An ecological framework for the planning, design and management of urban river greenways

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Abstract

Major approaches to ecological design were reviewed and compared. Naturalistic, ecosystem science, and landscape ecology approaches were applied to the development of an ecological framework for the planning, design and management of urban river greenways. The framework also incorporated ecological knowledge related to the planning and design process, design and management of natural areas, and theory and methodology from landscape ecology. It provides a systematic procedure for facilitating the protection, ecological enhancement, and linkage of present and potential natural areas in urban river greenways. One component of the framework, the assessment, has been described in detail and applied to the South Saskatchewan River Valley in Saskatoon, Canada. The framework is not case-specific and its main value is to provide an integrated approach to the ecological planning, design, and management of urban river greenways.

1. Introduction

Alterations in the landscape have occurred almost everywhere on the Earth's surface. On the North American continent, much of the land has been modified for human use. In no place is this more evident than in urban areas. Urbanization involves large transformations of land, air, energy resources, and human populations. These transformations are having major ecological consequences for urban habitats. More specifically, urban landscapes are progressively becoming deficient of areas with significant ecological value for the following reasons:

(a) traditional urban development has tended to isolate and restrict natural areas to remnant patches and corridors (Andrews and Crammer-Byng, 1981), and the remaining patches are often negatively impacted by fluxes of energy, species and nutrients from the surrounding urban matrix

(b) previously functioning ecosystems, such as wetlands and grasslands, have often been separated from a supporting structure

(c) natural areas that do persist often become overutilized by recreational use and facility development

(d) remnant patches and corridors have often been developed into 'cultural' or 'natural' parks, suitable for human use, but lacking the characteristics required to support the native species that originally inhabited the land (Cook, 1991).

Nearly all major cities have been built on rivers. River corridors in highly industrialized cities, where major waterways have served transportation and related industrial functions, have been almost totally altered from their natural state. In less industrialized cities, such as those in the prairie region of Canada, river corridors have been altered but not obliterated from the landscape.

There has been increasing public concern for the protection of urban river corridors (Little, 1990). Numerous river commissions have been established in an effort to plan use and protection. So far, limited inventories of natural and cultural areas (Dorney and Higgs, 1978; Rogers and Rowntree, 1988), isolated preservation (Sukopp and Hejny, 1990) or reclamation of sites (Bradshaw, 1982) have occurred in these corridors as part of ongoing conservation programs. There is reason to be optimistic about combining human use and natural environments as many river cities are rediscovering their waterfronts and commissioning planning studies (Kim et al., 1991). There has been, however, no overall framework for the ecological planning, design and management of urban river greenways.

The primary purpose of this study was to apply existing ecological knowledge to the conceptual and physical planning, design and management of an urban river valley greenway. The goal was to develop a framework from a review of existing concepts and models in the literature. This framework would facilitate the establishment of an ecological network to link remnants of natural communities along a river valley corridor and to provide a guide for future planning, design and management.

The objectives of the study were: (a) to review the literature on ecology and design that relate to the protection, ecological enhancement, and design of urban natural areas, (b) to apply this information in the development of an ecological framework for the planning, design and management of an urban river greenway, (c) to illustrate the utility of the framework by applying one component of the framework through a case study example, and (d) to generalize potential applications of the framework for planning, design and management of an urban river greenway.

The framework should facilitate the protection and ecological enhancement of present and potential natural areas in urban river greenways. The procedure should also integrate present isolated conservation activities into a more comprehensive land-use planning process.

1.1. Approaches to ecological planning, design and management

Various authors have suggested alternatives (e.g. Jensen, 1939; Hough, 1984; Bradshaw, 1986; Morrison, 1991) to traditional approaches to landscape development. Three approaches to landscape study that have been used to produce ecological 'fit' were considered as possible bases for development of the framework: naturalistic, ecosystem science, and landscape ecology. All three have advantages and disadvantages, as noted in Table 1.

The naturalistic approach has tended to be site-specific and design-oriented. It has attempted to reproduce nature by replicating the structure and general appearance of the vegetation and to a lesser extent plant associations (Gustavsson, 1982; Ruff, 1982; Tragay, 1982; Austin, 1984; Rintoul, 1986). The focus has been on vegetation. In the urban context it has involved the introduction of natural elements such as woodlands, meadows, and wetlands (Hough, 1990) through landscape design.

Ecosystem science has considered the processes as well as the structure of natural areas. In landscape planning this has meant involving natural processes such as succession, landform development, etc. within the plan for the landscape (e.g. Fabos and Caswell, 1977), or "working with nature rather than against it" (Tragay, 1982, p. 31).

Landscape ecology has dealt with assemblages of ecosystems occurring in a geographically defined region (Haber, 1990). The subject of study in landscape ecology has been the landscape, its structure, function, and change (Naveh and Lieberman, 1984; Forman and Godron, 1986). In the city, landscape ecology has dealt with the management of individual patches and corridors as elements of the whole landscape. When considering the remnants of natural areas within an urban fabric, all three approaches have had important roles to play: naturalistic has provided a basis for landscape design; ecosystem science a basis for landscape planning; and landscape ecology a basis for landscape management. All three approaches were incorporated within the framework.

Table 1
Comparison of the characteristics of three approaches to landscape study: naturalistic, ecosystem science and landscape ecology

Characteristic	Approach		
	Naturalistic	Ecosystem science	Landscape ecology
Scale	Site specific	Organism, population, community	Land unit: ecoregion, ecodistrict, etc.
Components	Woodlot, meadow, wetland	Natural systems, agroecosystems	All components
Focus	Vegetation	Biotic and abiotic	Biophysical and cultural
Operational framework	Structure	Ecosystem structure and function; Systems analysis	Landscape and structure, Function and change; Vertical and horizontal Heterogeneity; Systems analysis
Philosophical base	Habitats, plant communities	Systems integrity and expression	Holism, Synthesis
Collective effort	Multi-disciplinary	Interdisciplinary	Transdisciplinary
Application	Design	Planning	Management

1.2. Objectives for an ecological framework

1.2.1. Biophysical objectives

An overall objective in the development of the framework was to maintain both species diversity and ecological processes. Several important biophysical functions were considered as objectives within four categories: biological diversity, sustaining hydrologic processes, climate improvement, and utilitarian (e.g. Cook, 1991).

Biological diversity has been used to describe the variety of flora and fauna, the ecological functions they perform, and the genetic diversity they contain (Wilcox, 1984). The loss of populations, species, and entire ecological communities in human population centers and their surrounding landscapes has been considerable and well documented (e.g. Emery, 1986; Goode, 1986; Council of Europe, 1987;

Gilbert, 1989; Crombie, 1990; Gordon, 1990). When establishing objectives for biological diversity, species composition becomes critical, and indigenous, rare, and endangered species should be given high priority. Corridors and patches can be suitable for wildlife habitat and migration between landscape elements.

Hydrologic processes have a significant influence in the development of landscape structure and in future landscape function. Drainage corridors kept in a natural state will act as a filter to catch possible contaminants from adjacent lands. Well-vegetated corridors also help to reduce erosion by stabilizing banks.

A well-vegetated valley in an urban context can make a significant contribution to meso- and microclimate improvement. The 'urban heat island' can be partially mitigated through preservation of existing vegetation and extensive new plantings (Sukopp and Werner, 1982). On the micro scale, vegetation cover provides shade, wind protection, and cooling through evaporation. These conditions provide better environments for wildlife habitat by providing relief from extremes of the elements.

Many of the biological reasons for protecting natural habitats in urban areas are utilitarian. The usefulness of plants in erosion control, watershed protection, waste water management, noise abatement, and pollution control have many tangible economic benefits (e.g. Grey and Deneke, 1978).

1.2.2. Socioeconomic objectives

Socioeconomic objectives can be divided into general categories such as connecting with nature, and aesthetics, among others (health-related benefits, economics, etc.) (e.g. Cook, 1991). Protecting natural areas gives people an opportunity to connect with nature. Various authors have suggested that the visual beauty and richness of surroundings can be enhanced by natural areas (Wohlwill, 1983; Shaw, 1985; Kaplan and Kaplan, 1989). Although these are important objectives, they are beyond the scope of this paper to deal with in detail.

2. Materials and methods

2.1. Development of an ecological framework

An ecological framework that met the stated objectives, but was oriented towards a different environment, has been developed by Cook (199 1) for an urban ecological network for the city of Phoenix, Arizona, USA. An underlying assumption in the framework was that some existing landscape elements must be modified to establish an ecological network within an already established urban infrastructure. Cook's (1991) framework has been adapted in this study, for application to the South Saskatchewan River Valley in Saskatoon, Canada, an urban river greenway in a prairie environment.

The framework began with an ecological planning process (McHarg, 1969; Cook, 1991), and built in ecological design process (Hough, 1984; Lyle, 1986), ecological knowledge that related to the design of natural areas (Smith and Theberge, 1986), and theory and methodology from landscape ecology (Vink, 1983; Naveh and Lieberman, 1984; Forman and Godron, 1986). The result was a framework (Fig. 1) that included an Assessment of natural and cultural resources, and the formation of Greenway's spatial structure.

2.2. Assessment of natural and cultural resources

Assessment begins with an inventory and description of the existing and potential resources. These are classified as 'landscape elements' according to characteristics relevant to a river valley greenway and then assessed for relative ecological worth. These must span several scales, recognizing that ecological functioning is hierarchical but connected between scales. Quality, quantity and location of remnant corridors and patches are then assessed while considering inter-relationships with the surrounding urban matrix (Cook, 1991).

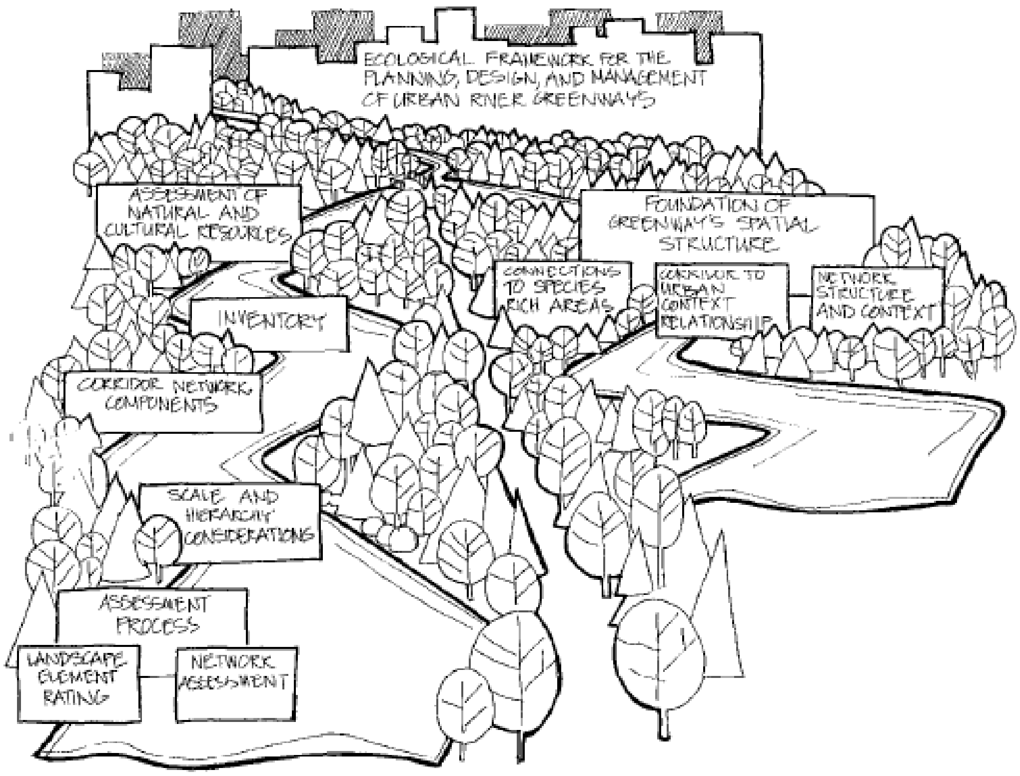

Fig. 1. An ecological framework for the design, planning and management of an urban river greenway (adapted from Cook, 1991).

2.2.1. Inventory

There are established methods for mapping landscape elements in developed landscapes. Some of these (e.g. Sukopp and Weiler, (cited in Sukopp, 1990, p. 1)) proved to be quite appropriate for this study as they allowed for reclamation, and provided a separate step for assessment of landscape elements: (a) ‘representative mapping’ in which examples of all types of use are mapped and the results transferred to all areas with the same use structure, and (b) ‘comprehensive mapping’ in which the biological and ecological features of all landscape elements are mapped.

2.2.2. Corridor network components

Various landscape elements found within a river corridor and its urban context can be classified as patches and corridors (Forman and Godron, 1986). Each has inherent characteristics that make them more or less valuable in an urban ecological network.

2.2.3. Scale and hierarchy considerations

If a network is to function effectively the scale and hierarchy become critical issues. It is important to consider scale in terms of contextual criteria, species diversity, spatial relationships, and management units. Noss (1983) has recommended at least three scales in an attempt to integrate these perspectives: (a) a community or single habitat is an area less than a few hectares with uniform vegetation structure (site scale), (b) a series of habitats or communities (local scale), and (c) a large geographic region (regional scale). Landscape ecology (e.g. Forman and Godron, 1986) also considers scale and hierarchy through landscape elements as components of the larger landscape.

2.2.4. Assessment process

Ecological assessment techniques can be categorized into indicator-species, inventory, and system-based approaches. An indicator-species approach uses individual species which represent more complex data; an inventory approach uses classification separate from assessment; and a system-based approach uses criteria including rarity, diversity, naturalness, and structural differentiation. The latter is the most widely adopted approach for ecological assessments (Margules and Usher, 198 1; Smith and Theberge, 1986). Aggregate values from the established criteria are used to form a quantitative description of relative worth.

2.3. Formation of Greenway's spatial structure

There are three main criteria that affect the spatial structure of a corridor network: connections to species-rich areas, corridor to urban context relationship, and network structure and content.

2.3.1. Connections to species-rich areas

At all scales, species-rich areas should be connected using corridors to facilitate migration of species. In urban landscapes, source pools for native species may be limited, so connection to other more natural areas becomes crucial for many species of wildlife.

2.3.2. Corridor to urban context relationship

Within an urban landscape matrix 'edge effect' has a significant impact on the quality of corridors and patches, and the importance of spatial configuration and connectivity has been well documented (Ahern, 1991). Native plant and animal species often struggle for existence because of competition with edge species that are often not native and considered weedy. Forman and Godron (1986) have shown that edges extend 10-15 m or more into a patch or corridor. Consequently, the surrounding matrix dramatically impacts on smaller patches or narrow corridors.

2.3.3. Network structure and context

The goals of enhancing connectivity and providing suitable conditions for habitat can be promoted by appropriate development of structure and content relationships. Various spatial distribution models of islands and corridors use riparian corridors as the skeleton to which patches of varied sizes are linked. In general, patches will be most important as habitat, and corridors as migration routes. Harris (1984) has suggested a distribution of patches along corridors at progressively greater distances from a species source pool. Nearer the pool the patches are smaller and closer together. Patches are also frequently located at junctions of corridors and function as nodes. Noss and Harris (1986) have suggested that each landscape should have one or more multiple-use-modules (MUM). A MUM is a well-protected habitat core of sufficient size to support interior species (Fig. 2). A concentric buffer should provide decreasing effects from external influences to the interior of the MUM. Forman and Godron (1986) have also suggested providing alternative loops within the network to promote migration and decrease the potential of movement-inhibiting barriers.

Many researchers have shown that larger patches will support more species, and that the largest possible sizes are preferable. However, the realities of urban land-use planning are such that extensive areas cannot be devoted entirely to nature conservation, Thus, optimal shapes or configurations and minimum corridor widths become more important at a local scale because the magnitude of the resource is much smaller. Fig. 3 illustrates examples of comparative shapes and configurations for nature preserve design (Diamond, 1975). Habitat structure can often be determined by studying existing natural landscapes. Natural disturbances, such as fires in prairie grasslands, are important elements. However, certain human-induced disturbances can deplete habitat quality. Activities such as mowing significantly reduce species richness (Hobbs, 1988), as do soil compaction and trampling.

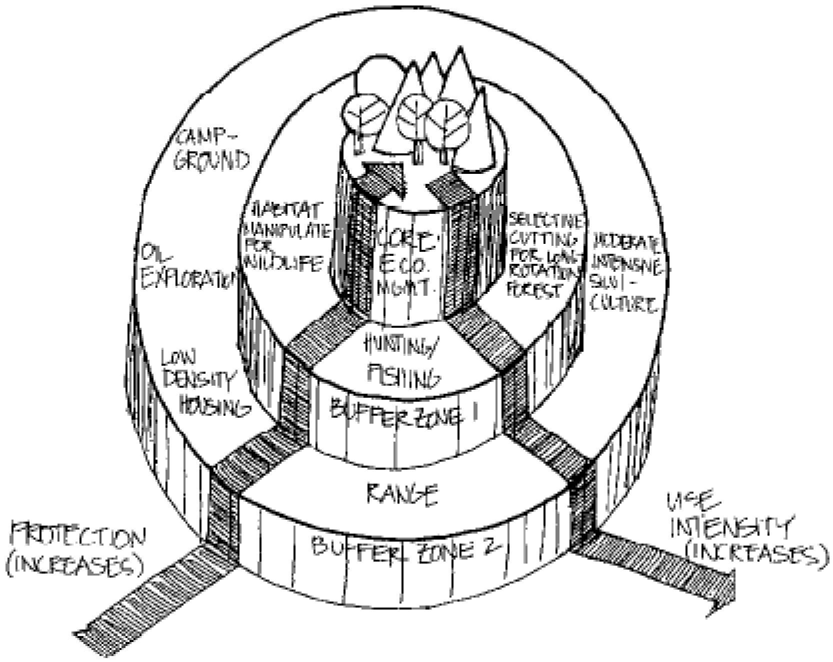

Fig. 2. A Multiple-Use-Module (MUM) has a well-protected habitat core of sufficient size to support interior species. Concentric buffers provide decreasing effects from external influences (adapted from Noss and Harris, 1986).

2.4. Overview of the environmental framework

The framework, then, is an outline for ensuring that landscape planning, design and management incorporate the crucial landscape ecology issues. Application of the framework requires that each of the components be considered in detail. The next section describes in detail how the assessment of natural and cultural resources component of framework can be applied to an existing urban river greenway, the South Saskatchewan River Valley in Saskatoon. The approach taken here could be applied to all other components of the framework.

2.4.1. Application of the assessment component

The process for applying the assessment components of the framework includes an Inventory of landscape elements, corridor network components, scale and hierarchy considerations, and a landscape element assessment process (similar to that illustrated in Fig. 1):

(I) Inventory of landscape elements. The study area can be described by a simple mapping and listing of the landscape elements present.

Fig. 3. Schematic representatives of comparative shapes and configurations for nature preserve design (adapted from Diamond, 1975). A description of each example is as follows (Diamond, 1975): A, a large reserve will hold more species than a small reserve because of species–area relationships; B, for the same reason, a single large reserve is preferable to several small reserves of equal total area, assuming that all represent the same habitat type; C, if it is necessary to have multiple small reserves, they should be grouped as closely as possible to minimize isolation; D, arranging small reserves in a cluster, as opposed to a linear fashion, will also facilitate movement among the reserves; E, connecting the reserves with corridors will make dispersal easier for many species; F, by making reserves as circular as possible, dispersal within the reserve will be enhanced and the negative effects of edges will be minimized.

Table 2
Determination of corridor network components: each landscape element is determined to be patch, corridor, or part of the matrix (e.g. Forman and Godron, 1986)

Landscape element	Classification
River corridor	
Drainage corridors	Corridor
Floodplain	Corridor
Adjacent parks	Patch
Transecting transportation and	
Utility corridors	Corridor
Vegetated slopes	Corridor
Vegetated upland	Corridor or patch
Agricultural fields	Patch
Urban context	
Parks	Patch or corridor
Transportation and utility	
Corridors	Corridor
Cemeteries	Patch
Allotment gardens	Patch
Drainage corridors	Corridor
Schools and other institutions	Patch

(2) Corridor network components. The attributes of each element should be considered and the landscape elements identified as patch, corridor, or matrix (see Table 2) (Forman and Godron, 1986). The approach corresponds to Agger and Brandt’s (1988) method of comparing corridor and patch landscape elements.

(3) Scale and hierarchy considerations. Attributes of each identified landscape element should be further subdivided and consideration of local site variations in topography, aspect, and soils used to reduce the areas even further.

(4) Assessment process. Many approaches have been developed for the comparison of natural areas and to facilitate decision-making in conservation (Gehlbath, 1975; Goldsmith, 1975; Wright, 1977; Margules and Usher, 1981; Game and Peterken, 1984; Smith and Theberge, 1986). Bourdages et al. (1992) have suggested that methods initially developed for estimating ecological value and prioritizing the selection of natural areas to be preserved can also be used in urban land-use management.

The two assessment processes used in the framework are: (i) landscape element rating - a system-based approach, modified from an evaluation scheme by Wright (1977) -is used to evaluate the relative quality of the landscape elements. This approach has been the most widely adopted approach for ecological evaluation (Smith and Theberge, 1986). The ecological value of landscape elements are assessed according to the six criteria he presented: plant species diversity, degree of naturalness, species rarity, plant community structure, landscape category, and sensitivity to disturbance (Tables 3 and 4) (Wright, 1977). The overall ecological value is determined by the summation of all criteria values, with a maximum of 18 (three for each individual criterion). (ii) network assessment - another analysis method can be used to measure the links in the landscape. Each landscape element is assessed for its present status and potential in providing links according to the following criteria: landscape element size and shape, connection to species-rich areas, degree of edge, and habitat structure (see Table 5).

3. Results

The assessment of natural and cultural resources, as described above, was applied to a case study of the South Saskatchewan River Valley in Saskatoon, Canada.

3.1. Study area description

The study site is located in the city of Saskatoon, Canada, on the South Saskatchewan River. The Meewasin Valley Authority, an urban river greenway organization, commissioned a study of the landscape ecology of the South Saskatchewan River corridor through Saskatoon (Fig. 4). A study site was selected which had a maximum of ecological diversity and had an overall mix of landscape elements that represented the whole of the Meewasin Valley.

Table 3
Landscape element rating: each landscape element is assessed according to six criteria, with a value from 1 to 3 assigned for each criterion. The values are summed to give the total ecological value (adapter from Wright, 1977)

Plant species diversity (/3)
+
Degree of naturalness (/3)
+
Species rarity (/3)
+
Plant community structure (/3)
+
Landscape category (/3)
+
Sensitivity to disturbance (/3)
=
Total ecological value (/18)

Table 4
Landscape element rating: score descriptions for criteria (adapted from Wright, 1977)

I.	*Plant species diversity*
	1. Small number of species present
	2. High species diversity
	3. Outstanding diversity for particular habitats type(s)
II.	*Degree of naturalness*
	1. Natural areas are being progressively destroyed
	2. Some natural areas are preserved
	3. Pristine natural areas are evident
III.	*Species rarity (plant or animal)*
	1. Species characteristic of region
	2. Site supporting good populations or local rarity or local endangered species
	3. Site supporting good/limited populations of natural rarity *or* site supporting good population of regional rarity *or* many species at limits of distribution
IV.	*Plant community structure (structural differentiation)*
	1. Plant community structure not evident
	2. Good stratification of vegetation types in plant communities
	3. Near-natural plant community structure in both horizontal and vertical patterns of vegetation
V.	*Landscape category*
	1. Agricultural or artificial landscapes. Human interference continuing
	2. Semi-natural landscape with native flora and fauna present. Human interference has altered the vegetation pattern from the original, but still high scientific interest. Very little of moderate human interference
VI.	*Sensitivity to disturbance*
	1. Very little buffer to protect from surrounding human activities or very little threat of increase of surrounding human activities
	2. Some protection from surroundings human activities *or* possible threat if human activities increase
	3. Adequate buffer zone of large site which can withstand human activities *or* in need of immediate protection. Main feature of site threatened by encroachment of human activity

The river is part of the major drainage system for the prairies of southwest Saskatchewan, Canada. Within the city the valley is narrow compared with the broad valley and floodplain just south of the city. The fine-textured lake basin deposits and till found within the city do not erode as easily as the sands to the south. Therefore the river occupies a narrow, deep valley with steep, terraced banks. (see Figs. 5 and 6).

The river valley today is a diverse water-created pattern of channel scars, creeks, islands, riverbanks, terraces, valleys, aquifers, and wetlands. It exists in an area substantially different from the surrounding semiarid prairie (see Figs. 7 and 8) - an ecosystem within an ecosystem. The study site was a

Table 5
Network assessment: each landscape element is assessed for its present status and potential for providing links according to the four criteria listed

I	*Size and shape*
	Optimal size and configuration of existing or recreated patches and corridors for an urban environment needs further study before an assessment can be made
II.	*Connections to species-rich areas*
	1. Completely isolated from species-rich areas
	2. Limited connection to species-rich areas
	3. High connectivity for species movement
III.	*Degree of edge*
	1. Vegetation dominated with edge species
	2. Some evidence of interior species
	3. Optimal ratio of interior species to edge
IV.	*Habitat structure*
	1. No evidence of a unified arrangement of habitat areas with non-existent buffer
	2. Some assemblance of habitat areas with limited buffer
	3. Optimal arrangement of remnant habitat patches and corridors with sufficient buffer

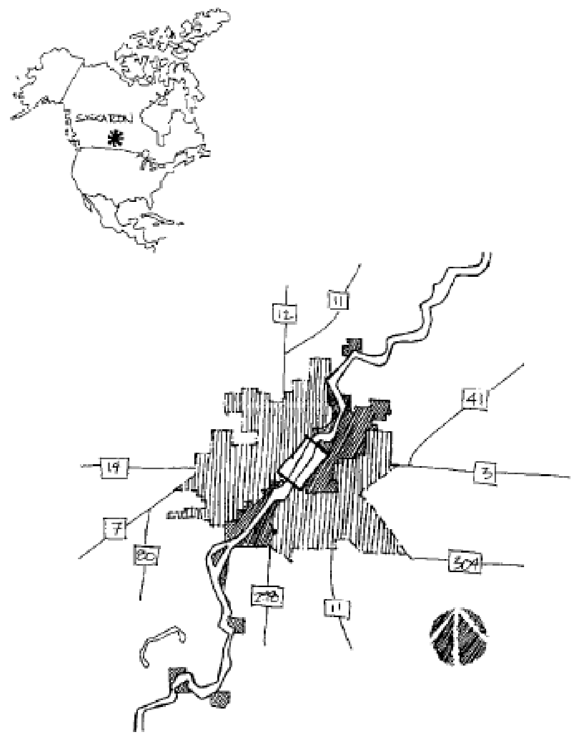

Fig. 4. Study area context.

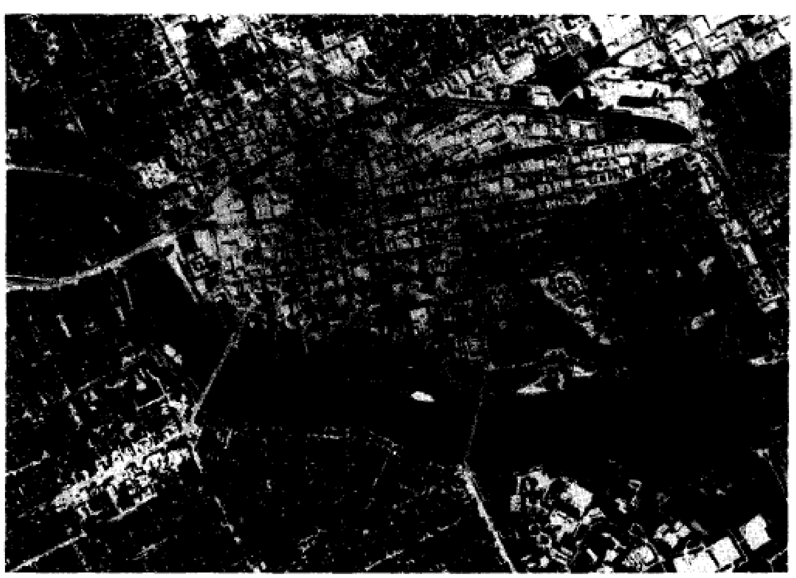

Fig. 5. Aerial view of the South Saskatchewan River Valley in Saskatoon, Canada.

Fig. 6. View of the narrow, deep river valley with steep terraced banks.

Fig. 7. Aerial view of the river bank adjacent to the University of Saskatchewan Campus.

Fig. 8. View of the river valley with prairie grassland in the foreground and urbanized areas of Saskatoon in the background.

Table 6
Landscape elements found in study site

1. Drainage corridors
2. Floodplain
3. Earth-fill areas
4. Adjacent parks (Kinsmen)
5. Adjacent parks (Mendel)
6. Trails (Meewasin trail including adjacent vegetation, desire lines)
7. Transportation corridor lands
8. Transecting transportation and utility corridors lands (railway bridge, University of Saskatchewan irrigation canal)
9. Vegetated slopes
10. Eroded slopes
11. Outfall sites
12. Upland grassland
13. Upland grassland mowed
14. Upland shrubs
15. Irrigated lawns
16. Agricultural fields
17. Hedgerows

subset of the river valley, containing all the biophysical patterns listed above. The urban matrix included a university, an art gallery, and parks. A recent inventory (Saskatoon Natural History Society, 1991) found that only about 26% of the within-city valley was assessed as supporting relatively natural conditions on the full slope from crest to channel.

An inventory of the study site led to the identification of 17 landscape elements as listed in Table 6. These landscape elements were assessed using Table 3 to determine the landscape element rating for each element, with the results listed in Table 7. These results were used to rank and group the landscape elements nd indicate how far removed the elements were from the ecological criteria (Table 8).

Next, a network assessment was undertaken, using Table 5. The results, listed in Table 9, indicated the same general pattern as the landscape assessment rating. With respect to providing linkages in the landscape, valleys, vegetated slopes, and upland shrubs had the highest values relative to the other landscape elements. Although the upland grassland areas were considered to have moderate ecological value in the first analysis, they scored lower in the network analysis. This result is probably due to localized ecological integrity and low connectivity potential between patches.

While the assessment for both landscape elements and network revealed component relationships based on ecological criteria, the justification for the retention or modification of these would require further assessment. The factors in this assessment would include management and amenity-use criteria, including operation and maintenance costs, initial capital costs, public concerns, political acceptance, site disruption, and community use.

3.2. Implications of landscape element assessment

The results of the case study indicated that no element had high ecological value in any of the analyses, and only a few had moderate value. The first priority, then, in the conservation of this urban river valley greenway, should be to search for any natural landscape remnants that have survived at a smaller scale,

Table 7
Landscape element rating for each element in the study site

Landscape element	Ecological criteria[a]						Total
	I	II	III	IV	V	VI	
1. Drainage corridors	2[b]	2	2	2	2	2	12/18
2. Floodplain	1	2	1	1	1	2	8/18
3. Earth-fill areas	1	1	1	1	1	1	6/18
4. Adjacent parks (Kinsmen)	1	1	1	1	1	1	6/18
5. Adjacent parks (Mendel)	1	2	1	2	1	1	8/18
6. Trails	1	1	1	1	1	1	6/18
7. Transportation corridors	1	1	1	1	1	1	6/18
8. Transecting transportation corridors	1	2	1	1	1	1	7/18
9. Vegetated slopes	2	2	1	2	2	2	11/18
10. Eroded slopes	1	1	1	1	1	1	6/18
11. Outfall sites	1	1	1	1	1	1	6/18
12. Upland grassland	2	2	1	1	2	1	9/18
13. Upland grassland (mowed)	1	1	1	1	1	1	6/18
14. Upland shrubs	2	2	1	2	2	1	10/18
15. Irrigated lawns	1	1	1	1	1	1	6/18
16. Agricultural fields	1	1	1	1	1	1	6/18
17. Hedgerows	1	2	1	1	1	1	7/18

[a]Ecological criteria: I, Plant species diversity; II, Degree of naturalness; III, Species rarity; IV, Plant community structure; V, Landscape category; VI, Sensitivity to disturbance.
[b]Scoring: 1, low value; 2, moderate or good value; 3, very high value. Score descriptions can be found in Table 4.

Table 8
Landscape element ratings: landscape elements in the study site were ranked and grouped according to the results of the landscape element ratings

Overall individual degree of fit category	Landscape element rating
1. Drainage corridors	12
2. Vegetated slopes	11
3. Upland shrubs	10
4. Upland grassland	9
5. Floodplain Adjacent parks	8
6. Transecting transportation corridor Hedgerow	7
7. Earth-fill areas Adjacent parks Trails Transportation corridors Eroded slopes Outfall sites Upland grassland (mowed) Irrigated lawn Agricultural field	6
	Decreasing landscape ecological quality

Table 9
Network assessment: a measurement of the links in the study site

Landscape element	Connectivity criteria[a]				Total
	I	II	III	IV	
1. Drainage corridors	–	1[b]	2	2	5/9
2. Floodplain	–	2	1	1	4/9
3. Earth-fill areas	–	1	1	1	3/9
4. Adjacent parks (Kinsmen)	–	1	1	1	3/9
5. Adjacent parks (Mendel)	–	1	1	2	4/9
6. Trails	–	1	1	1	3/9
7. Transportation corridor lands	–	1	1	1	3/9
8. Transecting transportation corridor lands	–	2	1	1	4/9
9. Vegetated slopes	–	2	1	2	5/9
10. Eroded slopes		1	1	1	3/9
11. Outfall sites	–	1	1	1	3/9
12. Upland grassland	–	1	1	1	3/9
13. Upland grassland (mowed)	–	1	1	1	3/9
14. Upland shrubs	–	2	1	2	5/9
15. Irrigated lawns	–	1	1	1	3/9
16. Agricultural fields	–	1	1	1	3/9
17. Hedgerows	–	1	1	1	3/9

[a]Connectivity criteria: I, Size and shape (further study required); II, connections to species-rich areas; III, degree of edge; IV, habitat structure.
[b]Scoring: 1, low value; 2, moderate or good value; 3, very high value. Scoring descriptions can be found in Table 5.

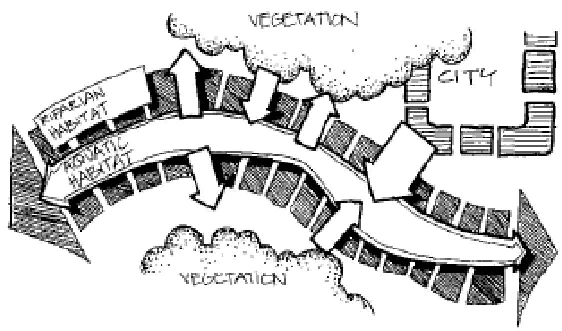

Fig. 9. Corridor habitats, patches of vegetation, and background matrix showing flows. Design should minimize barriers between the river valley and adjacent vegetation patches.

protect them, and then extend the habitat around these nuclei. Indigenous plants should be used in extending their boundaries and ecological networks could be initiated by linking these remnants.

Landscape elements which are far removed from the ecological criteria but have high modification potential should be considered for ecological enhancement, while those with low value and low modification potential are candidates for facility development.

To continue the use of the ecological framework would require similar detailed application in the formation of the ecological network's spatial structure (as shown in Fig. 1). This exercise would result in the protection, ecological enhancement, and linkages of present and potential natural areas in the river valley corridor.

3.3. Implications for planning, design and management

One essential characteristic of an ecological approach is to maximize the adaptation of the plant species to their environment and to simulate natural conditions in their management. An ecological understanding of the river valley landscape is a necessary prerequisite for the design and management of existing and potential natural areas as well as extensively used ones. The following is a discussion on some ecological design considerations.

Table 10
Design for diversity (adapted from Noss, 1986)

Scale	Area	Goal	Approach
Regional	Saskatoon and region	Regional diversity preserve sufficiently large areas of unaltered indigenous ecosystems on regional scale interconnect habitat patches	Landscape management
Local	River valley in Saskatoon mosaic of parks mosaic of plant communities	Local diversity (between habitats) maintain variety of successional stages intersperse different habitat types	Landscape planning
Site	Park adjacent to river Plant community	Site diversity (within habitat) increase structural complexity	Landscape design

3.3.1. Planning, design and management approach

An optimal spatial structure of an ecological network must be developed utilizing three scales: site, local, and regional. Planning, design and management should also be applied at all three scales (see Table 10).

At the site level, a managed ecosystem is a collection of responses to the physical environment, availability of species, and management over time (Baines, 1987). As the remnant natural areas are normally not large enough to buffer outside influences, they must be considered managed ecosystems. However, management and/or maintenance can be minimized by landscape design in concert with the biological and physical environment. One example would be consideration of the aspects of slopes. In the study site, south-facing slopes would promote different flora and fauna than northfacing slopes. Tree and shrub establishment would be more likely to be successful away from the direct sun. Hardy native 'scrub' species should be planted first, as pioneers, and then more sensitive plants could be established in the ameliorated microclimate.

At the local (ecosystem) level the fundamental structural elements include the remnant corridor and patch habitats and the background matrix of the city. Landscape planning should minimize isolation of natural landscape remnants and maximize linkages to provide for flows of energy, mineral nutrients, and species. An example of this would be to minimize barriers between the river valley and adjacent vegetation patches (Fig. 9).

At the regional level, a typical management objective would be to ensure that indigenous plant species be used, and that diverse plant communities with spatial heterogeneity be created in the valley.

3.3.2 Other issues

A number of issues require consideration in the successful implementation of an ecological approach. With respect to the quality of habitat for wildlife, the retention of existing natural vegetation within a river corridor is first priority, followed by any necessary plant community restoration. A high-quality habitat requires the full diversity of natural vegetation, and it is maintained by the functioning of ecological processes. Resources such as leaf litter, tree hollows, dead trees, and diverse invertebrate communities cannot be easily created by simply planting trees and shrubs.

Where restoration is required, plant communities should be developed on the basis of their ability to adapt to changing site conditions and to create a diversity of environments for people. Management requires an integrated approach where maintenance depends on site differences and intensity of use.

Overall, the success of the ecological framework approach depends on planning, design and management being coordinated and integrated; this can only be achieved through the establishment of teams with appropriate expertise and a framework to facilitate implementation.

4. Discussion

Planners, designers and managers need clear guidelines, based on scientific evidence, if ecological concepts are to be applied. Although it is often impractical to set aside sufficiently large habitats in urban areas, use of the ecological framework outlined in this study will allow an increase in the effective size and functioning of patches and corridors. This can be achieved through control of disturbances, carrying out edge treatments, and making management arrangements with neighboring jurisdictions. As new knowledge becomes available, this information can be incorporated into the framework.

Controlling disturbance should include curtailing management actions that reduce the effective size of habitats, for example, preventing mowing and trampling of herbs and shrub layers of remnant patches. The value of small isolated patches for nature conservation can be improved by techniques to increase their effective size and to limit human access and disturbance. Management agreements with neighboring jurisdictions could be arranged to protect the edges of the remnant natural areas. A public education program could teach local residents the principles of nature conservation in cities and help them to understand the link between landscape ecology and aesthetic appeal. This could enhance public care and stewardship of natural areas (Thorne and Huang, 1991).

4.1. Areas requiring further study

Through this study several areas have been identified for further study, including: (a) comparative applications of the ecological framework to test reliability; (b) development of more explicit and detailed criteria for landscape assessment; (c) urban habitat planning, design, and management; (d) minimum size requirements for different habitats; (e) necessary maintenance of desired successional phases; (f) carrying capacity of different habitats within cities; and (g) indices of urban biodiversity. Many of these topics are being actively investigated at the regional level, but not at the municipal or city level.

5. Summary

This study has introduced a procedure to facilitate the protection and enhancement of natural areas in urban river greenways. The literature review developed the premise that an integrated landscape approach was necessary for ecological planning, design, and management. An ecological framework was developed which related ecological knowledge to the planning, design, and management process. The results of applying the assessment component of the framework indicated that an ecological value could be determined for the landscape elements of a river corridor. This facilitated the systematic review of these elements to identify areas that need protection and/or enhancement to maintain an ecologically functioning urban river greenway. Other components of the framework could be applied in a similar manner. Potential theoretical and practical applications of the overall framework have been identified to indicate its usefulness.

As natural areas in urban environments become more fragmented and threatened, using approaches like the ecological framework in landscape planning, design, and management might begin to reverse the trend. It is not too late, in many cases, to begin the healing process and allow nature to begin to play a more important role in the health of cities through ecologically functioning urban river greenways.

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