Frankincense: Tapping into a Sustainable Future

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Frankincense tree © BrangdonJ

Frankincense (syn. Olibanum) is the name for the resinous exudate from trees in the genus *Boswellia* (Burseraceae: Sapindales). The resin is composed of a mixture of terpenes, terpenoids, and gum, and is produced and stored in canals in the inner bark. The resin functions to protect the tree in response to pathogen and insect attacks, and humans have used it for thousands of years both in religious ceremonies and for its transcending and medicinal properties (Groom, 1981; Langenheim, 2003; Pickenhagen, 2017). It was used in Mesopotamia as early as 3,000 B.C. to honor the gods and has been found in ancient Egyptian tombs (Archier and Vieillescazes, 2000; Mathe *et al.*, 2004; Hamm *et al.*, 2004; Pickenhagen, 2017). Frankincense also makes an appearance in the works of the Roman naturalist Pliny the Elder and was praised by the renowned Islamic doctor Ibn Sina (Avicenna).

Modern science has upheld many therapeutic properties of Frankincense. More than 300 chemical components have been isolated from the essential oils alone, and together with the resin have analgesic, anti-inflammatory, antimicrobial, antiseptic, psychoactive, and sedative properties (Gupta *et al.*, 1997; Mertens *et al.*, 2009; Moussaieff and Mechoulam, 2009; Rashan *et al.*, 2019; Rhind, 2019). It is also extensively used in Ayurvedic medicine, Oriental medicine, and perfumery.

Varieties
The taxonomy of *Boswellia* is dynamic, with recent years seeing both the addition and removal of species from the genus (Thulin, 2007; Thulin *et al.*, 2008; Thulin *et al.*, 2019; Thulin, 2020). This is partially due to new species being discovered, and genetic or comprehensive analyses that have revealed species differentiation. There are 23 recognized species, with a 24th species provisionally described from photographs (Thulin, 2020). Almost all 23 species are used for medicine or incense locally where they occur; approximately nine (39%) varieties experience significant international trade (Table 1). Although Frankincense essential oils are best known for their resinous, balsamic, and citrus-peppery notes, their fragrance profiles are diverse (Table 1). Rather than thinking of Frankincense as a single product, we should see it for what it is: a rainbow of diversity – in scent, chemistry, therapeutic action, and conservation status.

Common essential oils used in Aromatherapy are sourced from *Boswellia sacra* (Oman and Yemen), *B. carteri* and *B. frereana* (Somaliland[1] and Somalia); *B. serrata* (India). *B. neglecta* (Kenya, Ethiopia, Somalia), *B. rivae* (Ethiopia, Somalia), and *B. papyrifera* (Ethiopia, Sudan, Eritrea) also make an occasional appearance, while *B. dalzielii* (Burkina Faso, Nigeria, Mali) and *B. occulta* (Somaliland) are substantially rarer oils only now making an appearance on the international market in pure form (DeCarlo *et al.*, 2019a; DeCarlo *et al.*, 2019b; Johnson *et al.*, 2019a; Johnson *et al.*, 2019b; Thulin, 2020) (Table 1) (Figure 1).

Non-commercial species are most often used locally. *Boswellia pirottae* (Ethiopia) is used as incense in churches, while *B. ovalifoliolata* (India), *B. elongata*, *B. socotrana*, and *B. ameero* (Socotra) are used locally in traditional medicine for oral health, to calm an upset stomach, for cuts or lesions, and to ward off "evil spirits" (Miller and Morris, 2004; Thulin, 2020). They may also come to market as adulterants of other

[1] Although not internationally recognized, Somaliland has functioned independently since 1991 with a separate government, currency, military, health, legal, and education systems, and stable democracy.

Boswellia spp.	Country/region	Common resin name(s)	Major components	Therapeutic activity	Fragrance profile
carteri	Somaliland Somalia (Puntland)	Beeyo, Mohor (tree)	α-pinene, α-thujene, myrcene, sabinene, limonene, *d*-3-carene, viridiflorol, *p*-cymene, β-caryophyllene	Antimicrobial; Antiviral; Anti-inflammatory; Analgesic; Chondroprotective; Anxiolytic; Vulnerary; Anti-acetylcholinesterase; Antifungal; Antinociceptive; Cannabimimetic; Immunostimulant	Fresh; Rich; Floral (blossom); Sweet-resinous; Slightly citrus (lemon); Slightly coniferous
dalzielii	Burkina Faso Mali Nigeria	Janawhi; Cricognimu	α-pinene, myrcene, limonene, α-thujene, *p*-cymene	Antimicrobial; Antiviral; Anti-inflammatory; Analgesic; Chondroprotective; Antibronchitic; Gastroprotective; Anxiolytic; Vulnerary; Anti-acetylcholinesterase; Antifungal	Fresh; Earthy-resinous; Coniferous; Green-lemon like; Sweet-woody
frereana	Somaliland Somalia (Puntland)	Maydi; Yagcar (tree)	α-thujene, α-pinene, *p*-cymene, sabinene	Antimicrobial; Antiviral; Anti-inflammatory; Analgesic; Anxiolytic; Antifungal; Anti-acetylcholinesterase	Fresh; Rich; Slightly sweet resinous; Woody; Earthy; Black peppery
neglecta	Ethiopia Kenya Somalia (Puntland)	Borena Type Olibanum (Ethiopia); Dakkara (Kenya)	α-pinene, α-thujene, terpinen-4-ol, *p*-cymene	Antimicrobial; Antiviral; Anti-inflammatory; Analgesic; Chondroprotective; Anxiolytic; Vulnerary; Anti-acetylcholinesterase; Hypotensive; Antinociceptive	Resinous; Sweet-woody; Balsamic; Citrus
occulta	Somaliland	Mohor madow; Beeyo	methoxyalkanes, 4,10-di-*epi*-guaiol, serratol	Antiprotozoal; Anti-itch; Anti-inflammatory (cutaneous)	Fresh; Etherial green-resinous; Vanilla creme
papyrifera	Ethiopia Eritrea Sudan	Etan; Tigray Type Olibanum (Ethiopia)	Octyl acetate, octanol	Anti-inflammatory; Anxiolytic; Antispasmodic; Analgesic	Slightly black licorice-sweet; Ambergris-like; Sour citrus; Leathery-terpeney
rivae	Ethiopia Somalia Kenya	Mirafur; Ogaden Type Olibanum	α-pinene, β-pinene, δ-3-carene, limonene	Antimicrobial; Antiviral; Anti-inflammatory; Analgesic; Chondroprotective; Antibronchitic; Gastroprotective; Anxiolytic; Anti-acetylcholinesterase; Immunostimulant; Mucolytic	Diffusive; Sweet-resinous; Slightly black peppery; Green lemon-like; Fresh-coniferous; Balsamic
sacra	Oman Yemen	Hoojri; Najdi; Shathari; Shaabi	α-pinene, myrcene, sabinene, limonene, δ-3-carene E-β-ocimene/limonene chemotype	Antimicrobial; Antiviral; Anti-inflammatory; Analgesic; Chondroprotective; Antibronchitic; Gastroprotective; Anxiolytic; Vulnerary; Anti-acetylcholinesterase; Mucolytic	Rich; Fresh; Sweet-resinous; Slightly woody; Green-peppery; Sweet-coniferous
serrata	India	Dhup; Salai; Salai Guggul	α-thujene, α-pinene, camphene, sabinene, β-pinene, myrene, limonene, β-phellandrene	Antimicrobial; Anti-inflammatory; Analgesic; Antifungal; Sedative; Antinociceptive	Sweet-resinous; Black peppery; Earthy-resinous; Terpeney
Therapeutic activity: Camarda *et al.*, 2007; Mertens *et al.*, 2009; Abbas *et al.*, 2016; Al-Yasiry and Kiczorowska, 2016; Azam *et al.*, 2016; Mikkhaeil *et al.*, 2003					

Table 1. Nine common internationally traded *Boswellia* spp., their geographic location, vernacular name(s), major chemical components, reported therapeutic activities, and fragrance profile descriptors.

Figure 1. Frankincense resins collected from (L to R): *Boswellia dalzielii*, *B. rivae*, *B. papyrifera*, and *B. carteri*. Photos © Stephen Johnson.

products – *B. ovalifoliolata* is sometimes used as a replacement for *Commiphora wightii* resin, and *B. microphylla* and *B. ogadensis* (Southern Ethiopia) resin may be collected alongside other Frankincense and Myrrh resins (Saha *et al.*, 2015; SPJ pers. obs. February 2020).

B. sacra or *B. carteri*?

There has been a long-running debate about whether *B. sacra* from Oman and Yemen and *B. carteri* from Somaliland and Somalia are separate or the same species. Most botanists have considered them to be the same but highly variable species called *B. sacra* (Thulin and Warfa, 1987; Thulin, 2020). The reason is that there is a shared continuous range of variation, and many intermediate characteristics between what is thought of as classic *B. sacra* and classic *B. carteri*. However, there are some observable differences. *Boswellia sacra* tend to have curly leaves, multiple trunks, and dense crowns while *B. carteri* tend to have flatter leaves, a single trunk, and thinner crowns (Figure 2). Further, *B. sacra* tends to produce oils with 60%+ α-pinene with many minor components while *B. carteri* is known for oils with less than 50% α-pinene and significant other components such as limonene, myrcene, and sabinene (Table 2, p48). Woolley *et al.* (2012) also found distinct differences between these species based on enantiomeric pair ratios and optical rotation. Yet, there have been documented reports of each species taking the opposite appearance and producing oils more consistent with the other species, even though are in different geographic locations (Table 2). There are also reports of intraspecific chemical variations within the same geographic location (Al-Saidi *et al.*, 2012; SPJ personal communication about unpublished research samples, October 2018).

In summary, the prevailing opinion among some experts is that there is a single, variable species called *Boswellia sacra*. Still, genetic studies need to be conducted to definitively determine their status, and it is suggested to maintain the use of different names since *B. sacra* and *B. carteri* denote specific expectations of the origins of their oils, chemistry, and fragrance profiles.

The tapping process involves making cuts into the bark of the trunk and/or branches. The resin is found in canals located in the bark, and when cut, the resin seeps to the surface of the wound and can easily be collected (Figure 3). The trees are not harvested until they have grown to 10-20cm in diameter, which generally takes 10-40 years in the wild (Lemenih and Kassa, 2011; DeCarlo *et al.*, 2017). The trees' lifespan is poorly known but is estimated to be around 100 years and possibly up to several hundred years in rare cases (Farah, 2008; Tolera *et al.*, 2013). Each Frankincense species has a specific season considered the best for resin collection, typically a period of 3-6 months during the dry season (mostly November-April; Somaliland—also June-September). Tapping trees outside of the dry season is considered poor practice by most traditional knowledge systems. The first taps at the beginning of the season are very shallow, barely cutting into the bark—harvesters sometimes refer to this as 'priming the tree' to produce resin. Most Frankincense trees should receive between 3-16 cuts, depending on the size and health of the tree (although overharvesting[2] by putting

[2] Overharvesting refers to putting too many cuts on an individual tree or cutting too deeply into the tree.

Figure 2. *Boswellia carteri* trees in Somaliland (L) vs. *B. sacra* tree in Oman (R). Left photo © Stephen Johnson, right photo © Dr. S. Canney Davison.

Table 2. The percentage (%) of main chemical constituents among and within nine common internationally traded *Boswellia* spp.

Boswellia spp.	carteri	carteri	carteri	carteri	dalzielii	dalzielii	frereana	neglecta	occulta	papyrifera	rivae	sacra	sacra	sacra
Chemotype	α-pinene	limonene α-pinene	mixed	α-thujene	α-pinene	α-pinene myrcene						α-pinene	limonene e-β-ocimene	
Country	Somalia Somaliland	Somalia Somaliland	Somalia Somaliland	Somalia Somaliland	Burkina Faso Nigeria Mali	Burkina Faso Nigeria Mali	Somalia Somaliland	Kenya Ethiopia Somalia Somaliland	Somaliland	Ethiopia Eritrea Sudan	Ethiopia Somalia	Oman Yemen	Saudi Arabia Somalia Eritrea Oman Yemen	India
Constituent														
α-pinene	43.2-78.1	19.6-32.3	12.6-39.8	2.3-14.8	42.6-72.1	22.4-49.0	3.0-63.0	16.7-50.7	tr-2.4	0-3.3	5.3-66.2	59.4-81.4	5.3	0-11.2
α-thujene	0.36-11.7	0.1-12.7	trace-14.0	32.9-50.6	1.2-11.1	4.4-10.5	14.5-43.9	12.7-21.3	0.1-0.6			0-1.0	6.6	11.7-69.8
β-caryophyllene			2.08									0.22		
β-pinene							0.3-4.1	0-13.1	tr-0.1		0-11.3	1.3-2.0	1.8	0-7.5
d-3-carene			0-27.0								6.2-17.3	0-13.6		
e-β-ocimene													32.3	
estragole														6.7-11.6
incensole										0.4-15.3				
incensyl acetate										1.8-12.8				
kessane									0-0.4					1.0-8.0
limonene	0.53-18.6	28.0-50.6	0.8-14.9	1.0-4.8	0.8-4.0	11.5	0.5-2.7		tr-0.1	0-9.9	9.6-28.0	1.7-15.6	33.5	
methoxydecane									26.6-47.9					
methoxyoctane									3.6-9.2					
myrcene	2.3-12.1	0-4.2	0.4-25.7	0-2.9		8.3-19.7			tr-0.1			1.0-11.4	6.9	0-38.0
octanol									0-0.2	2.5-8.9				
octyl acetate			0-13.9						0-0.2	32.7-81.5				
p-cymene	1.7-5.0	1.7-4.1	0.7-11.8	4.3-19.7	Tr-15.8		1.7-13.0	0-11.8	0.1-0.8			0.7-1.2	0.2	0-12.5
sabinene	2.3-7	0.4-4.9	1.4-27.5	5.6-10.9			3.3-8.0		0.1-8.3			0.3-2.5	5.2	
serratol	0-5.9	0-3.1	0-1.8						2.7-31.8					
terpinen-4-ol							0.4-1.7	5.3-29.9	tr-0.6					

Boswellia spp.	Country	Tear grade	Harvesting method(s)	Notes
carteri	Somaliland Somalia	Grades 1-3	Actively tapped	
dalzielii	West Africa	Not graded	Actively tapped and untapped	Traditionally, bark is harvested, and resin is a byproduct; some trees are being transitioned to active tapping
frereana	Somalia	Grades 1-5	Actively tapped	
neglecta	Kenya	Not graded	Untapped	
occulta	Somaliland	Grades 1-3	Actively tapped	
papyrifera	Ethiopia Sudan	Grades 1-5	Actively tapped	
rivae	Ethiopia	Not graded	Untapped	
sacra	Oman	Grades 1-4	Actively tapped	Grades are sometimes subdivided (e.g. Hojary divided into Royal Green Hojary and regular Hojary)
serrata	India	Grades 1-4	Actively tapped	

Table 3. The tear grades and harvesting method within each country of nine common internationally traded *Boswellia* spp.

more than 16 cuts on a single tree is common in some areas). After harvesters have put the initial taps on the tree, they wait for a period of approximately 2-3 weeks for resin production. Subsequently, the resin is scraped off of the tap, and the wound is reopened slightly deeper to allow more resin to exude. This cycle repeats 6-12 times for the rest of the harvesting season. The last 2-3 tapping cycles are highly productive and often produce the best quality Frankincense because at this stage, the resin canals are larger, numerous, and deeper (Lemenih and Kassa, 2011; Al-Aamri, 2014; DeCarlo *et al.*, 2017). One tree can produce on average 0.5 kilos of resin per year (Ali *et al.*, 2009; Al-Aamri, 2014; Tolera *et al.*, 2015; Cherenet *et al.*, 2020). Traditional practices most often mandate a rest period for the trees to allow them to regain their vigor. While the period varies from species to species, it is generally thought that after 2-3 years of tapping, the tree should be allowed to rest (untapped) for 1-2 years. A tree that lives until 100 and is actively tapped after reaching for example 10 years of age should, at the very most, be actively tapped for 67.5 years, or 75% of its life.

Conversely, natural collection involves no tapping. *Boswellia neglecta* and *B. rivae* are generally untapped (Table 3). Instead, the resin periodically bursts through their bark, due to minor insults from grazing animals or simply built-up pressure, and can be collected from the bark or the ground around the tree.

Once collected, resin is often sorted into different grades based on perceived quality. Grading systems differ for each species but are typically based on the size and color of the resin tears. Larger, lighter-col-

Figure 3. (L) Proper harvesting tap on *B. papyrifera* tree, with hand to show size. Just below the current tap is a dark patch where the previous year's tap is healing. Photo © Stephen Johnson. (R) Proper harvesting tap on *B. carteri* tree, Somaliland. Photo © Anjanette DeCarlo

ored tears are considered more desirable in most species; tears with bits of bark stuck to them are considered less desirable. This does not hold true in *B. rivae*, *B. dalzielii*, and *B. neglecta*, which are not graded (Table 3). Burfield (2016) reports that oil quality is dependent on the grade of the tears whereby the superior grades are the freshest, yield more oil, and have an ideal fragrance profile. Conversely, Al-Saidi *et al.* (2012) found no correlation between traditional grade and yield or composition. Furthermore, many buyers of resin for distillation often don't bother to grade the resin as it has not been found to consistently affect yield or composition, with the exception of some variations characterized by greater volatilization and oxidation in the lower grades due to the larger relative surface area of smaller tears, compared to an equal volume or weight of larger tears from the same tree (SPJ pers. comm. with industry).

Land tenure and management systems

Actively tapped species generally have much stronger land tenure systems in place than do untapped species because of the energy investment in tapping. Land is typically privately owned by individuals, by the government, or is communal land (Farah, 1994; Lemenih and Kassa, 2011). Privately owned land is commonly passed down patrilinearly, with the landowner either choosing to harvest the land themselves or rent it out to landless harvesters (Table 4).

Land owned by the government (a common system with Ethiopian *B. papyrifera*) may be rented as a concession to private companies or granted to local cooperatives. Harvesters are often organized into small work parties headed by a leader (the landowner or a foreman) and rounded out by 2-10 or more harvesters that are most often the leader's kin or landless harvesters hired on contract (Farah, 1994; Farah, 2008).

Boswellia spp.	Country	Conservation status	Assessment year	Threats	Land tenure & management systems
carteri	Somalia Oman Yemen (Global)	NT	1998	Overharvesting, insect attack	Family-owned/controlled farms, land often rented to contract harvesters, little outside influence
carteri	Somalia Oman Yemen (Global)	VU (preliminary assessment)	in progress	Overharvesting, insect attack	Family-owned/controlled farms, land often rented to contract harvesters, little outside influence
dalzielii	West Africa (Global)	LC (preliminary assessment)	in progress	Bark harvesting, grazing	Communal grazing land, open access dominated by people from villages nearby
frereana	Somalia Somaliland (Global)	VU (preliminary assessment)	in progress	Insect attack, fragmented populations	Family-owned/controlled farms, land often rented to contract harvesters, little outside influence
neglecta	Ethiopia Somalia Kenya (Global)	LC (preliminary assessment)	in progress	Grazing	Communal grazing land, open access dominated by people from villages nearby
occulta	Somaliland (Global)	EN (preliminary assessment)	in progress	Small area of occupancy, <5 habitats, overharvesting, insect attack	Family-owned/controlled farms, land often rented to contract harvesters, little outside influence
papyrifera	Ethiopia	VU (preliminary assessment)	in progress	Overharvesting, fire, grazing, insect attack, land conversion	Land owned by government, leased either to exporting companies as concessions with private contract harvesters, or granted to local cooperatives of harvesters
rivae	Ethiopia Somalia Kenya (Global)	LC	2018	Grazing	Communal grazing land, open access dominated by people from villages nearby
sacra	Somalia Oman Yemen (Global)	NT	1998	Overharvesting, grazing	Family-owned packets of tribal land; almost all harvesting contracted to outside harvesters
sacra	Somalia Oman Yemen (Global)	VU (preliminary assessment)	in progress	Overharvesting, grazing	Family-owned packets of tribal land; almost all harvesting contracted to outside harvesters
serrata	India (Global)	LC (preliminary assessment)	in progress	Overharvesting, land conversion, grazing	Unknown; at least some harvesting in protected areas by local communities
serrata	India (Delhi)	Interesting, Rare and Threatened	2015	Unknown	Unknown

Table 4. The conservation status, assessment year, management systems, and land tenures of nine common internationally traded *Boswellia* spp. IUCN statuses: LC = Least Concern; NT = Near Threatened; VU = Vulnerable; EN = Endangered. *Boswellia carteri* and *B. sacra* are recognized as the same species per Thulin, 1998; Thulin, 2020. Assessments in progress (Thulin, 2020).

Conversely, non-tapped Frankincense species are most often found on communal lands, collectively owned with open access to all (Tables 3 and 4). Resin collection is left to whomever reaches the trees first and is often a source of supplementary rather than primary income. Main benefactors of this system are pastoral families who collect the resin as they herd their animals.

Threats to Frankincense

Frankincense species generally face some combination of five threats: fire, land conversion, overharvesting, grazing, and insect attack. Fire and grazing tend to reduce regeneration of young plants, while land conversion, overharvesting, and insect attack result in the death of adult trees (Al-Aamri, 2014; Bongers *et al.*, 2019; DeCarlo *et al.*, 2020). Consequently, actively tapped species tend to be at greater risk of decline, as they are susceptible to damage from over-tapping (Figure 4). Furthermore, intensive tapping reduces the ability of the trees to reproduce and weakens their innate resin defense mechanism against insect invasion and pathogens.

Figure 4. A properly harvested *B. papyrifera* tree in Ethiopia (L) and an over-harvested *B. carteri* tree in Somaliland (R), showing too many cuts and scarring. (L) Photo © Stephen Johnson, (R) photo © Anjanette DeCarlo.

Non-tapped *B. rivae* and *B. neglecta* are preliminarily assessed as Least Concern in accordance with the International Union for Conservation of Nature (IUCN) due to seemingly widespread and abundant populations (Alemu *et al.*, 2018, Thulin, 2020). Although there are indications of unsustainable management of tapped *B. dalzielii* and *B. serrata* species in some areas of West Africa and India, they too are preliminarily assessed as Least Concern. Conversely,

reported threatened species include *B. papyrifera*, *B. frereana*, and *B. occulta*. *Boswellia sacra* and *B. carteri*, assessed as one species (*B. sacra*) in 1998 as Near Threatened, is currently undergoing re-assessment as threatened (Thulin, 1998; Bongers *et al.*, 2019; Thulin, 2020) (Table 4). These species face different, and some of the same, threats. For example, *B. occulta* habitat is limited to <5 small areas, *B. frereana* is susceptible to insect invasion, *B. papyrifera* is challenged by overharvesting, grazing, land conversion, and fire, whereas *B. sacra* is heavily impacted by camel grazing and *B. carteri* is impacted by overharvesting (Table 4). It is important to take account of regional variations—some habitats are home to species which are heavily overharvested and likely in decline, while species in different habitats benefit from well-managed systems whereby overharvesting is minimal and regeneration occurs. Therefore, it is crucial to understand that a sustainable source of any particular batch of Frankincense essential oil also depends on the harvested trees' geographic origin.

Harvesters

Exporters, except for those trading Ethiopian *B. papyrifera*, often hold land concessions and hire and train their own resin harvesters. Most harvesters are independent of the companies buying and exporting the Frankincense. The links between the companies and the harvesters themselves are traditionally weak, most frequently with layers of middlemen in between and limited opportunity or interest to check on the condition or management of the source trees. Most often, resins are purchased from nearby villages rather than from the farms themselves; this means that while the buyers may have a good idea of the geographic origin of the resins, visiting the actual farms to check on the condition of the source trees is rare. As a result, management of the trees is almost always controlled by the landowners and harvesters directly interacting with them rather than the exporting companies. Despite the claims of many companies, this continues to be true today, and direct monitoring of the harvested trees is generally limited.

The traditional supply chains of most resins involve significant exploitation of the harvesters. Frankincense harvesting is not considered a desirable or well-paid occupation, with harvesters rarely earning more than a few dollars per kilogram of resin and often ending up trapped in cycles of debt (Farah, 1994;

DeCarlo and Ali, 2014; SPJ pers. comm. with harvesters in Puntland and Ethiopia). When harvesters are living so marginally, it can be difficult for them to make long-term, sustainability-based management decisions rather than immediately getting as much resin as they can. There have been some positive efforts to produce change, with some companies making a greater effort to purchase directly from harvesters, pay a higher price, and make investments in harvesting communities.

Organic certification has been used for many Frankincense species as a way of assuring quality; and even though all wild-harvested Frankincense is organic, certification may be used to claim higher quality. Although this does help to encourage greater transparency of the geographic origins of the resin, it may not be able to accurately identify the specific source trees or guarantee that the harvesting is sustainable (Johnson *et al.*, 2019a). FairWild certification has also been used in limited cases and presents a higher level of assurance of good practices. However, the requirements can be difficult to implement and maintain in remote areas, and the high costs of certification can be prohibitive for smaller companies.

Knowns and unknowns
Despite the long relationship between people and *Boswellia* trees, there are still many unanswered questions. The trees often grow in remote, inaccessible locations, and scientific studies on the ground have been limited. Consequently, there are still many uncertainties on taxonomy, chemotypic diversity, genetic diversity, and conservation statuses.

Multiple species have been identified in the last two years, both from new material being collected (*B. occulta*) and current species being re-examined (*B. samhaensis*, *B. scopulorum*, *B. aspleniifolia*, and *B. "hesperia"*). Given the limited access to many areas with Frankincense, coupled with the small, insular ranges of species such as *B. ogadensis*, *B. globosa*, and *B. occulta*, it is likely that species remain undiscovered or undocumented. Similarly, while there is tremendous chemical variation among species, there is limited information on why and where the variation occurs; the geographic variation data that does exist are often held privately as proprietary information.

Likewise, few strong field studies have been conducted to document the conservation status of the trees. They can be quite exorbitant, ranging in price from $5,000US-$20,000US or more, and areas such as Puntland (Somalia), Sudan, and Yemen are too unstable and dangerous to conduct in-depth, time-consuming field studies. This is because of insurgents, war, or bandits, and in many cases, accessing these areas at all is prohibitively dangerous. As a result, our understanding of the conservation status of Frankincense trees is often limited to reports in the form of anecdotes, rapid and less costly surveys (DeCarlo *et al.*, 2020), or studies of only a single, accessible population (Soumya *et al.*, 2019; Hido *et al.*, 2020; Lvončík *et al.*, 2020). These kinds of reports give us valuable insight into what the trees are experiencing (e.g., health, threats, harvesting pressure) in different parts of their ranges, but they should be interpreted with caution. This is because they may not capture the complete range of variation in population health and management practices. For instance, DeCarlo *et al.* (2020) found concerns about overharvesting in Somaliland; however, practices in Puntland, where there are other significant populations of *Boswellia*, were not examined. Furthermore, most surveys are conducted on accessible, rather than remote, populations. These are also the populations that are most likely to experience elevated harvesting pressure, human disturbance, and land conversion.

Comprehensive data collection, targeting each species, is needed before we can ascertain with confidence their conservation status. On-the-ground quantitative and qualitative surveys of each population, and the communities connected to them, would provide information on harvesting practices, demographic structures, regeneration, and mortality rates. Additionally, this would allow for collection of genetic material, which could help clarify species (for instance, between *B. carteri* and *B. sacra*), and provide an understanding of the genetic diversity within and among populations, which is imperative for long-term conservation and sustainability initiatives (Coppi *et al.*, 2010).

Sustainable harvesting
Is sustainable Frankincense production ultimately possible? Yes, but ensuring sustainable, ethical supply chains to help protect these species is a complex process.

First, it is critical to be able to trace the Frankincense to the source trees; otherwise, it is impossible to know the condition of the trees and to establish effective monitoring protocols. The resin should be traced not just to the regional villages serving as collection hubs, but also to the farms themselves and therefore to the trees. This allows companies to identify the condition of trees on each farm and population trends, and gauge the amount of regeneration. Using technologies like GPS to map the farm locations, shot codes[3] to trace individual bags of resin, and blockchain[4] to preserve information can enhance transparency and indicate the origins of the resins.

Second, companies that buy Frankincense should invest in the communities that produce it. Harvesters cannot be expected to use long-term sustainable management practices if they're not able to feed their families. Harvesters should be paid higher prices for their resin, but these price increases should be tied to using sustainable harvesting practices. Additionally, to take pressure off the trees as a sole livelihood, investments into the harvesting communities should be made to support alternative sources of income, food security, and clean water. Permaculture would be a good option and mixing cash crops and subsistence crops. Frankincense honey is also now being produced from wild trees in Oman, which supports a healthy ecosystem and gives additional value to the trees through enhanced reproduction because of increased pollination. Several people have been working on cultivating Frankincense trees both *in situ* and *ex situ*, in Somaliland, Oman, Israel, India, and the United States (Figure 5). Propagating the trees can be a powerful way to supplement natural regeneration, and plantations could be a good way to take harvesting pressure off wild trees. However, any *ex situ* commercial plantations would need to include robust access and benefit sharing plans and investments into alternative livelihoods for harvesting communities. For many harvesters in places like Somaliland and Puntland, Frankincense is one of the

only significant livelihood options; cultivating their trees without compensating them for lost income would be deeply unfair. Blending multiple Frankincense species, especially less threatened species, is another option to maintain the desired chemical and scent profile while distributing the harvesting pressure more evenly across species.

Figure 5. *B. sacra* seedlings in a nursery in Oman (L) and *B. frereana* trees in a former plantation in Puntland, Somalia (R). Photos © Stephen Johnson.

With the increasing attention on the status of Frankincense trees, there are heightened efforts to coordinate research and disseminate accurate information on these supply chains. For instance, the Global Frankincense Alliance was created in early 2020 to collate and disseminate accurate information on the Frankincense trees, communities, and supply chains, and to promote greater collaboration and networking of the companies, researchers, and consumers interested in protecting them. There are also efforts to regulate the trade of Frankincense more strongly, for instance through the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES), with the goal of protecting the trees by reducing/regulating international trade. However, trade is a double-edged sword: while the high demand is responsible for some overharvesting, the economic worth of highly valuable trees protects the land from conversion and the trees from bark stripping, a fate that frequently befalls less valuable trees. Additionally, weak governance in many areas and strong informal domestic and cross-border trade networks mean that high-level regulation may do little other than drive the trade underground and/or reduce the value of the trees, putting them at additional risk.

Consumer guidelines
It can be challenging to locate ethical and pure sources of plant material and extracts. The companies that convey the implementation of sustainable practices may not always be engaged in recognized and legal management. Without the understanding of how a

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[3] Shot codes are small barcodes that can be read by a standard cell phone camera and that contain a unique identifying number. Placing a shot code on a bag of resin would give a record of where the bag originated and how/where it was transported.

[4] A blockchain is a distributed ledger of data or transactions, consisting of copies (or blocks) linked by cryptographic hash functions. The data in the blockchain is exceedingly difficult to manipulate because it would require independent modification of at least 51% of the ledgers (often representing thousands of copies).

fair and sustainable management system operates, it is common to find that clever "transparent" marketing can leave you convinced that the purchases you make are in the best interest of the plant, Indigenous communities, and the planet.

The most effective tool you can use to make informed decisions is education. This requires having an understanding of the conservation status of a species, knowing which questions should be asked of the harvester, supplier, distiller, or retailer, and requesting proof of permits, GC-MS reports, and/or data when necessary. These will vary across species and primarily depend on their conservation status, and whether they are trade-protected (CITES). Below are some ways to procure Frankincense resin and its extracts so that you, too, are tapping into a sustainable future.

Questions for a resin harvester, supplier, or wholesaler:
1. How and what time of year was the resin harvested?
2. How many cuts were put on each tree?
3. Which country and region do the resins come from and what traceability (e.g., GPS coordinates, shot codes and blockchain) procedures are in place? Do you have proof?
4. What monitoring practices are in place to ensure tree health?
5. What is being done to prevent overharvesting?
6. What are some of the challenges you face? No supply chain is perfect; if the supplier is unwilling to admit there are challenges and say what they are doing to address them, that's a red flag.
7. What threat(s) does the species face?
8. Has the conservation status of the species been determined?
9. Are you purchasing the resin directly from the harvester?
10. Do you help invest in harvesting communities? If so, how?

Questions for an essential oil, hydrosol, or CO_2 producer or retailer:
1. Does the producer or retailer have answers to the ten questions designed for the resin harvester, supplier, or wholesaler?
2. Is there a GC-MS report available for species authentication and to rule out likely adulterants and/or contaminants?

3. When and how was the resin extracted?
4. How do you store your products?
Tip: Know the shelf life of a particular oil, extract, or hydrosol. They will vary and proper storage may extend a shelf life. Avoid products that are old or improperly stored. Oxidation can affect the efficacy and safety of an essential oil. Monoterpene-rich essential oils are more prone to oxidation and should be contained in airtight containers and stored in dark and cool places. Hydrosols should be "cared for like a fine wine; cool, dark, and constant" (Harman, 2015).

Conclusion
Frankincense is one of the most complex aromatics, with a rich history, diverse chemistry, and complicated, unique harvesting systems. Each *Boswellia* species produces a unique resin and faces a different conservation outlook, and with the intricacies of these supply chains, it can seem overwhelming to try to ethically source Frankincense. However, by understanding more about how these resins are harvested and making sure suppliers are supporting fair, equitable, and sustainable supply chains, it is possible to ensure a vibrant future for the Frankincense trees and the communities that rely upon them. ❧

Statement

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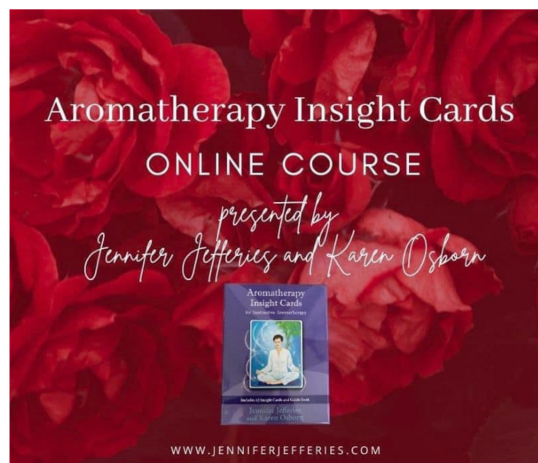
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