Floricultural Potential for Adaptable, Wind-Tolerant, Flowering Perennial, *Artemisia arctica* Less. ssp. *arctica* ‘Boreal Wormwood’

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EXECUTIVE SUMMARY

Artemisia arctica ssp. *arctica*, commonly known as ‘Boreal Wormwood’, is an herbaceous perennial of the family *Asteraceae* which grows to a height of approximately 25-40 cm and produces subtle, slightly aromatic, drooping, yellow to slightly red, disk flowers from July to September. It is natively found within inhospitable environments throughout the meadows and mountains of Northwestern North America and Northeast Asia. Consequently, this subspecies is extremely adaptable and resilient, possessing the ability to withstand: highly acid to slightly alkaline soil pH, moderate to dry soil moisture levels, low to moderately-high soil nitrate levels, soil disturbance caused by frequent freeze and thaw events, intense sunlight, high winds, violent storms, moderately-high heat stress and extreme cold. Accordingly, this subspecies has excellent market potential as a hardy, adaptable, low-maintenance, herbaceous, flowering perennial for retail and wholesale nursery markets in northern climates. Specifically, its late bloom-time, as well as its storm, flood and drought tolerance, make it an appealing option for consumers seeking to add mid- to late-summer seasonal interest to their gardens, and improve their landscaping’s resilience to global climate change. Historically, this subspecies was also used by native peoples to treat a large diversity of ailments, ranging from diabetes and cancer to the common cold, and may possess phytotherapeutic benefits that would enable it to be marketed as a value-added, medicinal product. From a production standpoint, *Artemisia arctica* ssp. *arctica* roots easily, making it an excellent candidate for rapid propagation and market introduction. Its resilience to colder temperatures also makes it an excellent choice for high-tunnel production in the Upper Midwest. Moreover, its potential obligate, long-day photoperiod requirement may enable it to be forced year-round for late-fall flowering to compete with crops such as *Echinacea* and *Chrysanthemum*, or for flowering during early May to take advantage of Mother’s Day sales.

I. INTRODUCTION

A. Study Species.

Artemisia arctica Less. ssp. *arctica* is a terrestrial, herbaceous, perennial of the family *Asteraceae*, producing mildly fragrant and unassuming, drooping, yellow to slightly red, disk flowers and growing to a height of approximately 25- 40 cm (Hultén 1968; Shultz 2006) It is classified as a subshrub or hemicryptophyte, based upon Raunkiaer's life-forms classification system, due to its woody roots and herbaceous stems, which are green to reddish, smooth to slightly hairy (Hultén 1968; Beentje and Williamson 2016). Leaves are approximately 5-8 cm long by 2-3 cm wide, arranged in a circular configuration around the base of the plant, staggered on the upper stem and with smooth to slightly hairy leaf texture (Figures 1 and 2). Petioles are absent; thus, the leaves are sessile (Hultén 1968). *Artemisia arctica* ssp. *arctica* blooms in mid- to late summer (Shultz 2006, 2012). If allowed to spread freely in the landscape, it naturally forms clumps by vegetative reproduction via stolons and may also proliferate by wind dispersal via seed (Hultén 1968; Shultz 2006).

Figure 1. *Artemisia arctica* ssp. *arctica*, also known as *Artemisia norvegica* ssp. *saxatilis*. Illustration from Swedish Botanist, Carl Axel Magnus Lindman's "Bilder ur Nordens Flora" published 1901-1905 (Lindman 1905)

Figure 2. *Artemisia norvegica* ssp. *saxatilis*, Aug 12, 2006, Alpine County, California, US © 2006 Steve Matson (Matson 2006)

B. Taxonomic Classification and Geographic Distribution in the Wild.

Artemisia arctica ssp. *arctica*, more commonly known as 'Boreal Wormwood' or 'Boreal Sagebrush', is synonymous with a number of distinct binomial classifications including: *Artemisia arctica* ssp. *comata* (Rydberg) Hultén, *Artemisia norvegica* var. *pacifica* Gray, *Artemisia arctica* subsp. *ehrendorferi* Korobkov, *Artemisia norvegica* var. *piceetorum* S. L. Welsh & Goodrich, *Artemisia norvegica* ssp. *saxatilis* (Bess.) Hall & Clements, *Artemisia arctica* ssp. *beringensis* (Hultén) Hultén, *Artemisia chamissoniana* Bess., *Artemisia chamissoniana* Bess. var. *saxatilis*, *Artemisia chamissoniana* Bess. var. *unalaschcensis*, *Artemisia chamissoniana* var.

katzebuensis Bess., *Artemisia longepeduculata* Britt. & Rydb., and *Artemisia cooleyae* Rydb. (Hultén 1968; Shultz 2006; USDA NRCS 2019). This unusually large number of synonymous botanical names is likely attributable to the subspecies' large geographic range and the correspondingly high probability of rediscovery and reclassification.

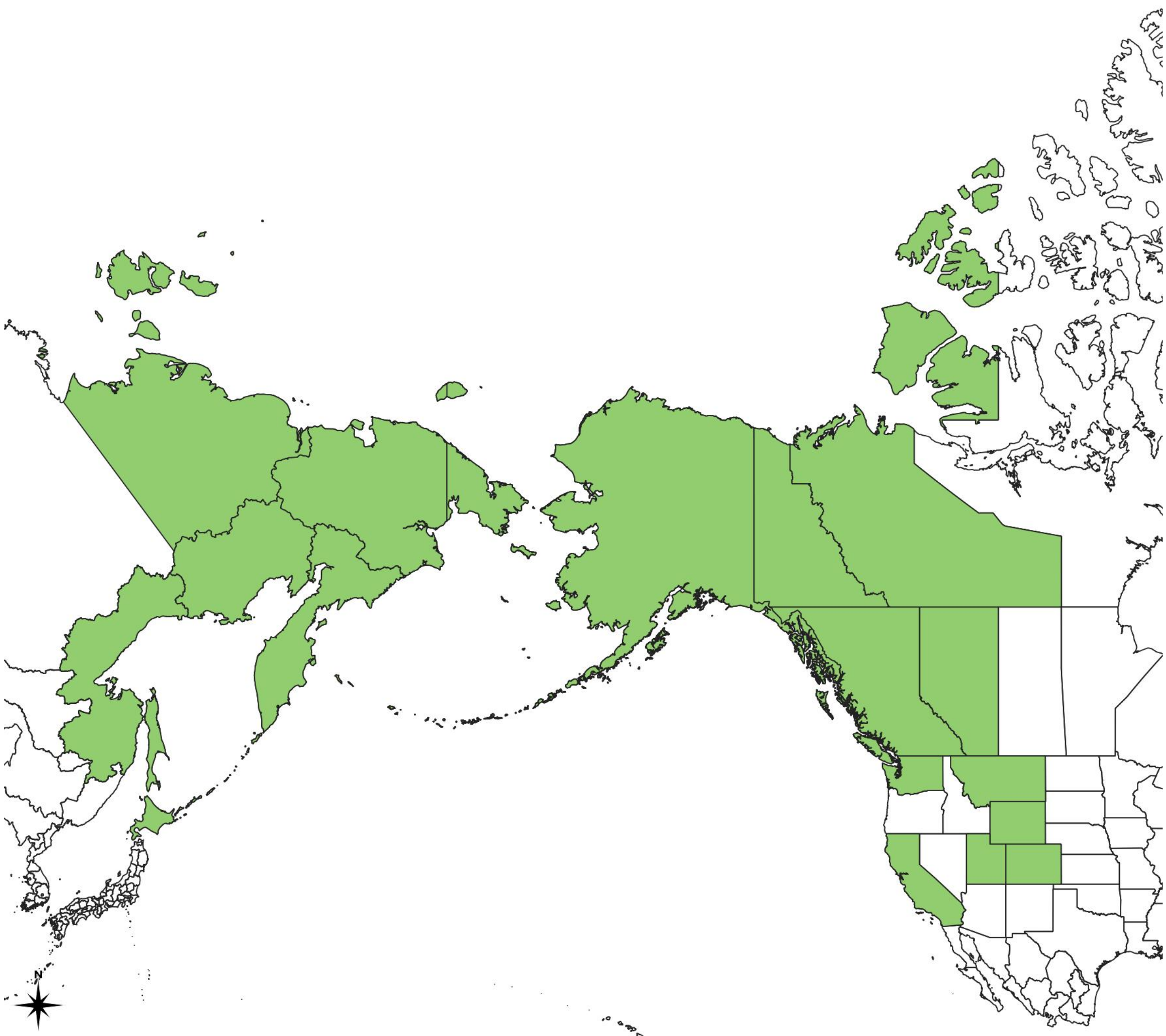

Figure 3. *Artemisia arctica* ssp. *arctica* is native across: the Northwestern United States, Western Canada, Eastern Russia and Northern Japan. Created using ESRI shapefile (Upadhyay 2019)

Artemisia arctica ssp. *arctica* can be found throughout the meadows and mountains of Northwestern North America and Northeast Asia up to an elevation of approximately 3,800 meters (Figure 3). Within the United States, this subspecies is native to portions of: California, Utah, Colorado, Wyoming, Montana, Washington and Alaska. *Artemisia arctica* ssp. *arctica*'s native range in Canada spans from the provinces of British Columbia and Alberta in the South, to Yukon, and the Northwest Territories, including Western Victoria Island, Banks Island and the Southern Queen Elizabeth Islands in the North (Hultén 1968; Shultz 2006; Taylor 2006; USDA NRCS 2019). Within Russia, this subspecies is native to: the federal subject of Chukotka Autonomous Okrug across the Bering Strait and bordering the western shoreline of the Sea of Okhotsk, including the peninsula of Kamchatka in the North, the island of Sakhalin in the south; and the Eastern portion of the Sakha Republic immediately south of the Laptev and East Siberian Seas. In Japan, this *Artemisia arctica* ssp. *arctica* is native to the northern island of Hokkaido (Hultén 1968).

Within the Shumagin Islands, south of the Alaska Peninsula and east of the Aleutian Islands, this subspecies inhabits windswept, southern slopes between 250 and 300 m above sea level. It is joined there by low-growing perennials and is subject to cool, humid, cloudy conditions with strong winds and strong and frequent autumn and winter storms. Mean annual precipitation is moderate, around 870 mm, and includes moderately-high annual snowfall of approximately 122 cm per year (Heusser 1983).

Moving to the northern coast of Alaska, within the Prudhoe Bay region, *Artemisia arctica* ssp. *arctica* grows amongst patches of short shrubs and sedges adapted to soil movement caused by the action of frequent freezing and thawing events. Large portions of this region lack vegetation and are covered by lichen. Soils are xeric (dry), possessing a moisture content of approximately 19%, and can be classified as mineral gelolls, indicating that mean summer soil temperatures are less than 5C and have a dark, humus-rich, surface horizon (O-horizon) (Walker and Everett 1991; Huang et al. 2011). The soil in this region is also high in Ca and Mg, causing it to be slightly alkaline with a pH of approximately 7.3. Soil surfaces are snow-free during spring melt, thawing to a depth of 33 cm in the summer. Winters are generally moist and cool, whereas summers tend to be warm and dry (Walker and Everett 1991).

Just south of the Prudhoe Bay region, within the Brooks Range foothills of Alaska, *Artemisia arctica* ssp. *arctica* inhabits two primary microclimates. The first is characterized by a relatively barren landscape comprised of exposed, south-facing, rocky slopes, which are subjected to severe winds and populated by lichen, forbs and subshrubs. Soils are xeric and acidic with a pH around 4.7. Soil organic matter content is high, around 5.5%, and nitrate levels are low, around 4.5 ppm. By late summer, soils thaw to a depth of more than 100 cm with no snow cover in May. The second microclimate in this region is characterized by steep, north-facing, well-drained, wind-sheltered slopes exposed to extreme sun and moderately deep annual snow cover of approximately 57 cm. Soils are acidic, possessing a high organic matter content of approximately 29.6%, and contain moderately-high levels of nitrate around 12 ppm. Soil moisture content in this region is moderate and highly variable (Walker et al. 1994)

In British Columbia, *Artemisia arctica* ssp. *arctica* inhabits a region called the Spruce Willow Birch Zone (SWB) which encompasses an area just south of the timberline. Mean annual temperatures range between -0.7C and -3C with a moderately-low, mean annual precipitation of between 460-700mm, 35-60% of this occurring as snowfall. Winters are extended and cold, and summers are short and cool, producing temperatures above 10C for 1-3 months and generating violent storms. Within the spruce Willow Birch Zone (SWB), *Artemisia arctica* ssp. *arctica* occupies three subzones. The first is comprised of dry, subalpine, grasslands, with shallow soils derived from calcium-rich, alkaline, parent materials. Vegetation consists predominantly of forbs and grasses. At middle to lower alpine elevations, *Artemisia arctica* ssp. *arctica* may be found within herb meadows consisting of well-drained, deep soils bordering mountainous streams vegetated predominantly by broad-leaved forbs. Located on exposed, steep, south-facing slopes, *Artemisia arctica* ssp. *arctica* also inhabits a zone of grassy tundra comprised of light, discontinuous winter snow cover and a well-developed, herbaceous perennial layer (Meidinger and Pojar 1991).

Regarding this subspecies' tendency to become invasive, species of the genus *Artemisia* are known to produce a large number of wind-dispersed seeds. However, intraspecific competition, insect herbivory and disease significantly reduce germination percentages. Moreover, seeds from this genus are typically short-lived and do not produce a seed bank. Increased fire frequency, brought about by global climate change, has also severely reduced native populations of *Artemisia* species (Meyer 2008). Consequently, it is highly unlikely that *Artemisia arctica* ssp. *arctica* could become invasive. Moreover, no published incidences of invasiveness could be identified.

II. CROP SPECIES

A. History and Potential Uses.

Historically, *Artemisia arctica* ssp. *arctica* was used by the Canadian aboriginal peoples to treat back pain, suggesting it may have mild analgesic properties (Uprety et al. 2016). A decoction (boiled extract) of the plant is also documented as having been ingested by Native American peoples to treat: diabetes, cancer, the common cold, and used as an eyewash for treatment of eye ailments, suggesting that it may have antiseptic properties (Moerman 2009; Amidon et al. 2014; Ramzan 2015; Quattrocchi 2016). The efficacy and safety of using *Artemisia arctica* ssp. *arctica* to manage or treat any of these conditions, however, has not been documented or evaluated. Nonetheless, given its historical use, further research should be conducted concerning the suitability of *Artemisia arctica* ssp. *arctica* for these purposes, particularly for treating symptoms of diabetes given the large number of sources corroborating its usage for this purpose (Amidon et al. 2014; Ramzan 2015; Quattrocchi 2016). Considering its historical use as a decoction, the plant is edible. However, routine consumption without preparation in this manner has not been formally documented.

Beyond its potential phytotherapeutic benefits, this subspecies' ability to withstand: highly acid to slightly alkaline soil pH, moderate to dry soil moisture levels, low to moderately high soil nitrate levels, soil disturbance caused by frequent freeze and thaw events, intense sunlight, high winds and violent storms, make it an attractive candidate for breeding resilience and adaptability into composite-flower *Asteraceae* crops, including sunflowers (*Helianthus annuus*) and daisies (multiple genus). This resilience also indicates that, once domesticated, *Artemisia arctica* ssp. *arctica* could make an excellent flowering perennial marketed for vegetating exposed, inhospitable areas of landscaping. As global climate change continues to intensify storm severity and frequency, increase the likelihood of flood and drought conditions, and alter regional hardiness zones, *Artemisia arctica* ssp. *arctica*'s tolerance of severe conditions may offer a solution for consumers seeking to prepare their landscaping for these changes. The subspecies' wide, native geographic range also suggests it is likely adaptable to a large diversity of production environments, potentially making it ideal for commercial production in colder, less-productive climates.

Currently, there is no evidence to suggest that *Artemisia arctica* ssp. *arctica* has been utilized within breeding programs or domesticated for commercial production. Consequently, there are no cultivars of *Artemisia arctica* ssp. *arctica* currently available on the market. Moreover, no nurseries or seed retailers of *Artemisia arctica* ssp. *arctica* could be identified, including those specializing in native plants. This indicates that there is a clear gap in the market for this subspecies.

Figure 4 lists examples of firms suited to handling *Artemisia arctica* ssp. *arctica* and their place within the horticultural distribution chain should this subspecies be introduced for commercial production. Given its suitability for production and sale in less-hospitable, northerly climates, breeding efforts to domesticate *Artemisia arctica* ssp. *arctica* would likely occur initially within northern university breeding programs, such as the University of Minnesota. Once sufficiently developed, this effort could subsequently be adopted by private-sector flower breeding companies, such as Syngenta Flowers. During a small trial conducted at the University of Minnesota’s educational growing facilities as part of the writing of this publication, it was determined that 3-node *Artemisia arctica* ssp. *arctica* cuttings root easily both with, and without 1000 ppm indole-3-

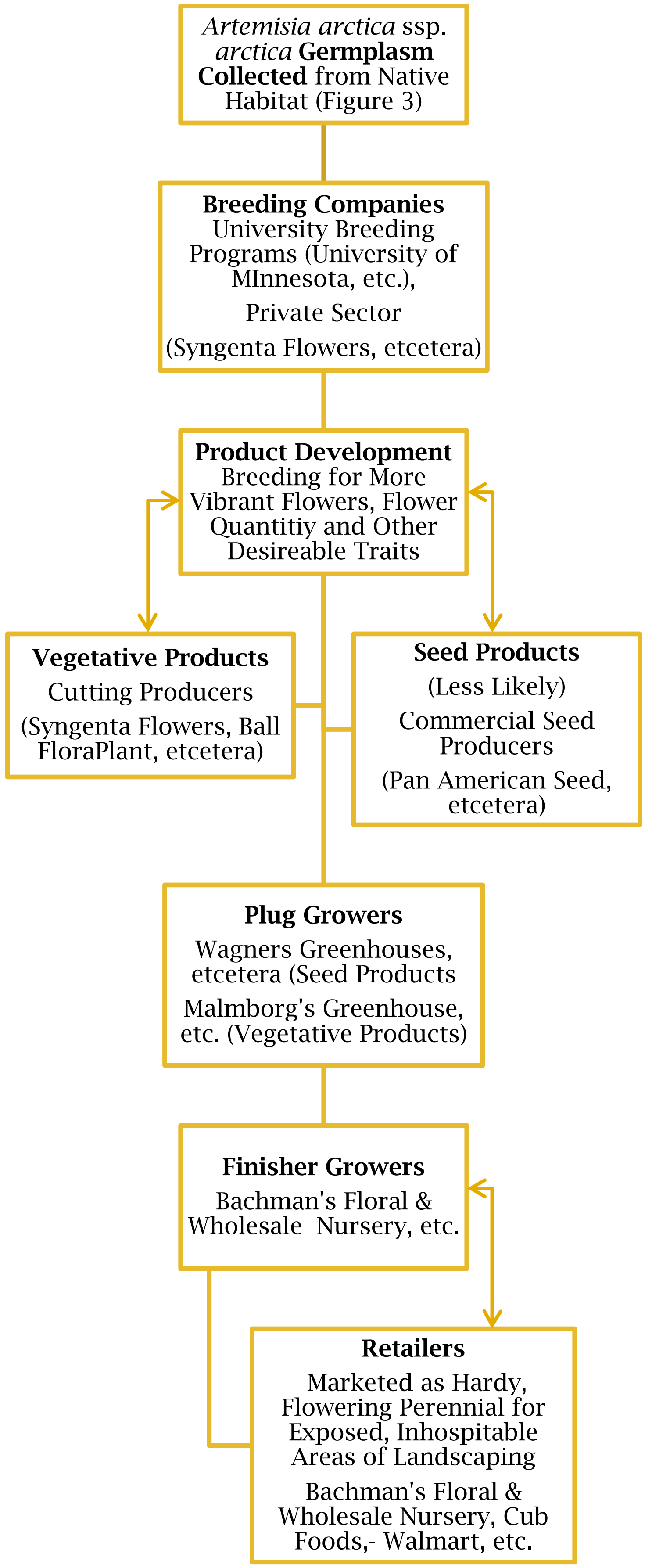

Figure 4. Potential horticultural distribution chain for *Artemisia arctica* ssp. *arctica* ‘Boreal Wormwood’

butyric acid (IBA) in talc when placed on a mist bench within standard, sterile germination media. Due to the relative ease in which vegetative products are introduced to the market, this subspecies would most likely be predominantly vegetatively propagated. The private-sector breeding companies could also participate in cutting or seed production, indicating functional overlap could occur between the breeder and producer levels of this subspecies' horticultural distribution chain. Cutting and seed producers could include firms such as: Syngenta Flowers (cuttings), Ball FloraPlant (cuttings) and Pan American Seed Company (seeds), among others. Seed and vegetative plug growers, including firms such as Wagners and Malmborg's Greenhouses respectively, could produce plugs of *Artemisia arctica* ssp. *arctica* for finisher growers such as Bachman's Floral & Wholesale Nursery. Finisher growers could subsequently either retail these plants directly to consumers as hardy, potted, flowering, herbaceous perennials for landscaping and garden use, or sell them to other retailers, including box stores such as Walmart, among others.

III. PRODUCTION INFORMATION

A. Anticipated Cultural Requirements.

As noted previously, *Artemisia arctica* ssp. *arctica* is a flowering, herbaceous, perennial subshrub (Hultén 1968). Accordingly, the subspecies' vegetative foliage dies back during the winter, leaving only its woody roots and dormant buds lying just beneath the soil line from which new vegetative growth emerges the following spring (Beentje and Williamson 2016). Given it occupies an extremely large native growing range, this subspecies could be marketed for use in hardiness zones ranging from 7a in the South to 1a in the North (Hultén 1968; Walker et al. 1994; Shultz 2006; Taylor 2006; USDA ARS 2012; USDA NRCS 2019). Similarly, *Artemisia arctica* ssp. *arctica* natively inhabits an extremely wide range of heat zones, spanning from 7 (greater than 60 to 90 days per year above 30C) on the high end to 1 (less than 1 day per year above 30C) on the low end (AHS 1997). This indicates that *Artemisia arctica* ssp. *arctica* possesses both a moderately-high heat stress tolerance, and is also extremely resistant to cold damage. Moreover, this subspecies thrives in microclimates subjected to severe winds, violent storms and frequent freezing and thawing events (Heusser 1983; Meidinger and Pojar 1991; Walker and Everett 1991; Walker et al. 1994). *Artemisia arctica* ssp. *arctica* also inhabits a wide variety of growing conditions, ranging from: moderately high to extremely low pH, high to low soil organic matter content, moderately high to low soil nitrate content, moist to xeric soil moisture content and intense to overcast light conditions (Heusser 1983; Meidinger and Pojar 1991; Walker and Everett 1991; Walker et al. 1994).

Given its lifecycle, cold hardiness, heat tolerance, freeze-thaw tolerance, wind resistance, storm resistance, microclimate adaptability and annual dormancy requirement, this subspecies would likely be most appropriately positioned as a hardy, adaptable, low-maintenance, herbaceous, flowering perennial for garden and landscaping use in northern climates. Importantly, given the aboveground, vegetative portion of this plant dies-back in early fall around September and throughout the winter, this subspecies only provides seasonal interest in spring and summer (Shultz 2006; Taylor 2006). Consequently, marketing efforts would likely need to highlight the perennial's summer flowers and foliage. *Artemisia arctica* ssp. *arctica* already possesses attractive flowers which, particularly if enhanced by breeding efforts, predispose it for positioning as a flower crop (Hultén 1968). Should future medical research lend credence to the phytotherapeutic benefits associated with consuming a decoction prepared from this subspecies, it could also be marketed as a value-added food product, such as a tea or tincture, or sold in large quantities to drug manufacturers as a source of active ingredient (Amidon et al. 2014; Ramzan 2015; Quattrocchi 2016).

In its native environment, *Artemisia arctica* ssp. *arctica* thrives in well-drained, moderately-dry soils (Heusser 1983; Meidinger and Pojar 1991; Walker and Everett 1991; Walker et al. 1994). This suggests that well-drained, synthetic media comprised of slightly higher proportions of sand or perlite would likely be most effective for use in commercial production of this subspecies. Moisture regimes also tend to be highly variable in *Artemisia arctica* ssp. *arctica's* native habitat (Walker et al. 1994). Tolerance of this condition in the wild suggests that this subspecies would also likely tolerate frequent dry-down periods within a production setting, which could potentially be leveraged as part of an integrated pest management program to control moisture-loving, pathogenic soil fungi, including: pythium, phytophthora, rhizoctonia and thielaviopsis. Soil pH in *Artemisia arctica* ssp. *arctica*'s native habitat can be as alkaline as 7.3, or as acidic as 4.7 (Meidinger and Pojar 1991; Walker and Everett 1991; Walker et al. 1994). Consequently, maintaining soil pH in the middle of this range, around 6.5, would likely be sufficient for commercial production.

Regarding fertilizer requirements, *Artemisia arctica* ssp. *arctica* natively grows in soils containing large amounts of organic matter derived from parent materials that are high in Ca and Mg (Meidinger and Pojar 1991; Walker and Everett 1991; Walker et al. 1994). Despite possessing high levels of organic matter, low soil temperatures in this subspecies' northern habitat limit microbial decomposition, leading to low soil nitrate levels. Conversely, moderately-high nitrate levels have also been recorded in other areas of *Artemisia arctica* ssp. *arctica's* native range (Walker et al. 1994). In addition, some *Asteraceae* crops tend to respond most favorably to a nitrogen fertilizer comprised of a 50:50 ratio of nitrate and ammonium. Taken together, a moderate fertilization rate of approximately 125 ppm, 50:50, nitrate and ammonium fertilizer, supplemented with calcium and magnesium using a product such as Cal-Mag, would likely be most appropriate for commercial production of this subspecies (Santamaria et al. 1998; Muniz et al. 2009; Ball Seed 2019).

Like many other woody and herbaceous perennials, *Artemisia arctica* ssp. *arctica* possesses a short taproot (Taylor 2006). Therefore, in order to prevent encircling roots from developing during containerized production, use of a deeper pot would likely be required. For this reason, and given that *Artemisia arctica* ssp. *arctica* grows to a height of approximately 25-40 cm, a standard #1 nursery pot would likely serve as an adequate finishing container in commercial production (Hultén 1968). During a small trial conducted at the University of Minnesota's educational growing facilities as part of the writing of this publication, it was determined that a standard 72-plug tray was sufficient for rooting cuttings of this subspecies in sterile germination media. Moreover, due to the small size of this subspecies' seed, standard 288 plug trays would likely be sufficient for commercial production of *Artemisia arctica* ssp. *arctica* plugs (Meyer 2008).

Lighting and temperatures in this subspecies' natural habitat range from cool and cloudy to warm with extremely high light intensity (Heusser 1983; Meidinger and Pojar 1991; Walker and Everett 1991; Walker et al. 1994). Consequently, growing temperatures in the middle of this range, around 20C to 25C during the day and 15C to 20C at night (+5 DIF), would likely be sufficient for commercial production of this subspecies. A morning dip to approximately 10C for the first two to three hours at sunrise could likely be deployed in order to shorten excessive internodal elongation. In the event that plant growth regulators are required, as shown in Table 1, moderate growth control of *Artemisia schmidtiana* has been achieved by application of: B-Nine, a tank mix of B-Nine and Cycocel, Bonzi, and Sumagic (Lattimer and Scoggins 2018). However, given the effects of temperature, photoperiod and plant growth on internode elongation are highly plant-specific, additional research is required in order to determine the most effective plant growth regulators and concentrations for height control in this subspecies. In addition, effective growth regulators would need to be registered for use on *Artemisia arctica* ssp. *arctica* prior to commercial application. This subspecies produces flowers between early July and early September under a photoperiod of approximately 14 hours per day in its southernmost habitat within the Sierra Nevada region of California, and 15 hours per day in Northern Colorado (Holway and Ward 1965; Shultz 2006; Meyer 2008; Shultz 2012). Consequently, induction of flowering after sufficient vegetative growth has occurred would likely require a long-day photoperiod of at least 14 hours per day. Whether or not *Artemisia arctica* ssp. *arctica* possesses obligate or facultative, long-day, photoperiod requirements for flower-bud initiation or flower development is uncertain. Prior to applying long-day treatment, a photoperiod of less than 14 hours per day could potentially be used to achieve desired height and delay flowering. This is substantiated by the fact that exposure of *Artemisia arctica* ssp. *arctica* transplants to continuous, long-day photoperiods over a 250-day period immediately following dormancy resulted in reduced stem elongation in comparison to wild specimens (Yoshie 2008). Additional treatments to encourage flowering would need to be identified through future research.

TABLE 1. Plant growth regulators, application frequency and concentrations moderately effective for growth control in *Artemisia schmidtiana* which may also prove useful for growth control in *Artemisia arctica* ssp. *arctica* (Lattimer and Scoggins 2018)

Trade Names	Active Ingredient	Concentration	Application Frequency
B-Nine, Dazide	Daminozide	5,000 ppm	Sprayed 2x During Production Cycle
B-Nine, Dazide tank mixed with Citadel, Cycocel	Daminozide & Chlormequat chloride	5,000 ppm / 1,500 ppm	Sprayed 1x During Production Cycle
Bonzi, Paczol, Piccolo, Piccolo 10 XC	Paclobutrazol	200 ppm	Sprayed 1x During Production Cycle
Concise, Sumagic	Uniconazole-p	30-60 ppm	Sprayed 1x During Production Cycle

Optimal germination of *Artemisia* seeds occurs at approximately 17C (Taylor 2006). Consequently, maintaining mist bench temperatures at this level continuously (+0 DIF) would likely most effectively stimulate germination of this subspecies within a commercial production setting. At least 2 weeks of moist stratification around 3C and high light levels are also necessary to remove seed dormancy (Meyer 2008). Consequently, stratified seeds would likely need to be sown uncovered on a mist bench and subjected to high light intensity for best results. Misting every ten minutes for a duration of 7 seconds each cycle would likely provide sufficient moisture for germination. A mist cycle more frequent than once every 10 minutes would likely be sufficient to root *Artemisia arctica* ssp. *arctica* cuttings on a production scale. In comparison to the seed germination configuration, a higher constant temperature of approximately 20C (+0 DIF) and a lower light intensity would likely be required in order to maximize relative humidity and minimize transpiration. As mentioned previously, 72-plug trays and sterile germination media, with or without treatment of cuttings with 1000 ppm IBA in talc, was sufficient to induce rooting in 3-node *Artemisia arctica* ssp. *arctica* cuttings. As is typically the case, no fertilizer should be used in either mist bench configuration. Additional research would be necessary to determine optimal germination and rooting conditions beyond those listed here.

Artemisia arctica ssp. *arctica* produces a large number of seeds per plant within 2 years of establishment during each annual reproductive cycle (Meyer 2008). This quality would likely make this subspecies well-suited to commercial seed production. *Artemisia arctica* ssp. *arctica*'s composite flowers are comprised of monoecious, pistillate (male) florets on the outside rim with perfect (male and female) florets in the center (Taylor 2006). Because this subspecies is wind-pollinated, fans could likely be used to pollinate seed production stock. Each central floret develops a single, small achene (seed) that is covered with a wispy pericarp designed to aid in wind dispersal. Removal of this pericarp would be necessary to reduce seed moisture content and improve storage conditions. This would likely require seeds to be pelletized in order to improve ease of handling after pericarp removal due to their small size (Meyer 2008). Cultural requirements would likely be similar to those mentioned above for containerized plants. However, exposure to a long-day photoperiod would likely need to be started as soon as possible in order to stimulate flowering, minimize vegetative growth and maximize seed production (Shultz 2006; Meyer 2008; Shultz 2012). During a study which examined days to: growth initiation, flower bud initiation, and bud scale differentiation in a number of reproductively mature, native, Japanese forbs transplanted to a 24C, long-day growth chamber shortly after a brief (less than 4 weeks), cold-induced dormancy, it was revealed that no flower buds formed on *Artemisia arctica* ssp. *arctica* transplants after 250 days of observation (Yoshie 2008). This result suggests that this subspecies likely possesses an obligate vernalization requirement for flowering. Based on available research, however, the exact vernalization period required to induce flowering in a production setting is not known. Exposure to 5C for a period of approximately ten weeks is effective for inducing dormancy in a number of flowering perennials (Nordwig and Erwin 1996). Given the long winters characteristic of *Artemisia arctica* ssp. *arctica*'s native habitat, it may be inferred that a vernalization treatment of ten or more weeks at 5C would likely be necessary after each production cycle in order to induce dormancy and reinitiate flowering and seed production (Heusser 1983; Meidinger and Pojar 1991; Walker and Everett 1991; Walker et al. 1994). Seeds ripen September through December and can be shaken from flowers once mature. Seed viability lasts only 2-3 years, but may be extended up to 5 years if stored at a moisture content of 6% to 8% below 10C (Meyer 2008**).** Additional research would be necessary to determine best strategies for seed cleaning, harvest, pollination and vernalization.

Maintenance of stock plants for the production of cuttings would likely require identical fertilizer, temperature and media parameters as mentioned previously for containerized production. Photoperiod, however, would likely need to be reduced below 14 hours per day in order to stimulate vegetative growth and reduce flowering. Treatment with 500 ppm Ethephon every 2 to 4 weeks using a product such as Florel ® may also be necessary to maintain sufficient vegetative growth and stimulate satisfactory branching for cutting production (Monterey Lawn & Garden 2019). Given a cold treatment to induce dormancy and flowering would not be required, cuttings could likely be produced continuously indoors. The feasibility of continuous cutting production, as well as the effectiveness and appropriate rates of ethephon application would require further research.

B. Market Niche.

Considering *Artemisia arctica* ssp. *arctica* flowers between July and September, a selling timeframe between mid-July and mid-August would likely provide the largest number of blooms for marketing purposes (Shultz 2006; Meyer 2008; Shultz 2012). If it is determined that this subspecies possesses an obligate long-day photoperiod requirement, given that it blooms during a photoperiod greater than 14 hours per day in its native habitat, continuous long-day treatment in a greenhouse after an adequate vernalization period could potentially be used for year-round forcing (Shultz 2006; Meyer 2008; Shultz 2012). This indicates that *Artemisia arctica* ssp. *arctica* could potentially be programmed for late-fall flowering to compete with crops such as chrysanthemums (*Chrysanthemum* x*grandiflorum* L.), or for flowering during early May to take advantage of Mother's Day sales.

While attractive, this subspecies' blooms are significantly less exuberant than other hardy, yellow-tinged, flowering perennials including: chrysanthemums, gaillardia (*Gaillardia* × *grandiflora*), coneflower (*Echinacea purpurea*) and black-eyed Susan (*Rudbeckia hirta*). *Artemisia arctica* ssp. *arctica* also has an unusual growth habit, possessing a long, thick inflorescence and small, low, vegetative foliage (Hultén 1968). This growth habit suggests that it could be extremely difficult to encourage a bushier shape in this subspecies by pinching, or via the application of growth regulators. Height control for shipping purposes would also likely be difficult and could quickly result in fewer flowers. Breeding efforts would likely need to focus heavily on reducing the length of *Artemisia arctica* ssp. *arctica*'s inflorescence, increasing the number of inflorescences, and increasing the height and size of its lower foliage to increase proportionality. The subspecies' tendency to die back in the winter also means that it fails to provide winter, architectural interest, placing it at a disadvantage in comparison to other herbaceous, flowering perennials, such as Coneflower.

As mentioned previously, this subspecies would likely be most appropriately positioned as a hardy, adaptable, low-maintenance, herbaceous, flowering perennial for garden and landscaping use in northern climates to add mid- to late-summer seasonal interest. *Artemisia arctica* ssp. *arctica* may also offer phytotherapeutic benefits and could subsequently be marketed as a value-added, medicinal product (Moerman 2009; Amidon et al. 2014; Ramzan 2015; Quattrocchi 2016). For this reason, another member of the *Asteraceae* family, *Echinacea*, particularly yellow-tinged varieties such as *Echinaceae paradoxa*, and cultivars such as 'Sunrise' and 'Harvest Moon,' would likely be *Artemisia arctica* ssp. *arctica*'s biggest market competitors. Echinacea has been historically prized for its immune-boosting, wound-healing, and anti-inflammatory properties and has been incorporated and sold within countless value-added products. Moreover, the plant is hardy, capable of inhabiting hardiness zones 3 through 9, and extremely adaptable. Like *Artemisia arctica* ssp. *arctica*, if provided well-drained soils, *Echinaceae* will tolerate partial sun to full sun, high heat and drought. It also has a similar stature and growth habit, reaching a height of approximately 60 to 90 cm tall and having a long, terminal inflorescence (Libbey and Rupp 1996; Kaiser et al. 2016).

Marketing Story:

A unique, herbaceous perennial with bright-yellow flowers grows on an inhospitable section of garden in the back of an exposed, storm-weathered section of a northern Minnesotan farmstead. Its unusual foliage and bright-yellow flowers add late-summer seasonal interest amidst other, more conventional flowering perennials. This quirky plant, sporting subtle, unusual, yellow, moon-shaped flowers, stands by itself, highlighted by the expanse of exposed fields behind it, the only plant in the garden able to withstand the direct exposure to the strong winds and increasingly severe summer storms brought about by global climate change. You take in the view of your garden, sipping a cup of tea brewed from its foliage and reflect how little you've done to maintain the plant and how reliably it returns to the landscape each spring (despite last winter's polar vortex). After trying countless other perennials in that spot without success: Chrysanthemums, Gaillardia, Coneflower and Black-Eyed Susan, which now grow together in a more hospitable area, closer to the house and nearby stand of trees, you wonder what you would have planted had you not purchased those pots of Boreal Wormwood. If this seems too good to be true, it isn't. Straight from Northern Alaska, Boreal Wormwood can handle it all: high pH, low pH, good soils, poor soils, moist soils, dry soils, partial shade, full sun, high winds, severe storms, heat stress, severe cold, freeze-thaw damage, you name it! Seeds, cuttings, plugs and potted plants available mid-July 2021!

IV. PRODUCT INFORMATION GUIDE (PIG) & CROP SCHEDULES

As mentioned previously, given its size and short taproot, *Artemisia arctica* ssp. *arctica* could be sold in standard, #1 nursery containers as a potted, herbaceous perennial to wholesale and retail nursery markets (Hultén 1968). Due to the subspecies' tall inflorescence and relatively large container size, shipping of finished plants would likely be expensive and somewhat limited. Consequently, finishing would likely occur close to the subspecies' target markets. Given *Artemisia arctica* ssp. *arctica* natively inhabits hardiness zones ranging from 7a in the South to 1a in the North, and considering its primary market within the United States would largely be located in the Upper Midwest due to its excellent cold tolerance, finishing would likely occur predominantly within this region, but could also occur as far south as the Sierra Nevada region of California (Hultén 1968; Walker et al. 1994; Shultz 2006; Taylor 2006; USDA ARS 2012; USDA NRCS 2019). Suitable controlled environment structures for finishing could include both high-tunnels, and greenhouses in cases where enhanced control over scheduling and environmental conditions are required. Because *Artemisia arctica* ssp. *arctica* likely requires vernalization at 5C, greenhouse production would likely be favored in the South, within hardiness zones 7-5, due to lack of adequate, consistent winter cooling, and to improve temperature and growth regulation during hot periods. High-tunnel production would likely be favored in the North, within zones 5-3, due to consistent, winter cooling and the corresponding ability to avoid electricity and infrastructure costs associated with vernalization in electric coolers. Considering the warmer temperatures characteristic of southern regions are particularly suited to rapid, vegetative growth, cutting production would likely occur within zones 5-7. Seed production, on the other hand, which requires vernalization prior to the start of each production cycle, would subsequently be more efficient in cooler, northern climates within zones 5-3. Globally, given its large, native, geographic range, this subspecies could also likely be finished in close proximity to markets in Canada, Russia and Japan.

Regarding the probable production timeframe for *Artemisia arctica* ssp. *arctica* seed products grown in a greenhouse setting, stratification to shipping of forced, containerized plants could likely occur within 32 weeks. This duration is based upon the fact that this subspecies: does not flower until the second year of establishment, 2 weeks of moist stratification at 3C are required in order to overcome seed dormancy, 3 weeks are required for germination, at least 10 weeks of vernalization are likely required in order to induce flowering, and the growing season in its northern range spans from approximately mid-June to late-August (Bonde 1965; Heusser 1983; Meidinger and Pojar 1991; Walker and Everett 1991; Walker et al. 1994; Romanovsky and Osterkamp 1995; Nordwig and Erwin 1996; Meyer 2008; Yoshie 2008). Based upon available research, however, the exact number of weeks required to overcome juvenility prior to vernalization, and the minimum vernalization length required to induce flowering, is not known. This and the following production timeframes could consequently be shortened if: future research reveals that reproductive maturity is achieved prior to completion of this subspecies' native, 11-week growing season; juvenility is overcome by controllable environmental cues; or the subspecies requires less than 10 weeks of vernalization treatment in order to induce flowering. In addition, given *Artemisia arctica* ssp. *arctica* produces flowers between early July and early September, at least 4 weeks of long-day photoperiod exposure would likely be required in order to force flowering prior to shipping (Holway and Ward 1965; Shultz 2006; Meyer 2008; Shultz 2012). The exact number of weeks of long-day exposure necessary to do this, however, is also unknown. Consequently, if future research reveals that fewer than 4 weeks of long-day exposure are required for forcing prior to shipping, this would also shorten the production timeframes listed here. Application of growth regulators for height control would likely be required after vernalization, around week 28, and could be minimized by breeding efforts selecting for reduced internodal elongation. Table 2 outlines a possible greenhouse production schedule for *Artemisia arctica* ssp. *arctica* seed products based upon the subspecies' native lifecycle and the probable cultural requirements outlined in section III. A.

The number of weeks necessary to produce *Artemisia arctica* ssp. *arctica* vegetative products in a greenhouse setting would likely be less than the number of weeks required for the production seed products. Given seed stratification and germination would not be required, rooting of cuttings to shipment of forced, containerized plants could likely occur within approximately 23 weeks. As mentioned previously, during a small trial conducted at the University of Minnesota's educational growing facilities, it was determined that 3-node

Artemisia arctica ssp. *arctica* cuttings root easily in approximately 4 weeks, both with, and without application of 1000 ppm indole-3-buturic acid in talc, when placed on a mist bench within standard, sterile germination media. Moreover, an additional 4 weeks in the greenhouse was necessary before noticeable, vegetative growth was observed. For this reason, 8 weeks of growth would likely be required prior to vernalization of vegetative products, as opposed to 18 weeks required in the case of seed products. Additional research would be necessary in order to determine the optimal concentration of indole-3-buturic acid for maximal rooting performance, as well as the minimum number of weeks required prior to vernalization in order to minimize this production timeframe. The remainder of the production schedule for vegetative products would likely be identical to the production schedule for seed products. Table 3 outlines a possible greenhouse production schedule for *Artemisia arctica* ssp. *arctica* vegetative products based upon available information.

High-tunnel production schedules for *Artemisia arctica* ssp. *arctica* seed and vegetative products would necessarily be significantly longer than greenhouse production schedules due to lack of insulation and associated environmental control during the winter months. The total timeframe for producing seed and vegetative products of this subspecies in a high-tunnel, from seed stratification and rooting of cuttings, to shipment of forced, containerized plants, would likely span approximately 78 and 52 weeks respectively. Given *Artemisia arctica* ssp. *arctica* is extremely cold hardy, polyethylene-covered high-tunnels would likely provide sufficient protection against winter conditions in zones 3-5 (Hultén 1968; Walker et al. 1994; Perry 1998; Shultz 2006; Taylor 2006; USDA ARS 2012; USDA NRCS 2019). Additionally, high-tunnels would likely require ventilation fans in order to prevent internal temperatures from reaching a threshold adequate to stimulate premature shoot emergence and germination. Black ground cloth would also likely be required in order to prevent the emergence of weeds for pest and disease control. Given conditions in zone 4 around the second week of April mimic those present at the start of the growing season in *Artemisia arctica* ssp. *arctica's* northern habitat, mist application for germination would likely need to be started at this time (Romanovsky and Osterkamp 1995). After vernalization, ridge vents would also likely need to be cut into the high-tunnel's polyethylene cover, and its doors opened at night around mid-march, in order to harden-off plants prior to full cover removal in late March to early April (Perry 1998). Possible high-tunnel production schedules for *Artemisia arctica* ssp. *arctica* seed and vegetative products grown in hardiness zone 4 are shown in Tables 4 & 5 respectively.

Seed and cutting production would likely occur within a greenhouse setting given this configuration enables the producer to: control cross-pollination in the case of seed production, reduce viral contamination in the case of cutting production, and manipulate environmental parameters for year-round production of cuttings. For this reason, *Artemisia arctica* ssp. *arctica* seed and cutting production schedules would likely be extremely similar to the schedule outlined in Table 2 for production of seed products in a greenhouse setting. In the cutting production schedule, however, short-day photoperiod and application of ethephon would likely need to be substituted for long-day photoperiod in week 7 in order to prevent flowering. Moreover, vernalization would likely not be required because induction of flowering would not be necessary. Consequently, cutting production could likely begin as early as 7-18 weeks after seed stratification. If it is determined that *Artemisia arctica* ssp. *arctica* possesses obligate, long-day photoperiod requirements, cutting production could likely be maintained continuously after initial establishment of stock plants. As mentioned previously, the feasibility of continuous cutting production, as well as the effectiveness and appropriate rates of ethephon application would require further research.

Regarding the probable seed production schedule, as mentioned previously, *Artemisia* seeds: ripen September through December, can be shaken from flowers once mature, last 5 years if stored at a moisture content of 6% to 8% below 10C, require pericarp removal to reduce moisture during storage, and likely require pelletization due to their small size**.** This subspecies is also wind-pollinated, indicating that fans could likely be used for pollination of seed production stock (Meyer 2008)**.** Consequently, fans would likely need to be applied during week 28, and a second vernalization treatment would likely need to be administered during week 39 in order to ripen seeds and start the next round of seed production. Seed collection, pericarp removal and seed storage requirements would also likely need to occur during this time. Moreover, growth control is not necessary for successful seed production and growth regulators would consequently not need to be applied during week 28. Seed production, from seed stratification to harvest, would likely require between 39 and 47 weeks, depending on seed ripening time. As mentioned previously, additional research would be necessary in order to determine optimal strategies for seed cleaning, harvest, pollination and vernalization. Possible seed and cutting production schedules for *Artemisia arctica* ssp. *arctica* are shown in Tables 6 & 7, respectively.

TABLE 2. Possible production schedule for *Artemisia arctica* ssp. *arctica* seed products in a greenhouse setting (propagation through finishing)

Week	Container	Media	Growth Phase	Treatment
		Propagation		
1	288 Plug Trays	Moist, Sterile Germination Media	Stratification	Sow Uncovered in 288 Plug Tray, Administer 2 Weeks Moist Stratification at 3C
3	288 Plug Trays	Sterile Germination Media	Germination	Move to Mist Bench, High Light Intensity, Constant Temperature 17C (+0 DIF) Mist 7s Every 10 Minutes
4	288 Plug Trays	Sterile Germination Media	Hardening-Off	Place on Capillary Mat, pH Approximately 6.5, 125 ppm 50:50 Nitrate/Ammonium Fertilizer Supplemented with Calcium and Magnesium (Cal-Mag), Day Temperature 20C to 25C, Night Temperature 15C to 20C (+5 DIF), Morning Dip to Approximately 10C for the First 2-3 Hours at Sunrise, Long-Day Photoperiod >14 Hours/Day,
		Finishing		
7	Standard #1 Nursery Pots	Well-Drained, Synthetic Media, Slightly Higher Proportions of Sand and/or Perlite	Transplant and Vegetative Growth to Overcome Juvenility	Dry-Down Periods for Fungus Control, pH Approximately 6.5, 125 ppm 50:50 Nitrate/Ammonium Fertilizer Supplemented with Calcium and Magnesium (Cal-Mag), Day Temperature 20C to 25C, Night Temperature 15C to 20C (+5 DIF), Morning Dip to Approximately 10C for the First 2-3 Hours at Sunrise, Long-Day Photoperiod >14 Hours/Day,
18	Standard #1 Nursery Pots	Well-Drained, Synthetic Media, Slightly Higher Proportions of Sand and/or Perlite	Acclimation and Vernalization	Vernalization Treatment at 5C in cooler for at Least 10 Weeks

28	Standard #1 Nursery Pots	Well-Drained, Synthetic Media, Slightly Higher Proportions of Sand and/or Perlite	Deacclimation, Forcing, Flower Bud Initiation and Development, Height Control	Dry-Down Periods for Fungus Control, pH Approximately 6.5, 125 ppm 50:50 Nitrate/Ammonium Fertilizer Supplemented with Calcium and Magnesium (Cal-Mag), Day Temperature 20C to 25C, Night Temperature 15C to 20C (+5 DIF), Morning Dip to Approximately 10C for the First 2-3 Hours at Sunrise, Long-Day Photoperiod >14 Hours/Day, Growth Regulators as Necessary (Table 1)
32	Standard #1 Nursery Pots	Well-Drained, Synthetic Media, Slightly Higher Proportions of Sand and/or Perlite	Shipping	Shipping in standard, #1 nursery containers as potted, herbaceous perennials to wholesale and retail nursery markets

TABLE 3. Possible production schedule for *Artemisia arctica* ssp. *arctica* vegetative products grown in a greenhouse setting (propagation through finishing)

Week	Container	Media	Growth Phase	Treatment
		Propagation		
1	72-Plug Trays	Sterile Germination Media	Rooting	Stick Cuttings in 72-Plug Trays, Mist greater than once every 10 minutes for 7 seconds each cycle, 20C (+0 DIF), lower light intensity in comparison to seed germination, treatment with 1000 ppm IBA in talc optional, no fertilizer, 3-node cuttings
5	72-Plug Trays	Sterile Germination Media	Hardening-Off Vegetative Growth to Prepare for Dormancy	Place on Capillary Mat, pH Approximately 6.5, 125 ppm 50:50 Nitrate/Ammonium Fertilizer Supplemented with Calcium and Magnesium (Cal-Mag), Day Temperature 20C to 25C, Night Temperature 15C to 20C (+5 DIF), Morning Dip to Approximately 10C for the First 2-3 Hours at Sunrise, Long-Day Photoperiod >14 Hours/Day,
9	72-Plug Trays	Sterile Germination Media	Acclimation and Vernalization	Vernalization Treatment at 5C in Cooler for at Least 10 Weeks
		Finishing		
19	Standard #1 Nursery Pots	Well-Drained, Synthetic Media, Slightly Higher Proportions of Sand and/or Perlite	Transplant Pre-Vernalized Liners, Deacclimation, Forcing, Flower Bud Initiation and Development, Height Control	Dry-Down Periods for Fungus Control, pH Approximately 6.5, 125 ppm 50:50 Nitrate/Ammonium Fertilizer Supplemented with Calcium and Magnesium (Cal-Mag), Day Temperature 20C to 25C, Night Temperature 15C to 20C (+5 DIF), Morning Dip to Approximately 10C for the First 2-3 Hours at Sunrise, Long-Day Photoperiod >14 Hours/Day, Growth Regulators as Necessary (Table 1)
23	Standard #1 Nursery Pots	Well-Drained, Synthetic Media, Slightly Higher Proportions of Sand and/or Perlite	Shipping	Shipping in standard, #1 nursery containers as potted, herbaceous perennials to wholesale and retail nursery markets

TABLE 4. Possible high-tunnel production schedule for *Artemisia arctica* ssp. *arctica* seed products grown in hardiness zone 4 (propagation through finishing)

Week	Container	Media	Growth Phase	Treatment
		Propagation		
1st Week of Nov.	288 Plug Trays	Moist, Sterile Germination Media	Stratification	Sow Uncovered in 288 Plug Tray within Moist, Sterile Germination Media within Covered High-Tunnel, Apply Ventilation to Keep Temperatures Below 3C
2nd Week of April	288 Plug Trays	Sterile Germination Media	Germination	Mist 7s Every 10 Minutes Until Germination in Covered High-Tunnel

1st Week of May	288 Plug Trays	Sterile Germination Media	Hardening-Off	Place on Capillary Mat, pH Approximately 6.5, 125 ppm 50:50 Nitrate/Ammonium Fertilizer Supplemented with Calcium and Magnesium (Cal-Mag), Open High-Tunnel Doors at Night and Cut Ridge Vents in Polyethylene Cover
		Finishing		
2nd Week of May	Standard #1 Nursery Pots	Well-Drained, Synthetic Media, Slightly Higher Proportions of Sand and/or Perlite	Transplant, Vegetative Growth to Overcome Juvenility	Remove Polyethylene Cover, Dry-Down Periods for Fungus Control, pH Approximately 6.5, 125 ppm 50:50 Nitrate/Ammonium Fertilizer Supplemented with Calcium and Magnesium (Cal-Mag)
2nd Week of Nov.	Standard #1 Nursery Pots	Well-Drained, Synthetic Media, Slightly Higher Proportions of Sand and/or Perlite	Acclimation and Vernalization	Natural Acclimation in Open High-Tunnel Complete, Re-install Polyethylene Cover for Winter Protection and Vernalization
2nd Week of Mar.	Standard #1 Nursery Pots	Well-Drained, Synthetic Media, Slightly Higher Proportions of Sand and/or Perlite	Deacclimation	Open High-Tunnel Doors at Night and Cut Ridge Vents in Polyethylene Cover, Dry-Down Periods for Fungus Control, pH Approximately 6.5, 125 ppm 50:50 Nitrate/Ammonium Fertilizer Supplemented with Calcium and Magnesium (Cal-Mag),
1st Week of Apr.	Standard #1 Nursery Pots	Well-Drained, Synthetic Media, Slightly Higher Proportions of Sand and/or Perlite	Forcing, Flower Bud Initiation and Development, Height Control	Dry-Down Periods for Fungus Control, pH Approximately 6.5, 125 ppm 50:50 Nitrate/Ammonium Fertilizer Supplemented with Calcium and Magnesium (Cal-Mag), Growth Regulators as Necessary (Table 1)
1st Week of May	Standard #1 Nursery Pots	Well-Drained, Synthetic Media, Slightly Higher Proportions of Sand and/or Perlite	Shipping	Shipping in standard, #1 nursery containers as potted, herbaceous perennials to wholesale and retail nursery markets

TABLE 5. Possible high-tunnel production schedule for *Artemisia arctica* ssp. *arctica* vegetative products grown in hardiness zone 4 (rooting through finishing)

Week	Container	Media	Growth Phase	Treatment
		Propagation		
1st Week of May	72-Plug Trays	Sterile Germination Media	Rooting	Stick Cuttings in 72-Plug Trays, Mist 7s Every 10 Minutes Until Germination in Covered High-Tunnel
1st Week of June	72-Plug Trays	Sterile Germination Media	Hardening-Off	Place on Capillary Mat, Open High-Tunnel Doors at Night and Cut Ridge Vents in Polyethylene Cover, pH Approximately 6.5, 125 ppm 50:50 Nitrate/Ammonium Fertilizer Supplemented with Calcium and Magnesium (Cal-Mag)
		Finishing		
2nd Week of June	Standard #1 Nursery Pots	Well-Drained, Synthetic Media, Slightly Higher Proportions of Sand and/or Perlite	Transplant, Vegetative Growth to Overcome Juvenility	Remove Polyethylene Cover, Dry-Down Periods for Fungus Control, pH Approximately 6.5, 125 ppm 50:50 Nitrate/Ammonium Fertilizer Supplemented with Calcium and Magnesium (Cal-Mag)
2nd Week of Nov.	Standard #1 Nursery Pots	Well-Drained, Synthetic Media, Slightly Higher Proportions of Sand and/or Perlite	Acclimation and Vernalization	Natural Acclimation in Open High-Tunnel Complete, Re-install Polyethylene Cover for Winter Protection and Vernalization
2nd Week of Mar.	Standard #1 Nursery Pots	Well-Drained, Synthetic Media, Slightly Higher Proportions of Sand and/or Perlite	Deacclimation	Open High-Tunnel Doors at Night and Cut Ridge Vents in Polyethylene Cover, Dry-Down Periods for Fungus Control, pH Approximately 6.5, 125 ppm 50:50 Nitrate/Ammonium Fertilizer Supplemented with Calcium and Magnesium (Cal-Mag),

1st Week of Apr.	Standard #1 Nursery Pots	Well-Drained, Synthetic Media, Slightly Higher Proportions of Sand and/or Perlite	Forcing, Flower Bud Initiation and Development	Dry-Down Periods for Fungus Control, pH Approximately 6.5, 125 ppm 50:50 Nitrate/Ammonium Fertilizer Supplemented with Calcium and Magnesium (Cal-Mag), Growth Regulators as Necessary (Table 1)
1st Week of May	Standard #1 Nursery Pots	Well-Drained, Synthetic Media, Slightly Higher Proportions of Sand and/or Perlite	Shipping	Shipping in standard, #1 nursery containers as potted, herbaceous perennials to wholesale and retail nursery markets

TABLE 6. Possible production schedule for *Artemisia arctica* ssp. *arctica* seeds

Week	Container	Media	Growth Phase	Treatment
1	288 Plug Trays	Moist, Sterile Germination Media	Stratification	Sow Uncovered in 288 Plug Tray, Administer 2 Weeks Moist Stratification at 3C
3	288 Plug Trays	Sterile Germination Media	Germination	Move to Mist Bench, High Light Intensity, Constant Temperature 17C (+0 DIF) Mist 7s Every 10 Minutes
4	288 Plug Trays	Sterile Germination Media	Hardening-Off	Place on Capillary Mat, pH Approximately 6.5, 125 ppm 50:50 Nitrate/Ammonium Fertilizer Supplemented with Calcium and Magnesium (Cal-Mag), Day Temperature 20C to 25C, Night Temperature 15C to 20C (+5 DIF), Morning Dip to Approximately 10C for the First 2-3 Hours at Sunrise, Long-Day Photoperiod >14 Hours/Day,
7	Standard #1 Nursery Pots	Well-Drained, Synthetic Media, Slightly Higher Proportions of Sand and/or Perlite	Transplant and Vegetative Growth to Overcome Juvenility	Dry-Down Periods for Fungus Control, pH Approximately 6.5, 125 ppm 50:50 Nitrate/Ammonium Fertilizer Supplemented with Calcium and Magnesium (Cal-Mag), Day Temperature 20C to 25C, Night Temperature 15C to 20C (+5 DIF), Morning Dip to Approximately 10C for the First 2-3 Hours at Sunrise, Long-Day Photoperiod >14 Hours/Day,
18	Standard #1 Nursery Pots	Well-Drained, Synthetic Media, Slightly Higher Proportions of Sand and/or Perlite	Acclimation and Vernalization	Vernalization Treatment at 5C in cooler for at Least 10 Weeks
28	Standard #1 Nursery Pots	Well-Drained, Synthetic Media, Slightly Higher Proportions of Sand and/or Perlite	Deacclimation, Forcing, Flower Bud Initiation and Development, Pollination	Dry-Down Periods for Fungus Control, pH Approximately 6.5, 125 ppm 50:50 Nitrate/Ammonium Fertilizer Supplemented with Calcium and Magnesium (Cal-Mag), Day Temperature 20C to 25C, Night Temperature 15C to 20C (+5 DIF), Morning Dip to Approximately 10C for the First 2-3 Hours at Sunrise, Long-Day Photoperiod >14 Hours/Day, Apply Fans for Pollination Purposes
39	Standard #1 Nursery Pots	Well-Drained, Synthetic Media, Slightly Higher Proportions of Sand and/or Perlite	Acclimation, Vernalization and Seed Ripening	Vernalization Treatment at 5C in cooler for at Least 10 Weeks, Mechanical Harvest of Ripe Seed by Shaking, Pericarp Removal, Pelletization, Storage at 6% to 8% Moisture Content Below 10C.
39-47	Seed Germination Testing and Shipment			

TABLE 7. Possible production schedule for *Artemisia arctica* ssp. *arctica* cuttings

Week	Container	Media	Growth Phase	Treatment
1	288 Plug Trays	Moist, Sterile Germination Media	Stratification	Sow Uncovered in 288 Plug Tray, Administer 2 Weeks Moist Stratification at 3C
3	288 Plug Trays	Sterile Germination Media	Germination	Move to Mist Bench, High Light Intensity, Constant Temperature 17C (+0 DIF) Mist 7s Every 10 Minutes
4	288 Plug Trays	Sterile Germination Media	Hardening-Off	Place on Capillary Mat, pH Approximately 6.5, 125 ppm 50:50 Nitrate/Ammonium Fertilizer Supplemented with Calcium and Magnesium (Cal-Mag), Day Temperature

				20C to 25C, Night Temperature 15C to 20C (+5 DIF), Morning Dip to Approximately 10C for the First 2-3 Hours at Sunrise, Short-Day Photoperiod < 12 Hours/Day,
7	Standard #1 Nursery Pots	Well-Drained, Synthetic Media, Slightly Higher Proportions of Sand and/or Perlite	Transplant and Vegetative Growth	Dry-Down Periods for Fungus Control, pH Approximately 6.5, 125 ppm 50:50 Nitrate/Ammonium Fertilizer Supplemented with Calcium and Magnesium (Cal-Mag), Day Temperature 20C to 25C, Night Temperature 15C to 20C (+5 DIF), Morning Dip to Approximately 10C for the First 2-3 Hours at Sunrise, Application of 500 ppm Ethephon Every 2-4 Weeks, Short-Day Photoperiod <12 Hours/Day,
18	Standard #1 Nursery Pots	Well-Drained, Synthetic Media, Slightly Higher Proportions of Sand and/or Perlite	Continuous Cutting Production and Shipping	Remove 3-Node Cuttings from Stock Plants for Shipping. Dry-Down Periods for Fungus Control, pH Approximately 6.5, 125 ppm 50:50 Nitrate/Ammonium Fertilizer Supplemented with Calcium and Magnesium (Cal-Mag), Day Temperature 20C to 25C, Night Temperature 15C to 20C (+5 DIF), Morning Dip to Approximately 10C for the First 2-3 Hours at Sunrise, Short-Day Photoperiod <12 Hours/Day,

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VI. LITERATURE CITED

AHS. 1997. American Horticultural Society Plant Heat-Zone Map. In C. H. Marc and Meteorological Evaluation Services Co. Inc. (Eds.). Alexandria, VA: American Horticultural Society.

Amidon, C., R. Barnett, J. Cathers, B. Chambers, L. Hamilton, A. Kellett, E. Kennel, J. Montowski, M. A. Thomas and B. Watson. 2014. Artemisia - An Essential Guide from the Herb Society of America. In C. Amidon, M. A. Thomas, E. Kennel and B. Watson (Eds.), (pp. 70). Online: The Herb Societiy of America.

Ball Seed. 2019. 2020 Seed Product Information Guide (In English). Pan American Seed Company

Beentje, H. and J. Williamson. 2016. The Kew Plant Glossary: An Illustrated Dictionary of Plant Terms. p. 160. In: S. Whitehead (ed.), The Kew Plant Glossary (In English). Royal Botanic Gardens, Kew. Richmond, Surrey, TW9 3AB, UK.

Bonde, E. K. 1965. Further studies on the germination of seeds of Colorado alpine plants (In English). University of Colorado Press. Boulder.

Heusser, C. J. 1983. Pollen diagrams from the Shumagin Islands and adjacent Alaska Peninsula, southwestern Alaska. 12: 279-295.

Holway, J. G. and R. T. Ward. 1965. Phenology of Alpine Plants in Northern Colorado. Ecology 46: 73-83.

Huang, P. M., Y. Li and M. E. Sumner. 2011. Handbook of soil sciences: properties and processes. CRC Press

Hultén, E. 1968. Flora of Alaska and neighboring territories a manual of the vascular plants (In English). Stanford, Calif. : Stanford University Press. Stanford, Calif.

Kaiser, C., R. Geneve and M. Ernst. 2016. Echinacea. In F. a. E. University of Kentucky College of Agriculture, Cooperative Extension Service, (Ed.), (Vol. CCD-CP-52, pp. 1). Online.

Lattimer, J. G. and H. Scoggins. 2018. Using Plant Growth Regulators on Containerized Herbaceous Perennials. In V. C. Extension (Ed.), (Vol. PUBLICATION 430-103, pp. 18).

Libbey, D. and L. A. Rupp. 1996. Selection and Culture of Landscape Plants in Utah, A Guide for Castleland RC&D Carbon, Emery, Grand and San Juan Counties. In Utah State University Extension (Ed.), (Vol. HG 500, pp. 13). Online.

Lindman, C. A. M. 1905. Bilder ur Nordens flora: på grundvalen af Palmstruchs" Svensk botanik," (Vol. 3) (In Swedish). Wahlström & Widstrand

Matson, S. 2006. *Artemisia norvegica* ssp. *saxatilis* (JPEG). Available from University of California, Berkeley CalPhotos https://calphotos.berkeley.edu/cgi/img_query?seq_num=197915&one=T

Meidinger, D. and J. Pojar. 1991. Ecosystems of British Columbia.

Meyer, S. E. 2008. Artemisia L.: sagebrush. In: F. T. Bonner and R. P. Karrfalt (eds.). The Woody Plant Seed Manual. United States Department of Agriculture. Online.

Moerman, D. E. 2009. *Artemisia arctica,* Boreal Sagebrush. p. 83 Native American medicinal plants: an ethnobotanical dictionary. Timber Press, Inc. .

Monterey Lawn & Garden. 2019. Florel (R) Brand Growth Regulator. In Bayer AG (Ed.). Fresno, CA.

Muniz, M. A., J. G. Barbosa, J. A. S. Grossi, M. Y. Orbes and P. G. Sá. 2009. Production and quality of pot chrysanthemum fertirrigated with different nitrate/ammonium relations. Bioscience Journal 25: 75-82 (In Portuguese).

Nordwig, G. and J. Erwin. 1996. Forcing Perennials. In University of Minnesota (Ed.), (Vol. 45, Number 2, pp. 14).

Perry, L. P. 1998. Herbaceous Perennials Production (Vol. NRAES-93) (In English). Natural Resource, Agriculture, and Engineering Service Cooperative Exension (NRAES). Ithaca, New York.

Quattrocchi, U. 2016. CRC world dictionary of medicinal and poisonous plants: common names, scientific names, eponyms, synonyms, and etymology (5 Volume Set) (Vol. 1) (In English). CRC press. Boca Raton, FL.

Ramzan, I. 2015. Phytotherapies: Efficacy, Safety, and Regulation (In English). John Wiley & Sons

Romanovsky, V. E. and T. E. Osterkamp. 1995. Interannual variations of the thermal regime of the active layer and near-surface permafrost in northern Alaska. Permafrost and Periglacial Processes 6: 313-335.

Santamaria, P., A. Elia, G. Papa and F. Serio. 1998. Nitrate and ammonium nutrition in chicory and rocket salad plants. Journal of Plant Nutrition 21: 1779-1789.

Shultz, L. M. 2006. Artemisia norvegica subsp. saxatilis. p. 530. In: Flora of North America Editorial Committee (ed.), Flora of North America North of Mexico (In English). New York and Oxford.

Shultz, L. M. 2012. *Artemisia norvegica* subsp. *saxatilis*. Available from University of California, Berkeley Jepson Flora Project Retrieved 3/30/2019 http://ucjeps.berkeley.edu/eflora/eflora_display.php?tid=49293

Taylor, J. E. 2006. Artemisia arctica. Available from U.S Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fire Sciences Laboratory Fire Effects Information System (FEIS) Retrieved 4/1/2019 https://www.fs.fed.us/database/feis/plants/shrub/artarc/all.html

Upadhyay, A. 2019. World country boarder shapefile (ESRI Shapefile). https://map.igismap.com/maps/layer_view/work20180912045957:continentsshp06/757

Uprety, Y., A. Lacasse and H. Asselin. 2016. Traditional Uses of Medicinal Plants from the Canadian Boreal Forest for the Management of Chronic Pain Syndromes. 16: 459-466.

USDA ARS. 2012. USDA Plant Hardiness Zone Map. In PRISM Climate Group - Oregon State University (Ed.). Online: United States Department of Agriculture Agricultural Research Service.

USDA NRCS. 2019. Artemisia arctica Less. ssp. arctica boreal sagebrush. The PLANTS Database Retrieved 2/26/2019, from The National Plant Data Team https://plants.usda.gov/core/profile?symbol=arara2

Walker, D. A. and K. R. Everett. 1991. Loess Ecosystems of Northern Alaska: Regional Gradient and Toposequence at Prudhoe Bay. 61: 437-464.

Walker, M. D., D. A. Walker and N. A. Auerbach. 1994. Plant communities of a tussock tundra landscape in the Brooks Range Foothills, Alaska. 5: 843-866.

Yoshie, F. 2008. Dormancy of alpine and subalpine perennial forbs. Ecological Research 23: 35-40.