INFERRING INTRODUCTION HISTORY AND SPREAD OF *FALCARIA VULGARIS* BERNH. (APIACEAE) IN THE UNITED STATES BASED ON HERBARIUM RECORDS

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ABSTRACT

Herbarium records were studied to infer the introduction history and spread of the exotic Eurasian sickleweed (*Falcaria vulgaris* Bernh.) in the United States. The spread of the plant was reconstructed using the location of early collections as the possible sites of primary introduction, and the location of subsequent collections as potential pathways along which this species spread. Herbarium records indicate that sickleweed was first introduced no later than 1922, and independent introduction of this plant took place in the East Coast and in the Midwest of the United States. The species has spread to 37 counties of 15 states of the United States. No recent sickleweed record has been reported for the last 17 years in the U.S. except Iowa, Nebraska and South Dakota. The plant has been characterized as an aggressive weed by experts in the latter two states, where it is already well established and has infested the Fort Pierre National Grassland and Buffalo Gap National Grassland in South Dakota, and is reported from several sites along Nebraska roadsides. It is essential to verify the existence of sickleweed in the areas from where the herbarium specimens were previously collected to help identify the areas at risk. Control strategies need to be implemented and policy should be developed to establish the participation of public lands managers, transportation departments and private land-owners to control and manage this species before it becomes a more widespread invader.

Keywords

Falcaria vulgaris, herbarium specimen, introduced plant, sickleweed.

INTRODUCTION

A tremendous exchange of biotas has occurred since the exploration age began in the early 15th century (Mooney and Cleland 2001). Some introduced plant species were advertently introduced for their medicinal, ornamental and forage values and some were introduced for the production of fiber, timber and fuel wood (Cox 2004). In many cases, exotic plants were accidentally introduced as crop seed contaminants or animal fodder, with domesticated animals and ship ballast, and as hitchhikers with military movements (Mack 1991; Sakai et al. 2001; Cox 2004; Chauvel et al. 2006). Theoretically, very few introduced plants become invasive; however, recently the number of introduced invasive plant species has reached more than 1000 in the United States alone (Mooney and Cleland 2001; USDA, ARS 2012). With the increase in the number of invasive plant species and their range expansion, the urgency to study the biological process of plant introduction, establishment, spread and invasion in novel habitats is being realized (Pimentel et al. 2000).

Herbarium records are the most reliable primary source of information to reconstruct introduction and colonization history of a species when detailed historic data are not available (Strother and Smith 1970; Mack 1991; Barney 2006). Herbarium specimen labels provide valuable information that can be used to document the time of introduction of non-native plants (Wester 1992; Woods et al. 2005; Valliant et al. 2007), the number of independent introductions (Barney 2006), the early invasion pathways in the introduced range (Lavoie et al. 2007; Stuckey 1980) and distributional changes of plants over time as in *Ambrosia artemisiifolia* (Chauvel et al. 2006; Lavoie et al. 2007), *Bouteloua curtipendula* (Laughlin 2003), *Bromus tectorum* (Novak and Mack 2001; Valliant et al. 2007), *Cortaderia selloana* and *C. jubata* (Lambrinos 2001), *Oenothera* spp.(Mihulka and Pysek 2001), *Solidago* spp. (Weber 1998), *Vincetoxicum* spp.(Sheeley and Raynal 1996) and many other species (Woods et al. 2005). However, herbarium specimen based information can sometimes be misleading because of errors associated with incorrect identification and geographic and temporal biases (Delisle et al. 2003; Chauvel et al. 2006; Crawford and Hoagland 2009). In addition, results tend to be spurious if a long history of specimen collections is not considered (Pysek and Prach 1993). Therefore, herbarium data need knowledgeable and cautious interpretation.

Falcaria vulgaris Bernh. (Syn. *F. rivini, F. sioides*; family Apiaceae; 2n = 22 [Goralski et al. 2009]), commonly known as sickleweed, is native to the European part of the former Soviet Union, the Caucasus, Western Siberia and Central Asia. It is also distributed in the central and southern parts of Western Europe, the Mediterranean, Asia Minor, and Iran. It is an introduced species in Africa, and North and South America (Larina 2008). It has been reported in sixteen states in the United States (USDA, NRCS 2011) and exhibits disjunct distribution in the Midwestern and Eastern USA. In the Midwest, its range includes the states of Illinois, Iowa, Kansas, Louisiana, Missouri, Nebraska, Oklahoma, South Dakota, Wisconsin and Wyoming; and in the East Coast, it includes Maryland, Massachusetts, New York, Pennsylvania, Virginia and West Virginia. In South Dakota, it occurs in the Fort Pierre National Grassland (FPNG; ca. 3200 ha infested in

2005), Buffalo Gap National Grassland (BGNG; ca. 40 ha), and locally on the campus of South Dakota State University (Korman 2011). Several large populations of sickleweed occur in six counties in Nebraska (our field observation; R. Kaul and K. Decker, University of Nebraska) where this species has been labeled a Category II invasive plant (invasive species whose eradication is still feasible; NISC 2011). No literature suggests invasiveness of this plant in any states other than South Dakota and Nebraska.

The sickleweed plant body is usually 30-60 cm tall with upright solid stems and a fleshy tap root; leaves are pinnately divided into 3-5 leaflets that are linear or linear-lanceolate and often curved to give the leaflets a sickle shape; leaflet margins have denticles. The inflorescence is a compound umbel with white flowers (Larina 2008). The flowers are andromonoecious and protandrous (See Knuth and Muller 1908). Phenotypic plasticity of its growth habit [annual or biennial (Clapham et al. 1989) or even perennial (Bojnansky and Fargasova 2007; Korman 2011)] and reproductive system [monoecism (See Knuth and Muller 1908) and vegetative propagation through rootstocks (Gress 1923; Larina 2008; Korman 2011)] help make this plant aggressive. Korman (2011) showed that this plant is negatively impacting species diversity and forage production of native grassland at FPNG.

Information on the introduction and distribution of sickleweed in the United States is fragmented and scant. Gress (1923) first reported this species in the United States (Pennsylvania). There are also short notes on the detection of this species in other states (Gates 1940, Kansas; Fernald 1942, Missouri; Thomas and Raymond 1987 Louisiana). Additionally, this species has been included in the annotated checklists of some state floras, e.g., Steyermark 1963, Missouri; Eilers and Roosa 1994, Iowa; Woods et al. 2005, Kansas; MacRoberts and MacRoberts 2006, Louisiana; Magee and Ahles 2007, Massachusetts; Rhoads and Block 2007, Pennsylvania. Except for these reports of this species at the regional level, there is no in-depth study on its introduction and distribution at the national level. Information for species introduction and spread in a new habitat can help predict the invasiveness of introduced species and may also be useful for control (Ricciardi et al. 2000; Kolar and Lodge 2001; Lambrinos 2001; Lavoie et al. 2003; Dybas 2004; Lerdau and Wickham 2011). In addition, this information can give clues on probable sites of invasion (Weber 1998). We are using herbarium records and relevant literature to study the introduction history and spread of sickleweed and to determine current distribution in the USA. The objectives of this study are to assess and infer 1) when and where this species was introduced, 2) current temporal spread of the species and 3) the number of independent introductions.

METHODS

Specimens from herbaria in the sixteen states, where the USDA Plants Database has reported the occurrence of sickleweed, were examined. The list of the herbaria (Appendix 1) was obtained from *Index Herbariorum* (http://sciweb.nybg.org/science2/IndexHerbariorum .asp), a directory of public herbaria of the

world. Herbarium curators/collection managers of these herbaria were contacted for information on their holdings of sickleweed. The information requested for each specimen included voucher/accession number, date collected, collector(s) and collection locality. As the collections of many introduced species can be unmounted or unprocessed in herbaria, we requested information on unmounted sickelweed specimens (if any) as well. The small number of specimens and the monotypic nature of the genus led to fast communication of data from herbaria and experts. Information was also obtained from online specimen databases (BKL, HUH, ISM, KANU, KSC, LSU, Oklahoma Vascular Plant Database, RM, TROPICOS). Abbreviations for these herbaria follow those of Holmgren et al. (1990). Most sickleweed specimens were housed in the major agricultural herbaria in the Midwest (ISC, NEB, SDC); these were visited to examine the sickleweed specimens. Vouchers that had been collected by the same collector from the same locality on the same date (duplicates) were regarded as one specimen following Chauvel et al. (2006). Specimens collected from countries other than the United States were not included in this study. The sites of earliest collections of herbarium specimens were considered to be the possible sites of early introduction, whereas the sites of subsequent collections were interpreted to be the possible pathways along which this species spread. Following Barney (2006), we assumed that the species is always present once it was collected from a county. Based on this assumption, a temporal distribution map of the species (at county level) was constructed using ArcGIS 9.3 (ESRI 2008).

RESULTS

Falcaria vulgaris specimens in herbaria—Among the 178 herbaria contacted, we received responses from 76 herbaria. Among these, 42 herbaria (BALT, BDWR, BTJW, BUPL, CAMU, CORT, DEK, DWC, DWU, ECH, EMNH, FWVA, ILL, ISU, KEN, KNOX, KSTC, LAF, LSUS, LYN, MCN, MOAR, MOR, MVSC, MWI, NWOSU, NYS, ORU, PHIL, PLAT, RMS, RUHV, SDU, SEMO, SMS, TAWES, URV, VAS, WARM, WILLI, WVW and YELLO) had no sickleweed specimens. At the remaining 34 herbaria (BH, BHSC, BKL, CM, CSCN, DUR, F, FARM, GH, ISC, ISM, KANU, KSC, LSU, MASS, MO, NEB, NEBC, NLU, NO, ODU, OKL, OKLA, OMA, PA, PH, RM, SDC, UMO, UWM, UWSP, VPI, WIS and WVA), we found 195 sickleweed specimens collected from the United States. After excluding the duplicate specimens, we examined a total of 143 sickleweed specimens. These specimens were collected from 1922 to 2011 from 32 counties of 15 states. We noted 5 more counties where sickleweed has been reported (J. T. Kartesz, Biota of North America) but for which we found no specimen evidence. Among the 16 states from which USDA Plants Database reported the occurrence of sickleweed, we were unable to locate sickleweed specimens from Maryland in any of the herbaria we contacted. To our knowledge, sickleweed has been reported from 37 counties in 15 states in the United States. The majority of specimens examined were from Iowa, Nebraska, and South Dakota, and there were no collections from any other state made during the last 17 years (Table 1). GH houses the highest number of

Table 1. Earliest and the most recent specimen records of Falcaria vulgaris in the United States

STATE	OLDEST HERBARIUM RECORD	VOUCHER INFORMATION	MOST RECENT HERBARIUM RECORD	VOUCHER INFORMATION
Illinois	28 June 1955	Rexroat, 49125, ISM	11 July 1957	Martens, s.n., SOTO
Iowa	1 Oct 1930	Harmon, s.n., GH; ISC	20 Aug 2011	Nepal, Neupane and Piya, 101, SDC
Kansas	29 May 1932	Anthony, s.n., KANU	28 June 1951	Blocker, 26719, KSC
Louisiana	28 Apr 1984	Thomas and Raymond, 88299, NLU	15 May 1984	Thomas and Taylor, 88740, NLU
Massachusetts	25 Aug 1989	Sorrie and Weatherbee, 4884, GH; NEBC; MASS	25 Aug 1989	Sorrie and Weatherbee, 4884, GH; NEBC; MASS
Missouri	19 July 1941	Miller, 35958, UMO	10 Sept1991	Ellis, s.n., MO
Nebraska	16 Sept 1946	Kinch, s.n., GH	20 Aug 2011	Nepal, Neupane and Piya, 101, SDC
New York	1 Aug 1923	Holtzoff, 289002, BKL	30 May 1928	Holtzoff, 289003, BKL
Oklahoma	30 July 1957	Engleman, 105664, OKL	1 July 1974	Hamman, s.n., DUR
Pennsylvania	2 Sept 1922	Gress, s.n., GH	29 July 1962	PH
South Dakota	9 June 1961	Unknown, s.n., SDC	20 May 2009	Korman, 470, SDC
Virginia	27 June 1974	Harril and Wise, 31616, VPI	16 Aug 1980	Wieboldt, 71984, VPI
West Virginia	5 Aug 1954	Hicks and Bartley, 32, WVA	5 Aug 1954	Hicks and Bartley, 32, WVA
Wisconsin	29 July 1981	Thompson, 0013345, WIS	11 Aug 1991	Thompson, 0013345, WIS
Wyoming	9 Sept 1995	Dorn, 600764, RM	9 Sept 1995	Dorn, 600764, RM

specimens collected from different states, including the oldest collections from Iowa, Oklahoma, Massachusetts, Nebraska, Pennsylvania, and Wisconsin. SDC houses the highest number of recently collected specimens.

Information from Herbarium Records

***Collection history of Falcaria vulgaris*—**Sickleweed was first reported by Gress (1923) as a new species to the United States. He was the collector of the oldest specimen of sickleweed, which was collected from the agricultural field at Mercersberg, Franklin County, Pennsylvania, on September 2, 1922 (Figure 1). This specimen is housed at Gray Herbarium (Gress, s.n., GH) with a duplicate at Carnegie Museum of Natural History (Gress, s.n., CM). Sickleweed was subsequently reported in New York (August 1923; Holtzoff, 289002, BKL), West Virginia (August 1954; Hicks and Bartley, 32, WVA), Virginia (June 1974; Harril and Wise, 31616, VPI), and Massachusetts (August 1989; Sorrie and Weatherbee, 4884, GH; NEBC; MASS). The specimen collected from Massachusetts in August 1989 (Sorrie and Weatherbee, 4884, GH; NEBC; MASS) represents the most recent collection from the East Coast.

The oldest specimen from the Midwest is from Sioux County, Iowa, collected on October 1, 1930 (Harmon, s.n., GH, ISC). The next report was from Atchison County, Kansas, in 1932. The species was then reported from Missouri (July 1941; Miller, 35958, UMO), Nebraska (September 1946; Kinch, s.n., GH), Illinois (June 1955; Rexroat, 49125, ISM), Oklahoma (July 1957; Engleman, 105664, OKL), South Dakota (June 1961; Unknown, s.n., SDC), Wisconsin (July 1981; Thompson, 0013345, WIS), Louisiana (April 1984; Thomas and Raymond, 88299, NLU) and Wyoming (September 1995; Dorn, 600764, RM). After 1995, specimens were collected only from the states of Iowa, Nebraska and South Dakota. The oldest and latest herbarium specimens collected from different states in the United States are presented in Table 1.

***Collection site*—**The first herbarium specimens from the East Coast (Pennsylvania) and the Midwest (Iowa) were both collected from agricultural fields. In Pennsylvania, the first sickleweed specimen was collected from a field where clover (*Trifolium* spp.) and timothy grass (*Phleum pratense*) were being cultivated. Similarly, the oldest herbarium specimen from South Dakota was collected from an agricultural field, but most of the recent specimens are from grasslands (FPNG and BGNG, South Dakota). In Nebraska, most specimens were collected from the roadsides with the specific locality not provided. Table 2 shows the number of sickleweed specimens collected from different habitats at different time periods.

***Introduction, spread and naturalization*—**On most of the sickleweed herbarium labels, the species is noted to be introduced and native to Europe and Asia, but without a mention of the actual country of origin of the accession. The status of the plant was given as "naturalized", "adventive" or "common" in most of the counties at the time of collection, but in few cases the plant was described as "rare". There is no information on how this species was introduced to the United States. There exists, however, some literature about collector's observation of the species in the field that provides some valuable clues. Gress (1923) report-

Figure 1. Earliest record of F. vulgaris from Pennsylvania- collector Gress. (Image Source: Emily Wood, GH).

Table 2. Number of sickleweed specimens collected from different habitats during different time periods.

YEAR	AGRICULTURAL LAND	RAILROAD/ ROADWAY	GRASSLAND	UNKNOWN	TOTAL
1920-1940	5	2		2	9
1941-1960		2	3	6	11
1961-1980	1	1	1	2	5
1981-2000		10	3	2	15
2001-2011		5	150		155

ed this species as new to the United States, whereas Cratty (1930), Gates (1940), Thomas and Raymond (1987) mentioned this species as new to Iowa, Kansas and Louisiana, respectively. Collectors have also mentioned that the species was new to the state on some of the herbarium labels. In most cases, the species was detected long after introduction and by the time it had become established as a relatively large population (Fernald 1942; Thomas and Raymond1987). A century long collection of sickleweed specimens in the USA shows that the spread of the species is concentrated mainly in the Midwest (Figure 2a-d).

DISCUSSION

Sickleweed herbarium records in the introduced range—In the United States, sickleweed has been collected since 1922, but the number of sickleweed collections is relatively small (Table 2). There is no record of collection from the East Coast and some states in the Midwest (except Iowa, Nebraska and South Dakota) for the last 17 years. Usually, adventive species are repeatedly collected if they persist and are abundant (Wester 1992). In some cases, the lower genetic diversity of introduced plants results in inbreeding depression thereby causing the species to disappear (Ellstrand and Elam 1993). In the Czech Republic, Pergl et al. (2012) reported the disappearance of *Heracleum mantegazzianum* from 76% of the sites where the species had once colonized. In United States, sickleweed may likewise have disappeared from several sites where it had once colonized. Mitchell and Tucker (2000) and Weldy and Werier (2012) reported that sickleweed has disappeared from New York. However, it is not possible to ensure the extinction of a species from a specific locality merely on the basis of herbarium data. Sometimes collectors show no interest in collecting a species once it is represented in the herbarium from a particular locality (Stuckey 1980; Chauvel et al. 2006). This is true for many exotic plant species. Although no sickleweed specimen has been collected recently in Massachusetts and Pennsylvania, the plant has been listed in a recent publication as an adventive species for Massachusetts and Pennsylvania (Magee and Ahles 2007; Rhoads and Block 2007; The Pennsylvania Flora Project) recognizing that the plant may still occur in these states. To reconstruct the spread of the plant, we assumed that the species was potentially present in each of the counties where it was once collected.

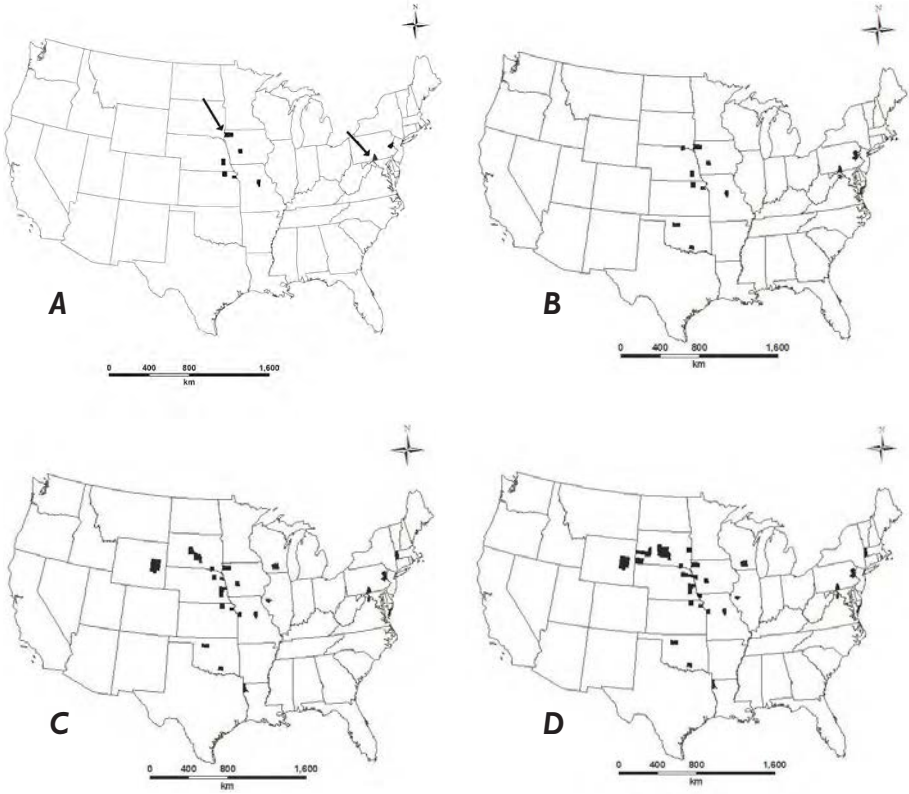
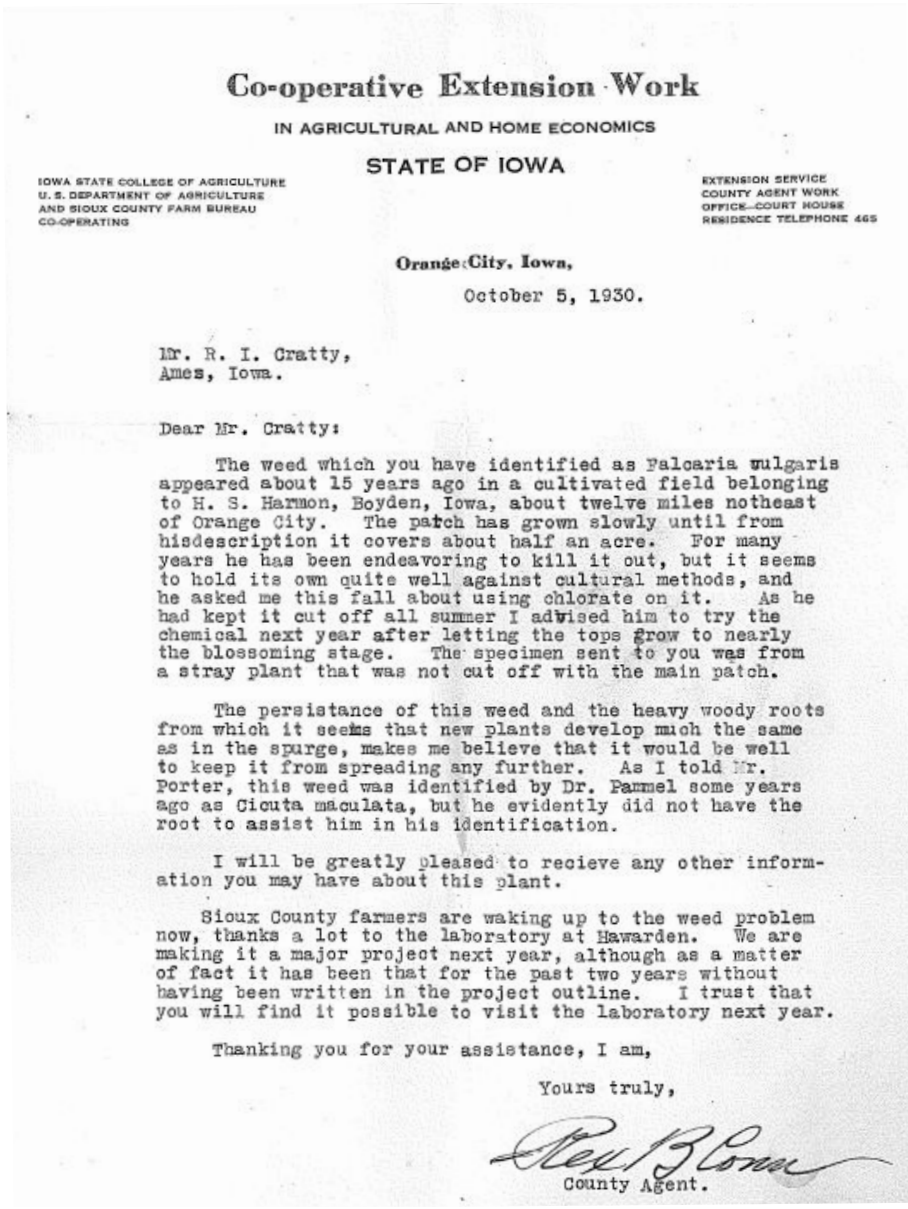


Figure 2. Spatial distributions of sickleweed records in the United States counties up to (a) 1950 (b) 1975 (c) 2000 and (d) 2012. The arrows in Figure 2(a) indicate the counties of primary introductions. The distribution maps were created using our data, information from herbarium records and geo reference data from BONAP (Biota of North America Program).

Introduction and spread of sickleweed—Sickleweed was introduced in the first quarter of the twentieth century in the United States. According to Gress (1923), the farmer whose field in Pennsylvania was the source of the earliest USA collection had detected the plant about five years before the collection date. In the Midwest, sickleweed was first collected in 1930 from a farm field in Iowa. A letter sent by the county agent of Sioux County to the curator of ISC, R. I. Cratty (Figure 3), mentions that the species was previously misidentified as *Cicuta maculata*. Also, Cratty (1930) mentions that the farmer of the field where the specimen was collected had detected this weed about 15 years before the collection date of the specimen. It is not unusual that introduced plants are noticed only after they are well established and cover a large area (Wester 1992). It appears that sickleweed was detected approximately at the same time in the early 20th century in the East Coast and in the Midwest of the United States. Cox (2004) reported that several ruderal plants have been introduced accidentally to the USA from Europe as contaminants in crop seed and animal fodder (Cox 2004). Since sickleweed was first reported as weed from agricultural fields



Co-operative Extension Work

IN AGRICULTURAL AND HOME ECONOMICS

STATE OF IOWA

IOWA STATE COLLEGE OF AGRICULTURE
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CO-OPERATING

EXTENSION SERVICE
COUNTY AGENT WORK
OFFICE—COURT HOUSE
RESIDENCE TELEPHONE 465

Orange City, Iowa,

October 5, 1930.

Mr. R. I. Cratty,
Ames, Iowa.

Dear Mr. Cratty:

The weed which you have identified as Falcaria vulgaris appeared about 15 years ago in a cultivated field belonging to H. S. Harmon, Boyden, Iowa, about twelve miles notheast of Orange City. The patch has grown slowly until from hisdescription it covers about half an acre. For many years he has been endeavoring to kill it out, but it seems to hold its own quite well against cultural methods, and he asked me this fall about using chlorate on it. As he had kept it cut off all summer I advised him to try the chemical next year after letting the tops grow to nearly the blossoming stage. The specimen sent to you was from a stray plant that was not cut off with the main patch.

The persistance of this weed and the heavy woody roots from which it seems that new plants develop much the same as in the spurge, makes me believe that it would be well to keep it from spreading any further. As I told Mr. Porter, this weed was identified by Dr. Pammel some years ago as Cicuta maculata, but he evidently did not have the root to assist him in his identification.

I will be greatly pleased to recieve any other information you may have about this plant.

Sioux County farmers are waking up to the weed problem now, thanks a lot to the laboratory at Hawarden. We are making it a major project next year, although as a matter of fact it has been that for the past two years without having been written in the project outline. I trust that you will find it possible to visit the laboratory next year.

Thanking you for your assistance, I am,

Yours truly,

Rex B Conn

County Agent.

Figure 3. Letter sent by county agent Rex B. Conn to R. I. Cratty (ISC curator) informing about the occurrence of sickleweed in Sioux County, Iowa.

in both the East Coast and the Midwest states, we assume that this species was introduced accidentally, and perhaps as a seed contaminant.

If introduced species have commercial value, then they could have been purposely introduced; otherwise they could be assumed to be accidentally introduced (Wester 1992). In some parts of its native range, sickleweed has been traditionally used as a medicinal herb to treat skin ulcers, stomach disorders, liver diseases, and kidney and bladder stones, and has also been eaten as a vegetable (See Khazaei and Salehi 2006). Fernald (1942) reported the occurrence of a sickleweed population in Missouri near a community with a large number of German immigrants, suggesting the population could have been intentionally introduced from central Europe.

Based on the distribution map constructed using herbarium specimens (Figure 2), we see two disjunct distributions with earliest detections on both the East Coast and in the Midwest being nearly simultaneous. We therefore propose two primary introductions of sickleweed in the United States. The sickleweed population in Franklin County, Pennsylvania, is possibly the source population for the East Coast and the population in Sioux County, Iowa for the Midwest. Propagules then may have been dispersed from these primary sites to the other sites (Figure 2a) through various mechanisms. Transportation of plant propagules occur through the attachment of seeds to muddy vehicles or tires used for human and freight transportation (Kowarik and von der Lippe 2007). Additionally, the cutting and transporting of hay that included sickleweed with mature seed could account for the spread. Furthermore, when the sickleweed plant senesces, it breaks at the nodes, and plant segments tumble in the wind to disperse the seed (See Limpert et al. 2004; Korman 2011). Also, the seeds might have been transported from the primary sites by mammals and birds. For example, there is some evidence of sickleweed seeds being transported from the plant's native range to other countries within Europe by ducks and other water birds (Brochet et al. 2009). If molecular data derived from analysis of herbarium specimens and extant populations were combined with the herbarium data, which is a commonly used approach (see Novak and Mack 2001; Valliant et al. 2007), better insight into the entry and spread of sickleweed in the USA could be had.

Current control effort and future prospects—Attempts to control sickleweed at FPNG in South Dakota have shown how difficult this weed can be once it becomes established. It was first detected at FPNG in 1992, and at that time this species had infested only 65 hectares of land. But attempts to manage the outbreak began only after a decade had passed and the plant was spreading aggressively and overtaking the grassland vegetation. An attempt to control the species spread by using prescribed fire proved ineffective. Herbicide treatment with Dupont Telar XP® has been practiced since 2004 to control spread of the weed and has proven effective with repeat applications, although not all of the area infested has been treated and new patches are being found outside of treated areas (Korman 2011) with current infestation now an estimated 6,000 acres. This example illustrates the need to eradicate exotic plant infestations as soon as they are detected. Eradication of invasive species can be easy when a few plants are found early by appropriate survey, or the population size is small and confined to

a small area (Wester 1992), but when the area of infestation increases, the cost of control and management increases exponentially (Rejmanek and Pitcairn 2002).

In Nebraska, we observed the occurrence of several large populations of sickleweed along roadsides. According to Pysek and Prach (1993), if invasive species occur along roadsides or railroad tracks, these sites not only harbor the plant, but also serve as corridors for their spread. Plants growing along roadsides are more likely to be transported by vehicles and may also spread to nearby pastures and hay fields by means of wind or other agents. In Nebraska, sickleweed is listed as a Category II invasive plant by the Nebraska Invasive Species Council (2011). Thus far, no major program has been launched for its control and management (K. Decker, University of Nebraska - Lincoln), but recently the large population in Lancaster County, Nebraska, has been herbicided and all plants appear to be dead (R Kaul, University of Nebraska- Lincoln). Infestations at FPNG and BGNG in South Dakota and along roadsides in Nebraska that represent diverse habitats make it necessary that control strategies involve cooperation among public land managers, transportation departments, and private landowners to hope for effective long term control and management. This study on the distribution and spread of sickleweed is pursued for purposes of realizing better control strategies and management practices in the region. In this paper, we present information compiled to interpret the status of recent sickleweed populations relative to those of the past. The absence of recent sickleweed records from states other than Iowa, Nebraska, and South Dakota suggests that this species is growing undetected or not currently present in those states. However, should it become established over a period of time, it may become invasive elsewhere when a sufficient number of propagules are transported to congenial environments as discussed by Kolar and Lodge (2001). In this study we used herbarium data to reconstruct the introduction history of sickleweed and its subsequent dispersal in the United States. Additionally, knowing the environmental limits of this plant along with the dispersal pathways will help us predict the areas that are vulnerable to future invasion.

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LITERATURE CITED

Barney, J.N. 2006. North American history of two invasive plant species: phytogeographic distribution, dispersal vectors, and multiple introdutions. Biological Invasions 8:703-717.

Bojnansky, V., and A. Fargasova. 2007. Atlas of seeds and fruits of Central and East European flora. Springer, The Netherlands.

Brochet, A., M. Guillemain, H. Fritz, M. Gauthier-Clerc, and A.J. Green. 2009. The role of migratory ducks in the long-distance dispersal of native plants and the spread of exotic plants in Europe. Ecography 32:919-928.

Chauvel, B., F. Dessaint, C. Cardinal-Legrand, and F. Bretagnolle. 2006. The historical spread of *Ambrosia artemisiifolia* L. in France from herbarium records. Journal of Biogeography 33:665-673.

Clapham, R., T.G. Tutin, and D.M. Moore.1989. Flora of the British Isles. Cambridge University Press, NY.

Cox, G.W. 2004. Alien species and evolution. Island press, Washington DC.

Cratty, R.I. New weed is given name of sicklewort. Des Moines Register, 23 November, 1930.

Crawford, H.C., and B.W. Hoagland. 2009. Can herbarium records be used to map alien species invasion and native species expansion over the past 100 years? Journal of Biogeography 36:651-661.

Delisle, F., C. Lavoie, M. Jean, and D. Lachance. 2003. Reconstructing the spread of invasive plants: taking into account biases associated with herbarium specimens. Journal of Biogeography 30:1033-1042.

Dybas, C.L. 2004. Invasive species: The search for solutions. Bioscience 54:615-621.

Eilers, L.J., and D.M. Roosa. 1994. The vascular plants of Iowa: an annotated checklist and natural history. University of Iowa Press, Iowa City, IA.

Ellstrand, N.C., and D.R. Elam. 1993. Population genetic consequences of small population size: implications for plant conservation. Annual Review of Ecology and Systematics 24:217–42.

ESRI. 2008. ArcGIS, version 9.3. Environmental Systems Research Institute, Redlands, CA.

Fernald, M.L. 1942. Misinterpretation of Atlantic coastal plain species. Rhodora 44:238-246.

Gates, F.C. 1940. Recent migrational trends in the distribution of weeds in Kansas. Transactions of the Kansas Academy of Science 43:99-117.

Goralski, G., P. Lubczyńska, and A.J. Joachimiak. 2009. Chromosome Number Database. Available at http://www.binoz.uj.edu.pl:8080/chromosomes/ [Cited April 06, 2011].

Gress, E.M.1923. *Falcaria rivini* a plant new to the United States. Rhodora 25:13-14.

Holmgren, P.K., N.H. Holmgren, and L.C. Barnett. 1990. Index Herbariorum. Part I, The herbaria of the world, 8th ed. IAPT and the New York Botanical Garden, NY.

Khazaei, M., and H. Salehi. 2006. Protective effect of *Falcaria vulgaris* extract on ethanol induced gastric ulcer in rat. Iranian Journal of Pharmacology and Therapeutics 5:43-46.

Knuth, P., and H. Muller. 1908. Handbook of flower pollination. Clarendon Press, Oxford.

Kolar, C.S., and D.M. Lodge. 2001. Progress in invasion biology: predicting invaders. Trends in Ecology and Evolution 16:199-204.

Korman, B.L. 2011. Biology and ecology of Sickleweed (*Falcaria vulgaris*) in the Fort Pierre National Grassland of South Dakota. Thesis. South Dakota State University, Brookings, SD.

Kowarik, I., and M. von der Lippe. 2007. Pathways in plant invasions. Pages 29-47 in W. Nentwig, editor. Ecological Studies. Springer, Berlin.

Lambrinos, J.G. 2001. The expansion history of a sexual and asexual species of *Cortaderia* in California, USA. Journal of Ecology 89:88-98.

Larina, S.Y. 2008. *Falcaria vulgaris* Bernh. Interactive agricultural ecological atlas of Russia and neighboring countries. In A.N. Afonin, S.L. Greene, N.I. Dzyubenko and A.N. Frolov, editors. Economic plants and their diseases, pests and weeds. Available at http://www.agroatlas.ru/en/content/weeds/Falcaria_vulgaris/ [Cited June 04, 2011.]

Laughlin, D.C. 2003. Geographic distribution and dispersal mechanisms of *Bouteloua curtipendula* in the Appalachian Mountains. American Midland Naturalist 149:268-281.

Lavoie, C., M. Jean, F. Delisle, and G. Letourneau. 2003. Exotic plant species of the St Lawrence River wetlands: a spatial and historical analysis. Journal of Biogeography 30:537-549.

Lavoie, C., Y. Jodoin, and A.G. de Merlis. 2007. How did common ragweed (*Ambrosia artemisiifolia* L.) spread in Quebec? A historical analysis using herbarium records. Journal of Biogeography 34:1751-1761.

Lerdau, M., and J.D. Wickham. 2011. Non-natives: four risk factors. Nature 475:36-37.

Limpert, E., K. Ammann, P. Bartos, W.K. Graber, G. Kost, and J.G. Fuchs. 2004. Airborne migration of obligate nomads demonstrates gene flow across Eurasia. Pages 339-352 in D. Werner, editor. Biological Resources and Migration. Springer, NY.

Mack, R.N. 1991. The commercial seed trade: An early disperser of weeds in the United States. Economic Botany 45:257-273.

MacRoberts, B.R., and M.H. MacRoberts. 2006. An updated, annotated vascular flora of Caddo Parish, Louisiana, with notes on regional phytogeography and ecology. SIDA Contributions to Botany 22:1191-1219.

Magee, D.W., and H.E. Ahles. 2007. Flora of the Northeast: a manual of the vascular flora of New Enlgand and adjacent New York, 2nd ed. University of Massachusetts Press, Amherst, MA.

Mihulka, S., and P. Pysek. 2001. Invasion history of *Oenothera* congeners in Europe: a comparative study of spreading rates in the last 200 years. Journal of Biogeography 28:597-609.

Mitchell, R.S., and G.C. Tucker. 2000. Revised checklist of New York state plants. New York State Museum, Albany.

Mooney, H.A., and E.E. Cleland. 2001. The evolutionary impact of invasive species. Proceedings of the National Academy of Sciences 98:5446-5451.

NISC (2011) Invasive plants of Nebraska. Available at http://snr5.unl.edu/invasives/pdfs/Invasive%20Plant%20Lists/NE%20Invasive%20Plants%20List%20Only%204-14-11.pdf [Cited 5 November, 2011].

Novak, S.J., and R.N. Mack. 2001. Tracing plant introduction and spread: Genetic evidence from *Bromus tectorum* (Cheatgrass). Bioscience 51:114-122.

Pergl, J., P. Pysek, I. Perglova, and V. Jarosik. 2012. Low persistence of a monocarpic invasive plant in historical sites biases our perception of its actual distribution. Journal of Biogeography, Published online before print doi:10.1111/j.1365-2699.2011.02677.x.

Pimentel, D., L. Lach, R. Zuniga, and D. Morrison. 2000. Environmental and economic costs of nonindigenous species in the United States. Bioscience 50:53-65.

Pysek, P., and K. Prach. 1993. Plant invasion and the role of riparian habitats: a comparison of four species alien to central Europe. Journal of Biogeography 20:413-420.

Rejmanek, M., and M.J. Pitcairn. 2002. When is eradication of exotic pest plants a realistic goal? Pages 249-253 in C.R. Veitch and M.N. Clout, editors. Turning the tide: the eradication of invasive species. IUCN SSC Invasive Specialist Group, Gland, Switzerland and Cambridge, UK.

Rhoads, A.F., and T.A. Block. 2007. The plants of Pennsylvania: an illustrated manual, 2nd ed. University of Pennsylvania Press, Philadelphia.

Ricciardi, A., W.W.M. Steiner, R.N. Mack, and D. Simberloff. 2000. Toward a global information system for invasive species. Bioscience 50:239-244.

Sakai, A.K., F.W. Allendorf, J.S. Holt, D.M. Lodge, J. Molofsky, K.A. With, S. Baughman, R.J. Cabin, J.E. Cohen, N.C. Ellstrand, D.E. Mncauley, P. O'Neil, I.M. Parker, J.N. Thomson, and S.G. Weller. 2001. The population biology of invasive species. Annual Review of Ecology and Systematics 32:305-332.

Sheeley, S.E., and D.J. Raynal. 1996. The distribution and status of species of Vincetoxicum in eastern North America. Bulletin of the Torrey Botanical Club 123:148-156.

Steyermark, J.A. 1963. Flora of Missouri. Iowa State University Press, Ames, Iowa.

Strother, J.L., and A.R. Smith. 1970. Chorology, collection dates, and taxonomic responsibility. Taxon 19:871-874.

Stuckey, R.L. 1980. Distributional history of *Lythrum salicaria* (Purple loosestrife) in North America. Bartonia. Proceedings of the Philadelphia Botanical Club 47:18.

Thomas, R.D., and L.R. Raymond. 1987. *Falcaria vulgaris* Bernh. (Apiaceae): New to Louisiana. The Southwestern Naturalist 32:279.

USDA, ARS. 2012. National Genetic Resources Program. Germplasm resources information network (Online Database). National germplasm resources laboratory, Beltsville, Maryland. Available at http://www.ars-grin.gov/cgi-bin/npgs/html/noxweed.pl [Cited 14 March 2012].

USDA, NRCS. 2011. The Plants Database. National Plant Data Center, Baton Rouge, LA 70874-4490 USA. Available at http://plants.usda.gov [Cited 16 April 2011].

Valliant, M.T., R.N. Mack, and S.J. Novak. 2007. Introduction history and population genetics of the invasive grass *Bromus tectorum* (Poaceae) in Canada. American Journal of Botany 94:1156-1169.

Weber, E. 1998. The dynamics of plant invasions: a case study of three exotic goldenrod species (*Solidago* L.) in Europe. Journal of Biogeography 25:147-154.

Weldy, T., and D. Werier. 2012. New York flora atlas. Available at http://newyork.plantatlas.usf.edu/ [Cited 2 february, 2012].

Wester, L. 1992. Origin and distribution of adventive alien flowering plants in Hawaii. Pages 99-154 in C.P. Stone, C.W. Smith and J.T. Tunison, editors. Alien plant invasions in native ecosystems of Hawaii: Management and research. University of Hawaii, Manoa.

Woods, T.M., S.C. Strakosh, M.P. Nepal, S. Chakrabati, N.B. Simpson, M.H. Mayfield, and C.J. Ferguson. 2005. Introduced species in Kansas: floristic changes and patterns of collection based on an historical herbarium. SIDA Contributions to Botany 21:1695-1725.

Appendix 1. List of Herbaria contacted

STATE	ACRONYMS OF THE HERBARIA
Illinois	CACS, EIU, CHIC, F, ILLS,ISM, ISU, KNOX, MOR, NRRL, DEK, SIU,CEL, WARK
Iowa	MOVC, GRI, ILH, ISC, GRI, LCDI, BDI, SICH, ISTC, WET
Kansas	KSTC, FHKSC, KSC, SAL, KANU, WASH
Louisiana	LSU, LSUS, LTU, MCN, THIB, NATC, SELU, NO, USLH, NLU, NOLS
Maryland	BALT, MARY, SUHC, TAWES, US
Massachusetts	AC, CUW, WMGC, GH, NASC, NMMA, NEBC, HNUB, PM, SCHN, SPR, HDSM, MASS, WELC
Missouri	MCJ, MODNR, MO, MWSJ, NEMO, NMSU, SEMO, SMS, SOTO, UMO, WARM, WJC
Nebraska	CSCN, HNWU, NEBK, OMA, NEB,
New York	BKL, GRCH, BH, ECH, HHH, DH, SOUT, HPH, NY, NYS, ROCH, SBU, CORT, SYRF, BING, PLAT, SUCO, SIM, SYR, VAS
Oklahoma	ECSC, NOSU, NWOSU, OKLA, ORU, DUR, WHO, CSU, OKL, OCLA, TULS
Pennsylvania	ANSP, BUPL, CM, IUP, KEN, MVSC, MOAR, MCA, FMC, PAM, PAC-MA, RPM, LAT, SLRO, SWC, ABFM, PHIL, DWC
South Dakota	DWU, AUG, BHSC, SDC, SDU
Virginia	CVCW, HAVI, EHCV, GMUF, JMUH, FARM, LFCC, LYN, MWCF, ODU, RUHV, SARC, WILLI, URV, VA, VCU, VDAC, VIL, VPI, VSUH, ROAN, WYCO
West Virginia	DEWV, FWVA, MUHW, MVC, WVA, WVW
Wisconsin	CART, MIL, SNC, UWW, FDLW, UWEC, UWJ, UWL, UWM, WIS, OSH, UWGB, USWP, SUWS
Wyoming	BTJW, CWC, RMS, RM, YELLO