of this genus by the fragrance industry, particularly in comparison to the use by other industries which is hampered by the lack of global HS codes identifying species of *Boswellia* in international trade. Compared to estimates presented in Bongers *et al* (2019) the fragrance industry use of frankincense may be <1% of total global trade, with the vast majority of trade in resin for incense and more recently essential oil. However, the fragrance industry shows a clear trend in increased trade over a short time period with documented figures. If this increase is mirrored in related trades backed up with robust evidence then a clear increase in pressure on harvesting would be demonstrated.

Further, estimates from Bongers *et al* (2019) are for international trade and do not include estimates for domestic consumption and the concomitant pressure on harvesting due to domestic demand. There are currently few accurate estimates of this, although it may vary considerably: for example there are informal suggestions that the majority of frankincense harvested in Ethiopia remains within state borders compared to the majority traded internationally from Somaliland.

- **CITES Listing**

PC25 Sum. 3 (Rev. 1) noted that “harvest of many species for international trade is often not sustainable and several species currently traded meet the listing criteria for inclusion in Appendix II” and that “Range States may wish to consider including Boswellia species in CITES Appendix III where the cooperation of other Parties is required to support national regulation”.

We encourage Parties to consider examining the possibility of including *Boswellia* species in Appendix III, and the potential benefits this might achieve in terms of resources and required capacity development alongside additional data gathering and assessments of whether trade regulation would be beneficial, as a first stage action.

However we make no formal recommendations pertaining to listing either the genus *Boswellia* or any of its constituent species at this stage.

- **Summary**

The current project is working towards achieving practical outcomes based upon additional data gathering and analyses to fill knowledge gaps and subsequently inform decision making to conserve Boswellia species in situ – with reduced threat from a variety of factors that include pressures from international trade.

A Frankincense Resource Portal will hold verified and updateable taxonomic, distribution and harvesting information to support decision making.

Data is being gathered and analysed for all *Boswellia* taxa in all range States. The focus on species range States and specific species currently in trade does not recognise the significant threat from geographical expansion, additional threats beyond international trade, and the changes in fashion, marketing and use of all *Boswellia* taxa in future trade activities and developments.