# How the West Was Lost: Reconstructing the Invasion Dynamics of Yellow Starthistle and Other Plant Invaders of Western Rangelands and Natural Areas

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## Introduction

One of the most common ways exotic plant species are introduced into new regions is through the planting of contaminated crop seed. The weed science literature is brimming with accounts of new invasive exotic species that were introduced as seed contaminants in shipments of crop seed. The authors of many of those accounts attempted to reconstruct the subsequent range expansion of the invasive species by mapping the collection locations noted on herbarium specimen sheets. A few published analyses of invasive species, such as those for cheat grass (*Bromus tectorum* L.) and Russian thistle (*Salsola tragus* L.), have used additional information such as the expansion of railways and roads to develop more detailed descriptions of the introduction and subsequent expansion of invasive species. However, no study has incorporated data describing the introduction and expansion of the new crops and cropping systems that are directly responsible for the introduction and range expansion of the invasive exotic species. This omission represents a tremendous loss of information about the introduction and range expansion dynamics of a large number of important invasive species.

In the following sections of this paper I will describe how yellow starthistle (*Centaurea solstitialis* L.) and several other invasive species were introduced as part of a forage crop/weed system and how the range expansion process of the invaders is correlated with the expansion of the forage crop/weed system. Examples from the medium scale invasion of a portion of the Sacramento Valley and the large scale invasion of the western United States will be used to illustrate the complexity of invasion processes. I'll conclude with an example of how this crop/weed system conceptualization can be combined with basic biological and ecological information to aid in determining the most effective management decisions.

## Forage Crop/Weed Systems

The sowing of crop seed contaminated with weed seed is widely recognized as one of the most important sources of invasive plant species. Many weed seeds are moved great distances and are widely dispersed into disturbed environments. Most of the introduced weed species never escape the boundaries of the cropping systems but the few species that do escape are successful invaders of adjoining natural areas, reserves, and grazing land.

Geography and crop production practices are the two most important factors that determine the species composition of the weed component of each crop/weed system. Geography determines the suite of native species that can potentially move with the crop seed from the site of seed production to the site of introduction. Crop production practices select which native species actually join the existing crop/weed system and which exotic or cosmopolitan species continue to be moved with the crop/weed system. For example, the harvesting of grain crops tends to select species that mature seed at the same time as the grain crop while the grazing or cutting of forage crops tends to select species that can survive and reproduce after repeated removal of photosynthetic tissue.

The most important leguminous forage crops in the United States are alfalfa (*Medicago sativa*) and red clover (*Trifolium pratense*). These forage crops provide concentrated supplies of nitrogenous compounds which enable dairies and stockyards to be operated on very small parcels of land conveniently located near their markets. Alfalfa crops also enable ranches to operate in the dry regions of the west as large amounts of nutritious hay may be grown along stream courses or in irrigated fields and stored for use when the rangeland plants are dormant.

Because alfalfa and clover have different geographical origins and have been subjected to different crop production practices their forage crop/weed systems tend to have distinct weed species assemblages. A long term study conducted during the 1920's tested seed lots moving in international trade and identified approximately 500 species of weeds in alfalfa and clover seed (Hillman and Henry 1928). Of course not all of those species became invasive but several of them are among the worst plant invaders in the western United States and in alfalfa and clover growing regions around the world. Table 1 presents data on a small number of the invaders (shading indicates native ranges of weed species).

Table 1. Weed Seed Contaminants in Crop Seed

| Alfalfa Seed | | | | | | | | | Hillman and Henry (1928) Proc. Int. Seed Testing Assn. No. 6, October , Page 1<br>P = present in <10% of samples<br>1 = present in 10% to 19% of samples<br>2 through 9 are similar percentage intervals<br>Shading indicates native range of weed species | Red Clover Seed | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Middle Western States | Central Valley | Lake County | Modoc County | Argentina | France | Italy | Spain | Turkestan | Weed Species | Idaho & Washington | Oregon | North Central States | Chile | Central Europe | France | Italy |
| P | 2 | P | | 1 | 3 | 2 | 6 | 1 | Centaurea solstitialis | | | | | | P | P |
| | | | | | | | | 9 | Acroptilon repens | | | | | | | |
| | | | | | | | | 3 | Alhagi pseudalhagi | | | | | | | |
| | | | | | | | | | Centaurea maculosa | | | | | P | | |
| | | | | P | | | | | Achnatherum brachychaetum | | | | | | | |
| | P | | | | | | | | Eremocarpustse igerus | | | | | | | |

The history of primary and secondary introductions can also be reconstructed from the Hillman and Henry study by comparing the historical and geographical development of alfalfa and clover farming with the native ranges of the weed species that accompanied the alfalfa seed. The clover cropping system evolved in northern Europe and clover fanning was introduced in North America during pre-Revolutionary times. Initially, clover fanning was almost entirely confined to moist regions east of Minnesota, Iowa, Missouri, and Arkansas. Much later, clover was grown in the Pacific Northwest west of the Cascade Ranges and in some mountain meadows of the Intermountain West. In contrast, the alfalfa cropping system evolved in southern Europe, the Middle East, and western Asia. While very small amounts of alfalfa (known also as Lucern and ewiger Klee) were grown in a few of the Atlantic states and in a few fields in Minnesota and Canada by English, French, and German settlers, its status as a commercial crop began when it was introduced in California during the 1850's (Stewart 1926). Alfalfa farming then spread rapidly northward and eastward into other western states.

Until 1898 almost all alfalfa growing in the western United States originated from seed which had been either imported directly from Chile or harvested locally from plants that were descendants of Chilean seed. Reports from Californians who visited Chilean alfalfa fields indicate that the fields were productive for about twenty years before they required tilling and replanting. There isn't much data describing alfalfa cropping techniques in Chile but there is a substantial amount of data for Argentina which planted its first alfalfa fields with Chilean seed and later imported large quantities of French seed (Gibson and Fream 1896). The weed

literature of Argentina indicates that these alfalfa fields developed a characteristic weed flora that included yellow starthistle (See Roseveare 1948, page 209).

The farmers of the Intermountain West and northern Great Plains discovered that their fields of Chilean alfalfa ("Common alfalfa") would be killed every few years during especially cold winters. In 1898 N. E. Hansen, a United States Department of Agriculture seed explorer, journeyed to the steppes of northern Turkestan (Kazakhstan) to collect seed from cold hardy ecotypes of alfalfa and small quantities of seed were brought back to the United States for testing (Hansen 1909). The seed was carefully cleaned and grown by research universities and small amounts were distributed to select farmers in the northern plains states until about 1905. The hardy Turkestan ecotypes were initially praised for their cold hardiness but they soon fell out of favor with farmers because of their low productivity.

During the first two decades of the twentieth century there was an enormous increase in demand for alfalfa seed in the western United States. This change was driven by federal homesteading policies and by enormous irrigation projects. The large number of new farmers produced a correspondingly large demand for crop seed which could not be met by domestic seed producers. The homesteading farmers typically had no prior farming experience and very little cash (Raban 1996). This set of circumstances led to huge imports of the cheapest available alfalfa seed.

Commercially grown alfalfa seed from irrigated fields in southern Turkestan (the area southeast of the Aral Sea in Turkmenistan, Uzbekistan, and Kazakhstan), Armenia, and Iran began to enter the United States in 1903. The seed from all of these countries was marketed as "Turkestan" (Hansen 1909). By 1906 enormous quantities of this commercial "Turkestan" alfalfa seed were being imported to satisfy the demand created by an alfalfa boom in the western United States.

The commercially produced "Turkestan" alfalfa seed was primarily distributed by European seed companies and contained large amounts of weed seed. Most western European countries as well as Argentina, Canada, and South Africa had enacted laws preventing the sale for domestic use of crop seed containing weed seed. The United States did not have any legal protections in place until 1912 when the allowable weed seed content was limited to 3% or less by weight for seed in international trade. State laws were generally more lax than Federal laws and only required accurate labels indicating the percent weed seed content by weight in each seed lot.

The huge demand in the United States for alfalfa seed and the time lag in implementing legal protections made the United States a dumping ground for poor quality and adulterated alfalfa seed. It was common practice for both European and domestic seed suppliers to save the screenings (e.g. weed seed and dead alfalfa seed) to "grade down" or dilute premium seed lots to make a greater profit (Brown and Crosby 1906). For example, in 1906 5,688,689 lb. of commercial "Turkestan" alfalfa seed were imported which included 275,572 lb. of screenings. The geographical correspondence between alfalfa seed-producing regions and origins of weed species were so close in some cases (e.g. Russian knapweed and "Turkestan" alfalfa) that weed scientists and alfalfa buyers used weed species to identify the origin of alfalfa seed lots (Brown 1914).

The enormous international trade in alfalfa seed resulted in a worldwide distribution of the weed component of the forage crop/weed system. Extensive information about the introduction and range expansion of the forage crop/weed system exists because of the great economic importance and relatively recent development of the forage crop. This includes information about the sources of alfalfa seed and the weed seed contaminants that are characteristic of each source region. The forage crop information also includes substantial information about when and where the crop was introduced and the farming practices that were used to produce crops and solve weed and pest problems. This forage crop/weed system data can be combined with local weed observations and herbarium information to reconstruct the invasion dynamics of many invasive species.

## The Medium Scale Invasion of California by yellow starthistle

Current estimates suggest that approximately 20 million acres of California have been invaded by yellow starthistle and the rate of range expansion appears to be exponential (M. Pitcairn pers. comm., Maddox and Mayfield 1985). The results of field surveys conducted in 1958, 1965, and 1985 indicate that the area of land occupied by yellow starthistle increased rapidly beginning in the 1940's (Maddox and Mayfield 1985). There is a tendency to incorrectly interpret the exponential range expansion curve presented by Maddox and Mayfield as

indicating that yellow starthistle did not become invasive until the 1940's. However, tum-of-the-century historical accounts of yellow starthistle's rate of range expansion clearly describe it as a very invasive species. One way to reconcile the data is to interpret them as describing a multiple step invasion process and that is the approach I have taken in this paper.

There are no definitive records documenting yellow starthistle's introduction into California as a seed contaminant in Chilean alfalfa seed. However, the early reports of county agricultural commissioners state that yellow starthistle was introduced in California as a contaminant in alfalfa seed. Much later, a few researchers apparently misinterpreted a paper describing the worldwide distribution of yellow starthistle and concluded that the weed was introduced as a contaminant of alfalfa seed imported from Turkey (See Maddox et al. 1985 for distribution maps). The earliest record of commercial alfalfa production in California dates from 1851 (Cameron 1859) and the alfalfa seed was imported from Chile not Turkey. In fact, alfalfa was commonly referred to as Chilean clover and was heavily promoted as an ideal feed for dairy cows and stockyards (Hendry 1923). Because alfalfa was brought to Chile from Spain in the 1600's, it is highly likely that all introductions of yellow starthistle prior to 1903 were ultimately of Spanish origin. The origins of yellow starthistle introduced after 1903 are more difficult to identify because of the nature of the alfalfa trade but Spain, France, and Italy, are the most likely source countries.

Alfalfa cropping techniques and field locations have changed dramatically in California. During the 1850's and 1860's alfalfa was grown on natural river levees or in river bottoms near San Francisco, Sacramento, and Marysville. From 1870 until about 1905 irrigated alfalfa production expanded rapidly over many areas of the state as early water projects were completed. The locations of all pre-1900 herbarium specimens of yellow starthistle are clustered near the pre-1900 sites of alfalfa production and consumption.

An example of historical changes in crop production practices for Yolo County in the southern Sacramento Valley and observations of the spread of yellow starthistle provide a detailed account of the multiple step invasion process. Crop and animal production practices are fairly well documented for Yolo County which is bordered by the Sacramento River and the city of Sacramento to the east, and Putah Creek to the south. Alfalfa was first introduced along the river levees of Putah Creek and the Sacramento River in the 1850's and 1860's. Farmers at both locations grew alfalfa to feed their dairy and stock animals. The land between the foothills of the inner coast range which is located about twenty miles west of the Sacramento River, and the five to eight mile wide marsh that paralleled the levy of the Sacramento river, was intensively dry-farmed in wheat and barley from the 1850's until about 1900 when crop yields declined sharply. The vegetation of the foothills of the inner coast range is annual grassland and oak woodland. Range cattle were relocated to the foothills when the open ranges on the valley floor were closed in 1867 by legislation enacted to protect farm crops from grazing animals. In the 1870's many irrigation canals were built near the city of Woodland (10 miles north of Putah Creek and 2 miles west of the marsh) and many irrigated alfalfa fields were established in this area (Mann et al. 1911). The alfalfa grown on the irrigated fields was transported as hay to other farms and cities.

The distribution of yellow starthistle is not well documented for this area but a handful of reports by botanists such as Willis Jepson and by county agriculture commissioners provide useful information. It was a common weed by 1900 and by 1909 it was invading old grain fields and was moving rapidly along major roads. In 1917 it was reported to have spread throughout the Sacramento and San Joaquin Valleys and was considered to be a serious problem in grain fields. One report (Newman 1917) lamented:

> *It is a common impurity in alfalfa and other agricultural seeds. It is found in baled hay, in straw packing materials, and in the sweepings from grain and stock cars. It is transported by wind, by traveling stock, by the annual overflow of streams, in irrigation ditches, and along rights of way. Even the birds carry seeds.*

Then, suddenly, the reports of the weed's rapid rate of range expansion stop and do not begin again until the 1980's. The information about crop production techniques, the changes in distribution of yellow starthistle, and the fact that the weed has very limited dispersal capabilities without the aid of humans or animals (Newman 1917, Roché 1991) suggests the following multiple step invasion process.

During the 1850's and 1860's the range expansion of yellow starthistle was restricted to areas along river levees. Seed dispersal by humans and animals was limited to local sites as the alfalfa crop was consumed on site and stock animals were transported short distances to nearby towns. Some of the adjacent overflow land or marshland was probably invaded but both the farms and the overflow land were surrounded by vast areas of productive, dry-farmed, wheat and barley fields that were plowed and planted only after the winter rains had begun. Winter plowing was necessary because it was impossible for horse powered gang plows to till dry soil. Most yellow starthistle seed germinates soon after the first significant fall rains and winter plowing would have eliminated any yellow starthistle seedlings that established prior to crop planting.

In the 1870's irrigated alfalfa farming expanded throughout California and increased the transport of alfalfa hay over moderate distances. During this period alfalfa was grown within a matrix of barley, wheat and rye fields that were rapidly declining in productivity. Alfalfa was also dry farmed as part of a grain-legume crop rotation system (Mann et al. 1911). Typically, dry-farmed alfalfa fields were overrun with weeds after three years and they were then plowed and left fallow for a year or two to replenish soil moisture for subsequent grain crops. Between 1870 and 1900 yellow starthistle probably established locally dense populations near irrigated and dry farmed alfalfa fields and along roadways.

The use of tractor pulled plows and harvesting combines to plow and harvest fields of both wheat and alfalfa spread yellow starthistle seed into wheat fields. By 1915 yellow starthistle was a serious problem in wheat fields and the County Commissioner of nearby Sutter County determined that whole fields of grain were lost in some parts of the county from the yellow starthistle (Newman 1917).

During the period between 1920 and 1940 the area of land occupied by yellow starthistle probably decreased. Yellow starthistle was still an extremely invasive weed but its populations on the valley floor were being held in check or eliminated by the intensification of crop production techniques. Additionally, herbicides such as sodium arsenite and sodium chlorate were first developed in the 1930's and were widely used on roadside weeds in the valley.

Sometime during the 1930's or 1940's yellow starthistle invaded the foothill rangelands and began what was in effect a second invasion of California. Alfalfa, wheat, and barley crop production practices had changed and yellow starthistle was no longer a part of those crop/weed systems. Instead, it became incorporated into a grazing/weed system. The extensive road building in the foothills during the 1940's and 1950's and the presence of large numbers of animals to disperse seed initiated the exponential rate of range expansion described by Maddox and Mayfield and resulted in the extremely large populations of yellow starthistle that are now a common sight in the foothills.

## The Large-Scale Invasion of the Western United States

Yellow starthistle made the leap to a grazing/weed system more rapidly in other parts of the United States. It was first introduced into many western states from California in the 1870's and 1880's as part of the alfalfa-weed system. For example, the initial introductions in eastern Oregon and Washington were made when alfalfa hay was grown as a naturally irrigated winter hay crop along isolated watercourses. During the 1880's and 1890's small irrigation ditches were built to increase the amount of feed that could be grown. In 1902, reclamation homesteads were authorized by the Federal government and by 1935 a large part of the dry interior was settled and irrigated. The irrigation projects were located in the center of vast areas of rangeland and there were no intervening grain fields to slow the invasion process. Oral histories of some of the early settlers of the region confirm that yellow starthistle was introduced as part of an alfalfa/weed system (Roché 1965).

## Why History Matters

The reconstructed invasion dynamics of the weed component of the alfalfa/weed system provides important information about the extent of human aided dispersal of a large number of invasive species. The historical information can be combined with biological information such as each species' natural dispersal ability to aid managers of natural areas in deciding how to spend their limited weed control funds. For example, a number of agencies and private landowners in the Yellowstone area have entered into a cooperative agreement to manage

noxious weed species and have published “Guidelines for Coordinated Management of Noxious Weeds in the Greater Yellowstone Area”. Appendix 2 of that document lists the control priorities for a number of noxious weeds. Russian knapweed, which was spread across the western United States in commercial "Turkestan" alfalfa seed and which is a poor natural disperser, is assigned to the highest priority group. Because we know that the alfalfa/weed system which was responsible for the widespread distribution of Russian knapweed no longer exists, it might be a more effective strategy to control only new populations of Russian knapweed and allocate extra resources to species with greater natural dispersal abilities.

## Conclusions

The reconstructed invasion dynamics show that yellow starthistle invaded the western United States in a multiple step process. In California, agricultural fields and roadsides were first invaded as the weed component of the alfalfa/weed system became embedded in other agricultural systems of the Sacramento and San Joaquin Valleys. Then, much later, the weed component made contact with the rangelands and became part of a grazing/weed system and the current period of exponential range expansion began. The two step invasion process was repeated in many western states over a much shorter period of time because there were no barriers to seed dispersal between the rangelands and agricultural fields. In addition, the conversion of the alfalfa/weed system to a grazing/weed system combined with the import of enormous amounts of contaminated alfalfa seed represents a “big bang" event in the history of invasive species in the western United States. The after effects of that event are still being felt in the rangelands and natural areas as many extremely invasive species in several genera (*Centaurea, Acroptilon, Cardaria*, etc.) continue to expand their ranges.

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## References

Brown, E. and M. L. Crosby. 1906. Imported low-grade clover and alfalfa seed. United States Department of Agriculture, Bureau of Plant Industry, Miscellaneous Papers. 311: 17-30.

Brown, E. 1914. Commercial Turkestan alfalfa seed. United States Department of Agriculture, Bureau of Plant Industry, Bulletin. 138: 1-7.

Cameron, W. E. 1859. Quintay Ranch. Transactions of the California State Agricultural Society. 1958:363-364.

Gibson, H. and W. Fream. 1896. Lucem in Argentina and England. The Indian Agriculturist. 21(3):82-83.

Hansen, N. E. 1909. The wild alfalfas and clovers of Siberia, with a perspective view of the alfalfas of the world. United States Department of Agriculture, Bureau of Plant Industry, Bulletin. 150: 1-31.

Hendry, G. W. 1923. Alfalfa in history. Journal of the American Society of Agronomy. 15:171-176.

Hillman, F. H. and H. H. Henry. 1928. The incidental seeds found in commercial seed of alfalfa and red clover. Proceedings of the International Seed Testing Association. October, No. 6:1-20.

Maddox, D. M. and A. Mayfield. 1985. Yellow starthistle infestations are on the increase. California Agriculture. 40(11/12):4-5.

Maddox, D. M., A. Mayfield, and N. H. Poritz. 1985. Distribution of yellow starthistle *(Centaurea solstitialis)* and Russian Knapweed *(Centaurea repens)*. Weed Science. 33:315-327.

Mann, C. W., J. F. Warner, H. L. Westover, and J. E. Ferguson. 1911. Soil survey of the Woodland area, California. United States Department of Agriculture, Bureau of Soils, Advance Sheets - Field Operations of the Bureau of Soils, 1909.

Newman, 0. W. 1917. Yellow star thistle. California State Commission of Horticulture, Monthly Bulletin. 6: 27-29.

Raban, J. 1996. Bad Land, and American Romance. Random House Inc., New York.

Roche, B. F. Jr. 1991 Achene dispersal in yellow starthistle *(Centaurea solstitialis* L.). Northwest Science. 66: 62-65.

Roce, B. F. Jr. 1965. Ecological Studies of Yellow Starthistle *(Centaurea solstitialis* L.). University of Idaho, Moscow. Ph.D. Dissertation.

Roseveare, G. M. 1948. The grasslands of Latin America. Imperial Bureau of Pastures and Field Crops. Bulletin 36.

Stewart, G. 1926. Alfalfa Growing in the United States and Canada. MacMillan Co., New York.