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Research article

Market-based opportunities for expanding native seed resources for restoration: A case study on the Colorado Plateau

Ashley L. Camhi[a,*], Charles Perrings[a], Brad Butterfield[b], Troy Wood[c]

[a] EcoServices Group, Arizona State University, USA
[b] Department of Biological Sciences and Merriam-Powell Center for Environmental Research, Northern Arizona University, Flagstaff, AZ, 86011, USA
[c] 507 E Charles Road, Flagstaff, AZ, 86001, USA

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ABSTRACT

The National Seed Strategy for Rehabilitation and Restoration aims to increase the use of native seeds in rehabilitation and restoration projects. This requires the development of a native seed supply industry. This paper examines the challenge of developing native seed supply for Bureau of Land Management (BLM) land holdings in the Colorado Plateau, USA. On the demand side of the market, native seed requirements are linked to events that trigger the need for restoration, such as wildfires, which are highly variable. The variability of demand is moderated somewhat by fire management and seed acquisition policies, but remains high. Acquisitions of native seeds are typically smaller in quantity and more variable than acquisitions of non-native seeds. Prices of native seeds are typically higher and more variable than prices of non-native seeds, while the price elasticity of demand for native seeds is typically lower than for non-native seeds. The variability of demand for native seeds has discouraged development of a native seed supply industry. We find that adoption of policies to stabilize demand, supported by contracts with growers, could help to encourage the emergence of a strong field-grown native seed sector in the Colorado Plateau.

1. Introduction

Rangelands in the western United States have been substantially affected by a number of factors, including climate change, grazing pressure, and the introduction of invasive species such as Bromus tectorum, Euphorbia esula, and a number of Centaurea species. Consequences include changes in the fire regime, reductions in forage quality, the loss of wildlife habitat, lower plant and animal diversity, and the degradation of soil and water resources (DiTomaso, 2000). Historically, interventions to repair the damage have involved seeding with introduced exotic grasses selected for their forage characteristics and ability to establish and colonize rapidly. In the last two decades, however, seeding priorities have shifted towards native plants and the rebuilding of diverse, resilient communities (Wood, T., Doherty, K., Padgett, 2015). Revegetation with native species following fire has been shown both to reduce the abundance of fire-prone invasive species, and the frequency of wildfires. This, in turn, reduces long-term fire management costs—potentially by enough to offset the costs of revegetation (Epanchin-Niell et al., 2009). It has also been shown to improve water quality, and resistance to invasive species (Eastburn et al., 2018.)

At the national scale, this change in perspective led the Bureau of Land Management (BLM), and other government land management agencies (the U.S. Department of Agriculture (USDA), U.S. Forest Service (USFS); U.S. Department of the Interior National Parks System; and Utah Department of Natural Resources Division of Wildlife Resources), to institute policies to encourage the use of native plant materials in rehabilitation plantings (Richards et al., 1998). These policies were supported by Executive Memoranda and Orders (Clinton, 1994, 1999). Since that time growing public interest in restoring and protecting biodiversity, repairing degraded ecosystems, and slowing the spread of exotic vegetation has contributed to greater emphasis on the use of native plant materials (Shaw et al., 2005), initially formalized in documents recommending use of native species whenever feasible (U.S. Department of the Interior and U.S. Department of Agriculture, 2002).

The current National Seed Strategy for Rehabilitation and Restoration, developed by a consortium of public and private interests led by the BLM, aims to build a seed industry for rehabilitation and restoration (Plant Conservation Alliance, 2015). Its overall goal is to ensure the

* Corresponding author. Arizona State University, USA.
E-mail addresses: alcamhi@asu.edu (A.L. Camhi), charles.perrings@asu.edu (C. Perrings), bradley.Butterfield@nau.edu (B. Butterfield), trowood@umail.iu.edu (T. Wood).

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availability of genetically appropriate seed reserves to restore viable, productive plant communities. Within this overall goal it has four more specific objectives: (1) to identify seed needs and ensure the reliable availability of genetically appropriate seed; (2) to identify research needs and to conduct the research needed to provide genetically appropriate seed and to improve technology for native seed production and ecosystem restoration; (3) to develop tools to enable managers to make timely, informed seeding decisions for ecological restoration; and (4) to develop strategies for internal and external communication (Oldfield and Olwell, 2015; Plant Conservation Alliance, 2015).

One challenge posed by the change in priorities is the limited supply of native seeds. When the primary focus of rehabilitation was site stabilization, exotics such as crested wheatgrass, alfalfas, and clovers, or "cultivars" of native species selected to provide forage, were favored (Monsen and McArthur, 1995; Plummer et al., 1968). The change in priorities has altered demand for native seeds, but the supply response has been limited. A lack of native plant materials after the extensive 1999–2000 wildfires led to the introduction of the Native Plant Restoration and the Native Plant Materials Development Programs by the USFS and the BLM (U.S. Department of the Interior and U.S. Department of Agriculture, 2002). While both programs have helped, native seed supply remains constrained and unstable. There are a number of reasons for this, but a survey of seed restoration suppliers in 2010 showed that the primary problem then lay with the unpredictability of demand for native seeds (Peppin et al., 2010). More specifically, suppliers had little incentive to invest in the provision of seed stocks as long as demand for those stocks was uncertain.

In this paper we consider the challenge of developing the market for native seeds for rangeland restoration and rehabilitation in BLM land holdings in the Colorado Plateau, an ecoregion located primarily in Utah and Colorado with smaller portions stretching into New Mexico and Arizona. The Plateau covers an area of 32,387 square miles, most of which is in public ownership. The BLM manages around 35% of the total area, through 16 field offices. Other major land categories are Tribal Lands (23%), USFS, NPS, or other Federal agencies (16%), and state and private land (26%) (Fig. 1). The BLM is the dominant player in Utah, since it controls so much of the land.

We investigate the development of the restoration seed market as it has evolved since the establishment of the Colorado Plateau Native Plant Program (CPNPP), initially known as the Colorado Plateau Native Plant Initiative. The CPNPP was launched by the BLM to improve both the quantity and variety of regionally adapted native plant materials for ecosystem restoration in the ecoregion (Bureau of Land Management, 2015). It was developed against a growing awareness of the advantages of native plant materials in restoration. By the end of the 20th century, when BLM land was described as being, at best, "in fair to poor condition" (Biederman, 1998), the range of plant materials native to the U.S. (grasses, forbs, and shrubs) had begun to increase (Carlson and McArthur, 1985; McArthur, 1988; Meyer and Kitchen, 1995; Monsen, 1987; Young et al., 1995). Range managers also had a growing interest in reconstructing natural plant communities using site indigenous and regionally adapted native plant materials rather than non-native and native "cultivars" (Allen et al., 1997; Jordan et al., 1990; Richards et al., 1998).

Within the Colorado Plateau, the native seed industry nevertheless remains poorly developed. Although the volume of wild seed collected has been increasing, wild seed was insufficient to meet demand in the Colorado Plateau throughout our study period (1998–2015). Market research on 47 species from the Intermountain and Pacific Northwest regions showed potential demand for these species to be around 2.5 million pounds a year, whereas seed secured through wild seed collection stood at around 370,000 pounds a year (Shaw et al., 2005). The supply of native wild collected seed also varies widely from year to year depending upon conditions—mainly weather. Limited availability of native seed makes revegetation with native seed more costly than revegetation with nonnative crested wheatgrass (Epanchin-Niell et al., 2009).

To understand the role of demand conditions in the development of

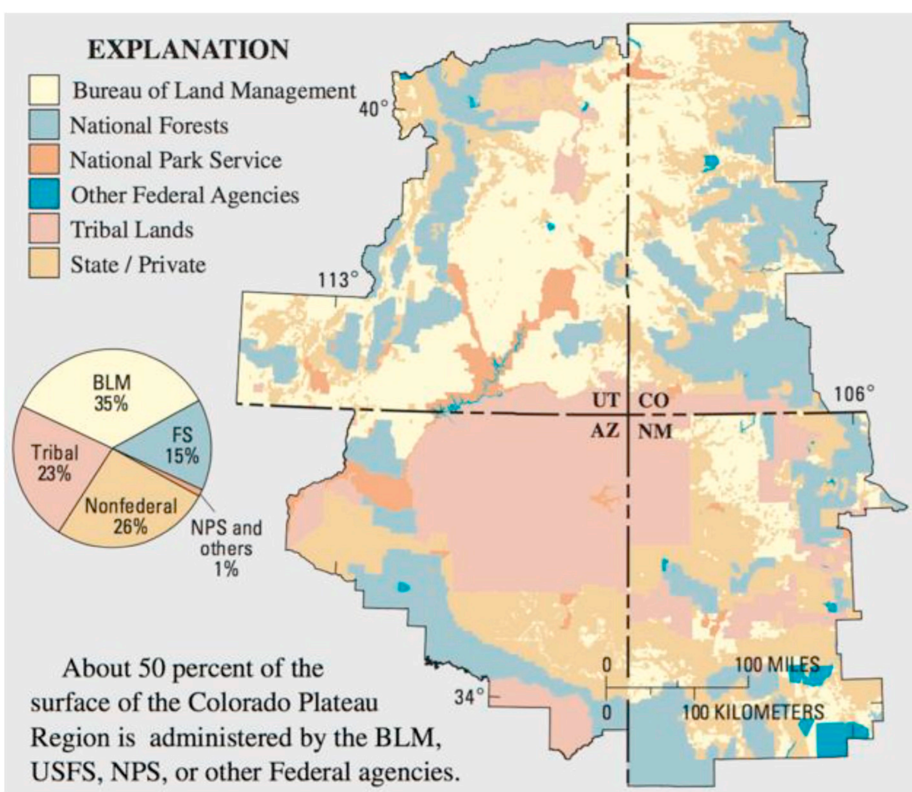


Fig. 1. Land status in the Colorado Plateau. Source: U.S. Department of the Interior

seed supply, we consider demand for native and non-native seeds in more detail, focusing on the segment of the market serviced by the Great Basin Research Center (GBRC). We ask how demand for native and non-native seeds varies with the relative price of seeds and with the fire regime. We then consider how limitations on the supply side of the market might be addressed by changes in acquisition strategies, and ask whether seed acquisition strategies might address the unpredictability of demand identified by Peppin et al. (2010).

2. Data and methods

Our analysis rests both on primary data and a review of the secondary literature on the use of native seeds in post-fire restoration in the region. Two main sources of data on restoration seed were used - records of the BLM's seed buys through the Boise Warehouse from fiscal year 1998 through 2015 and the GBRC's Seed Warehouse buys from fiscal year 2001 through 2014. These two sources both identified the seed companies that were selected for procurement annually and provided other information including:

- Restoration Project Name
- County where restoration occurred
- Restoration project acres
- Names of the seeds that were used in seed mixes for each project
- Pounds of seed species used in mixes (Pounds of live seed, pls.)
- Price per pound of seed species used in mixes
- Total cost of each seed species in the mix
- Total cost of the seed mix for the restoration project

For a more systematic analysis of the demand side of the problem we relied on invoices from the GBRC only. In total, 4,038 project seed invoices for BLM projects carried out on the Colorado Plateau were downloaded from the State of Utah Watershed Restoration Initiative website and put into a database containing all of the aforementioned information. Information on whether each species was native or non-native to the United States and the Colorado Plateau was then added using the USDA's plant database. The use of GBRC data puts the spotlight on one category of public land—BLM land in Utah. Since differences in both fire management regimes and native plant acquisition regimes across the Colorado Plateau might be expected to influence demand, this should be borne in mind in considering our results. Nevertheless, GBRC acquisitions have supported a representative sample of reseeding projects.

Demand was taken to be a function of the relative prices of native and non-native seeds, of aggregate expenditures on seed acquisitions, and on two features of the fire regime—the number of wildfires and prescribed burns, and the acreage affected by each. The two features of the fire regime were expected to have different effects. Data on the number of fires and the area burned were lagged by one year, reflecting the fact that reseeding following fires is typically delayed until the next growing season. Aggregate expenditure on seed acquisitions was taken as a proxy for the BLM restoration seed budget, although in practice this is determined in reaction to the fire regime in any given year.

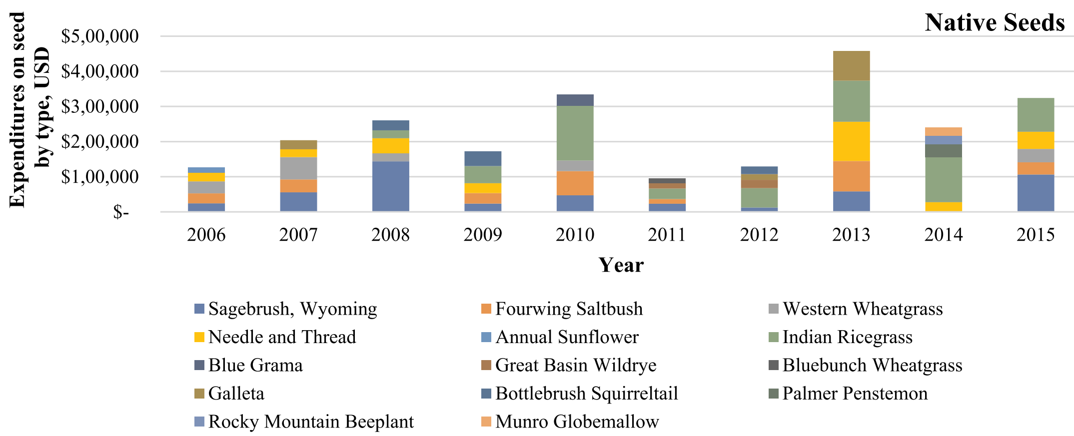
Average prices in nominal terms are shown in Fig. 2. Native seeds were significantly more expensive per pound than non-native seeds over the whole period, and the difference between them widened over time. While more non-native seed was acquired than native seed, aggregate expenditure on native seeds was greater than on non-native seeds. Fig. 3 reports expenditures on the top species acquired within each seed type. The composition of native and non-native species by quantity acquired is shown in Fig. 4. Amongst native seeds the dominant species throughout the period were Indian ricegrass and Western wheatgrass, with other species being added in periods of higher demand, especially Thickspike wheatgrass and Bluebunch wheatgrass. Only one new species appears to have been added during the period, Mountain brome, which was first used in 2015. Amongst non-native seeds, the same eight species were used in different proportions over the whole period, and the same five species—Small burnet, Alfalfa, Crested wheatgrass, Russian wildrye, and Sainfoin—were dominant in every period. While Russian wildrye remained a part of the mix, the quantity acquired declined over time.

On the demand side, we wished to understand both how sensitive the demand for both native and non-native seeds was to variation in prices, and how demand varied with the number of fires and the area burned. On price responsiveness, we wished to understand the price elasticity and cross-price elasticity of demand for native and non-native seeds—the relationship between a change in the quantity demanded and a change in both their own price or the price of the seed itself, and the prices of other seed types. We estimated two demand functions. The first identified the relation between the quantity demanded of each seed type and relative prices, total expenditure, and the fire regime. The second identified the relation between the share of expenditure on each seed type and prices relative to expenditure shares, total expenditures relative to a price index, and the fire regime. Aggregate data on acquisitions, prices and fire events are reported in Table 1. The estimated models are described in supplementary information.

3. Results

The data reveal coarse differences in the demand for non-native and native seeds for restoration. Between 2006 and 2015 an average of 97,206 lbs. of non-native seeds were acquired by GBRC, with a standard deviation of 30,917 lbs. In comparison, 63,835 lbs. of native seed were acquired, with a standard deviation of 26,662 lbs. There is also a large difference in the price of seeds. The average price of non-native seeds per pound in US dollars was 3.00 with a standard deviation of 0.74, while the average price of native seeds per pound in US dollars was 7.81 with a standard deviation of 2.31. That is, acquisitions of non-native seeds were

Fig. 2. Average Cost Per Pound of Seed purchased by the GBRC Seed Warehouse for BLM land restoration on the Colorado Plateau. Source: GBRC Seed Warehouse



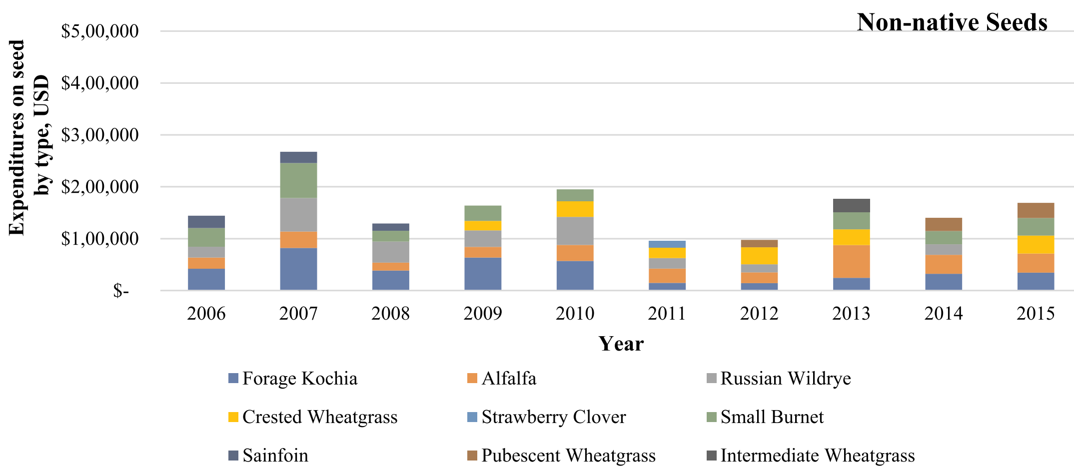


Fig. 3. Annual expenditures of native and non-native seeds acquired by the GBRC Seed Warehouse, 2006–2015. Source: GBRC Seed Warehouse

substantially greater and less variable than acquisitions of native seeds. Prices of non-native seeds were substantially lower and less variable than prices of native seeds.

The balance between non-native and native seed acquisitions changed over our study period. Across all BLM lands there was an increase in the share of total seed acquisitions accounted for by natives over the period. The trend was, however, sensitive to general economic conditions. Looking at seed buys by the Boise Warehouse for the BLM on a national scale from 1998 through 2015, for example, there is significant changes corresponding to fluctuation in the incidence of wildfires, but also an apparent structural break around 2008 when the economic crisis occurred. Prior to 2008, demand for both native and non-native seeds was rising rapidly. After 2008 demand was generally lower, but the proportion of native to non-native seed was increasing.

Our estimates of the changes in the quantity of native and non-native seed demanded, and the share of seed acquisition expenditures, are reported in Tables 2 and 3. These show that an increase in the own price of native seeds was associated with a smaller reduction in the quantity demanded of those seeds than an equivalent increase in the own price of non-native seeds. Specifically, our estimates of the percentage change in the quantity demanded of natives that follows a percentage change in its price (the own price elasticity of demand for natives) ranged between −1.39 (model 1) and −1.66 (model 2), while our estimates of the own price elasticity of demand for non-natives ranged from −1.93 (model 1) and −2.47 (model 2). Similarly, an increase in the price of natives was found to induce a smaller increase in the demand for non-natives, than vice versa. Our estimates of the percentage change in the quantity demanded of natives that follows a percentage change in the price of non-natives (the cross-price elasticity of demand for natives) ranged between 0.55 (model 1) and 0.67 (model 2), while our estimates of the cross-price elasticity of demand for non-natives ranged from 0.71 (model 1) and 0.75 (model 2). Computed annual elasticities are shown in Fig. 5. While the price elasticity of demand for native seeds was stabilizing over the period, the price elasticity of demand for non-natives was increasing.

The quantity demanded of both seed types increased with an increase in total expenditure. Once again, the effect was much stronger for native than for non-native seeds. A given increase in total expenditures was associated with a greater increase in demand for native relative to non-native seeds.

The most striking difference in response between native and non-native species concerns the fire regime. Our two indicators of fire are the total number of fires (wildfires plus prescribed burns), and the total acreage burned (by either wildfires or prescribed burns). Acquisitions of non-native species, (and the share of expenditure accounted for by non-native seeds) were found to be positive related to the number of fires, but negatively related to the area burned. By contrast, acquisitions of native seeds (and the share of expenditure accounted for by native seeds) were found to be negatively related to the number of fires, but positively related to the area burned (see Tables 2 and 3).

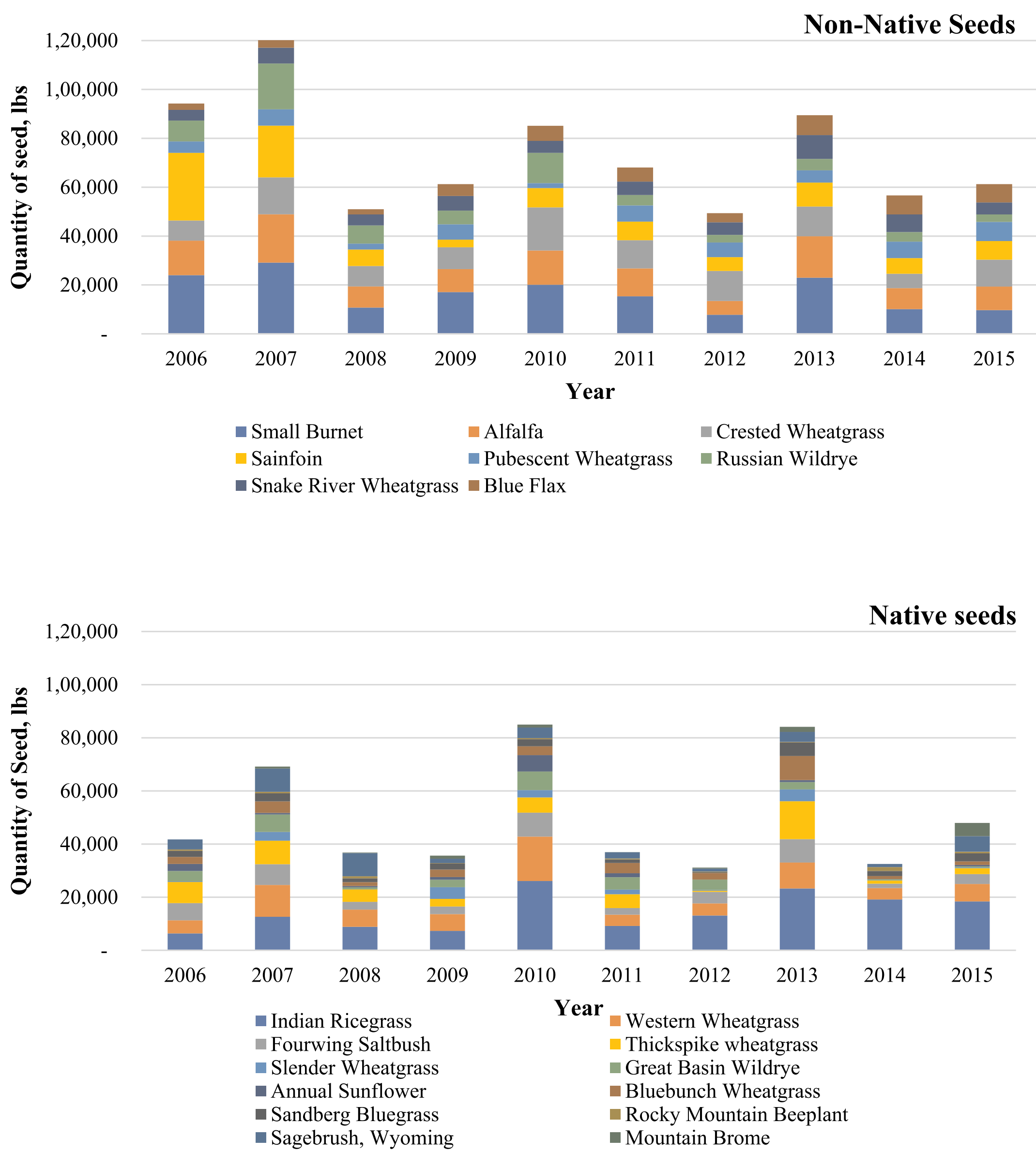


Fig. 4. The composition of native and non-native seeds acquired by the GBRC Seed Warehouse, 2006–2015. Source: GBRC Seed Warehouse

Table 1
Native and non-native seed acquisitions, prices, and expenditures.

Year	Quantity of non-native seeds	Quantity of native seeds	Price of non-native seeds	Price of native seeds	Total expenditure on seeds	Area burned	Number of fires
2005						221,578	453
2006	114,279.5	54,799.5	1.81	4.59	458,190.93	220,792	709
2007	15,7507	85,749	2.54	4.71	803,461.31	423,562	403
2008	71,305	50,810.5	3.04	8.55	651,210.09	8257	347
2009	88,880	45,660	3.27	7.99	655,155.01	49,979	378
2010	128,495	104,017	2.54	5.7	920,044.51	7401	344
2011	82,406	42,654.2	2.19	4.24	360,816.2	36,222	385
2012	56,309	42,642.4	3.19	6.56	459,546.59	126,898	501
2013	114,579	111,737	3.28	7.65	1,231,522.23	25,442	433
2014	71,714	41,373.7	4.15	10.94	750,539.94	12,439	272
2015	86,589	58,902	3.95	9.86	922,960.28		

Table 2
Quantity of native and non-native seed demanded.

	Coef.	Std. Err.	t	P>|t|
Non-native seeds				
ln price of non-native seeds	−1.799266	0.2392386	−7.52	0.002
ln price of native seeds	0.4801098	0.1817548	2.64	0.057
ln total expenditure on seeds	0.8157122	0.0564076	14.46	0
ln number of fires	0.4704877	0.0725833	6.48	0.003
ln acreage burned	−0.0833216	0.0155639	−5.35	0.006
constant	−0.4841196	0.7402985	−0.65	0.549
adjusted R squared 0.9789				
Native seeds				
ln price of non-native seeds	0.4788955	0.1942917	2.46	0.069
ln price of native seeds	−1.257965	0.1476076	−8.52	0.001
ln total expenditure on seeds	1.11331	0.0458101	24.3	0
ln number of fires	−0.3087565	0.0589467	−5.24	0.006
ln acreage burned	0.0518398	0.0126398	4.1	0.015
constant	−0.7358876	0.601215	−1.22	0.288
adjusted R squared 0.9906				

Table 3
Native and non-native seed expenditure shares.

	Coef.	Std. Err.	t	P>|t|
Non-native seed expenditure share				
ln price of non-native seeds	−0.300047	0.1073316	−2.8	0.049
ln price of native seeds	0.1696359	0.0815422	2.08	0.106
ln total expenditure on seeds	−0.0699543	0.0253066	−2.76	0.051
ln number of fires	0.185294	0.0325637	5.69	0.005
ln acreage burned	−0.0318405	0.0069825	−4.56	0.01
constant	0.5509145	0.3321263	1.66	0.173
adjusted R squared 0.9077				
Native seed expenditure share				
ln price of non-native seeds	0.2969001	0.1062987	2.79	0.049
ln price of native seeds	−0.1676727	0.0807574	−2.08	0.106
ln total expenditure on seeds	0.0690365	0.0250631	2.75	0.051
ln number of fires	−0.1838162	0.0322503	−5.7	0.005
constant	0.0315896	0.0069153	4.57	0.01
adjusted R squared 0.9079				

Wildfires are inherently stochastic, but prescribed burns are not. The relationship between wildfires and prescribed burns accordingly affects uncertainty in demand. This varies among states. In Utah, the focus of this report, wildfires accounted for the vast majority of fires, and for most of the area burned. There was a large spike in the area affected by fire in 2007 due to the Milford Flat fire, the largest fire on record in Utah at 363,052 acres. Another smaller but distinguishable spike occurred in 2012 due to a fire in Clay Springs that burned 107,846 acres (National Interagency Fire Center, 2016). By contrast, there was relatively little variation in the number or area of prescribed burns.

Our findings with respect to the different effects of the number and size of fires on demand for native and non-native species reflects an important property of the seed market. Fig. 6 shows the relation between the total number of wildfires and prescribed burns and the quantity of native and non-native seed used in restoration. It reveals two important features of the problem. The first is the lagged response in the application of seed for rehabilitation. A burn in one growing season generates demand for seed in the next growing season. This is reflected in our model specification. The second feature is that the proportion of native seeds in total seed acquisitions is smaller in years when aggregate demand is lower. In other words, demand for non-native seed appears to be more stable than demand for native seeds. The negative relation between the number of fires and native seed acquisitions may be a by-product of a commitment to maintain demand for non-native seeds in periods of low aggregate demand. Fig. 6 shows that basic restoration goals following fire are still met using non-native seeds, but that exceptional demand for restoration seed is (increasingly) met using native seeds. We find that an increase in the mean area burned increases the quantity of native seed demanded but has a small and negative effect on the quantity of non-native seeds demanded.

4. Discussion

On the demand side of the market we found a reduction in the price elasticity of demand for natives over the study period. Demand was becoming less sensitive to price. While this had the effect of stabilizing demand to some extent, it has so far left the supply side of the market largely unaffected. Despite the growth of demand for native seeds over the past three decades, most seed restoration companies servicing the Colorado Plateau believe that the native seed trade is likely to remain in the hands of relatively small-scale enterprises, run by independent operators (Seed company owner, personal communication).

Three issues are particularly important. First, many shrubs and forbs are difficult to grow and harvest. Second, there is little information on the agronomic potential of alternative species. Third, there is little incentive to develop agricultural methodologies for currently uncultivated species. While some forbs have proven to be amenable to agronomic increase, many shrub and forb seeds—Globe mallows, Showy goldeneye, Yellow salsify, Silvery lupine, and Oval leaf buckwheat—are generally collected in the wild. To this point, the demand for native seeds is neither great enough nor consistent enough to overcome these

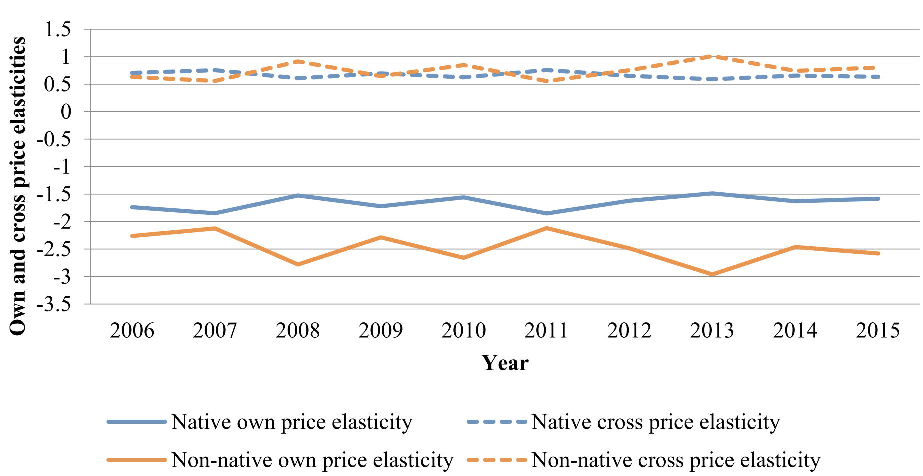


Fig. 5. Own and cross price elasticities of demand for native and non-native seeds acquired by GBRC Seed Warehouse for restoration projects on BLM land. Source: Authors' calculations

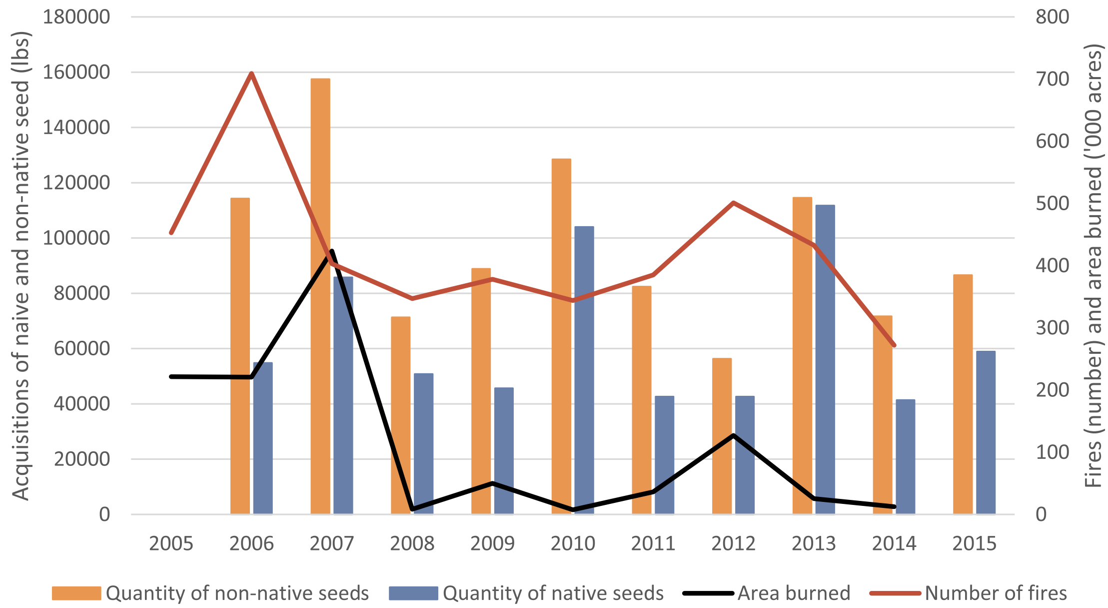


Fig. 6. Native and non-native seeds acquired for restoration on BLM land in the Utah section of the Colorado Plateau, and the number of wildfires and prescribed burns, 2005–2015. Source: Great Basin Research Center Seed Warehouse

issues. The problems observed in the early years of this century—that local seed markets dry up during low fire seasons, that stocks are insufficient in high fire seasons, and that funds for seed purchase are at the whim of Congress (Matthews, 2003)—persist.

The evidence to date suggests that while the native seed policy has meant greater willingness to increase spending on native seed acquisitions when resources are freed up in exceptional fire years, the most routine restoration priorities, site stabilization and reestablishment of forage, are still met by applying a small number of non-native species—Forage kochia, Alfalfa, Russian wildrye, and Crested wheatgrass—and some highly modified native cultivars. The BLM's stated goal is to use native seed for seedings or reestablishing plants in 'natural areas, wildlife habitat, wilderness study areas, or other sites with intact native plant communities' where objectives may include erosion control, gene pool preservation, habitat provision, recreation and watershed restoration. Non-native seed has, however, been preferentially used for emergency soil stabilization and weed control after fire (Lambert, 2005). Given evidence questioning the effectiveness of non-native seed in meeting post-fire rehabilitation objectives (Beschta et al., 2004), including protection against post-fire invasive species (Brooks and Pyke, 2000), there is increasing interest in securing adequate supplies of native species for post fire rehabilitation. There is some experimental evidence that seeding burned areas with native perennials may have little more effect on either vegetative cover or non-native invasive plants than seeding with non-native cereal grains that are either sterile hybrids or annuals with low reproductive potential (Keeley, 2006; Stella et al., 2010). Nevertheless, if the goal is to increase the supply of natives, then the issue is how to stimulate the market for field grown native seeds. We conclude by identifying two options.

A first option is ***stabilization of demand for native seed at levels that would encourage entry into the market.*** The lack of consistent and reliable demand is a disincentive to potential suppliers (Peppin et al., 2010). This issue has not yet been addressed. Advanced contracts could give growers an incentive to invest in field grown native seed production, and, in some instances, provide them with seed stock accompanied by associated production information. Since most past research on native species production has focused on development of grass species (Robichaud et al., 2000), it has been argued that this would be an appropriate first focus for the development of a market for native species (Peppin et al., 2010). Many of the most desirable grass species identified are readily available through commercial producers outside the region, however, it may be difficult for local growers to compete on cost. To assure a minimum level of annual demand the BLM might invest in the development of seed stocks at levels that would meet the seed requirements of an exceptional fire year. Increasing the region's storage capacity (U.S. Department of the Interior and U.S. Department of Agriculture, 2002) could address issues of on-demand availability and alleviate high market prices often associated with native seed in short supply (Jones and Young, 2005). Adequate long-term seed storage facilities would allow for seed to be purchased and stored in favorable seed production years (U.S. Department of the Interior and U.S. Department of Agriculture, 2002). This would stabilize availability during unfavorable seasons (Mortlock, 1998) or in exceptional fire years.

Successful examples of seed stockpiling include the Utah Division of Wildlife Resources Seed Warehouse in Ephraim and the BLM Seed Warehouse in Boise, ID. These warehouses maintain large seed inventories (more than 200,000 pounds) and a rich array of species. The Utah Division of Wildlife Resources has stockpiled native seed in its warehouse operation for more than 40 years. It is important to point out that they receive annual funding from the state for seed purchases on the order of 400,000–500,000 pounds. These seed resources have been used not only on Division and other State lands, but on Federal and private lands as well. The Boise BLM seed warehouse, which has been servicing public land needs in Idaho and other Western States since 1991, currently aims to have 2.5 million lbs. of seed on hand (P. Roller, Bureau of Land Management, personal communication).

A change in the balance between planned and unplanned rehabilitation projects might also stabilize demand. Since rehabilitation following fire is applied both in the case of wildfires and prescribed burns, there is scope for planning the demand for seed around prescribed burns in ways that encourage growers to increase the acreage committed to field grown native seed. We have noted that prescribed burn strategies followed by the BLM are different in different states. Prescribed burns have had the effect of increasing inter-annual variation in the area burned in some states (e.g. New Mexico), and reducing variation in others (e.g. Colorado). While the number and size of prescribed burns in the study area are small relative to wildfires, they could help stabilize demand (Fig. 7). If the BLM were to guarantee annual demand for native seed at some minimum level on a more continuous basis, that could help both stabilize the native seed market and encourage growers to enter the market. If there were an increase in the number of companies producing native seed this would increase competition, and limit fluctuations in the cost of native seed.

A second option would be to ***reduce current barriers to entry of small and medium size firms***.

Stabilization of the demand for native seeds would encourage existing seed suppliers to diversify the range of seeds they offer. But an additional step would be to reduce the barriers to entry of small scale producers. The restoration seed market differs from the wider seed market in the size of participating companies, the role of biotechnology, and the lack of appropriable patent rents. Companies in the restoration seed market are typically small, lack market power, and do not depend on proprietary seeds. Companies specializing in native seeds tend to be at the lower end of the restoration market size spectrum, and frequently lack the resources required to develop new product lines beyond wild seed collection. Dependence on collection incurs a range of transactions costs, and has important implications for a supplier's ability to guarantee seed quality and to meet contracted production targets. While native seeds are not expected to be genetically pure or stable, native seed supplies should still be free of seeds of other species, and free of diseases. Neither can be assured if suppliers have to rely on wild seed collection.

Issues that potentially disadvantage small-scale production of native seed include information imperfections in credit markets that limit the ability of lenders to accurately assess the risks of small-scale native seed production, the inability of borrowers to use wildland resources as collateral, and the fixed cost of information needed by firms to exploit available production technologies, to satisfy regulations and quality standards. There is scope for the BLM to encourage development of the native seed market by actions that would cut the cost of acquiring information, reduce risk, improve transactional efficiency, and lower the fixed costs of doing business.

Aside from the unpredictability of demand, Peppin et al. (2010) argued that further development of native seeds is limited by lack of production knowledge. The knowledge and tools necessary to initiate a native species market are available, but inadequate funding sources and insufficient information sharing hinder its development. Peppin et al. (2010) claimed that communication among producers, land managers, buyers, and researchers, as well as partnerships with local growers are vital to initiating a functional market. There is scope for the BLM to broker the supply of knowledge between producers and advisory services in different regions, thus reducing the cost of the information (the time and other resources suppliers need to commit to acquire that information) required by potential suppliers of native seeds to compete in the market. The CPNPP, for example, created a task force to identify gaps between available training and the training needed to understand the use of native seed in restoration across multiple agencies (federal, state, tribal, and local), nongovernmental organizations, private sector industries, and universities.

Longer-term supply contracts with field seed growers could also be useful in two different ways. Contracts could provide the stability in demand needed to encourage entry into the market. In reducing the associated risk of investment in developing field grown native seed operations, they could also reassure credit markets, thus reducing the cost of capital to entrants. There is currently an opportunity to increase native seed production if suppliers are given the proper incentives. If the fixed costs of entry, the cost of acquiring information, and the cost of capital can be reduced through information sharing mechanisms and contracts, both farmers and seed companies are more likely to make the shift towards increased production of native seeds, which in turn will stabilize seed costs.

It is beyond the scope of this paper to consider the relative marginal benefits of native and non-native seed in restoration projects, but this should clearly be a factor in determining whether it is worth making a commitment to minimum levels of demand. For example, Indian

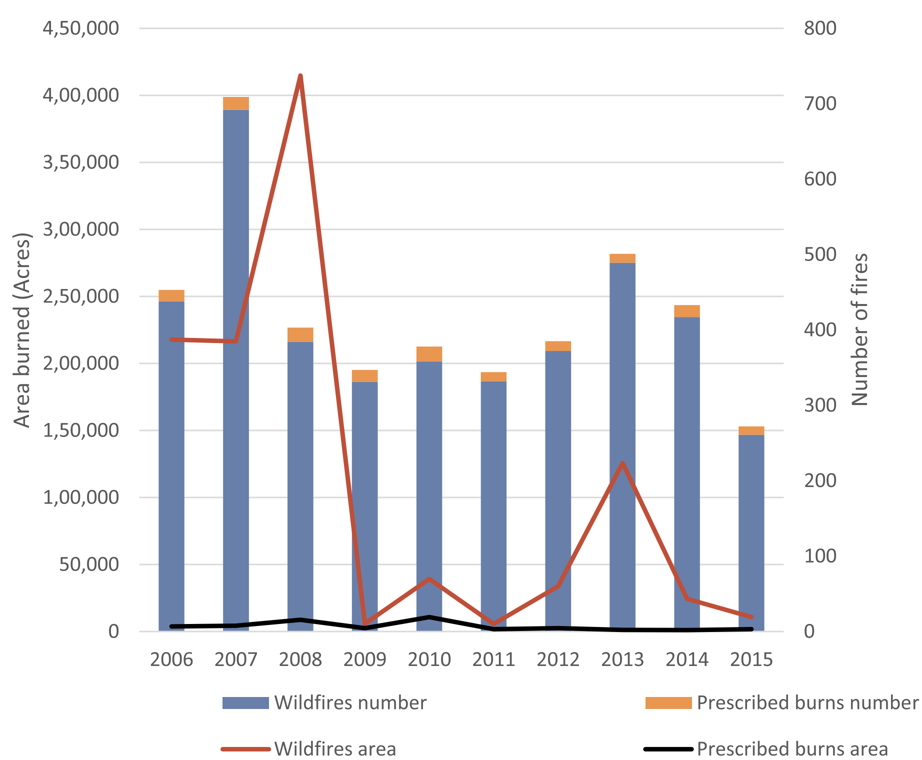


Fig. 7. Wildfires and prescribed burns in the study area, 2005–2015. Source: National Interagency Fire Center

ricegrass, the dominant native species, provides the same site stabilization services that many non-native species provide, but offers a range of additional benefits. It is an important forage plant for wildlife, being palatable in all seasons except late spring, and especially important in winter. It is preferred forage for elk in all seasons and for deer and antelope in spring, late fall, and winter. The seed was not only a staple food of many Native American people, but is eaten by birds, rabbits, mice, ground squirrels, prairie dogs and rats. The long dormancy and polymorphic character of its seeds also make it fire tolerant. What limits its potential (and its value in mixed seedings) is a low germination rate and an inability to compete against non-native grasses during establishment (Ogle et al., 2013). The extent to which these various traits affect the marginal value of Indian ricegrass relative to non-native species depends on land use. Indian ricegrass would be expected to have higher marginal value in landscapes of high conservation value, but potentially also in fire strategies that seek to build the seed bank as a way of encouraging natural regeneration of vegetation rather than securing a year of cover using non-native species.

Finally, there is evidence that the native seed policy is changing patterns of demand for native and non-native seeds, reducing the elasticity of demand for natives relative to non-natives and increasing the quantity of natives acquired in exceptional fire years. While this goes some way towards stabilizing demand, it is not enough. In the absence of a commitment to assure minimum levels of demand, supported by contracts with growers, it is difficult to see the emergence of a strong field-grown native seed sector in the Colorado Plateau.

Author contributions

AC, CP, BB, TW conceived and designed the research; AC and CP conducted literature review; AC and BB created database of restoration projects; AC and CP analyzed data for market analysis; CP and TW edited the manuscript.

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Appendix A. Supplementary data

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