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Research Paper

Linking ecology and aesthetics in sustainable agricultural landscapes: Lessons from the Palouse region of Washington, U.S.A.

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HIGHLIGHTS

- We measured aesthetic and ecological responses to variations in landscape structure.
- Erosion rates decreased with successive additions of conservation buffer elements.
- People preferred landscape scenes with greater amounts of buffer vegetation.
- GeoWEPP erosion modeling can help prioritize buffer placement at watershed scales.
- Aesthetic and ecological quality can coincide in agricultural landscape structure.

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ABSTRACT

Inspired by international escalation in agricultural sustainability debates, we explored the promise of landscape-scale conservation buffers to mitigate environmental damage, improve ecological function, and enhance scenic quality. Although the ecological benefits of buffer vegetation are well established by plot- and field-scale research, buffer adoption by farmers is limited. Landscape-scale approaches can address several obstacles by simultaneously considering ecological impact, economic efficiency, and aesthetic quality and preference in buffer placement and design. Within four watersheds of Washington's Palouse farming region, we examined relationships between ecological and aesthetic responses to the existing landscape structure plus three alternative scenarios, differentiated by successive increases in woody buffers. Methodology combined GIS analysis, digital image simulation, soil erosion modeling and mapping, and a landscape preference survey. Landscape ecological function, measured by erosion and deposition rates, improved as buffer elements were added into each successive scenario. Magnitude of improvements varied among scenarios and among watersheds, revealing opportunities for targeting buffers to maximize ecological benefits and economic efficiency. Concurrently, aesthetic preference, measured as scenic quality ratings, increased significantly ($p < 0.05$) from the existing landscape through the second successive scenario of improved ecological function. No preference difference was found between the second and third scenarios. Results expand current understanding of multifunctional relationships in agricultural landscapes and encourage future research on whether linking ecological and aesthetic quality in buffer design might favorably influence adoption. Results also suggest that, within certain landscape contexts, visually perceivable attributes can provide a relative and coincident indication of ecological function, aesthetic quality, and agricultural sustainability.

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1. Introduction

Ongoing environmental degradation, world population projections of nine billion by 2050, and recognition that most productive cropland is already in use have ignited renewed vigor in agricultural sustainability and food security debates (Chappell & LaValle, 2011; Godfray, Pretty, Thomas, Warham, & Beddington, 2011; NRC, 2010; The Royal Society, 2009). Considerable research has contrasted the merits and shortcomings of conventional versus alternative forms of agriculture to ensure future production while protecting biodiversity, natural resources, and ecosystem services (Chappell & LaValle, 2011; Scherr & McNeely, 2008; Tilman, Cassman, Matson, Naylor, & Polasky, 2002; Trewavas, 2001). Reexamination of opposing arguments, including those establishing the "land-sparing" versus "wildlife-friendly" farming dichotomy (Fischer et al., 2008; Green, Cornell, Scharlemann, & Balmford, 2005), reveals noteworthy agreement on several widely applicable, sustainability strategies, regardless of agroecosystem type employed.

Gaining particular consensus is the idea that landscape approaches, which coordinate multiple farms, are necessary to realize significant reductions in off-site environmental damage or improvements in ecosystem services (Maresch, Walbridge, & Kugler, 2008; Tscharntke, Klein, Kruess, Steffan-Dewenter, & Thies, 2005). One such strategy is integrating landscape-scale conservation buffer systems to complement on-farm sustainability practices that improve water infiltration, soil retention, and input efficiency (Bentrup, 2008; Groffman, Capel, Riitters, & Yang, 2007; Lowrance & Crow, 2002; Scherr & McNeely, 2008). In contrast to the small area upon which they are typically planted, permanent vegetation buffers can deliver disproportionately high amounts of ecological function and beneficial ecosystem services (Lovell & Sullivan, 2006). However, because empirical evidence on buffer function and efficacy is predominantly based on field-, plot-, and buffer-specific (windbreaks, field borders, grassed waterways, riparian plantings) studies, our understanding of how benefits translate to larger spatial scales is limited (Lovell & Sullivan, 2006; Smukler et al., 2010).

Understanding conservation buffer function at landscape or watershed scales may also help overcome social, economic, and policy obstacles that, so far, prevent widespread adoption of buffers despite their known ecological benefits. For example, when assessing collective off-site effects for buffer placement and design, not all farms will contribute equally to negative impacts on environmental quality or to positive influences on ecosystem services. This phenomenon, termed disproportionality, reflects variations in conservation behavior of farmers and in spatial location and biophysical setting of farms (Nowak & Pierce, 2007; Walter et al., 2007). By intentionally targeting buffers and encouraging and compensating buffer adoption in settings of high sensitivity and critical ecological function, a landscape approach can maximize societal and landowner benefits while minimizing monetary investments (Groffman et al., 2007; Maresch et al., 2008; Scherr & McNeely, 2008).

Moreover, agricultural landscapes contribute cultural benefits by functioning as everyday nature, open space, scenic beauty, and recreational areas that can sensuously delight and emotionally inspire (Antrop, 2000; Arler, 2000; Brady, 2006; Dubos, 1976; Lowenthal, 2007). Undeniably, humans have long held a multi-faceted and culturally ingrained connection with the countryside—a sentiment captured in the pastoral aesthetic, which conceptualizes agricultural landscapes as perpetually green, peaceful, comforting, and productive (Marx, 1964; Schauman, 2007). Despite negative environmental impacts associated with some agricultural practices, farmers are often collectively characterized as good stewards—implying devoted and enduring human–land relationships that ensure productivity and protect natural resources (Nowak & Pierce, 2007). This stewardship ethic is partially idealized in visions of agricultural landscapes as neat and well-kept patterns of barns, fields, fences, and rows of crops—visual qualities also explained by Nassauer's (1997) aesthetic of care.

Importantly, although people may be unmoved by scientific or moral arguments for resource conservation, they often feel strongly about the care and protection of landscapes that evoke sensuous and emotional gratification (Meyer, 2008; Parsons & Daniel, 2002; Stokes, Watson, & Mastran, 1997). Enhanced aesthetic quality is frequently presumed an ancillary ecosystem service that automatically accrues from incorporating buffers, particularly those comprised of tree and shrub (woody) species, into an otherwise homogeneous agricultural landscape. Several researchers (e.g., Décamps, 2001; Gobster, Nassauer, Daniel, & Fry, 2007; Lovell & Sullivan, 2006; Meyer, 2008) have recognized the potential for aesthetic experiences to serve as catalysts for motivating conservation and sustainable land-use behavior. Indeed, Lovell and Sullivan (2006) identified a limited understanding of the importance of aesthetic preference in buffer design as one of several obstacles to widespread buffer adoption in the US. Other obstacles included a need for watershed-scale research and for interdisciplinary approaches that explore relationships among economic, aesthetic, and ecological goals in highly productive agricultural landscapes (Lovell & Sullivan, 2006).

Landscapes of high aesthetic quality may or may not be compatible with high ecological function (Gobster et al., 2007). To understand how aesthetic experiences might motivate conservation behavior, we must first ask under what conditions, and to what extent, can ecological and aesthetic values coincide in perceptible landscape structure. To answer this question and begin to fill identified knowledge gaps, our study examined ecological and aesthetic responses to agricultural landscape changes induced by successive additions of woody buffers. A paucity of empirical research directly and purposely measures ecological–aesthetic relationships within the biophysical structure of active farmland and from the scale and perspective of everyday human experience.

In Europe, studies have been concerned with public visual preferences relative to cropping intensification on highly productive lands and to nature conservation and reforestation on less productive, abandoned farmland (e.g., Hunziker & Kienast, 1999; Lindemann-Matthies, Briegela, Schüpbachb, & Junge, 2010; Van den Berg & Koole, 2006). Other studies have focused on varying objectives such as landscape scenic value as a farmland preservation strategy (Schauman, 1988; Stokes et al., 1997), buffer design preference for mitigating conflicts at the urban–rural fringe (Sullivan, Anderson, & Lovell, 2004), and visual quality comparison of organic versus conventional agricultural systems (Egoz, Bowring, & Perkins, 2006). To our knowledge, no study has concurrently measured changes in ecological function and aesthetic preference in direct response to integrating woody conservation buffers within modern, intensively managed agricultural landscapes.

In environmental psychology, empirical studies using perception-based assessments generally interpret human preference for a particular landscape as a measure of its aesthetic quality. Preferred landscapes are understood as having high visual aesthetic quality (Daniel, 2001; Kaplan & Kaplan, 1989; Nassauer, 1995). Although cultural context and personal characteristics, knowledge, and experience certainly influence aesthetic judgment, an extensive body of research finds a notable consistency in preference for particular landscape attributes. Some of these preferred attributes exist to varying degrees in agricultural landscapes (Table 1). We hypothesized that several attributes would be enhanced with the integration of woody buffer systems. Furthermore, if the same buffer systems also improved water infiltration, enhanced soil retention, and/or reduced soil erosion, higher ecological and aesthetic quality would coincide in visually perceivable landscape attributes.

Table 1
Selected preferred landscape attributes, their explanatory descriptions and supporting theory/literature, and their potential to be perceived in existing agricultural landscapes versus alternative structural scenarios with tree/shrub conservation buffer systems.

Landscape attribute	Association, meaning, or value relative to aesthetic appeal/preference	Supporting theory/literature	Attribute potential in agricultural landscapes	
			Existing	With buffer system
Naturalness	Views, experience, and accessibility of natural or semi-natural landscapes or urban/suburban green spaces have restorative health benefits and are valuable indicators of place satisfaction, quality of life, emotional and physical well-being; human affinity for nature is thought an innate rather than acquired trait; green vegetation, particularly trees/shrubs, is generally associated with naturalness.	Arler, 2000; Biophilia Hypothesis (Kellert & Wilson, 1993); Kaplan & Kaplan, 1989; Kaplan, Kaplan, & Ryan, 1998; Purcell & Lamb, 1998; Stokes et al., 1997; Ulrich, 1984	Low-Med	High
Accessibility/ Locomotion	Amenable to explore or imagine living in the landscape; perceived ease of traveling through the terrain or pursuing outdoor recreational experiences (hunting, fishing, hiking, biking, scenic driving, wildlife viewing).	Antrop, 2000; Kaplan et al., 1998; Legibility Theory (Lynch, 1960); Nassauer, 1989	Low	Low–High (context dependent)
Sheltered viewpoints	Beneficial for early survival by providing shelter from inclement weather and the ability to see without being seen, inspect surroundings, hunt prey, avoid predators or harm, and orient from hilltop, overlook, or wooded edge. Related terms: prospect-refuge	Antrop, 2000; Prospect-Refuge Theory (Appleton, 1975); Purcell & Lamb, 1998	Low	High
Presence/Indication of water	Habitat component necessary for survival and reproduction; helps explain prevalence of settlements and higher property values near water or with water views; flowing water preferred over stagnant; includes indications of water/wetness, e.g., ribbons or patches of green vegetation in contrast with surrounding colors or textures.	Affordance Theory (Gibson, 1979); Habitat Theory (Appleton, 1975); Purcell & Lamb, 1998; Woodward, 2000	Low-Med (context-dependent)	Med-High (context-dependent)
Savanna-like	Open or semi-open expanse, grass-like groundcover, isolated or clumped canopy trees and shrubs, indication of water; enhances visibility, understanding, comfort, safety, security; presents a complex yet congruent scene; resembles the African savanna, an environment important to early human evolution. Related terms: savanna, park-like	Habitat Theory (Appleton, 1975); Lohr & Pearson-Mims, 2006; Parsons & Daniel, 2002; Savanna Hypothesis (Balling & Falk, 1982; Falk & Balling, 2010; Heerwagen & Orians, 1993; Orians, 1986)	Low-Med	High
Coherence[a]	Orderly arrangement of landscape elements into a pleasing pattern of cohesive and mutually reinforcing forms, elements, and relationships; observer easily understands and acquires information from the landscape as a unified, congruent whole. Related terms: harmony, unity, clarity, order	Antrop, 2000; Dee, 2001; Information Processing Theory (Kaplan & Kaplan, 1989); Murphy, 2005	Low	High
Complexity[a]	Richness in type and arrangement of forms and elements; arouses interest, heightens experience, and encourages further exploration and engagement. Related terms: variety, diversity	Antrop, 2000; Dee, 2001; Information Processing Theory (Kaplan & Kaplan, 1989); Murphy, 2005	Low	Med-High

[a] High complexity without coherence may be perceived as chaotic, disorienting, and unattractive; too much order without diversity becomes rigid, monotonous, and uninteresting (Antrop, 2000; Kaplan & Kaplan, 1989; Kaplan et al., 1998; Murphy, 2005). Design achieves high visual aesthetic quality by balancing complexity with coherence, expressed in Dee's (2001) unity with diversity concept.

To test our hypotheses, we used an interdisciplinary approach that combined several tools and methods for accomplishing the following objectives: (1) simulate alternative landscape scenarios of increasing ecological function with successive additions of conservation buffers in critical locations, (2) measure ecological function of each alternative landscape scenario via soil erosion modeling, (3) measure aesthetic function of each alternative scenario through a landscape preference survey, and (4) determine whether, or to what extent, ecological function and aesthetic quality coincide in visually perceptible agricultural landscape structure.

2. Methods

2.1. Study region

Positioned on Washington State's eastern border, Whitman County lies in the central core of the Palouse Grasslands Ecoregion and within a large, commercial grain production area (Fig. 1). The county's loessial hills of rich, deep soil are paradoxically notorious for producing some of the highest rainfed wheat yields in the world, and concurrently, some of the highest soil erosion rates (Duffin, 2007; Steiner, 1987).

Concerns about the impacts of soil erosion surfaced as early as the 1920s (Duffin, 2007). By 1978, 10% of the Palouse River Basin (PRB) had lost all of its topsoil to erosion and 60 percent of the land had lost 25–75% (USDA, 1978). Removal of nearly all of the native prairie, coupled with intensive agricultural practices, has also led to soil, fertilizer, and pesticide runoff into the Palouse River—ranked among the most polluted in the state by the late 20th century (Washington State DNR, 1998). As of 1994, voluntary erosion control practices had served to reduce mean annual erosion rates in the PRB by at least 10% (Ebbert & Roe, 1998). However, a complex mix of political, institutional, technological, and socio-economic factors have prevented the majority of Palouse farmers from

Fig. 1. Extent of the 46,879 km^2 (18,100 mi^2) Palouse Ecoregion, with Whitman County boundaries outlined in the central core(http://worldwildlife.org/ecoregions/na0813) (See reference Olson et al. (2001)).

implementing conservation techniques on a broad scale (Duffin, 2007). As a result, soil and water degradation continues.

On the other hand, farming activities are largely responsible for the Palouse landscape's renowned beauty. The cyclic and dynamic nature of crop production in this striking, undulating topography has been rendered by landscape artists and photographers for decades. The seasonally changing colors and textures, dancing plays of light and shadow, and waving fields of grain have also captivated more than a few visitors and residents alike (Fig. 2).

2.2. Viewshed site selection

Four viewsheds (landscape scene visible to the human eye from a fixed observation point) within Whitman County were visually captured at ground elevation using panoramic digital photography. Unlike expansive images captured from aerial or elevated viewpoints for tourist brochures, our photographs intentionally reflected more intimate, everyday scenes easily experienced on foot or bicycle or from a car window. Whereas all viewsheds are inherently unique (no two will have exactly the same characteristics), we selected study viewsheds with closely matched structural attributes according to the following criteria:

- Representative of a typical small-grain farming scene.
- Devoid of unique landmarks or unusual features.
- Located along the Palouse Scenic Byway.
- Inclusive of at least one visibly perceptible stream in the main valley.
- Distance of view allows recognition of landscape elements and spatial patterns with the unaided eye.
- Orientation of view captures most of the main valley and permits a reasonable balance between the visible and non-visible portions of the associated watershed (the region's complex, hilly topography prevents visibility of an entire watershed from a single, ground-level observation point).

All four viewsheds were photographed in a single day of early summer and within a constrained time period to ensure consistent color and lighting conditions. Camera tripod position for each viewshed panorama was documented with a global positioning system (GPS) and according to compass direction.

Fig. 2. Photographic example of the Palouse small-grain farming landscape in Whitman County, WA (photograph, "Glorious Day", by Inland Northwest photographer Alison Meyer, with permission, www.AlisonMeyerPhotography.com).

2.3. Spatial analysis for creating alternative landscape scenarios

A geographic information system (GIS) database, using ArcGIS v. 9.3.1 (www.esri.com), was developed for each viewshed/watershed study site. Base map layers of Whitman County were downloaded from the USDA Natural Resource Conservation Service (NRCS) Geospatial Data Gateway (http://datagateway.nrcs.usda.gov) and included the following: (1) 10-m resolution digital elevation model (DEM) (US Geological Survey, http://ned.usgs.gov); (2) digital ortho-rectified aerial image, 1-m ground sample distance (2009 National Agriculture Imagery Program (NAIP) Mosaic, USDA Farm Service Agency Aerial Photography Field Office); and (3) digital, vector-based, general soil map (2006 State Soil Geographic (STATSGO) database, USDA NRCS).

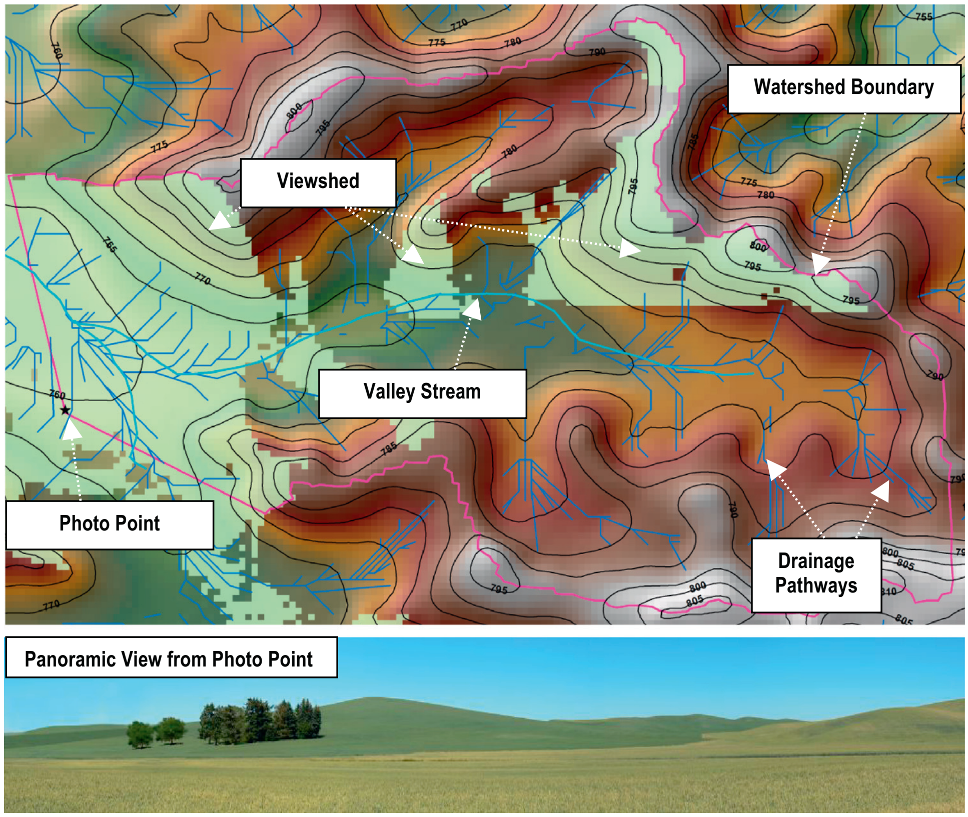


Fig. 3. GIS map of Study Site B, illustrating viewshed area, watershed boundary, drainage flowpaths, and valley stream, and panoramic photograph of the landscape scene viewed from the photopoint.

GPS-documented photopoints, viewsheds, watersheds, and surface drainage flowpaths were located and delineated using the data management and spatial analyst tools in ArcGIS (Fig. 3). The perennial stream flowing through each study site was digitized from the aerial photograph. A percent slope map layer was derived from the DEM and classified to match those associated with soil mapping units in the Whitman County Soil Survey (USDA, 1980). The physical characteristics of each study site are summarized in Table 2.

GIS analyses and supporting research (e.g., Bentrup, 2008; Berry, Delgado, Pierce, & Khosla, 2005; Mankin, Ngandu, Barden, Hutchinson, & Geyer, 2007; Tomer et al., 2009) helped identify locations where permanent conservation buffers had greatest potential to perform the following ecological functions:

- Stabilize streambanks of the main valley channel.
- Reduce, trap, and filter sediment and other pollutants in surface runoff to concentrated flowpaths.
- Retain soil on highly erosive areas, regardless of proximity to surface water features.

Subject to the DEM resolution (10-m), buffer width was intentionally minimized to align within the cultural and agricultural context of Whitman County, assuming the landscape would remain dominated by small-grain production. Ultimately, buffers were sized for the following three critical locations throughout all four study watersheds: (1) riparian buffers (RB), 10 m on either side of the perennial stream in the valley bottom, (2) hillslope drainage buffers (HDB), 5 m on either side of the intermittent, drainage pathways flowing laterally into the valley stream, and (3) steep slope buffers (SSB), on all areas greater or equal to 25% slope. Steep slope locations are soil units with a 6e or 7e land capability classification (highly erodible and not suited for cultivated crops) and without a prime farmland or farmland of statewide importance designation (USDA, 1980).

Table 2
Comparison of physical characteristics among study sites.

Study site	Characteristic					
	Viewshed area (ha)	Watershed area (ha)	Photopoint elevation (m)	View/Watershed elevations (range in m)	Dominant soil	Slope steepness (range in %)
Site A	37.2	112.5	556.3	536.6–635.0	Athena silt loam 7–25% slopes, well-drained, LCC[a] = 4e (non-irrigated)	0–57.1
Site B	26.5	86.7	758.3	751.9–812.5	Palouse silt loam 7–25% slopes, well-drained, LCC = 4e (non-irrigated)	0–43.4
Site C	37.5	73.2	762.6	754.2–812.7	Palouse silt loam 7–25% slopes, well-drained, LCC = 4e (non-irrigated)	0–40.2
Site D	33.1	51.1	791.9	787.1–843.7	Palouse silt loam 7–25% slopes, well-drained, LCC = 4e (non-irrigated)	0–40.9

[a] LCC = land capability classification; 4e = soils have very severe limitations due to erosion risk that restrict the choice of plants or require very careful management, or both (USDA, 1980).

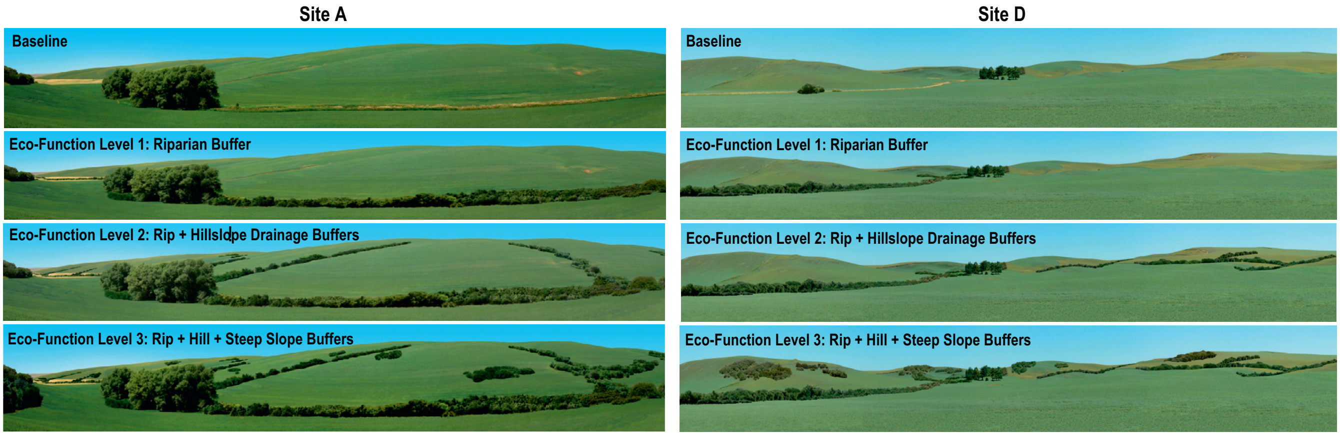


Fig. 4. Final Photoshop® simulations for two of the four study sites (A and D), illustrating the four sequential landscape buffer scenarios that represent increasing levels of ecological function (digital image simulation by Andrew Sewell, www.finewatercolors.com).

Sixteen land-use maps, four per study site, were then created to illustrate a Baseline landscape scenario plus three sequential alternative scenarios of increasing number and proportional area of buffer elements. Each consecutive change in landscape composition and configuration was presumed indicative of increasing ecological function. Herein, ecological function is defined as buffer system capacity to directly reduce erosion and/or increase deposition, and indirectly improve water quality by decreasing sediment yield to surface waters. For each study site, the Baseline landscape scenario was 100% winter wheat (WW) and, therefore, contained no buffer elements. The second scenario added the RB element to the WW monoculture and was named Eco-Function Level 1. The third landscape scenario, named Eco-Function Level 2, added the HDB elements to the RB elements in Level 1; the fourth scenario, Eco-Function Level 3, added the SSB to the RB and HDB in Level 2.

2.4. *Digital image simulation of alternative landscape scenarios*

Using digital image simulation (DIS) software (Adobe® Photoshop), four landscape images per study site were designed from the original panoramic viewshed photographs to match the 16 alternative scenarios developed in the GIS. Digital photographs of natural Palouse vegetation were captured under the same weather, timing, and lighting conditions as the viewshed photographs and used for simulating the added buffers. The shrub, Black Hawthorn (*Crataegus douglasii*), was chosen as the primary buffer species in the simulations because it is native and widely distributed throughout the region.

With the exception of cultivated fields, all cultural elements (roads, barns, houses, farm equipment) were digitally removed from the original photographs to maintain land ownership confidentiality. Removal of cultural elements also ensured that structural differences among viewshed sites, and in each successive landscape scenario, were isolated to amount and location of permanent buffer vegetation. The number and location of tree clumps were equalized among sites—either by adding or deleting trees while maintaining clump size relative to distance of view. These trees remained constant across all simulations (Fig. 4).

2.5. *Soil erosion modeling*

GeoWEPP (Minkowski & Renschler, 2008; Renschler, 2003, 2001), the geo-spatial, graphical user interface of the Water Erosion Prediction Project (WEPP) model (Flanagan & Nearing, 1995), was used to predict relative differences in sediment erosion and deposition rates (Mg/ha/yr) and soil loss (Mg/yr) to surface waters among the different landscape scenarios. Erosion and deposition estimates are based on user-inputs of climate, topography, soil type, land use, and management practices and the fundamentals of soil hydrologic and erosion science. Pertinent physical and biological processes are simulated, including evapotranspiration, water infiltration, surface runoff, rill and interrill erosion, sediment transport and deposition, snow melt and frozen soil effects, plant growth and canopy effects, and residue management and decomposition (Flanagan & Livingston, 1995).

We performed 16 soil erosion modeling runs using the four digital land-use maps developed in the GIS for each of the four study watersheds. Each run was set for a 50-year simulation period. The dominant soil type for each site was selected from the model's database. A climate file, specific to each site, was modified from the WEPP database of climate stations using the USDA Forest Service interactive web site (http://forest.moscowfsl.wsu.edu/fswepp; Elliot, Scheele, & Hall, 1999). Land-cover management was also selected from the database files and held constant across all 16 scenarios. The mulch-till winter wheat management was chosen for its intermediate position between conventional till and no till. The 20-year old, permanent, mixed forest management file was chosen as a close match for the Black Hawthorn buffer vegetation (Table 3).

GeoWEPP's flowpath method (Minkowski & Renschler, 2008) was used to maintain the diversity and spatial distribution of topography and land use and to obtain soil erosion/deposition predictions per 10-m grid cell. This method also predicts net soil loss—the amount of eroded soil entering the channel reaches—by averaging the soil loss from all flowpaths per subcatchment. Soil loss for the entire watershed is estimated by summing the subcatchment values. The number of subcatchments, overland flowpaths, and channels delineated by the model naturally varied across watersheds due to differences in area, topography, and elevation range. Although the landscape scenario in each successive modeling run remained constant across watersheds, the proportional area of land-use elements differed by watershed depending on site-specific topographic and hydrologic characteristics (Table 3).

2.6. *Landscape preference survey*

Population sampling protocol, questionnaire design, and implementation procedures for the landscape preference survey were guided by *Internet, Mail, and Mixed-Mode Surveys: The Tailored Design Method* (Dillman, Smyth, & Christian, 2009).

2.6.1. *Population sampling protocol*

Address-based sampling was used to obtain a representative sample of the target population—permanent, full-time residents

Table 3
GeoWEPP modeling inputs and parameters specific to each site and inputs and parameters held constant across study sites.

Modeling inputs and parameters specific to study site

	Site A	Site B	Site C	Site D
Soil				
WEPP file	WA\ATHENA(SIL).sol	WA\PALOUSE(SIL).sol	WA\PALOUSE(SIL).sol	WA\PALOUSE(SIL).sol
Soil name	Athena Silt Loam	Palouse Silt Loam	Palouse Silt Loam	Palouse Silt Loam
Climate[a]				
WEPP file	Washington\SITE Hwy 194 WA.cli	Washington\SITE Hwy 195N WA.cli	Washington\SITE Hwy 27 WA.cli	Washington\SITE Hwy 195S WA.cli
Mean annual ppt.	43.0 cm	58.0 cm	57.5 cm	58.6 cm
Elevation	583 m	785 m	791 m	810 m
TOPAZ[b] watershed delineation				
# Subcatchments	28	18	23	13
# Channels	11	7	9	5
# Flowpaths	2091	1777	1989	871
% Area of land-use elements[c] per landscape scenario				
Baseline	100% WW	100% WW	100% WW	100% WW
Eco-Function Level 1	97.2% WW 2.8% RB	96.9% WW 3.1% RB	97.0% WW 3.0% RB	96.9% WW 3.1% RB
Eco-Function Level 2	93.3 WW 2.8% RB 3.9% HDB	93.8% WW 3.1% RB 3.1% HDB	93.6% WW 3.0% RB 3.5% HDB	92.3% WW 3.1% RB 4.6% HDB
Eco-Function Level 3	78.2% WW 2.8% RB 3.9% HDB 15.2% SSB	89.8% WW 3.1% RB 3.1% HDB 4.0% SSB	91.0% WW 3.0% RB 3.5% HDB 2.6% SSB	85.7% WW 3.1% RB 4.6% HDB 6.6% SSB

Modeling inputs and parameters held constant across study sites

Critical source area	Minimum source channel length	Winter wheat management	Buffer management	Simulation duration
5 ha	100 m	Agriculture\winter wheat, mulch till.rot: 8/1 – Harvest, winter wheat (WA) 9/1 – Tillage, Chisel Plow 9/15 – Tillage, Field cultivation 9/20 – Tillage, harrow-spike tooth 9/25 – Tillage, harrow-springtooth (coil tine); anhydrous applicator 10/1 – Tillage, plant winter wheat (WA)	GeoWEPP\Tree-20 yr old forest.rot: Perennial, mixed forest Permanent cover, no harvest In-row plant spacing: 2 m Maximum canopy height: 5 m Maximum root depth: 2 m Initial canopy cover: 90% Initial rill cover: 100% Period over which senescence occurs: 300 days % Canopy remaining after senescence: 50% % Biomass remaining after senescence: 70%	50 years

[a] See Elliot et al., 1999; Rock:Clime (http://forest.moscowfsl.wsu.edu/fswepp).
[b] See Garbrecht & Martz, 1999. TOPAZ Overview (http://homepage.usask.ca/ lwm885/topaz/overview.html). Topographic Parameterization (TOPAZ) delineates subcatchments, channels, and flowpaths as part of the GeoWEPP modeling runs.
[c] WW = Winter Wheat; RB = Riparian Buffer; HDB = Hillslope Drainage Buffer; SSB = Steep Slope Buffer.

of Whitman County, WA. Because a majority of the county's residents live in the cities of Pullman and Colfax, a stratified random sampling protocol was used to ensure adequate representation of the rural residents. The sample addresses were obtained from Marketing Systems Group (http://www.m-s-g.com) via a delivery sequence file that contained all addresses on each U.S. Postal Service carrier's route in Whitman County. The final sampling frame included a total population of 15,571 households, comprised of 10,449 urban addresses (within Pullman and Colfax city limits) and 5122 rural addresses (within the remainder of Whitman County).

Accepting a ±5% sampling error and assuming maximum heterogeneity in sample responses from a target population of 16,000, requires just under 400 completed questionnaires (Dillman et al., 2009). Estimating a 33% response rate, we used a sample size of 1200, stratified into 800 urban households and 400 rural households.

2.6.2. Questionnaire booklet design

The survey questionnaire consisted of three sections and 31 primary questions, formatted as a mixture of single- and multiple-answer, binary choice (yes or no), and open- and closed-ended responses. The first section assessed residents' general satisfaction and level of attachment and engagement in the landscape. The landscape preference section followed, asking residents to rate the scenic quality of landscape alternatives on a 7-point bipolar, categorical scale, ranging from "very high" to "very low". Information about site locations, image simulations, conservation buffers, and ecological function was intentionally withheld from the survey instructions to ensure participants responded directly and intuitively to each scene's visual attributes. The final section collected demographic information including age, gender, employment, education, and ethnicity.

Refinements were made to the final survey design, question format, and landscape simulations based on the results and analysis of a pre-test. The 16 simulated landscape scenarios were selectively randomized into four versions of the questionnaire booklet so that each version included four images—one image of each scenario (Baseline + Eco-Function Levels 1, 2, and 3) without duplicating viewshed sites. To test whether scenario order of presentation influenced response, each version was further divided into the same two ordering sequences, for a total of eight versions. Finally, 150 copies of each survey booklet version were coded with unique identification numbers (linked to address) and mailed proportionately—50 of each version went to rural addresses (33%); 100 of each version went to urban addresses (67%).

2.6.3. Mail survey implementation procedures

A pre-notice letter was sent three days prior to the survey packet. The survey packet consisted of a cover letter, questionnaire booklet, $2 cash incentive, and pre-addressed, stamped return envelope. Instructions asked that the questionnaire be completed by the adult (age 18 and over) with the most recent birthday. A thank you/reminder postcard was sent to all sample addresses one week from the survey mailing date. A second and final reminder card was sent to non-respondents three and a half weeks after the first postcard mailing.

2.7. Statistical analyses

Statistical analyses tested the influence of landscape structure (independent variable)—presented as the four "treatments" of conservation buffers that differentiated the landscape scenarios—on landscape preference (dependent variable), measured by scenic quality ratings (http://www.jmp.com/software; ©2013 SAS Institute Inc.). Specifically, we used Chi-square and contingency table analyses to test the dependence of overall rating distribution on landscape scenario against the null hypothesis that the ratings were randomly distributed. Ordinal logistic regression was used to compare differences in rating distributions between each landscape scenario against the null hypothesis that differences were zero. We also converted rating categories to numerical values and then used box-and-whisker plots to illustrate additional statistical information about rating distributions.

3. Results

3.1. GeoWEPP modeling

3.1.1. On-site soil erosion and retention

Erosion modeling results are summarized in Table 4, quantifying changes in proportional area of each watershed classified into 10 ranges of mean annual soil erosion and deposition rates (Mg/ha/yr).

Table 4
Changes in percentage of total watershed area in each of 10 soil deposition/erosion rate classes for the 16 GeoWEPP modeling runs (four landscape scenarios per study site).

Study Site	Landscape Scenario[a] Modeling Runs			
Soil Deposition/Erosion Rates (Mg/ha/yr)[b]	Baseline (% Area)	Eco-Function Level 1 (% Area)	Eco-Function Level 2 (% Area)	Eco-Function Level 3 (% Area)
Site A				
Deposition > 2.25	6.1	6.0	5.9	5.5
Deposition < 2.25	3.1	4.5	5.6	12.2
0.0 ≤ Soil Loss < 0.6	27.7	27.9	31.3	38.4
0.6 ≤ Soil Loss < 1.1	4.5	5.3	8.8	9.1
1.1 ≤ Soil Loss < 1.7	3.8	4.2	6.5	6.1
1.7 ≤ Soil Loss < 2.25	4.0	4.1	5.3	4.9
2.25 ≤ Soil Loss < 4.5	14.3	13.6	13.8	12.0
4.5 ≤ Soil Loss < 6.75	11.2	10.4	7.3	5.0
6.75 ≤ Soil Loss < 9	8.2	7.7	4.4	2.6
Soil Loss ≥ 9	17.1	16.4	11.1	4.1
Site B				
Deposition > 2.25	5.5	5.5	4.0	3.5
Deposition < 2.25	1.5	3.1	5.2	7.6
0.0 ≤ Soil Loss < 0.6	40.6	42.2	48.0	47.5
0.6 ≤ Soil Loss < 1.1	4.4	4.5	8.2	8.8
1.1 ≤ Soil Loss < 1.7	2.5	2.4	4.3	4.2
1.7 ≤ Soil Loss < 2.25	1.5	1.7	2.9	2.9
2.25 ≤ Soil Loss < 4.5	4.5	4.4	4.5	5.4
4.5 ≤ Soil Loss < 6.75	4.0	3.8	2.7	2.6
6.75 ≤ Soil Loss < 9	4.7	4.0	2.5	2.5
Soil Loss ≥ 9	30.8	28.4	17.7	14.9
Site C				
Deposition > 2.25	5.9	6.3	5.7	5.5
Deposition < 2.25	3.2	4.7	6.4	7.9
0.0 ≤ Soil Loss < 0.6	39.6	41.2	45.8	46.6
0.6 ≤ Soil Loss < 1.1	3.3	3.3	5.9	6.0
1.1 ≤ Soil Loss < 1.7	2.5	2.4	3.7	3.7
1.7 ≤ Soil Loss < 2.25	2.0	1.7	2.7	2.7
2.25 ≤ Soil Loss < 4.5	5.5	5.1	6.5	6.8
4.5 ≤ Soil Loss < 6.75	4.9	4.2	4.4	4.3
6.75 ≤ Soil Loss < 9	4.1	3.7	3.5	3.3
Soil Loss ≥ 9	28.9	27.3	15.4	13.2
Site D				
Deposition > 2.25	5.9	6.1	4.9	4.7
Deposition < 2.25	2.0	3.3	6.3	10.5
0.0 ≤ Soil Loss < 0.6	37.4	37.9	45.2	44.1
0.6 ≤ Soil Loss < 1.1	4.2	4.2	7.5	8.6
1.1 ≤ Soil Loss < 1.7	2.3	2.4	5.2	4.8
1.7 ≤ Soil Loss < 2.25	1.8	2.1	4.9	4.7
2.25 ≤ Soil Loss < 4.5	5.4	5.5	8.8	8.7
4.5 ≤ Soil Loss < 6.75	4.9	4.8	5.1	5.3
6.75 ≤ Soil Loss < 9	3.5	3.6	3.4	3.1
Soil Loss ≥ 9	32.6	30.0	8.8	5.5

[a] Landscape Scenarios: Baseline = Winter Wheat, Eco-Function Level 1 = Winter Wheat + 10-m Riparian Buffer, Level 2 = Winter Wheat + 10-m Riparian Buffer + 5-m Hill Drainage Buffer; Level 3 = Winter Wheat + 10-m Riparian Buffer + 5-m Hill Drainage Buffer + Steep Slope Buffer (areas ≥ 25% slope).

[b] Soil erosion and deposition rates (Mg/ha/yr) are mean annual values for the 50-year simulation period. Metric conversions: 1 Mg (Megagram) = 1 metric ton = 1000 kg = 2200 lbs; 9 Mg/ha/yr = 4 tons/acre/yr.

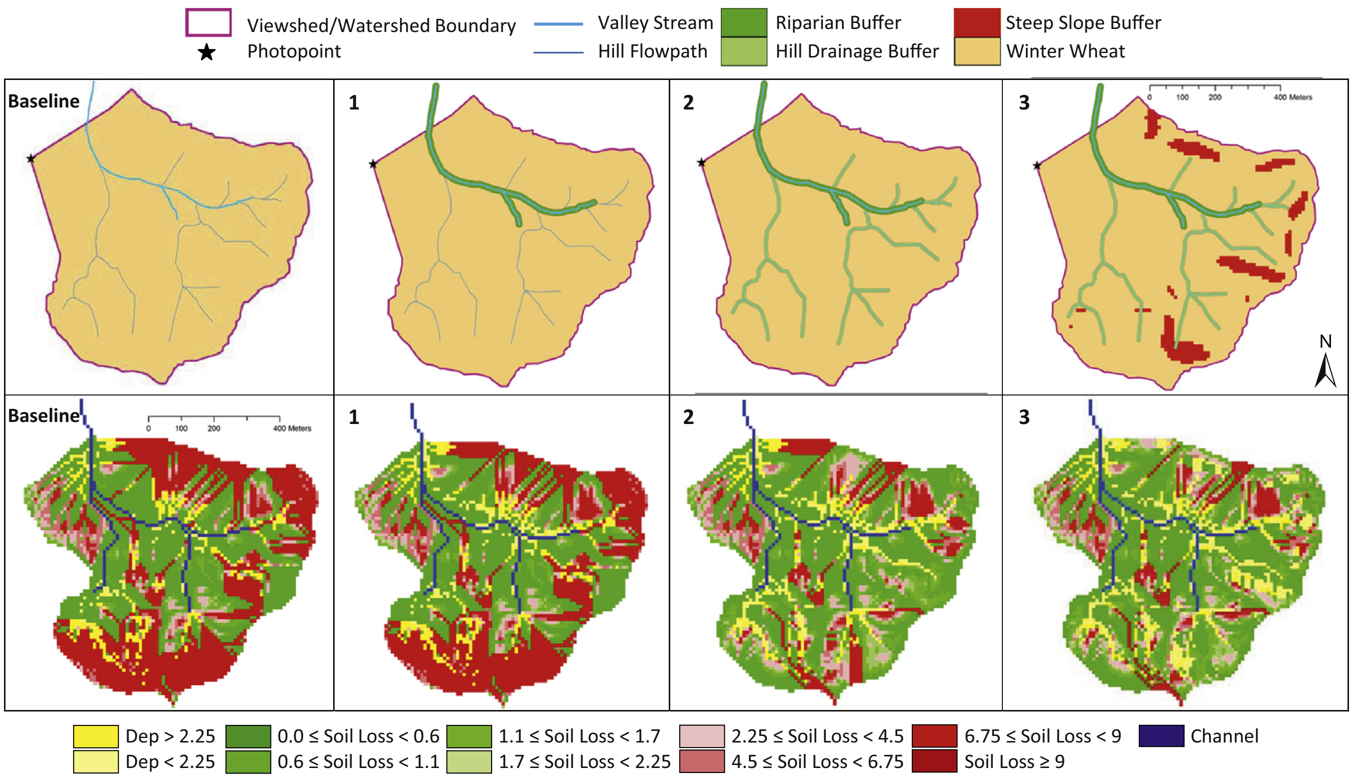


Fig. 5. GeoWEPP modeling results for the 50-year simulation period in Study Site D. Land-use maps in the top row depict the four successive landscape scenarios, Baseline and Eco-Function Levels 1, 2, and 3. Corresponding GeoWEPP maps in the bottom row depict changes in mean annual rates and spatial location and extent of soil erosion and deposition. Soil depositional areas by rate (Mg/ha/yr) are specified in yellow shades; soil erosional areas by rate (Mg/ha/yr) range from dark green (0.0 to <0.6) to dark red (≥9, or unsustainable).

Coinciding mapped results are illustrated for Watershed D in Fig. 5. The maximum range for erosion rates, ≥9 Mg/ha/yr, was chosen to identify areas with soil losses greater than the sites' most conservative Soil Loss Tolerance (*T*-value or *T*) of 9 Mg/ha/yr (all soils across study sites have *T*-values of either 9 or 11 Mg/ha/yr). *T*-value is defined by the USDA as "the maximum rate of annual soil erosion that will permit crop productivity to be sustained economically and indefinitely" (http://websoilsurvey.nrcs.usda.gov/).

From Baseline (no buffers) through Eco-Function Level 3 (RB + HDB + SSB), all four watersheds experienced a consecutive, overall increase in soil depositional area and an overall reduction in soil erosion rates (Table 4, Fig. 5). The smallest incremental increases in area of soil deposition occurred between Baseline and Eco-Function Level 1 (RB) in watershed D and between Level 1 and Level 2 (RB + HDB) in watersheds A, B, and C. The largest incremental increases in depositional area occurred between Baseline and Level 1 in watershed C and between Level 2 and Level 3 in watersheds A, B, and D. Proportional increases in area of soil deposition between Baseline and Level 3 equaled approximately 94% in Site A, 59% in Site B, 48% in Site C, and 93% in Site D.

For all watersheds, the smallest incremental reduction in area with soil erosion rates ≥9 Mg/ha/yr (exceeding *T*) occurred between Baseline and Eco-Function Level 1 (adding the RB). With the exception of watershed A, the most dramatic incremental reduction in area with rates exceeding *T* occurred between Level 1 and Level 2 (adding the HDB to the RB) (Table 4, Fig. 5). These reductions ranged from 28% to 18% of the watershed (a proportional reduction of 38%) in Site B to a reduction from 30% to 9% (a proportional reduction of 71%) in Site D. In watershed A, the greatest proportional decrease (63%) in area with erosion rates exceeding *T* occurred between Level 2 and Level 3. Comparing Baseline to Level 3, proportional decreases in area with erosion rates exceeding *T* ranged from 52% (Site B) to 83% (Site D).

Spatial changes also occurred under each erosion rate classification—overall, proportional area with lower rates increased and area with higher rates decreased (Table 4).

3.1.2. Soil loss to surface waters and off-site sediment yield

From Baseline through Eco-Function Level 3 (RB + HDB + SSB), all four watersheds experienced consecutive decreases in mean annual soil loss (Mg/yr) to surface waters (Table 5). All watersheds experienced the smallest incremental decrease in soil loss between Baseline and adding the riparian buffer in Eco-Function Level 1. The largest incremental decreases were in response to adding the hillslope drainage buffers (Eco-Level 2) for watersheds B (31%), C (41.5%), and D (61.3%). In watershed A, the largest incremental decrease (44.7%) in soil loss to the channel reaches was in response to adding the patch-type buffers on steep slopes (Eco-Level 3). Comparing Baseline to Eco-Level 3, decreases in soil loss ranged from 43.2% in Site B to 76.3% in Site D.

GeoWEPP's watershed method estimates sediment yield and sediment delivery ratio (SDR) to give an indication of off-site, or downstream, environmental impacts. In the model, sediment yield is defined as the amount of sediment leaving a watershed at its channel outlet. SDR is the ratio of sediment yield to total soil loss from within the watershed. With the ArcGIS 9.x version of GeoWEPP, the watershed method is unable to directly consider how the buffer scenarios influence sediment yield because only the dominant land use and one representative hillslope per subcatchment are used in the calculations. However, assuming the SDR for the Baseline is similar for all scenarios, sediment yield for each

Table 5
GeoWEPP modeling results, comparing mean annual soil loss to the surface water channels per landscape scenario for each watershed, for the 50-year simulation period. The Baseline sediment delivery ratio (SDR) can be multiplied by the soil loss values to obtain an estimate of sediment yield at the channel outlets.

Study site	Mean annual soil loss[a] to channels per landscape scenario[b]								
	Baseline		Eco-Function Level 1		Eco-Function Level 2		Eco-Function Level 3		
	SDR	Mg/yr[c] (Mg/ha/yr)	Mg/yr (Mg/ha/yr)	% Change (from Baseline)	Mg/yr (Mg/ha/yr)	% Change (from Level 1)	Mg/yr (Mg/ha/yr)	% Change (from Level 2)	% Change (from Baseline)
Site A	0.45	604.6 (4.3)	580.7 (4.1)	−4.0	438.9 (3.1)	−24.4	242.8 (1.7)	−44.7	−59.8
Site B	0.46	774.8 (7.5)	739.9 (7.1)	−4.5	510.7 (4.9)	−31.0	439.7 (4.2)	−13.9	−43.2
Site C	0.52	783.5 (7.6)	731.2 (7.1)	−6.7	427.8 (4.1)	−41.5	377.0 (3.6)	−11.9	−51.9
Site D	0.43	472.2 (9.7)	464.5 (9.5)	−1.6	179.9 (3.7)	−61.3	111.7 (2.3)	−37.9	−76.3

[a] Mean annual soil loss to the channels (soil eroded minus soil deposited) is calculated by GeoWEPP's flowpath method as the soil loss from all flowpaths averaged for each subcatchment within a watershed. Total soil loss from each watershed was then calculated by summing subcatchment values.
[b] Landscape Scenarios: Baseline = Winter Wheat, Eco-Function Level 1 = Winter Wheat + 10-m Riparian Buffer, Level 2 = Winter Wheat + 10-m Riparian Buffer + 5-m Hill Drainage Buffer; Level 3 = Winter Wheat + 10-m Riparian Buffer + 5-m Hill Drainage Buffer + Steep Slope Buffer (areas ≥ 25% slope).
[c] Metric conversions: 1 Mg (Megagram) = 1 metric ton = 1000 kg = 2200 lbs; 9 Mg/ha/yr = 4 tons/acre/yr.

scenario can be estimated by multiplying SDR by soil loss value. Baseline SDRs ranged from 0.43 for Site D to 0.53 for Site C (Table 5).

3.2. Landscape preference survey

3.2.1. Survey response rates and characteristics of respondents

Of the 1200 questionnaires mailed, 1139 were delivered successfully, resulting in a 5.1% undeliverable rate. Of the 1139 delivered, a total of 638 completed questionnaires were returned for an overall response rate of 56.0%. Of the completed questionnaires, 396 respondents (62.1%) were from urban addresses and 242 (37.9%) were from rural addresses.

Fifty-five percent of the respondents were women and 45% were men. The youngest respondent was 18, the oldest 97, and the median age was 52. More than one-half of the respondents worked full time, nearly one-quarter were retired, and nearly 60% held a bachelor, graduate, or professional degree. Fourteen percent of the respondents farmed or ranched, either full- or part-time. An overwhelming majority (87%) of respondents were white, which is representative of the low ethnic diversity in Whitman County. One-half of respondents lived in Whitman County for 20 years or more and 64% were highly to moderately familiar with the natural history and/or ecology of the county's landscapes. The analysis of the demographic data relative to scenic quality ratings is being prepared for a future manuscript.

3.2.2. Scenic quality ratings of alternative landscape scenarios

Frequency distribution analyses revealed that, overall, across the four landscape scenarios for each site, scenic quality ratings were highly skewed toward the positive rating categories. Even the Baseline scenarios with no buffer structure captured a relatively large portion (21%) of all the "very high" ratings. This result is understandable given the acknowledged beauty and charm of the Palouse landscape and the attitudes revealed by the survey respondents. A majority of the respondents are generally highly satisfied living in Whitman County, rate the existing scenery quite attractive, and feel a relatively strong emotional attachment to their landscapes. This information may also suggest that the pastoral aesthetic ideal is still very much alive here. Per recommended procedures to ensure adequate counts for the Chi-square contingency table analysis, we combined all responses labeled "moderately low", "low", and "very low" into a single category labeled "low".

Of all scenic quality ratings ($N = 2533$) across landscape scenarios, Baseline (no buffers) received the largest number and percentage of "low" ratings (Fig. 6). In contrast, Eco-Function Level 3 (all buffers) received the largest number and percentage of "very high" ratings. We found a highly significant association ($p < 0.0001$) between the distribution of the dependent variable, scenic quality rating, and the independent variable, landscape scenario. The number of "very high" ratings increased with each consecutive addition of buffer elements, while the number of "moderate" and "low" ratings consecutively decreased. The rating of "high" was chosen with the greatest frequency (mode) for each landscape scenario (Fig. 6).

When comparing rating distributions between each landscape scenario (Fig. 7), we found a significant difference ($p = 0.0215$) between the Baseline and the RB landscape structure (Eco-Function Level 1). We also found a significant difference ($p = 0.0455$) in the distribution of scenic quality ratings between the RB and the RB + HDB landscape structure (Eco-Function Level 2). No significant difference ($p = 0.1586$) was found between Eco-Function Level 2 and Level 3 (RB + HDB + SSB).

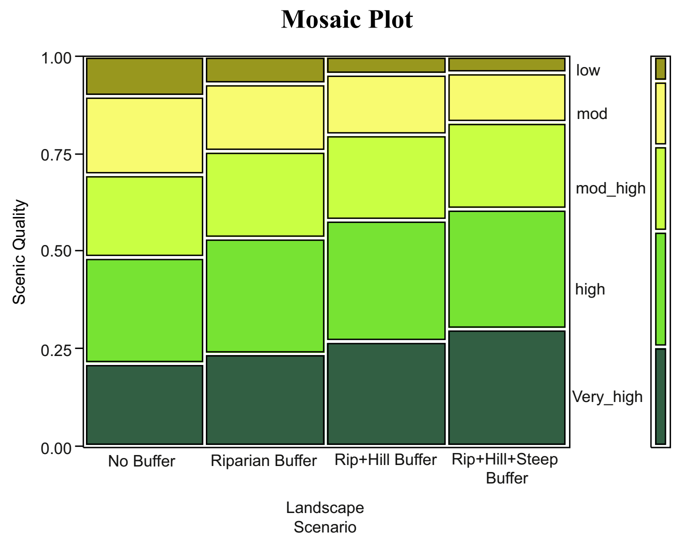
4. Discussion

4.1. Influence of landscape structure on ecological function

Explanatory mechanisms by which permanent buffers influence surface runoff dynamics of soil and water are well supported by established theory and plot- and field-scale empirical studies (Naiman, Décamps, & McClain, 2005; http://nac.unl.edu/buffers/index.html). That is, buffer vegetation can intercept rainfall, shorten overland flowpaths, and impede surface runoff—processes that reduce rainfall intensity and runoff volume and energy and, in turn, facilitate water infiltration, soil retention, and erosion reduction.

Similar to smaller-scale research results, our watershed-scale study found that a relatively small area of buffer vegetation can deliver a disproportionately large improvement in a watershed's ecological function. Unique to a watershed-scale study such as ours, is the opportunity to visually describe, identify, and prioritize buffer locations for maximizing benefits while minimizing costs (Lovell & Sullivan, 2006; Nowak & Pierce, 2007; Walter et al., 2007). Using GIS and GeoWEPP geospatial technology, mapped results visually demonstrate the spatial variability of soil movement and accumulation patterns in response to each watershed-scale buffer scenario (Fig. 5). Although overall landscape ecological function improved, as expected, with each consecutive addition of buffer elements, the magnitude of improvements differed among landscape scenarios and among study watersheds (Tables 4 and 5). Additionally, ecological function was not only influenced by the areal extent of the permanent vegetation, but also, if not more, by its spatial location and configuration.

For example, in Watershed A, the greatest reduction in unsustainable soil erosion rates occurred when buffers were added in Eco-Level 3, attributed to this site's much larger area of slopes ≥25% (Table 3). In the other three watersheds, the greatest reduction in proportional area experiencing unsustainable erosion rates occurred by adding buffers to the hillslope drainage pathways.



Contingency Table

Landscape Scenario	Cell Value Key	Scenic Quality Rating: Very High	High	Mod High	Mod	Low	Totals
No Buffers	Count Observed	**136**	**172**	**135**	**127**	**64**	**634**
(Baseline)	Total %	5.4	6.8	5.3	5.0	2.5	25.0
	Column %	21.0	22.8	24.4	30.5	39.8	
	Row %	21.5	27.1	21.3	20.0	10.1	
	Count Expected	162	189	138	104	40	
Riparian Buffer	Count Observed	**152**	**188**	**141**	**110**	**44**	**635**
(Eco-Function	Total %	6.0	7.4	5.6	4.3	1.7	25.1
Level 1)	Column %	23.4	25.0	25.5	26.4	27.3	
	Row %	23.9	29.6	22.2	17.3	6.9	
	Count Expected	163	188	139	105	40	
Rip + Hillslope	Count Observed	**170**	**199**	**138**	**99**	**27**	**633**
Drainage Buffer	Total %	6.7	7.9	5.5	3.9	1.07	25.0
(Eco-Function	Column %	26.2	26.4	25.0	23.7	16.8	
Level 2)	Row %	26.9	31.4	21.8	15.6	4.3	
	Count Expected	162	188	138	104	40	
Rip + Hill + Steep	Count Observed	**191**	**194**	**139**	**81**	**26**	**631**
Slope Buffer	Total %	7.5	7.7	5.5	3.2	1.0	24.9
(Eco-Function	Column %	29.4	25.8	25.1	19.4	16.2	
Level 3)	Row %	30.3	30.7	22.0	12.8	4.1	
	Count Expected	162	188	138	104	40	
Totals	Count Observed	**649**	**753**	**553**	**417**	**161**	**2533**
	Total %	25.6	29.7	21.8	16.5	6.4	100

Test	**Chi-Square**	**Prob > Chi-Square**
Likelihood Ratio	46.440	< 0.0001*
Pearson	47.199	< 0.0001*

Fig. 6. Mosaic plot and associated contingency table of scenic quality by landscape scenario. Chi-square analyses show that the probability of independence between the observed distribution of scenic quality ratings and landscape buffer scenario is less than 0.01% ($p < 0.0001$*).

For all watersheds, adding the riparian buffer in Eco-Level 1 contributed the least to reducing soil erosion rates (Table 4). These trends matched those predicted for soil loss to surface waters and sediment yield downstream (Table 5). Our findings agree with other studies concluding that locating buffers around headwater channel segments (intermittent and 1st- and 2nd-order perennial streams) has the greatest potential for retaining soil and, in turn, improving water quality (e.g., Bentrup, 2008; Meyer et al., 2003; Tomer et al., 2009). The riparian buffers (RB) surrounding the higher-order channel segment in the comparatively wider and flatter central valley are understandably less critical for intercepting overland flow and retaining sediment. Yet, beyond our research focus, RB vegetation simultaneously contributes ecological benefits not measured by GeoWEPP, such as stabilizing streambanks, providing wildlife habitat, enhancing biodiversity, and regulating stream temperatures (Naiman et al., 2005).

The GeoWEPP modeling also produced an unexpected result. Fig. 5 illustrates that beneficial changes in soil erosion and deposition occurred not only directly in, and adjacent to, areas with permanent vegetation cover, but also some distance upslope. This result was most dramatic when the HDB was added, demonstrated by the large reduction in area of unsustainable erosion rates between Eco-Level 1 and 2. We suggest several factors, which when combined, may provide an explanation for this phenomenon. The surface hydrology subroutines used in WEPP perform best for a single overland flow element (OFE) (e.g., the single land-use element in our baseline scenario) and less optimally with the introduction of multiple OFEs (e.g., the multiple land-use elements in our buffer scenarios) (USDA ARS, 1995).

Additionally, algorithms that calculate subsurface lateral flow and the shear stress and erosion associated with surface runoff use the average slope for each OFE. In highly complex topography, such as in our study sites, the average slope for each OFE in the buffer scenarios will differ from the single slope calculation used for one OFE (baseline scenario) and can cause the model to under- or over-predict erosion and deposition rates. A non-related WEPP study

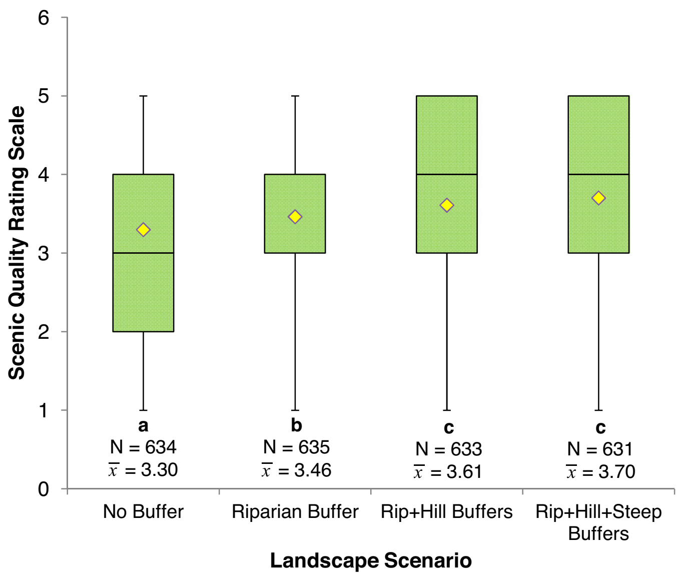


Fig. 7. Box-and-whisker plots of all scenic quality ratings, ranging from 1 ("low") to 5 ("very high"), for each landscape buffer scenario. The horizontal line inside the box represents the median (50th percentile), the ends of the boxes represent the 25th and 75th percentiles (interquartile range), the line extensions represent the remaining data points, and the diamonds indicate the mean. For the riparian buffer scenario, the median and 75th percentile are equivalent. Where indicated by a different lowercase letter above buffer-type scenario along the *x*-axis, landscape preference (scenic quality rating) distribution varies significantly according to ordinal logistic regression and Chi-Square tests.

in similar topography (Crabtree, 2007) found that adding multiple OFEs substantially increased subsurface flow, thereby decreasing surface runoff and erosion risk on some of the steeper slopes. In our watersheds, the overall result of these limitations was likely an underestimation of both soil erosion and deposition rates in response to additions of the buffer vegetation.

We are unaware of other empirical studies similar enough to our methodology and biophysical context to serve as direct comparisons. Our study is likely the first to use GeoWEPP's detailed flowpath method to predict the ecological influence of watershed-scale woody buffers in a topographically complex, agricultural setting. However, several studies have used GeoWEPP/WEPP to assess buffer and tillage management scenarios on soil loss and sediment yield at other spatial scales and geographical and topographical contexts (e.g., Renschler & Lee, 2005; Zhou, Al-Kaisi, & Helmers, 2009; Maalim, Melesse, Belmont, & Gran, 2013). In comparison, despite modeling limitations, the relative differences in predicted soil loss and erosion and deposition rates among our buffer scenarios appear reasonable and consistent.

Results also highlight the important *complementary* role watershed-scale, conservation buffers play in maintaining long-term soil productivity and water quality (Lowrance & Crow, 2002). Even with all three buffers in place, unsustainable erosion rates (≥9 Mg/ha/yr) persist on an average 9.4% of total watershed area. Likewise, eroded soil enters the surface waters at a rate of 293 Mg/yr and nearly 50% of that amount is discharged downstream. Thus, buffers work best in concert with good on-farm management that includes conservation practices such as terracing, cover cropping, maintaining crop residue, and no-till or strip-till cultivation (Bentrup, 2008; Zhou et al., 2009).

4.2. Influence of landscape structure on aesthetic preference

The finding of improved scenic quality with successive buffer additions to landscape structure is at least partially explained by established landscape preference theory (Table 1). The Baseline scenario represents essentially a vast, small-grain monoculture. Integrating corridors and patches of native, woody vegetation with each successive scenario enhances the naturalness of the landscape. The Biophilia Hypothesis (Kellert & Wilson, 1993) proposes that human affinity for nature and wilderness environments has a genetic component. Additionally, preference for open landscapes with scattered clumps of trees and shrubs is supported by the Savanna Hypothesis (Falk & Balling, 2010; Heerwagen & Orians, 1993) and Appleton's (1975) Habitat Theory and Prospect-Refuge Theory.

Information Processing Theory (IPT) (Kaplan & Kaplan, 1989) established complexity as a preferred landscape attribute because it arouses interest and encourages engagement, which heighten aesthetic experiences. This visual complexity, or diversity, is not only enhanced by adding more landscape elements, but also by the greater variety of shapes, colors, and configurations that the buffer vegetation imparts. Simultaneously, these new landscape configurations beckon recreational opportunities such as hunting, bird watching, or scenic driving.

Coherence is another preferred attribute in IPT because it balances complexity to achieve a visually congruent and unified landscape (Dee, 2001; Kaplan & Kaplan, 1989; Murphy, 2005). In the photographic and modeling simulations, buffer extent and placement were not random, but targeted specifically for high risk locations and desired ecological function, and designed consistently across all scenarios. The repeating pattern of shapes, colors, textures, and locations of buffer vegetation maintains a sense of harmony and coherence that, while visually pleasing, also contributes to understanding the scene. Orderly and consistent arrangements of agricultural landscape elements also align with the visual qualities indicative of our culturally perceived pastoral aesthetic (Marx, 1964; Schauman, 2007) and Nassauer's (1997) aesthetic of care.

Findings from other studies assessing the perceived visual quality of rural landscapes generally agree that aesthetic value improves with increasing diversity, degree of naturalness, and presence of wooded patches or corridors (e.g., Angileri & Toccolini, 1993; Arriaza, Cañas-Ortega, Cañas-Madueño, & Ruiz-Aviles, 2004; Lindemann-Matthies et al., 2010). Our finding of similar distributions (non-significant) in preference ratings for Eco-Level 2 (RB + HDB) and Eco-Level 3 (RB + HDB + SSB) (Fig. 7) may be explained by the more subtle visual differences between these two buffer scenarios (Fig. 4). Alternatively, this finding may indicate a landscape diversity optimum at Level 2 or 3. That is, adding buffer elements beyond what was visualized in Level 3 might result in lower preference ratings, similar to findings in Hunziker and Kienast's (1999) spontaneous reforestation study.

4.3. Potential for linking aesthetic and ecological quality in landscape structure

Uniquely, we took an empirical, interdisciplinary, watershed-scale approach to measure aesthetic and ecological responses to visually perceptible variations in content and configuration of landscape elements. We isolated the structural changes in each successive landscape scenario to the amount and location of permanent buffer vegetation by holding constant, to the extent feasible, other potential variables. Therefore, we confidently assert that differences among scenarios in preference (scenic quality ratings) and in ecological function (soil erosion/deposition rates) are in direct response to these structural changes. Supporting our hypothesis, study results indicate a coincident, positive trend in landscape preference and ecological function associated with consecutive additions of buffer elements to agricultural landscape structure (Fig. 8).

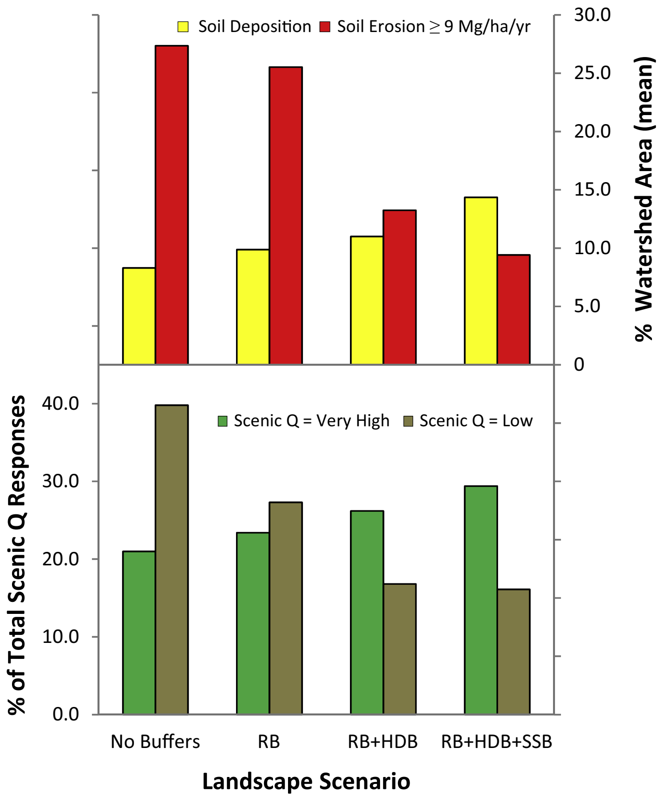


Fig. 8. Landscape structural relationships between ecological function and aesthetic quality. Proportional watershed area with soil deposition increases with successive additions of buffer elements; proportional watershed area with unsustainable soil erosion rates (≥9 Mg/ha/yr) decreases. Concurrently, proportion of "very high" scenic quality ratings increases with successive additions of buffer elements; proportion of "low" scenic quality ratings decreases. (RB = Riparian Buffer; HDB = Hillslope Drainage Buffer; SSB = Steep Slope Buffer).

Notably, we added structural elements indicative of improved ecological function to an agricultural landscape already legendary for its beauty. Furthermore, survey respondents were not privy to information related to image simulations, conservation buffers, and ecological function, and therefore, responded intuitively when rating the aesthetic quality of the scenes. Given this context and methodology, finding a parallel, positive relationship between ecological function and aesthetic quality in the same landscape structure is particularly powerful.

Finding this structural link between ecological and aesthetic function lends credibility to the assumption that woody buffers implemented for ecological benefits also enhance the aesthetic quality of intensively managed agricultural landscapes. Further, the finding provides an example of a landscape context in which the potential for coincident ecological and aesthetic quality is high. Beyond the scope of our study, economic and maintenance concerns are no doubt also highly influential in farmer and landowner decisions to plant permanent buffers (Lovell & Sullivan, 2006). Nonetheless, our findings can serve as the basis for future research that asks whether the aesthetic experience of this congruent ecological–aesthetic relationship can positively influence buffer adoption.

Our findings add to the paucity of larger-scale, interdisciplinary research examining the compatibility of cultural, production, and ecological functions toward the ideal of sustainable agricultural landscapes (e.g., Santelmann et al., 2004). Importantly, this empirical study also contributes a quantitative approach and associated findings to complement the extensive conceptual, theoretical, and philosophical discussions about ecological–aesthetic relationships in landscape structure (e.g., Burel & Baudry, 1995; Egoz et al., 2006; Gobster et al., 2007; Meyer, 2008).

5. Conclusions

Toward advancing agricultural sustainability research, we examined ecological and aesthetic responses to the structural integration of watershed-scale conservation buffer systems into Washington State's highly productive, Palouse farming region. Overall, ecological function improved with each successive addition of buffer vegetation. We demonstrated the power of GIS analysis and GeoWEPP modeling for quantifying and visualizing watershed-scale changes in rates and patterns of soil erosion and deposition in response to sequential buffer placement. Consequently, we found differences in magnitude of improvements by buffer location and study watershed, supporting the view that larger-scale analyses can help target conservation efforts to increase ecological and economic efficiency.

We also found a statistically significant increasing trend in visual aesthetic preference for landscape structure with greater amounts of buffer vegetation and simultaneously indicative of increasing ecological function. Thus, within the Palouse and similar biophysical landscape contexts, visually perceivable structural attributes can potentially provide a coincident indication of ecological function, aesthetic quality, and agricultural sustainability. This finding expands current understanding of multifunctional relationships in agricultural landscapes and encourages comparative studies of ecological–aesthetic relationships in different landscape and land-use contexts. Future research must also examine other factors that influence buffer adoption, including economic tradeoffs, vegetation maintenance, and compensation for providing landscape-scale ecosystem services.

Our research approach and methodology could easily be transferred or modified to test these landscape structure–function relationships in other agricultural systems, topographical contexts, and geographic regions with similar environmental concerns. GIS and GeoWEPP mapping and photographic simulation technologies allow practical and realistic visualization of landscape alternatives from a spatial perspective and scale of everyday human experience. We recommend WEPP developers improve algorithms and subroutines that currently limit the model's predictive capacity in watershed settings with complex topography. Reliable, precise, and visually-based analysis tools can engage local stakeholders in meaningful discussions and collaborative decision-making about agricultural landscape sustainability that is socially, culturally, and contextually relevant.

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