1. Background

Teasels (*Dipsacus* spp.; Dipsacales: Dipsacacae) are increasing their status as invasive weeds in non-agricultural habitats in the United States[1]. Invasive teasels occur in 43 states, being absent only from the extreme southeastern states, North Dakota, Alaska, and Hawai'i[2,3,4]. Teasels also occur in the Canadian provinces of Ontario, Quebec, British Columbia[5] and Manitoba[6]. Four states in the western and midwestern U. S. (CO, IA, MO, NM) have declared *Dipsacus fullonum* L. (common teasel) noxious, and *D. laciniatus* L. (cutleaf teasel) is noxious in Colorado and Oregon. Cultivated teasel, *D. sativus* (L.) Honckney, is also present in the U.S. Teasels are listed as invasive by twelve other states and are listed as affecting natural areas in four national parks[7].

The Dipsacaceae *sensu lato* is an exclusively Old World family, except in cases where species have been moved by humans. Thus, no members of the Dipsacaceae are native to the New World[1]. In addition, there are no plants of significant economic importance within the family Dipsacaceae[8]. The center of origin of the subgenus *Dipsacus* L., which includes all invasive *Dipsacus* spp. in N. America, appears to be in southern Europe, due to the greatest diversity and greatest number of endemic species in that region[9]. A molecular genetic study is underway to investigate the centers of origin of *D. fullonum* and *D. laciniatus* and the geographical origins of genotypes of these species that are invasive in the U.S.

There has been some confusion over the synonomy of teasel species. Common teasel (sometimes referred to colloquially as "Indian teasel") has frequently been called *Dipsacus sylvestris* (Huds.) rather than *D. fullonum*, particularly in the North American literature[10,11,12]. In addition, those who refer to common teasel as *D. sylvestris* have sometimes used *D. fullonum* as the name for cultivated (or "Fuller's") teasel, which is otherwise known as *D. sativus*. A detailed discussion of this taxonomic issue[13] concluded that the most appropriate name for common teasel is *D. fullonum*. In addition, because *D. fullonum* is the type species of the genus, the species name cannot be changed[14]. The Weed Science Society of America refers to common teasel as *D. fullonum*, cutleaf teasel as *D. laciniatus*, and cultivated teasel as *D. sativus*[15]. These are the names used by the EBCL teasel program.

Cultivated teasel heads were harvested in the pre-industrial era for use in carding or "teasing" wool fibers[16]. The intentional cultivation of teasel has been documented to as far back as 12th century France[17] and may date to the Roman empire[16]. Cultivated teasel (*D. sativus*) was still an important crop in Europe during the height of European colonization of other continents. This was likely the species of "fuller's teasel" that was introduced by John Bartram into Pennsylvania in 1728[18]. Stoner[19] described an aphid-transmitted virus disease from a "commercial planting of fuller's teasel ... south of Sunnyvale, Calif.," in May, 1948. Thus, *D. sativus* was still under cultivation in the U.S. in the mid-20th century. Topham[20] also states that teasels were being cultivated in the states of Oregon and New York in that period. Based on the above dates and locations, *D. fullonum* and *D. laciniatus* have had many opportunities for introduction into and spread across America over the course of two centuries. Despite its utility in the processing of wool, teasel was never a major crop. Relatively little acreage was needed to fulfill the demands of the industry. For example, in 1920 the entire British demand of 10,000,000 teasels could have been produced on fewer than 400 ha of land[16]. As a result, there is little scientific literature concerning teasel production or its associated pests.

Dipsacus sativus very closely resembles *D. fullonum* and has long been considered to have been domesticated from that species[21]. *Dipsacus laciniatus* is also similar in appearance to *D. sativus*, particularly the seeds and seedheads. Introduction and spread of *D. fullonum* and *D. laciniatus* in N. America (as well as other former European colonies) almost certainly arose, at least in part, from contamination of *D. sativus* seed, although the introductions themselves do not appear to have been recorded in the literature.

Spread of invasive teasels through commerce and general interest in the plant continues. Gardeners plant teasel for its striking appearance and purple flowers, its use in dried flower arrangements, and its attractiveness to butterflies, bumblebees, and

natural enemies of crop pests[10]. Teasel seed, as well as dried teasel flower arrangements (which include seed heads that may to contain viable seed), can be purchased through the internet. Also on the internet, one can find numerous teasel-related homeopathic medicinal items and testimonials to their purported efficacy[22,23,24]. Consumers wishing to utilize the plant for any of these purposes may be contributing to the spread of teasel by growing the plants in their gardens or inadvertently spreading viable seed. Teasel seed has also been used in birdseed mixes and may have spread through commercial birdseed sales.

2. Teasel life history and factors affecting weediness

Common, cultivated and cutleaf teasels are often considered biennials because sufficient energy for reproduction is normally gained in the first full year of growth, with bolting and flowering occurring in the second year. However, under adverse biotic or abiotic conditions (including herbivory or other natural enemy attack) the plant may need additional years to bolt, becoming less likely to do so with each passing year[25]. Given that reproduction only occurs once, no matter the length of the preceding vegetative period, these three *Dipsacus* species are properly referred to as monocarpic, short-lived perennials.

Seeds of common teasel germinate from spring to late summer[5], after which rosette leaves and a taproot form. The plant grows vegetatively as a rosette, storing energy in the taproot until there is sufficient storage to sustain bolting, flowering, and seed production; bolting has been linked to rosettes exceeding a minimum diameter of 30 cm[25]. Plants that achieve this size late in the year bolt the following spring. At the terminus of each stem a single ovoid to cylindrical seedhead forms. The seedhead on the central stem is the largest on the plant and it flowers first, usually in midsummer. Seedheads on secondary stems flower after the central head, over the course of up to 40 days[26].

Although self-pollination appears possible, allogamous fertilization, following cross-pollination facilitated by bumblebees, macrolepidoptera, and other insects, is the most common method of reproduction for *D. fullonum*[5] and *D. laciniatus*[9]. Seeds mature within the head in autumn and most fall from the head before the onset of winter, although some viable seed remain in the head into the following spring (Rector, unpublished data). In studies on *D. fullonum*, Werner[27] reported that virtually all of the seeds from a given plant (99.9%) fall within 1.5 m of the plant. Long range seed dispersal occurs mainly due to floating seeds in floodwaters or in other flowing waters (e.g. ditches or streams). Common teasel seeds can float up to 22 days without significant reduction in viability[5]. In years without flooding, dense teasel populations can build up as entire seed loads are successively dumped in one area.

Individual teasel plants compete for resources with neighboring plants by spreading large rosette leaves that shade the ground. Common teasel's taproot can extend deeper than the roots of many of its annual and biennial competitors in North America[5]. A teasel plant can produce up to 40 seedheads, the largest of which can produce up to 2000 seeds. Common teasel has been shown to tolerate elevated salinity levels in comparison to other roadside plant species, thus conferring a competitive advantage to teasel in areas where roads are salted in the winter months[28].

Common teasel occurs in dry-mesic and mesic savannas, wetlands, lake borders, agricultural fields, pastureland, successional fields, and developed land[29]. The plant grows best in full sun and in poorly drained soils, especially in areas prone to flooding. It is often found in moderately disturbed habitats where seed germination is enhanced[30]. Teasel can aggressively colonize prairie and savanna habitats, sometimes resulting in monocultures and the exclusion of native species[11,12]. It is difficult to calculate an economic value for the impact of these invasions.

3. Management options

Current management options for invasive teasels include herbicide treatment of rosettes, mowing of bolted and flowering stems, or, in environmentally sensitive settings, recruiting volunteers to dig up the deep taproots of rosettes and cut and remove

stems of bolted plants[11]. Fire is inappropriate where teasel populations occur along roads with heavy vehicular traffic and also inappropriate in many natural settings where the risk of wildfire is important. Effectiveness of the methods varies considerably[31]. Mowing of early-season stems is considered ineffective since plants can often bolt a second time, necessitating a second mowing. Mowing flowering plants is only effective if the heads are collected and removed -- otherwise the mower can scatter seedheads containing viable seed, even when heads are cut before seed reach full maturity[31,32]. Glyphosate and 2-4 D have proven effective in killing teasel, but applications over several years are required to manage an established population[33], and their use may be restricted in environmentally sensitive areas.

Given the difficulties controlling established teasel populations, alternative approaches to control are warranted. Biological control of teasel represents one available option. Because of the species-specific nature of biological control, where candidate agents are chosen after extensive host-specificity testing, it can be an effective option while minimizing effects on non-target species[34]. Biological control is a particularly attractive option for teasels in North America because of the close phylogenetic relationship between the two invasive teasel species, *D. fullonum* and *D. laciniatus*, as well as the absence of any economically important or native American members of the family Dipsacaceae.

Summary and Current Research Status

As invasive teasels continue to spread in the U.S., particularly on lands that are not intensively managed for weed control, the need for a self-sustaining management strategy, such as biological control, increases. Teasels present particular opportunities as biological control targets, given the absence of any North American relatives or economically important plants within the family. In their native ranges, *D. fullonum* and *D. laciniatus* rarely achieve the population sizes or densities that have induced five American states to list either or both as noxious species. Whether natural enemies of these teasels are responsible for keeping native populations in check is not known. However, based on the results of the initial literature and field surveys[4], it appears that natural enemies of *Dipsacus* spp. are both numerous and specific enough to yield promising biological control agents. These may then eventually be released in hopes of arresting the rate of spread of invasive teasels in the U.S. and reducing their populations there to the lower levels more typical in their native ranges.

Among the biological control candidates collected and identified to date by EBCL, the highest priority for research leading to possible release has currently been assigned to three insects and one mite that attack the first-year vegetative stage of the teasel plant. Damage at this stage is considered to be the most promising for biological control since it could delay flowering from one summer to the next and perhaps prevent it altogether. These chosen species are the chrysomelid beetle *Longitarsus strigicollis*, which feeds on foliage as an adult and may also feed on roots in the larval stage; the agromyzid fly *Chromatomyia ramosa*, which mines rosette leaves and may feed at the apical meristem late in larval development; the cimbicid sawfly *Abia sericea*, which feeds on foliage of both the rosette and bolting plants; and an undescribed eriophyid mite in the genus *Leipothrix* that occurs on many plant structures and may cause severe deformations. Among those candidates identified in the literature but not yet collected in the field, the most sought after species include the foliage-feeding nymphalid butterfly *Euphydryas desfontainii*, the root-boring noctuid moth *Papaipema arctivorens*, an aphid-transmitted virus described from California[19], and the powdery mildews *Erysiphe knautiae* and *Sphaerotheca dipsacearum*.

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