Economic Impact of Invasive Weed Species in Colorado: Phase I

Final Report

W. Marshall Frasier
Agricultural & Resource Economics
Colorado State Univeristy

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Key Personnel

Principal Investigator (August 2012 – present)

W. Marshall Frasier, Professor
Department of Agricultural and Resource Economics
Colorado State University
B331 Clark
Fort Collins, CO 80523-1172
Ph: 970-491-6071
marshall.frasier@colostate.edu

Principal Investigator (prior to August, 2012)

Craig A. Bond, Associate Professor
Department of Agricultural and Resource Economics
Colorado State University
B311 Clark
Fort Collins, CO 80523-1172
NOTE: Dr. Bond is now at RAND Corporation, 1200 S. Hayes St, Arlington, VA 22202-5050, 703-413-1100 x 5319. cbond@rand.org.

CSU student support: A. Patrick Behrer, Ashley Bennett, Jackson Dorsey, Solomon Geleta

CPW staff support: Robert Walters, Invasive Species Program Data Manager

Collaborators

Elizabeth Brown
Invasive Species Coordinator
Colorado Parks and Wildlife
6060 Broadway, Denver, CO 80216
office: 303.291.7362, cell: 303.547.8690
elizabeth.brown@state.co.us

Fred Raish
Colorado Weed Management Association
PO Box 364
Paonia, CO 81428
970-630-8525
fredraish@gmail.com

Contents

Introduction

For a number of years, the Colorado Weed Management Association (CWMA), an organization comprised of weed managers representing government agencies, private and commercial applicators, non-governmental organizations, and private citizens, has discussed the need to document the economic impact of invasive weeds across the state of Colorado (www.cwma.org). Although a variety of studies have been implemented in surrounding states, even basic Colorado-specific impacts have yet to be calculated. Phase I of this project addresses this gap by leveraging a formed partnership between the Colorado Department of Agriculture, Colorado Department of Natural Resources, CWMA, and Colorado State University to document the basic economic impacts of a prioritized list of terrestrial and aquatic noxious weeds to the State of Colorado.

Given the numerous and varied types of impacts of differential invasive species across the state (including but not limited to agriculture, energy, infrastructure, natural resources, tourism, and ecosystem services), this project is conceptualized as a sequence of interconnected yet reasonably separate studies. The first phase provides a rough outline of the impacts of selected species across the state. Funding permitting, additional phases may be completed that augment primary data and expand the scope of analysis.

Identified Species of Interest

Ten species were identified for analysis in Phase I on the basis of their presence and potential threat to Colorado, the interests of the partners, and the existence of out-of-state cost data that can be used for external validity:

- Cheatgrass (*Bromus tectorum*) (List C);
- Eurasian watermilfoil (*Myriophyllum spicatum*) (List B);
- Knapweeds – diffuse (*Centaurea diffusa*) (List B), meadow (*Centaurea pratensis*) (List A), Russian (*Acroptilon repens*) (List B), spotted (*Centaurea maculosa*) (List B), and Yellow starthistle (*Centaurea solstitialis*) (List A); and
- Thistles – Canada (*Cirsium arvense*), musk (*Carduus nutans*), and scotch (*Onopordum acanthium or O. tauricum*) (All List B).

Objectives

The objectives of Phase I of the project include:

- identify the uses affected by each of the ten identified species across Colorado
- estimate the extent of the physical infestation of each species on each identified use
- estimate the direct costs (lost benefits) of the infestation on each identified use
- estimate the direct impact on Colorado economy as the aggregate of costs imposed by the presence of ten identified species in all identified uses

Procedure

This first-cut analysis was governed largely by the commitment by all parties to use readily available "off the shelf" data with the overarching goal of identifying what is currently known and to inform pathways for subsequent analysis. This approach limits scope and nature of analysis of this phase but provides guidance for future data collection and analysis.

The overall objective of estimating the economic impact of weed species on the state economy is an ambitious one. The commitment to using available data, the core question for the current effort was distilled to determine the cost of weed species as: "the amount by which the productive value of state resources are diminished because of the presence of the weed species". Recognize that this first-cut analysis ignores many of the "costs" that invasive weed species impose on the economy that extend well beyond the services and activities supplanted by their presence. The present level of invasion is conditioned on recent and current weed control activities (both public and private) which have their own costs. Further, a given presence of invasive species represents a threat for further invasion that could result in the diminishment of future activities in the state. For the current study, only the value of given activities presumed diminished by the presence of the weed species are taken to be a direct cost. This generally follows the general philosophy used by Hirsh and Leitch, 1996.

In the study, we focused on three primary use components to estimate the loss of value. These included agricultural production, wildlife habitat, and recreation. For each of the three use components, the estimate of economic value supplanted by the presence of the weed species required an estimate of (a) the average economic value of a parcel of "non-invaded" land of given "use" character, (b) the proportion of diminishment of economic value due to "presence" of each weed species of interest, and (c) the proportion of land area "invaded" which supplanted the valued activity. The product of these three values provides the estimated "cost" of weed presence on a given parcel of land for the use category. Summing across all parcels and all uses within the State provides an estimate of the estimate of state-wide direct costs.

Data and Analysis

Presence of Invasive Weed Species

The primary driver necessary for the analysis is an accurate depiction of weed infestations across the state of Colorado. We used the Colorado Department of Agriculture's (CDA) QuarterQuad (QQ) mapping of noxious weeds for 2009 (latest available) as the best available depiction of current weed infestation. CDA requests data from the County Weed Supervisors on an annual basis and infested acreages estimates are per 9,000 acre QuarterQuad. A QuarterQuad is one quarter of a standard 1:24,000 U.S.G.S. 7.5min topographic quadrangle. Data is collected for ninety noxious weed species including the ten species targeted in this study. The map in Figure 1 depicts the geographic distribution of the presence reported of the ten species across the state.

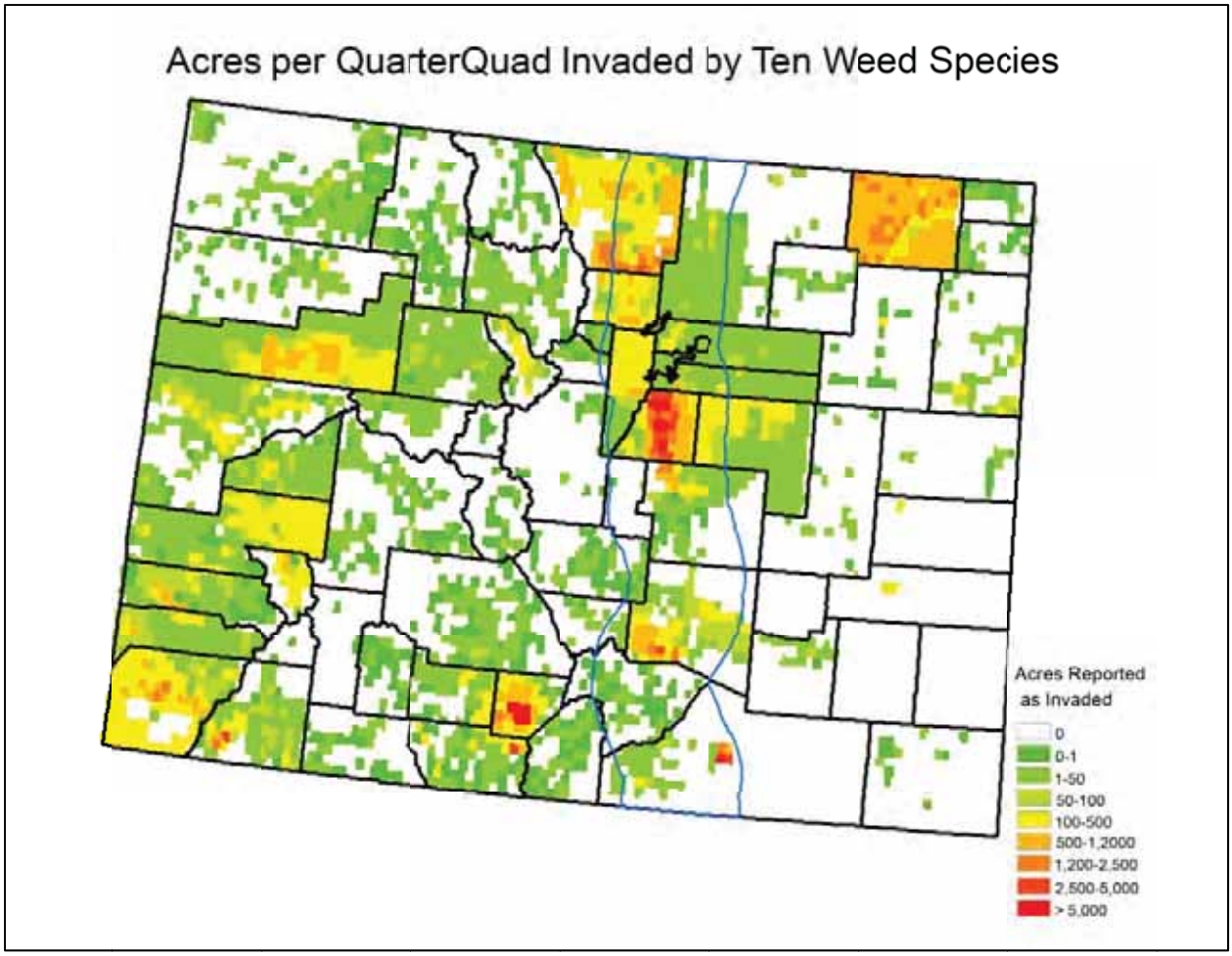

Figure 1. Acreage per quarterquad map unit (approximately 9,000 acres) reported infested by the ten selected weed species in 2009 Colorado Department of Agriculture Noxious Weeds database.

It should be noted that there are some serious limitations imposed for the economic analysis given the nature of the noxious weed inventory. Table 1 summarizes the reported incidence of each of the ten identified species by Agricultural Reporting District. First, it appears that there is significant under-reporting of weed species presence in the state. All 90 weed species which are tracked are reported to occupy just over 1.5 million acres (2.3% of Colorado's total land area) with the targeted "ten species" in this study accounting for over one third of this total. Over one-half of the QQ are reported to have none of the "Ten Species" and only one third of QQ are reported to have more than 25 acres of weeds across all ninty species. For this given analysis, if a weed is not reported as present in a QQ, then the estimated economic impact of invasive weed species will be zero for that QQ.

Further, the coarse resolution of the QQ mapping of weed species does not provide information about the distribution of the species within the 9,000 acre block which increases the error of attempting to associate weed presence with land use characteristics which are measured at a much finer resolution. There is also no information regarding the intermingling of weed species, their concentration, vigor, or other qualitative dimensions of invaded sites which

Table 1. Acres of Invasive Weed Species Reported to Colorado Department of Agriculture by County Weed Programs.

	Crop Reporting District						
Species	Northwest and Mountain	Northeast	East Central	Southwest	San Luis Valley	Southeast	Colorado
Cheatgrass	-	110,450	-	10,574	-	-	121,024
Musk Thistle	3,555	6,902	14,978	7,945	22	13,088	46,490
Diffuse Knapweed	573	31,862	91,170	156	1	14,381	138,143
Spotted Knapweed	289	122	204	8,707	1	116	9,439
Meadow Knapweed	2	-	-	512	-	-	514
Russian Knapweed	876	629	878	73,489	51,445	4,712	132,029
Yellow Starthistle	1	2	-	45	-	35	83
Candada Thistle	1,223	86,455	3,507	4,533	2,657	43	98,418
Eurasian Watermilfoil	-	183	51	-	5	8	247
Scotch Thistle	625	329	15,917	1,571	5	7,139	25,586
"Ten Species" Total	7,144	236,934	126,705	107,532	54,136	39,522	571,973
Percent of District/State	0.04%	3.12%	0.95%	0.88%	1.03%	0.33%	0.86%
Nintey Species Total	150,989	484,225	221,470	445,223	174,761	54,321	1,530,989
Percent of District/State	0.94%	6.38%	1.66%	3.62%	3.33%	0.45%	2.30%

certainly influence the impact of the presence of the species. The only option to carry forward with this analysis is to assume that the weed species are distributed across the underlying land uses (within each of the agricultural, habitat, and recreation components) in the same proportion at which these uses are present within the QQ. In reality, because weeds are often opportunists of specific circumstances, species presence tends to align disproportionately with specific land characteristics. The nature of the data precludes accurate depiction of this likelihood.

Agricultural Production

To identify the impact on agricultural production, it was necessary to identify the current land uses. USGS Landsat remote image data used to estimate these uses. This geo-referenced raster data classifies land uses into seventeen different Land Cover Classes. For our analysis, these seventeen classes were aggregated into six categories as summarized in Table 2.

Table 2. Definition of Land Use Categories Utilized in Study.

USGS Land Cover Class		Land Use Category for
Code	Category	Analysis
11	Open Water	Water
12	Ice/Snow	Forestland
21	Developed - Open Space	Other
22	Developed - Low Intensity	Other
23	Developed - Medium Intensity	Other
24	Developed - High Intensity	Other
31	Barren Land	Other
41	Deciduous Forest	Forestland
42	Evergreen Forest	Forestland
43	Mixed Forest	Forestland
52	Shrub/Scrub	Rangeland
71	Grassland / Herbaceous	Rangeland
81	Pasture / Hay	Pasture
82	Cultivated Crops	Cropland
90	Woody Wetlands	Wetlands
95	Emergent Herbaceous	Wetlands
	Uncoded	Uncoded

These data were analyzed to determine the proportion of each QQ that was determined to belong to a given Land Cover Class. These proportions were then applied to the total acreage of each given weed species to estimate the number of acres of a particular land use that were invaded by a given weed species. The total acres and proportions of invasion are summarized in Tables 3 and 4, respectively.

Table 3. Acres of Invasive Weed Species Reported as Correlated with Land Use in Colorado.

Species	Forestland	Rangeland	Cropland	Pasture	Other	Wetlands	Water	All Uses
Cheatgrass	5,059	61,487	46,072	1,909	4,867	1,176	450	121,024
Musk Thistle	13,370	24,024	2,481	1,042	4,362	940	270	46,490
Diffuse Knapweed	31,630	77,732	4,427	872	19,470	3,300	711	138,143
Spotted Knapweed	2,110	4,339	421	1,924	337	298	10	9,439
Meadow Knapweed	342	79	0	75	12	2	4	514
Russian Knapweed	21,632	76,536	3,503	16,867	5,814	7,196	480	132,029
Yellow Starthistle	38	37	0	4	2	2	0	83
Canada Thistle	30,727	36,578	17,063	3,395	5,700	3,453	1,497	98,418
Eurasian Watermilfoil	1	35	14	8	160	14	14	247
Scotch Thistle	3,389	17,811	605	371	2,846	486	79	25,586
"Ten Species" Total	108,297	298,657	74,586	26,468	43,569	16,866	3,515	571,973
Proportion of State-wide Invasion	19%	52%	13%	5%	8%	3%	1%	

Table 4. Proportion of Species Invasion Attributed to Identified Land Use.

Species	Forestland	Rangeland	Cropland	Pasture	Other	Wetlands	Water	All Uses
Cheatgrass	4%	51%	38%	2%	4%	1%	0%	100%
Musk Thistle	29%	52%	5%	2%	9%	2%	1%	100%
Diffuse Knapweed	23%	56%	3%	1%	14%	2%	1%	100%
Spotted Knapweed	22%	46%	4%	20%	4%	3%	0%	100%
Meadow Knapweed	67%	15%	0%	15%	2%	0%	1%	100%
Russian Knapweed	16%	58%	3%	13%	4%	5%	0%	100%
Yellow Starthistle	46%	44%	1%	5%	3%	2%	0%	100%
Canada Thistle	31%	37%	17%	3%	6%	4%	2%	100%
Eurasian Watermilfoil	1%	14%	6%	3%	65%	6%	6%	100%
Scotch Thistle	13%	70%	2%	1%	11%	2%	0%	100%
"Ten Species" Total	19%	52%	13%	5%	8%	3%	1%	100%

Among the ten selected weed species, cheatgrass, diffuse knapweed, Russian knapweed, and Canada thistle account for 86 percent of the invasion considered in this study. The summary in Table 4 spotlights the fact that rangelands are reported to be the predominant invaded land use for all weed species with meadow knapweed and yellow starthistle being significant invaders of forestland, cheatgrass also significant in cropland, and the majority of Eurasian watermilfoil being attributed to the "Other" land use category.

Due to the significant differences in spatial resolution (9,000 acres per QQ vs. less than one acre for a Landsat pixel), significant error is induced in attempting to match weed species with land use. This is best illustrated in the distribution of Eurasian watermilfoil with acreage showing in every category even though it is known to exist only in water bodies. Similar error is expected to exist across all weed species, though the error will be less for weed species that are more prevalent in land uses that are more dominant in proportion of given QQ. This error is highlighted to underscore the value of collecting weed species invasions at a finer geographic scale than has historically been done.

Taking the resulting distribution of weed species across land uses with in each QQ as summarized above, the next step is determine the cost of their presence. For this first-cut analysis, the approach was to estimate the amount of productivity reduction induced by the presences of the weeds. For this analysis, it was assumed that an acre of weed species invasion on agricultural lands completed eliminated the net value of production from that acre. This, of course, will vary from site to site but there is no evidence of the nature of the invasion in the weed data. Some acres of invasion will diminish the net value of production less, however, some invasions can reduce production below the total costs of production within a given year, causing negative returns in the short run. On balance, the "take-all" of annual net returns is not as extreme as it may appear on the surface. Clearly, lacking sufficient empirical evidence, this is another source of error in this study.

To estimate the monetary value of the net returns supplanted by the presence of weed species, the value of production was represented by the prevailing cash rental rates for each given land use. The primary agricultural activity for Rangeland, Pasture, Forestland, and Wetlands was taken to be grazing. Weed infested Cropland was taken to be non-irrigated. The Water and Other categories were taken to not have any agricultural activities. Table 5 summarizes the

Table 5. Average Cash Rental Rates for Agricultural Lands, 2009-2013 ($/acre/yr)

District	Pastureland	Cropland
Northwest and Mountain	4.18	20.00
Northeast	4.89	24.18
East Central	6.57	23.98
Southwest	5.53	27.23
San Luis Valley	6.33	28.55
Southeast	3.47	26.44
Colorado	5.10	24.80

Source: USDA-NASS "Quick Stats". http://quickstats.nass.usda.gov/

annual monetary value of an acre of undiminished grazing (applied to the four land use categories identified above) and dryland cropland as reflected by the annual cash rental rates. The productivity of lands in these uses varies across the state so fortunately USDA National Agricultural Statistics Service collects cash rental rates by Crop Reporting District. For this analysis the average reported rental rates for 2009-2013 were used.

Wildlife Habitat

The approach to determining the impact of weed presence on wildlife habitat follows the general approach for agricultural production. Within each QQ for which any of the ten species are present the composition of wildlife habitat that would be inhibited by the species presence was identified. In this case the Western Governors' Wildlife Council's crucial habitat index (CHI) was used as a proxy for wildlife habitat "production" for a given land area. The CHI score is a one to five rating that identifies a level of importance of habitat for multiple wildlife species in a given area. Figure 2 illustrates the geographic distribution of CHI values for Colorado.

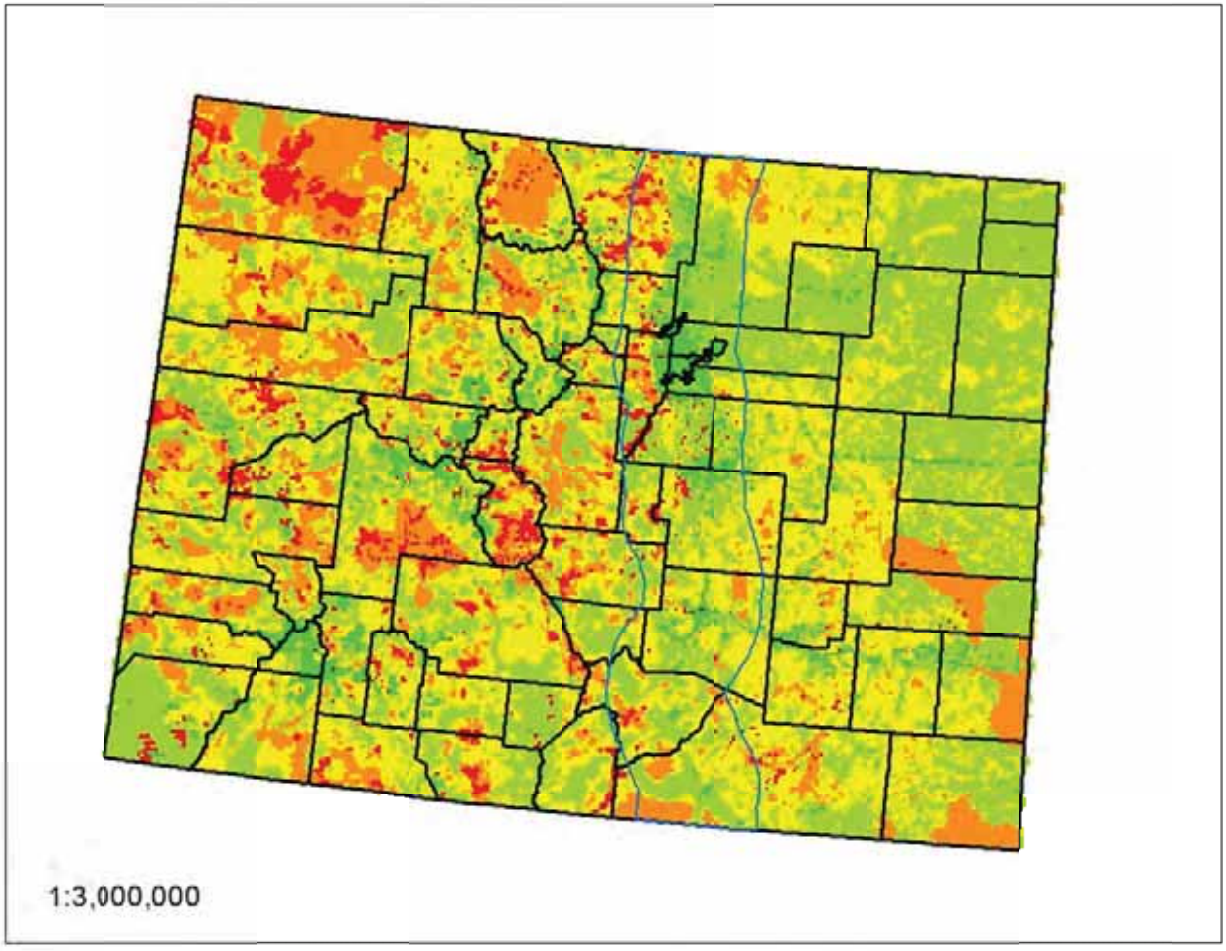

Figure 2. Western Governors Wildlife Council Crucial Habitat Index (CHI) (red is high [CHI=1], dark green is low [CHI=5])

The resolution of the CHI data is much finer than the weed invasion data so, again, any weeds present within a QQ were assumed to be linked with CHI values according to their proportion within the QQ. Lacking any evidence of the nature of the weed invasions within each QQ, presence of weed species on an acre was taken to fully diminish the value of habitat from its identified CHI value.

To estimate the monetary value of this reduction in habitat services, the monetary value of undiminished crucial habitat was assumed to decline linearly across CHI values from one to five allowing for differentiation between invaded sites with high habitat value and those with less value. Further investigation is necessary to identify whether the linear decline is merited.

With this modeling of structural response in value across CHI, identifying the monetary value of the most important habitats (CHI=1) allows the others to also be determined. In best cases, estimates of monetary values of habitat are difficult. We attempted to utilize the Benefit Transfer and Use Estimating Model Toolkit developed by Loomis et al. (2008) to derive terrestrial habitat values on certain criteria. Depending on the nature of the setting identified, values per acre ranged from zero to nearly ten thousand dollars per acre. The primary difficulty here was that none of the driving criteria are known at the QQ resolution so this approach was abandoned.

Ultimately a pair of separate studies (a willingness-to-pay study and a hedonic property study) were used to set a proxy monetary value for crucial habitat in the highest value. In a 1997 study Loomis and Ekstrand found that willingness to pay for 4.6 million acres of Mexican Spotted Owl habitat was $435 per acre. A 2003 U.S. Fish and Wildlife Service study found that based on a hedonic property study that households were willing to pay between $435 and $817 per acre to support open space critical to Preble's Meadow Jumping mouse habitat. The conservative result was to select the value of $434 per acre for this study. This is a present value of a tract of land in the highest condition. To make this commensurate with the annual values used elsewhere in the study, a four percent capitalization rate yields an annual cost of $17.36 per acre for lands with the highest habitat values being invaded by weed species.

Recreation

Tourism and recreation are strong economic drivers in Colorado. Invasive weed species have the potential to significantly diminish recreation values by their presence. However, not all of Colorado yields the same recreation opportunities or use. Most recreation valuation studies identify values in terms of dollars per visitor day for a given area or destination. For the study at hand, it is necessary to identify a value per acre of land that the presence of weed species diminishes recreational values. This proved to be far more difficult than for either agricultural or wildlife habitat values.

For this first-cut analysis, Theobald's index for the Human Use of Ecosystems was used as a proxy for recreational activity. For the purpose of this study this recreation index (RI) characterizes human activity on a one to ten scale with ten being the highest level. Figure 3 represents the spatial distribution of the index values across Colorado with red representing the lowest values and green representing the areas with the highest activity levels.

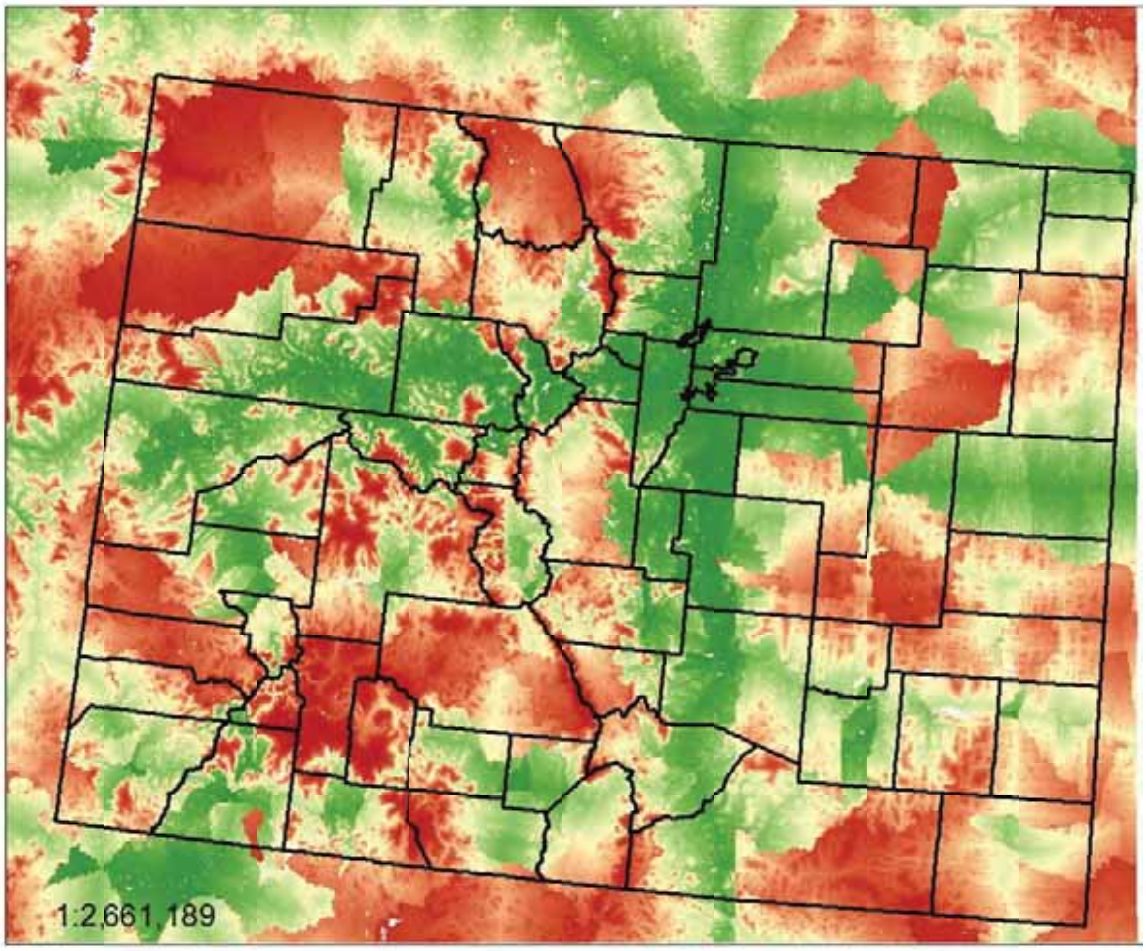

Figure 3. Recreation Index values for Colorado (red is low [RI=1], dark green is high [RI=10])

The resolution of the RI data is much finer than the weed invasion data so, again, any weeds present within a QQ were assumed to be linked with RI values according to their proportion within the QQ. Lacking any evidence of the nature of the weed invasions within each QQ, presence of weed species on an acre was taken to fully diminish the value of recreation from its identified RI value.

To estimate the monetary value of this reduction in recreation, the monetary value of undiminished recreation site was assumed to decline linearly across RI values from ten to one allowing for differentiation between invaded sites with high recreation value and those with less value. Further investigation is necessary to identify whether this linear decline is merited or how recreation values might be better represented and estimated.

With this modeling of structural response in value across RI, identifying the monetary value of the most important recreational sites (RI=10) allows the others to also be determined. Analytically this is straightforward, but there is practically no empirical evidence to identify monetary values that are calibrated to a given RI value.

Results

All of the data previously described for weed species invasion, land use, crucial habitat index, and recreation index was analyzed in GIS to create summary information for each QQ in the study area that was then compiled in a single Excel workbook. Drawing from this spatial database, the mean diminishment of each of the three categories of economic importance (agricultural production, wildlife habitat, recreation) was calculated for each QQ and then scaled by the monetary value per acre described previously. Table 6 summarizes the cost of the presence of the ten weed species as the total foregone direct economic value.

Table 6. Total Direct Cost to Colorado of Reported Invasion of Ten Weed Species ($/year)

District	Agricultural Production	Wildlife Habitat	Recreation*	Total Cost
Northwest & Mtn	28,346	77,021	53,919	159,286
Northeast	2,328,473	2,159,497	1,602,314	6,090,283
East Central	749,567	1,082,600	1,223,230	3,055,397
Southwest	646,831	1,080,528	733,403	2,460,763
San Luis Valley	326,075	411,370	462,611	1,200,055
Southeast	200,901	336,689	335,545	873,135
Colorado	4,280,192	5,147,706	4,411,022	13,838,920

* Recreation values are based on an assumed $10/acre for lands with a Recreation Index value of 10. Total Costs in this category will scale directly with this value (e.g. if RI=10 lands are valued at $100/acre, the total cost to recreation would be $44 million annually to Colorado).

Based on the evidence at our disposal, the total annual direct cost of the ten weed species is nearly $14 million annually with agricultural, wildlife, and recreational values all being similar. There are a number of caveats that must be considered before basing any important decisions on that number.

The first (and arguably most important) of these is quickly revealed by comparing the cost categories between the six Crop Reporting Districts. The Northeast District is highest in all categories. That should be viewed skeptically as a truth. However, a quick review of Figure 1 points quickly to why this is the case—more weed presence is reported here than in any other area of the state. Contrast this with the acreage of invasion reported in either the Northwest or Southeast Districts. Large portions of these areas report that none of the identified species are present. Following our procedures, this means that there is no economic cost of weed species in these areas. In short, regardless of the sophistication and accuracy of other elements of the analysis, the apparent under-reporting of weed invasions severely hampers our ability to generate an estimate of total cost that should generate any confidence in those who would use this number to justify any policy decisions. If anything, given the apparent under-reporting of weed invasion and the consistent analytic choices toward conservative values, the total cost values presented here should be viewed as rather extreme lower bounds on the true values.

The valuation of recreation values was particularly troublesome, so a choice was made to value land with the highest index value at $10 per acre annually. This provides easy scaling as the users of this data wish to consider outcomes at other peak values.

Conclusions and Implications

The overarching purpose of this phase of research was to identify a pathway to future research activities. It is clear that secondary data is clearly lacking in terms of being able to develop accurate estimates of the cost that invasive weed species impose on the Colorado economy. Ready availability of appropriate data on several fronts proves to be the primary limitation in this effort.

Most significantly, it seems apparent that that the inventory of weed infestation in the state is lacking. Many infested acres are reported, but reporting is voluntary, from a single source (county weed programs) and seems to be incomplete. Further, the coarse spatial resolution of the data (acres infested per 9,000 acre block) without any qualitative information beyond acres and species identifier would hamper any more sophisticated analysis. The nature of weed invasion is important when determining its effect on all three of our impact areas. This would include density on the landscape, geographic distribution within the reporting block, interactions with other invasive species, the degree of use diminishment, and other biological indicators of the state of the invasion. Qualitative information and finer spatial resolution can, to some degree, substitute for one another, though we presently have neither. The most useful analysis would benefit significantly from both.

The commitment to utilize only readily available data also provides very coarse representation of agricultural land uses, wildlife habitat, and recreational activities. Here data exist with much finer spatial resolution, but these are merely proxies to the various values of activities that are diminished by the presence of invasive weed species. Without better depiction of the state of weed invasion across time, there is little opportunity to model relationships against these use data to characterize statewide impairment due to invasions.

Finally, the approach utilized in this study comes short of reflecting the total “cost of weeds” to the Colorado due to procedural choices in the analysis. This was a starting point to assess only the foregone value of three impact areas due to presence of ten identified weed species (which itself proves difficult). Even if this could be accurately estimated, these costs are conditioned on an extensive and systematic effort to control weed species by both private landowners and public agencies. None of these costs are reflected in this analysis. Further, the full cost of an invasive stand of weed species on a given tract of land is more than the value of the activities that it supplants. This presence increases the risk of spread and future infestations to other lands which translates into greater expected diminishment of valued activities and services and/or increased control costs in the future. Limitations in current data availability prevent applying more sophisticated analysis that could reflect these additional dimensions on a state-wide basis.

Further Work

The analysis presented here focuses on data that is best suited to documenting the impact of terrestrial species. Eurasian watermilfoil was selected as one of the ten identified species to demonstrate the unique character of invasive aquatic weed species. Work is continuing following the same principles applied to the terrestrial species but utilizing data sources unique to the aquatic setting.

Given the issues identified in this study, now is the time to engage in conversation to identify whether further effort is warranted to improve upon the data and analysis utilized in this report. The results from this study suggest that the central question would be how invasions of invasive weed species across Colorado should be documented and reported in the future and the nature of the questions to be addressed with this information.

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Western Governors' Crucial Habitat Assessment Tool available online at http://westgovchat.org

Funding Partners for This Report

Yuma County

Pest Control District

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