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Ecological and Economic Sustainability of Non-Timber Forest Products in Post-Conflict Recovery: A Case Study of the Frankincense (*Boswellia* spp.) Resin Harvesting in Somaliland (Somalia)

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Abstract: Non-timber forest products have often been held out as potential tools for conservation and sustainable development, but sustainability assessments are frequently difficult and time-consuming, especially in conflict areas. Thus, rapid assessments can be useful in providing a broad overview of the harvesting system in order to generate meaningful conservation or development recommendations. Here, we use rapid assessment methodology, including semi-structured interviews and direct observations, to examine the frankincense harvesting system in Somaliland in 2010 and again in 2016 and 2017. We identified significant levels of overharvesting, driven by a breakdown of the traditional management system. Demand for resin and resin prices increased dramatically from 2010 to 2017, at the same time as the tree populations were declining, resource tenure security was weakening, drug use was increasing, and the supply chain was becoming more complex. These factors combine to incentivize short-term unsustainable practices, and the lack of traceability and transparency prevents international buyers from meaningfully engaging with the system. However, new technologies and approaches being employed mean that buyers will soon be able to clearly direct their purchasing in order to incentivize sustainable practices and purchase resin in an ethical manner.

Keywords: Frankincense; olibanum; Boswellia; essential oils; non-timber forest products; sustainability; resin harvesting; conflict areas; post-conflict recovery; Somalia

1. Introduction

Non-timber (or non-wood) forest products (NTFPs) are any biological materials other than timber that are harvested by humans from wild ecosystems and that confer local benefits [1,2]. One of the essential facets of the definition of NTFPs is that they provide local benefits, either as subsistence items or in the form of economic benefits by their sale. There was significant interest in the late 20th century in the prospect of commercializing NTFP harvests to make intact forests highly valuable, thereby preventing or postponing their clearance for timber [3–5]. Although this enthusiasm has since deflated, it has been replaced by a subtler and more nuanced appreciation of the role of NTFPs in conservation and livelihoods [2]. They are frequently vital livelihood components for poorer households, play roles in both poverty mitigation and alleviation, and provide a safety net in times of economic hardship.

Despite the value of NTFPs for livelihoods, there have been repeated questions as to the impacts and ecological sustainability of their harvesting. A meta-analysis by Stanley et al. (2012) found that over a third of studies found extraction unsustainable or inconclusive [6]. The likelihood of sustainable harvesting is dependent on numerous factors, including the target species' life history characteristics, the type of harvest, and the social, economic, and management context in which the harvesting takes place [7,8]. Generally speaking, species that are slow-growing, that require very specific conditions, and that are in areas of insecure tenure are less likely to be sustainably harvested. Commercialization, such as international commodities or conservation-through-use programs, may provide a financial incentive to protect the harvested species' population base, but this requires first and foremost that the income from the NTFP's trade incentivizes successful extraction and conservation [9–11].

Ensuring that product sales translate into conservation and development actions is often hampered both by the difficulty of tracing the supply chain from forest to final customer, and by the fact that thorough sustainability assessments may require substantial effort and time. This is especially true when the harvesting takes place in areas made difficult to access by war, conflict, instability, or general insecurity. Standard sustainability assessments are often not possible in such situations, necessitating a rapid assessment approach. The degree to which these can provide hard data on population trends or harvesting impacts depends on the exact methodology used. At minimum, an assessment would need to result in a broad understanding of the existing harvesting system and impact it is having on the target species and its ecosystem. In such situations, local ecological knowledge can be an important source of understanding (albeit one to be used cautiously) [12,13].

The frankincense industry in Somaliland (Northern Somalia) is an example of a major NTFP that is harvested in an area that is difficult and potentially dangerous to access. Frankincense is an aromatic oleo-gum-resin (hereafter, "resin") that is produced by trees in the genus *Boswellia* Roxb. ex Colebr. (*Burseraceae: Sapindales*) [14]. It is harvested by making small cuts into the trees' cambium and scraping off the exuded resin, re-opening the wound and preparing it for another harvest cycle [15–17]. The resins have been traded and used in medicine and ritual for up to 5000 years, making it one of the world's oldest international commodities [18,19]. Today, the resins are still used in medicine, incense, perfume, and cosmetics. The two main harvested species in Somaliland, *Boswellia sacra* Flueck. syn. *Boswellia carteri* Birdw. (hereafter "*Boswellia carteri*") and *Boswellia frereana* Birdw., are frequently distilled into essential oil for aromatherapy, perfume, and cosmetics [14]. Frankincense is one of the largest industries in Somaliland, supporting up to 10,000 harvester families in the 1980s and likely far more today [15].

Both frankincense species grow in the far eastern Somaliland province of Sanaag, as well as in neighboring Puntland [20]. Somaliland has gained a reputation for comparative stability and safety, but security is tenuous in the east, with frequent border clashes between Somaliland and Puntland forces and battles between local clan militias over resources [21]. In the frankincense-harvesting areas, governance is primarily carried out by traditional elders, and people are often wary of both outsiders and government personnel [22]. Consequently, despite the commercial significance of frankincense, little scientific work has been carried out in this area in the past several decades.

However, recent developments have underlined the need to understand the impact of the frankincense industry on the *Boswellia* trees. First, there has been significant growth in the global demand for essential oils, and consequently, in demand for frankincense resin [23]. Second, studies on other species of *Boswellia* have found decreasing populations and significant threats, including overharvesting, fire, grazing animals, land conversion, and insect attack [24–30]. In Ethiopia, the largest exporter of frankincense in the world, the main producing species, *Boswellia papyrifera* Hochst., is projected to be almost completely eliminated by 2050 [26,29]. Our concern was that the *Boswellia* trees in Somaliland might be on a similar trajectory. In this study, we conducted two rapid assessments of the frankincense harvesting in Somaliland, one in 2010 and again in a two-trip assessment in October 2016 and January 2017, addressing the following questions: (1) Based on both traditional knowledge and scientific studies in other *Boswellia* species, what are the best practices for frankincense

harvesting in Somaliland? (2) To what degree are these practices followed? (3) What are the impacts of different intensity of harvesting on the *Boswellia* trees? (4) What level of understanding and perceptions do the Somali have of the international frankincense industry, and does this have an impact on the forest? (5) How has the industry changed over the past six or seven years since the date of our first assessment? Based on our results, we discuss the status of the frankincense trees in Somaliland, changes in the frankincense trade, and implications for the future of the species, the industry, and the local communities.

2. Materials and Methods

2.1. Study Species

There are two main frankincense-producing species harvested in Somaliland, *Boswellia sacra* Flueck. syn. *Boswellia carteri* Birdw. and *Boswellia frereana* Birdw. Although *Boswellia carteri* is generally considered botanically synonymous with *Boswellia sacra*, the Somali tree populations are frequently referred to as *B. carteri* while the Arabian populations are referred to as *B. sacra* [20]. We follow this by hereafter referring to *B. sacra* syn. *B. carteri* simply as *B. carteri*.

Boswellia carteri (Mohor/Moxor in Somali) and *Boswellia frereana* (Yagcar in Somali) are both deciduous to semi-deciduous trees, rarely growing higher than 8 m. They sometimes have a distinct trunk and sometimes are branched from the base. *B. frereana* most commonly is highly branched near the base. The leaves are densely crowded on the shoot apices and the bark is frequently exfoliating. *Boswellia carteri* trees yield a milky yellow-brown aromatic gum resin locally called "beeyo". The resin from *B. frereana* trees yield golden colored and large tears called "maydi" (these words are sometimes used to describe the trees as well). *Boswellia* leaves are composed of 5–7 pairs of leaflets, 15–75 cm × 8–35 cm, oblong to oval and generally subglabrous. *B. frereana* is distinguished by the more oval leaflets and highly undulating leaves. *B. carteri* flowers have five white petals with a yellow-orange disk, while *B. frereana* has red to greenish-red petals and yellow, green, or purple disks [20,31].

Boswellia carteri trees grow from sea level up to 1400 m, preferring exposed rock as a substrate, and are often found in association with *Buxus hildebrandtii* Baill., *Dodonaea viscosa* Jacq., *Cadia purpurea* Forssk., *Dracaena ombet* Heuglin ex Kotschy and Peyr., and species of *Vachellia* and *Commiphora*. *Boswellia frereana* trees grow from sea level to 750 m, but prefer elevations below 500 m. They grow on exposed rocks or rocky soil, preferring gullies or water drainages. They are often found with *Moringa peregrina* (Forssk.) Fiori, *Lannea obovata* Engl., *Boswellia neglecta* S. Moore, *Dobera glabra* (Forssk.) Poir., *Cadaba longifolia* DC., *Adenium obesum* (Forssk.) Roem. and Schult., and species of *Commiphora* and *Vachellia* [20,31].

2.2. Study System

The study was conducted in the western and central Sanaag region of Somaliland (northern Somalia). The Republic of Somaliland is an unrecognized breakaway country, claiming independence from Somalia and operating as an independent country since 1991 (see Figure 1). Due to its unrecognized status, Somaliland lacks the ability to access many international mechanisms and programs (such as UNESCO World Heritage Sites) that are possible for recognized countries [32].

The Sanaag region consists of a hilly sub-coastal zone of variable width in the north and west, a steep limestone escarpment reaching well above 2000 m, and an uplifted plateau in the south that contains significant areas of gypsum. Precipitation varies with altitude, ranging from 700 mm annually at the peak of the escarpment to less than 100 mm in the subcoastal plain. Vegetation is sparse in subcoastal hills but gets increasingly dense at higher elevations [33].

The frankincense-growing areas in Somaliland are largely split between two major clans, the Habar Jeclo and the Habar Yonis, who are part of the Isaaq clan family, the dominant clan family in Somaliland. Further to the east, the territory transitions to the Warsangeli clan, part of the Darod clan family that

is dominant in neighboring Puntland. The Habar Jeclo and Habar Yonis clans are each divided into sub-clans and sub-sub-clans who control specific territories [34].

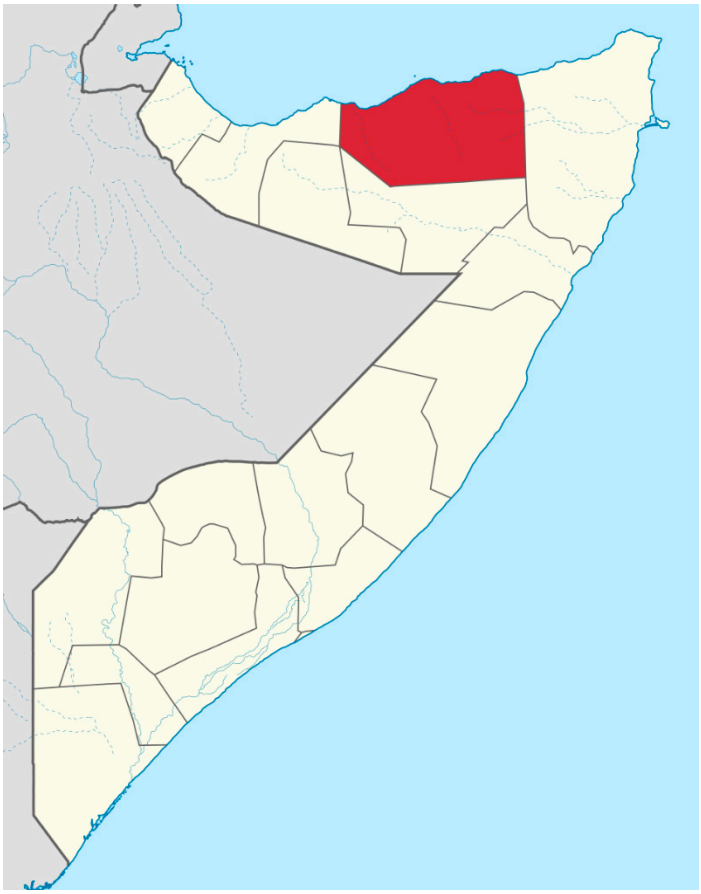

Figure 1. Map of Somalia showing the Sanaag region where the study took place.

Although most Somalis are traditionally pastoralists, herding camels and goats, the Habar Jeclo and Habar Yonis derive a significant portion of their income through frankincense harvesting [35]. Traditionally, harvesters have been partially nomadic, herding animals during part of the year and migrating to temporary harvesting camps during the harvesting season [15]. More recently, permanent villages have been established near the frankincense harvesting areas, allowing easier access. Frankincense harvesting areas are referred to as "farms" by the harvesters, are owned by families and are passed down patrilinearly [15,16]. Although official records do not delineate the boundaries of the farms, they are known very precisely by the owners themselves. Farm owners may either harvest the trees themselves or rent the farm to a harvester without land [15,16]. Management is individually determined, but traditional law (xeer) sets out certain rules to be followed, such as not unnecessarily harming the trees, not cutting branches for livestock fodder, and letting the trees rest periodically. Infractions and other disputes are handled by a trial with the relevant clan elders as judges [16]. Access to the land is controlled by the clans. The central governments in Hargeisa and Mogadishu have little control, and most governance is done by clan elders. There are frequently violent conflicts between clans over resources, especially water. Recent years have seen significant droughts that have devastated livestock and created numerous environmental refugees with limited economic options [21]. This is compounded by blood feuds. Often, the attitude after a deadly clash is that for peace to be achieved, an equal number must die on each side or a price paid usually in camels or brides. [34]. As a result, a given clash may then result in a series of revenge killings on each side. This, along with the distrust of outsiders, the potential for Al-Shabab terrorist activity, and previous

kidnappings in the area, makes the area difficult to access and potentially dangerous in which to spend significant periods of time.

2.3. Rapid Assessment Methodology

Given the limitations posed by the study system, we used a rapid appraisal approach to quickly gather observations on the health of the trees and the knowledge and perceptions of the harvesters and other key informants as per harvesting practices and the supply chain [36]. We carried out participatory semi-structured and narrative interviews and focus groups with a total of 31 participants in 2010 and 101 participants in 2016 and 2017. In 2016–2017, the participants consisted of 18 harvesters, 19 traders, 2 NGO workers, 41 harvesting community members in five village community meetings, 19 elders from harvesting areas, and two government personnel. We used the snowball method to identify further interviewees as we went along [37]. Semi-structured and narrative interviews were used in order to allow respondents to direct the conversation to aspects they considered especially important or impactful while maintaining a focus on key research questions. As a result, interviews with harvesters and traders often involved discussions of sustainability issues, whereas community meetings and elders largely focused on socio-economic and political issues. We used triangulation with at least three separate informants to authenticate key pieces of information. Information on the best practices for harvesting was compiled via a review of existing literature, interviews of key informants, and scientific studies conducted in *B. sacra* in Oman and *B. papyrifera* in Ethiopia and Sudan [27,38–40].

Direct observations of four frankincense harvesting locations were made in September-November 2010, observations of 10 harvesting locations were made in October 2016 and January 2017, and the evidence of harvesting practices (number and depth of cuts, condition of trees, etc.) was compared to the best practices. We walked through the harvesting locations and examined the number and depth of the cuts on the trees. If there were more than 12 cuts on the majority of trees (Table 1), we considered the area to be overharvested.

In January 2017, conditions permitted collection of forest density data in one of the 10 harvesting locations. Using a DJI Phantom 3 Pro drone, we filmed 10 transects of 125 × 36.5 m (4.57 hectares total area surveyed). Trees visible in the videos were categorized into healthy (100% intact crown), mostly healthy (66–99% intact crown), somewhat stressed (33–66% intact crown), stressed (1–33% intact crown), and dead (standing, fallen, or with a characteristic visible white mark on the rock where the tree stood). Crown intactness was judged based on the number of branch tips with leaves present and whether the leaves were damaged. Seedlings were not counted as they were too small to be reliably identified. Only trees with a majority of the crown visible were counted. Trees that were mostly outside the transect frame were not counted. Likewise, frankincense trees sometimes grew closely with other species, making it difficult to clearly discern which crown was which. We excluded these trees from the analysis. This location is a permanent settlement established right in the frankincense fields, with easy access to roads. Therefore, we would expect to see a higher than average level of overharvesting compared to areas that are more remote, lack easy access, and are only seasonally settled.

We conducted one field appraisal in September–November 2010, and two field appraisals in October 2016 and January 2017, and remained in contact with our key informants throughout 2017–2019.

In 2010, interviews were transcribed and coded using MaxQDA software according to our questions. This was done to clarify the context and relationships between the questions asked. The interviews were coded first deductively, resulting in seven main themes emerging, which were then used for a second round of coding, this time inductively. A code matrix chart was generated to show the relationships between the codes and the frequencies with which they were used by different stakeholders.

Table 1. Best practices for harvesting of frankincense in Somaliland, compiled from interviews with elders and existing literature.

	***B. carteri* (Beeyo)**	***B. frereana* (Maydi)**
Age of First Harvest	First tapping at 15–40 years old Only tap trees greater than 10 cm DBH	First tapping at 15–40 years old Only tap trees greater than 10 cm DBH
Harvesting Season	April-October (Xagaa) Harvesting outside this season is highly damaging to the trees.	September–June (Deyreed) Harvesting outside this season is highly damaging to the trees.
Resting of Trees	Tap trees for 2 years, then rest for 1 year If the milk does not immediately come out when cut, the tree should be rested. If the resin is red, the tree should be rested.	Tap trees for 2 years, then rest for 1 year If the milk does not immediately come out when cut, the tree should be rested. If the resin is red, the tree should be rested.
Cutting Cycles	8–10 cutting cycles per season First 3–5 cycles produce little resin. High resin production on cycles 6–8. 15–20-day intervals between cutting cycles	8–12 cutting cycles per season Best resin produced in the later cycles 15–30-day intervals between cutting cycles
Number of Wounds	Trees should receive 3, 6, or 9 cuts depending on size Young trees should not have more than 3 cuts The largest, oldest trees should not have more than 10–12 cuts	Trees should receive 3, 6, or 9 cuts depending on size Young trees should not have more than 3 cuts The largest, oldest trees should not have more than 10–12 cuts
Size of Wounds	The first cut should not be bigger than 3 × 4 cm Each cutting cycle makes the wound slightly larger The final wound should not be bigger than 6 × 10 cm	The first cut should not be bigger than 3 × 4 cm Each cutting cycle makes the wound slightly larger The final wound should not be bigger than 6 × 10 cm
Placement of Wounds	Wounds should be made in a channel along opposite sides of the trunk only Wounds should be at least 30 cm apart At low elevations, wounds should be made on sides opposite winds and sun. At high elevations, wounds should be made on sides facing winds.	Wounds should be made in a channel along opposite sides of the trunk only Wounds should be at least 30 cm apart
Gathering Resin	Resins should be removed at each 15–20 day cutting interval Resins should only be removed when they are no longer sticky Resin should be harvested at each interval	Resins should be removed at each 15–30 day cutting interval Resins should only be removed when they are no longer sticky Resin on the wound should be harvested at each interval, but resin running down to form tears should be harvested on the final cycle

3. Results

3.1. Best Practices for Harvesting Frankincense

Harvesting practices varied somewhat between the two species of frankincense, mostly in the time of year in which they are harvested (Table 1). For both species, respondents agreed that trees should not be tapped until they are at least 10 cm in diameter, that each tree should receive 3–12 taps depending on how large it is, that cuts should generally be shallow (not penetrating into heartwood), and that the trees should only be harvested for a single season each year. *Boswellia carteri* trees are to be harvested for three to six months during the summer season (Xagaa), while *B. frereana* trees are harvested for six to nine months during the winter season (Deyreed).

3.2. Current Practices and Sustainability of Harvesting

In 2010, overharvesting, lack of protection for the trees, and dying trees emerged as themes. These were strongly correlated with low income, indicating that poverty in the region was contributing to the unsustainable practices. Illegal harvesting ("thieves") was also noted as a factor contributing to tree mortality (Figure 2). In 2016/2017, the majority of harvesters (78%) and traders (63%) agreed that best practices were not being followed across much of the region, although there was not a clear consensus on which geographic areas were most affected. Traders were relatively reticent about the drivers of the overharvesting (only 21% cited a cause), but harvesters were more explicit. Many (78%) of the harvesters cited the impact of illegal harvesting, in which an outsider harvests trees that do not belong to them. Other issues most commonly identified were making too many cuts on individual trees

(72%) and conducting two harvests per year as opposed to just once (56%). Most harvesters (56%) agreed that an unusual number of adult trees had been dying recently. This was attributed both to overharvesting, illegal harvesting, and to attacks by a boring insect (locally called "xare", probably species of Cerambycidae or Buprestidae beetles), which were said to be increasing (28% of harvesters cited xare as a key issue). There were no clear geographic patterns in the responses.

Figure 2. The correlations after two rounds of coding of interviews from 2010. Larger boxes indicate greater correlation, and no box indicates no correlation. Color is not significant.

Interestingly, in 2010 the interviewees felt that *B. frereana* was under the strongest harvesting pressure, generating a sense that this species was of greatest sustainability concern. This was corroborated by field observations. In 2016 and 2017, by contrast, the understanding of the harvesting pressure had shifted, with the three largest exporting companies confirming that *B. carteri* was in far greater demand than *B. frereana*. This latter understanding was corroborated by our observations in which we observed a greater proportion of *B. carteri* trees that were overharvested relative to *B. frereana* trees.

In our direct observations, the majority of trees were receiving more than 12 cuts per tree (indicating overharvesting) in eight out of ten surveyed locations (Figure 3) with *B. carteri*, and one out of three locations with *B. frereana*. Whereas large adult trees, based on traditional and scientifically-established best practices, should not receive more than 10–12 taps (Table 1), we frequently observed trees with 20–40 cuts, many of which penetrated through the cambium to the heartwood. In some cases, we observed trees with 100 cuts or more, indicating severe overharvesting. In the one location where we were able to conduct transects, transect data indicate that of the observable trees, more than a quarter were dead (Table 2). A third of the trees were healthy or mostly healthy, while the rest (40%) were somewhat or very stressed. Even in overharvested areas, however, we observed fairly robust regeneration with a substantial number of seedlings.

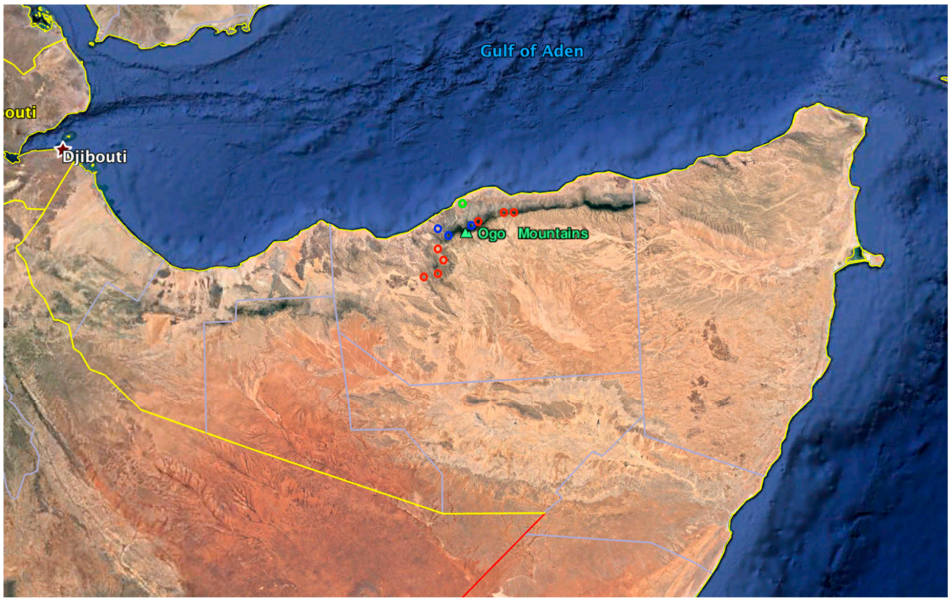

Figure 3. Surveyed locations in the harvesting region. Green points were surveyed only in 2010, blue points were surveyed in both 2010 and 2016–2017, and red points were surveyed only in 2016–2017.

Table 2. Health of 404 *Boswellia carteri* trees in 10 transects surveyed in one harvesting location in January 2017.

	Healthy	Mostly Healthy	Somewhat Stressed	Very Stressed	Dead
Total	45	84	97	65	113
%	11	21	24	16	28

Several reasons were identified for the high percentage of stressed and dead trees. All management of the frankincense trees is up to the individual landowners and harvesters, there is currently no centralized governance. Indeed, 66% of community members and 89% of the elders interviewed expressed strong distrust of government, NGOs, the exporting companies, and other non-local entities. Landowners can either harvest their own land or rent the land to someone else to harvest. Two harvesters and four traders stated that landowning harvesters tend to manage their trees better. However, the frankincense fields are passed down patrilinearly, and when there is a conflict in ownership between multiple heirs, it is resolved by rotating management, one heir has the right to harvest one year, while another heir is given the right to harvest the following year, etc. This has the effect of reducing management cohesiveness and continuity. The perception that making more cuts than recommended increased frankincense yield was commonly reported by younger harvesters, although this view was contradicted by elders and very experienced harvesters. Interestingly, in 2010 this perception led to overharvesting due to the low prices for resin and the harvesters' desperation to make ends meet. In 2016/2017, it was due to the pressure exporters were putting on harvesters to increase production, and harvesters' attempting to capitalize on the increasing prices (Table 3). Additionally, several traders and community key informants (though not the harvesters themselves) cited the increased use of khat, a commonly used drug with a moderate stimulant effect, as a driver of poor practices. Illegal harvesting emerged as a serious concern and was mentioned without provocation by the interviewees. Illegal harvesting was reported to have increased from 2010 to 2016–2017 overall. However, 2016 and 2017 were especially difficult as the result of a series of harsh droughts that increased the number of internally displaced environmental refugees. The illegal harvesting was said to be related to two primary factors: (1) Youth or internally displaced people, desperate for income, who are resorting to illegal harvesting, and (2) increased desire for khat, which encourages both unsustainable collection practices and illegal harvesting.

Table 3. Changes in the Somaliland frankincense market from 2010 to 2016/17.

2010	2016/17
One kg of average resin: $1 USD	One kg of average resin: $6–9 USD
Low demand	High demand
Landowners underbidding each other to sell their resin	Major exporters competing for a limited supply
Mainly exportation of resin for the Middle Eastern market	Exportation of resin for distillation into essential oil
Last FAO analysis (1987) in all Somalia: 200 tonnes of *B. carteri*, 800 tonnes of *B. frereana* [41]	Estimate of 1400–2000 tonnes of *B. carteri*; *B. frereana* market is greatly reduced

3.3. Frankincense Industry Evaluation

All traders interviewed agreed on three points:

1. There is little to no effective regulation of the industry;
2. they are seeing declining quality and quantities of resin;
3. traders frequently have to compete with each other for access to the resin.

The traditional system of purchasing resin requires the purchaser to provide a pre-payment of money or food to the harvesters and then collect the resin at the end of the season. However, in the current climate of competition, some harvesters would fail to honor the contract by selling their resin to a different, higher bidder at the end of the season. Likewise, some traders fail to pay for the balance of the resin unless the harvesters agree to sell the next season's resins as well. They may also inflate the value of the food pre-payments, effectively reducing harvester compensation (mentioned by 17% of harvesters, 89% of elders, 37% of community members interviewed). The competition grew much more intense from 2010 to 2016/2017, whereas prices were commonly as low as approximately $1/kg in 2010, they reached a zenith of $9/kg in 2016/2017. In 2010 the harvesters these low prices and demand meant that harvesters were desperate to sell their resin, and often under-bid each other in order to do so. By 2016/2017, the market had increased sufficiently that exporters were competing for access to the best resins and pushing harvesters to produce larger and larger amounts.

Conflicts in countries that have historically used a significant amount of *B. frereana* frankincense, such as Yemen and Libya, have depressed the trade in this resin (21% of traders), while the rapidly expanding essential oil market has driven a much greater demand for *B. carteri* resin (53% of traders, confirmed by 33% of harvesters). *Boswellia carteri* essential oils have long been used and continue to be used in perfumery and cosmetics, but the new aromatherapy and aromatic medicine markets for essential oils have driven much of the recent market expansion [23].

The supply chain also grew more complex from 2010 to 2016/2017. In 2010, Somali harvesters supplied resin directly to sorting houses, where it was cleaned and then sold via Somali middlemen primarily to Arab wholesalers. The wholesalers then sold the product onwards to importers in the USA, EU, and Asia (Figure 4).

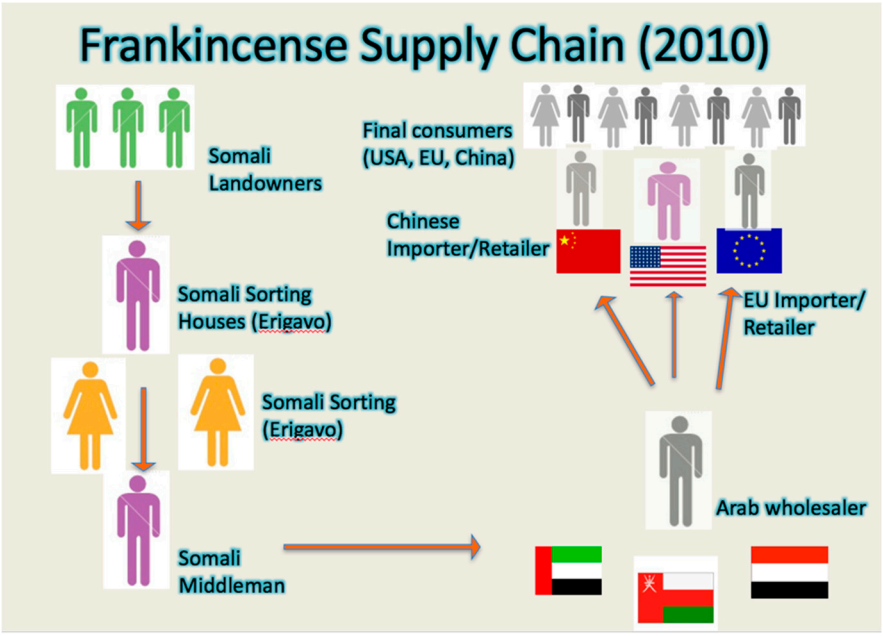

Figure 4. Somaliland frankincense supply chain in 2010.

By 2016/2017, the supply chain shifted (Figure 5). Somali-owned exporting businesses typically purchase the resin directly from landowners via middlemen they employed, then clean the resin at sorting houses they own or rent. The resin is then exported to distilleries in the USA, EU, or UAE, where it is often distilled into essential oil. These distilleries are most commonly owned wholly or partially by the Somali exporters. Thus, Somali companies have, in many cases, captured secondary manufacturing/value addition, a significant improvement since 2010 when only raw materials were exported.

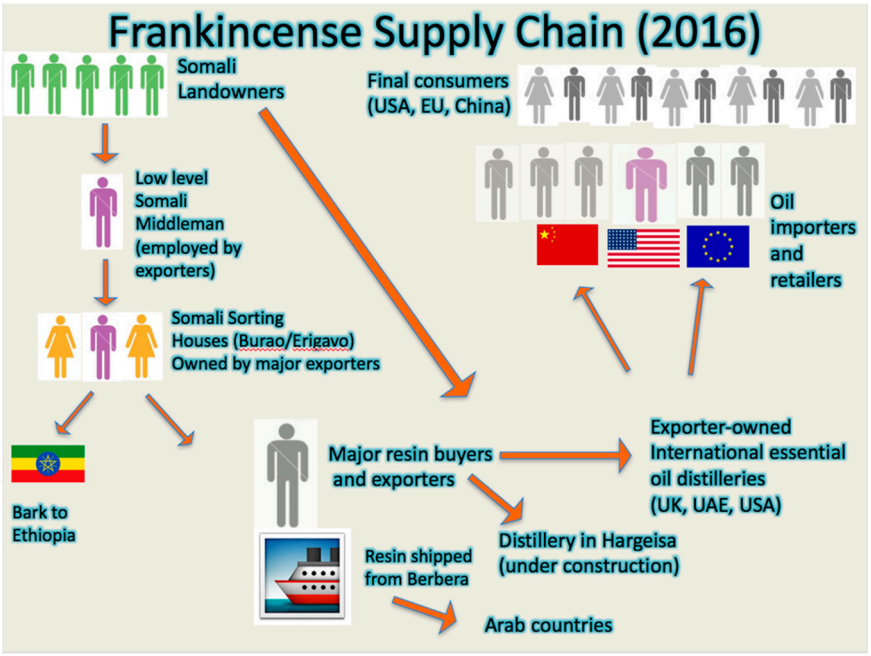

Figure 5. Somaliland frankincense supply chain in 2016.

4. Discussion

Our research aimed to use rapid assessment techniques to gain insight into the sustainability of frankincense harvesting in Somaliland, and the structure of the frankincense industry in Somaliland. Through our three field assessments in 2010, 2016, and 2017, we were able to determine the best practices for harvesting frankincense based on Somali traditional ecological knowledge and scientific studies in *B. sacra* in Oman and *B. papyrifera* in Ethiopia, compare these to current practices, and gain insight into the systems surrounding and driving harvesting behavior.

In this study, we used a rapid assessment approach to quickly gather data and gain an understanding of the systems at work in difficult to access and potentially dangerous area. There are positive aspects to this approach, such as the ability to quickly gain insight into the situation on the ground, but also drawbacks [12,36]. We have very few quantitative data on the ecology of the frankincense trees or the development status of the frankincense-harvesting communities. We, therefore, cannot (and do not try to) quantify the population trends of Somaliland's *Boswellia* trees. While our data largely indicate overharvesting and decline, some informants claim that there are large areas of untapped *Boswellia* trees that are perfectly healthy. As we have thus far seen no solid evidence (photos, videos, GPS points, specific locations, etc.) of such locations, we cannot say for certain whether they exist or not and if they do, how extensive they are. We do not rule out the possibility that further research may uncover such areas, but we do not currently have access to data for such areas. Further research will be needed to be able to quantify population trends, status, and ecology of *Boswellia* trees in Somaliland.

Overall though, in both the 2010 and the 2016/2017 field surveys raised concerns about the harvesting practices being used, and the pressures driving those practices. We observed varying degrees of overharvesting in the majority of the locations we visited. Furthermore, our informants reported elevated levels of tree mortality due to overharvesting, illegal harvesting, and insect attacks. The transect data from a single harvesting location is insufficient to extrapolate across the growing region. We cannot quantify the impact of the various pressures on the frankincense trees nor the population trends. The single location where we performed the transects, Madar Moge, is also a permanent community where people used to visit seasonally but are now permanently settled, with the trees easily accessible. We would expect to see higher levels of harvesting in such locations. Still, based on the body of available evidence, we conclude that it is likely that tree population

declines are occurring in some areas. In contrast to the lack of regeneration seen in other *Boswellia* populations [22,23], we observed fairly robust regeneration, indicating that the major concern with Somaliland frankincense populations is adult decline and mortality.

Although, according to harvesters, harvesting pressure switched from *B. frereana* to *B. carteri* from the first to second field assessments, in each case, harvesters expressed concern about the impact of the industry on the trees. The harvesting communities appear to be caught in a poverty trap, in which increasing demand for the resin and consequently rising prices have interfaced with the pervasive poverty and desperation to lead to resource overexploitation rather than improved economic development outcomes [42]. The strong kinship system in Somaliland also contributes to this problem by rapidly diffusing any economic profits [43]. Consequently, rising resin prices—from $1/kg in 2010 to $6–$9/kg in 2016/2017—do not appear to have resulted in improved lives.

First, the per capita resource base has likely decreased due to a mix of declining tree health and the increasing human population. Frankincense trees in the wild take decades to mature to the point of being able to be tapped for resin, which means that likely only a few individual trees matured to the point of being able to be tapped between 2010 and 2017. Additionally, the increased harvesting pressure has probably increased the overall adult tree mortality, reducing the total number of trees available for harvest. Finally, the increasing number of harvesters due to large family sizes meant that more people needed to be sustained off of fewer trees per individual.

Second, resource tenure security decreased. Although the same traditional systems were maintained (there was not necessarily a change in ownership of the land itself), individual harvesters were less able to count on their own resource. This was partially due to the increasing family sizes, and consequent rotational management system instituted: While one family member may use sustainable practices, they cannot necessarily be sure that other members of the family will use the same practices, which gives them an incentive to focus on short-term unsustainable gain rather than take a long-term view. Additionally, the increasing competition for resin amongst exporters and the market disturbances that resulted, such as exporters undercutting each other's contracts and prices increasing or falling according to the competition, have harvesters less sure about who they will be able to sell their resin to and at which price, an instability that again incentivizes short-term strategies. Illegal harvesting further reduced effective land tenure and increased in recent years due to a series of harsh droughts that increased the number of environmental refugees, as well as a youth bulge created by large family sizes and limited employment opportunities [44]. As a result, the number of potentially desperate people in need of income with few opportunities has increased, reducing landowners' confidence that their sustainable practices will result in long-term success.

Third, the increased prevalence of khat use has diverted funds from covering household needs to purchase the drug. Khat use also contributes to the breakdown of traditional practices and social identities, contributing to the overharvesting issues [45,46].

Market dynamics further complicate the pressures on frankincense harvesters. Price fluctuations and failure to honor sale agreements erode harvesters' confidence of a sufficient payout at the end of the season, while overall price increases incentivize maximizing resin collection while the prices are high. The switch from primarily *B. frereana* exports to primarily *B. carteri* exports also has the effect of re-shuffling harvesting pressure and income distribution, as not all families own both species of trees. Additionally, developing approaches to detect the variable chemical composition of frankincense essential oils has given companies an enhanced ability to discern between different types of resins [47]. Individual locations or villages often show unique chemical compositions (unpublished results from our laboratory). Although the differences may be modest between different villages, and the reasons for the variation are not yet known, they can still be commercially significant. Companies often target specific chemotypes, with some types more popular than others [48]. This contributes to the fine-scale spatially differential distribution of income and harvesting pressures.

The result of the interplay of these various factors is a vicious cycle. Harvesting pressure is intensified by the increasing prices, decreasing resource tenure security, and increasing population,

which leads to an increase in unsustainable practices and, thus, a declining resource base. The reduced number of adult trees then reduces the per capita resource availability and pushes prices higher due to the limited resource availability against an ever-expanding market. This cycle fuels unsustainable practices, increasing desperation, and declining tree health, quantity, and resin quality. In the course of the field surveys, we encountered numerous individual harvesters who were well aware of the issues and were attempting to maintain sustainable practices. However, given the systemic pressures that incentivize short-term strategies in the current situation, many harvesters are unable to make decisions based on their long-term interests, despite their depth of knowledge of the potential consequences. It would be unfair to blame people caught in a poverty trap for following what the system incentivizes.

Rising market demand clearly has a deleterious effect on the frankincense trees, but very low demand or bans can be just as damaging. Low prices can lead to overharvesting through desperation to make ends meet, as was the case in 2010. By contrast, a controlled/moderate demand for resin may prevent more damaging forms of use. Trees whose resin is of little value are frequently bark stripped in Somaliland, fate frankincense trees are likely to suffer if the resin cannot be sold (A.D. pers. comm. with harvesters). Grazing animals are generally kept out of the frankincense fields, a significant benefit that helps support tree regeneration by protecting seedlings and may be lost in the case of a ban.

The consideration of the impact of a reduced market is especially timely given the recent issue of whether the frankincense genus, *Boswellia*, should be listed in CITES Appendix II. Appendix II requires permitting by the country CITES Management Authority before the resin can be legally exported, which would obviously create problems in Somaliland, given the strained relations between the Federal Republic of Somalia and the unrecognized breakaway Republic of Somaliland. Whether CITES would be a help or hindrance to sustainability efforts is not clear, but efforts to organize international cooperation to improve the sustainability of the trade, in general, have been increasing. There was an international frankincense conference organized in 2018, and in 2019 an organization called the Global Frankincense Alliance was founded to promote cooperation between frankincense stakeholders. Other international mechanisms, such as the Convention on Biological Diversity and Nagoya Protocol, provide legal frameworks for the ethical sourcing of products like frankincense, and could stimulate donor interest in large-scale sustainable harvesting programs. The degree to which these efforts will impact the trees and communities in Somaliland remains to be seen.

The increasingly integrated supply chain and expanding international market have concentrated wealth in the hands of a small number of exporters without substantially improving the livelihoods of ordinary harvesters, despite the best intentions of some companies to effect positive changes. Key to the success of this effort will be the effective branding of the frankincense as a development product, so price premiums can be harnessed from socially conscious consumers. However, the frequent conflicts and limited access to the region have substantially reduced buyers' ability to trace where their resins come from and ensure that their purchases encourage sustainable practices. Product tracking is key for brand premium confidence from consumers. Although organic certification has been used in several cases in Somaliland as a way to prove sustainable practices, it has been shown to be ineffective at distinguishing the source trees and thus at ascertaining sustainable practices [46]. There is, furthermore, no evidence that organic certification has led to improved development outcomes. Consequently, buyers have difficulty making informed decisions and directing their economic power in a way that improves the situation rather than fueling the continued decline of the trees.

Although the trees are unlikely to become extinct in the near future, the systemic pressures that incentivize short-term unsustainable practices are concerning. The conflicts in the region have also reinforced a narrative of an inability of the international buyers to engage meaningfully with landowners and harvesters, and the lack of traceability and transparency in the supply chain have limited their ability to direct their buying in a productive direction. However, new approaches currently being employed give hope for the future. One supplier has obtained FairWild Certification, a much more rigorous certification that gives greater assurance of sustainability than organic certification, and others are employing blockchain-based apps or sophisticated supply chain management software

to improve their monitoring and demonstrate traceability. These new approaches have the potential to offer buyers the transparency needed to direct their purchasing in a way that helps incentivize long-term practices and break the cycle of a declining resource.

5. Conclusions

The Somaliland frankincense supply chain is experiencing significant pressure from increasing demand for resin, which has resulted in a high level of unsustainable harvesting without significantly increasing livelihood outcomes or community development. From 2010 to 2016–2017, the demand and resin prices have increased substantially, with a declining resource base and reduced resource tenure security, which has pushed harvesters into unsustainable practices in order to capitalize on the increased prices. This is due to systemic incentives towards short-term strategies, the poverty trap, and unsustainable practices, on the part of landowners and harvesters. At the same time, the opacity and lack of traceability of the current system have prevented meaningful engagement by the international buyers and has limited progress in establishing sustainable systems and development. New technologies and approaches being implemented now, however, offer a chance to break this damaging cycle, if buyers are willing to engage with them. The linkage of this effort to international environmental agreements such as the Convention on Biological Diversity is also likely to mobilize donor interest in the species and more sustainable harvesting methods being up-scaled.

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