O2

LANDSCAPE PATTERNS
ENVIRONMENTAL QUALITY ANALYSIS

Oldman Watershed Council
O2 Planning + Design

15 April 2013

Background

(Photo credit: AENV Watershed Indicators for Southern Alberta, 2008)

Ecosystem components and processes are interconnected and linked across landscapes

Holistic approaches to understand relationships between land use + environmental quality are needed

Project Goal: To form the basis of an effective cross-media, coarse filter approach to measure and manage environmental quality

Multi-scale approach

Primarily focused on research in Western North America

Project Overview

Summarized and classified findings from published literature identifying:

- Significant relationships between land use patterns and environmental quality
- Potential thresholds of environmental quality associated with distinct land use and land cover patterns

Literature Review:

Scanned: **>650 publications**

Reviewed: **172 pubications (30%)**

Biodiversity related studies = 61%

Water quality and quantity studies = 32%

(Image by Caitlin Smith, 2012)

Foundations: Pattern-based Landscape Models

PATCH

CORRIDOR

Patch-Corridor-Matrix Model:

The patch-matrix-corridor model describes landscapes as mosaics comprised of three principle components: patches, corridors, and a background matrix

NETWORK

Patches of habitat can be connected by habitat corridors, forming networks of regional connectivity

MATRIX

The matrix is the dominant, most modified patch type in a landscape

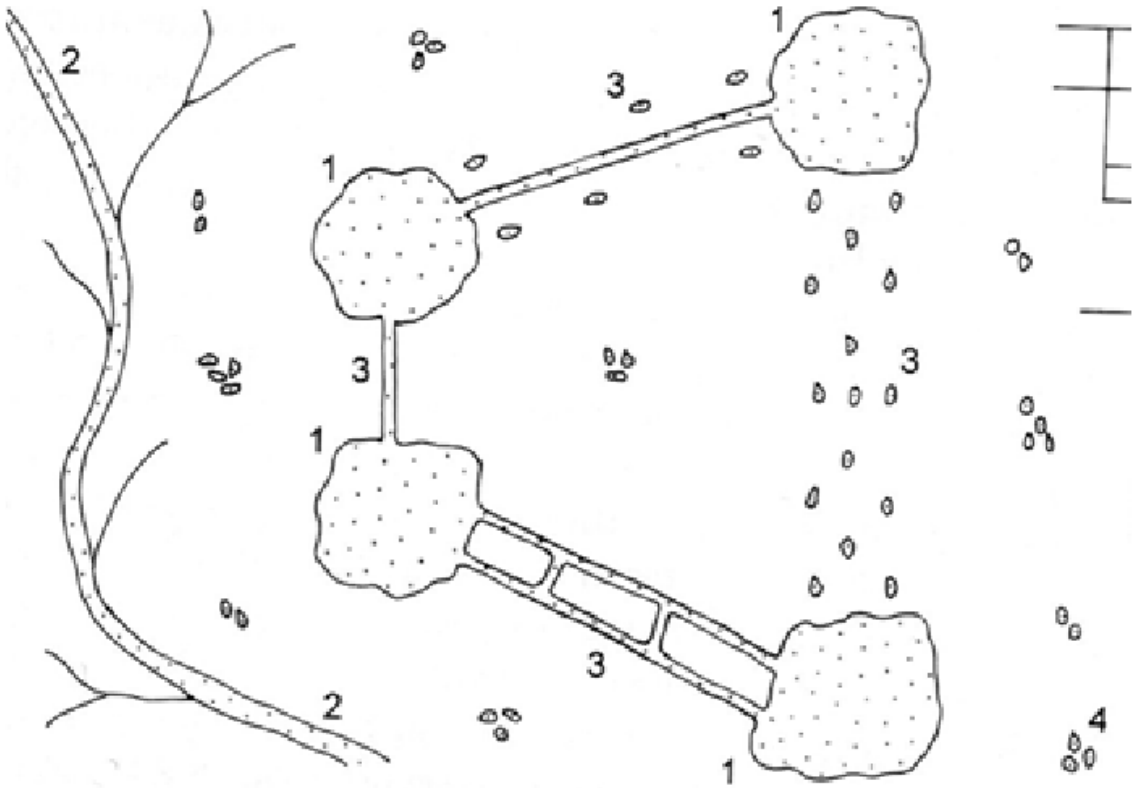
MOSAIC

Together these elements comprise a landscape mosaic

(REDRAWN AFTER DRAMSTAD1996 BY CAITLIN SMITH, 2012)

Recognizing Indispensible Landscape Patterns

(Indispensible Lanscape Patterns; Forman 1995)

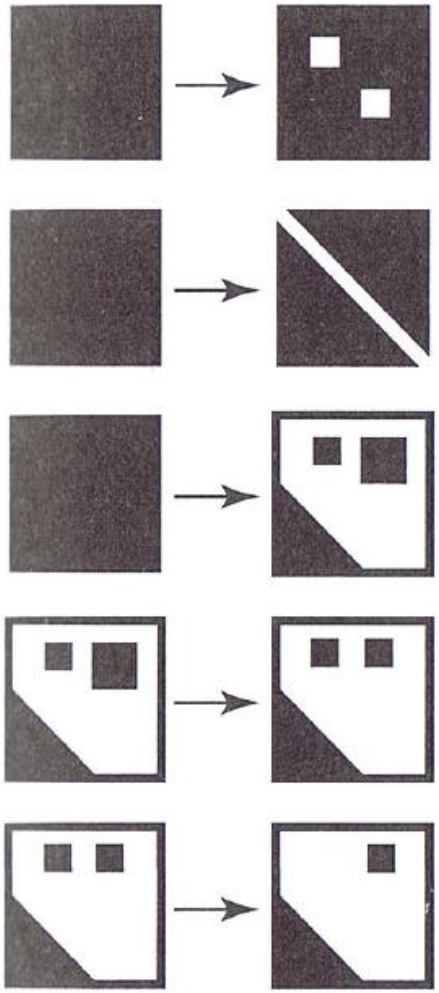


``Landscape pattern analysis is based on the premise that there are certain indispensible patterns in any landscape that, if maintained, will conserve the majority of essential landscape processes``

1) Large patches of natural vegetation
2) Riparian corridors
3) Connective corridors and stepping stones
4) Heterogeneous fragments of natural vegetation in the matrix

Recognizing Patterns of Landscape Change

Five main ways in which humans alter landscapes spatially:



	Example
Perforation →	Forest clearcut blocks, well pads
Dissection →	Roads, seismic lines, pipelines
Fragmentation →	Combination of above land uses
Shrinkage →	Agricultural intensification
Attrition →	Fire, timber harvest

IMAGE DERIVED FROM FORMAN (1995) BY LINDENMAYER AND FISCHER (2006)

The Importance of Spatial Scale

(Image derived from Bingmaps, March 2013)

Grain: The coarseness in texture or granularity of spatial elements composing a landscape

- Grain is often determined by the size of patches in a landscape

- Different species perceive and respond to landscape differently, at varying spatial scales

- Multi-scale analysis can be performed by the aggregate of watersheds at several spatial scales

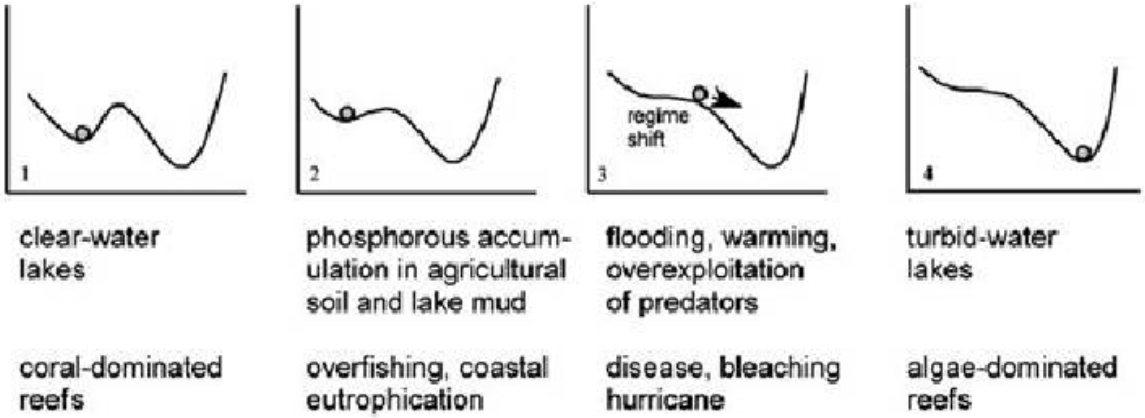
Example: a coarse grain landscape composed of large, regular patches of harvested forest blocks in a forest reserve west of Sundre, Alberta

Understanding Targets and Thresholds

Ecological thresholds represent a critical value of a stressor, ecosystem property, or landscape attribute at which species' rate of response to ecosystem change increases drastically

Conservation targets are parameters of biological health (often biotic indicators) used to assess and plan for a certain standard of environmental quality

TARGETS AND THRESHOLDS:



(IMAGE FROM FOLKE, C. ET AL., 2004. REGIME SHIFTS, RESILIENCE, AND BIODIVERSITY IN ECOSYSTEM MANAGEMENT. ANNUAL REVIEW OF ECOLOGY, EVOLUTION, AND SYSTEMATICS, 35, PP. 557-81)

Landscape Pattern Indicators

Significant Findings:

Cover and configuration are related

The relative importance of each fluctuates at certain thresholds of landscape cover

- Flather and Bevers 2002:

- Percent habitat largely explained population size

- When percent habitat dropped below 30-50%, habitat configuration was more important than habitat amount

1) Land Cover Indicators

2) Landscape Configuration Indicators

(Photo Credit: AENV Watershed Indicators for Southern Alberta 2008)

Land Cover Indicators

Wetland Cover

(Photo Credit: www.usask.ca)

Forest Cover

(Photo Credit: www.greenpeace.org)

Grassland Cover

(Photo Credit: www.terrainforma.ca)

Impervious Surface Cover

(Photo Credit: www.beyond.ca)

Agricultural Land Use Cover

(Photo Credit: Canadian Parliment, www.parl.gc.ca)

Wetland Cover

Significant Findings:

- Proportion (%) of the landscape/watershed in wetlands is a key indicator for water quality, flood control, and biodiversity (Mitsch and Gosselink 2000, Roth et al. 1996)
- Wetlands function differently depending on their position in the landscape downstream (Mitsch and Gosselink 2000)
- Small wetlands are critical components of the surrounding landscape that influence habitat suitability of larger wetlands (Naugle et al. 2001)
- Wetlands were found to work best, in terms of providing ecosystem services, as spatially distributed systems (Mitsch and Gosselink 2000)

Targets and Thresholds:

Taxa or Process	Target wetland cover	Finding	Location	Citation
Surface water quality	3-7%	Wetlands should comprise at least 3-7% of temperate watersheds for improved water quality	Midwest USA	Mitsch and Gosselink 2000
Water quality, biodiversity, etc.	>7.5% of watershed	Maintain or improve baseline conditions (>7.5%) for a range of watershed values	Red Deer River Basin, Alberta	O2 Planning + Design Inc. et al. 2013

Forest Cover

Significant Findings:

- Watershed water quality is highly dependent on the extent and proportion of forest land cover (Sullivan et al. 2007, Feller 2005, Fowler et al. 1988, Emelko et al. 2012)
- Water treatment costs decrease with higher percentages (up to 60%) of forest cover in a watershed (US Trust for Public Lands 2004, Freeman et al. 1998)
- Forest fires can cause nutrient and sediment loading in streams, negatively impacting water quality (Stein et al. 2012, Levine et al. n.d, Oliver et al. 2012, Emelko et al. 2012, Bladon 2008)

Targets and Thresholds:

Taxa or Process	Forest cover target	Finding	Location	Citation
Water quantity	<25%	When >25% of the watershed's forest cover is clearcut in a short period of time, there is a measurable increase in annual streamflows from the watershed.	Oregon	Adams and Taratoot 2001
Fish Habitat (bull trout)	<35%	Timber harvest on up to 35% or more of individual subbasins is projected to result in the extirpation of bull trout from up to 43% of stream reaches, especially those that support high densities of bull trout.	Alberta	Ripley et al. 2005

Grassland Cover

Significant Findings:

- Many area sensitive bird and mammal species require high percentages of native grassland cover to meet their basic habitat needs (USDA 1999, Taylor 2004, Downey 2004, Coppedge 2001)
- Natural fire regimes are essential to maintain habitat conditions for certain specialist grassland species (Fitzgerald et al. 1999)
- The amount and proportion of grassland in relation to other cover types can influence predation rates and trophic cascades (Bergin et al. 2000, Crooks and Soule 1999)

Targets and Thresholds:

Taxa or Process	Target grassland cover	Finding	Location	Citation
Birds	>5% tree cover; >20% shrub cover	Grassland bird species are affected when the amount of tree or shrub cover in the landscape exceeds 5% or 20%, respectively	Southern Alberta	O2 Planning + Design Inc. et al. 2008a
Birds	30-60%	When native grassland cover dropped below 60% at one site, and 30-40% at another site, the arrangement or habitat patches became more important to the survival of populations than habitat amount alone	Oklahoma	Coppedge et al 2001a

Impervious Surface Cover

Significant Findings:

- The amount of impervious surface area in a watershed is significantly negatively correlated with lower water quality and stream health (Booth 2008, Stewart et al. 2001, Arnold and Gibbons 1996)

- As impervious surfaces in the watershed increase, linear increases in aquatic nitrogen pollution are observed (O2 Planning + Design Inc. et al. 2008)

- Watersheds with IS >30% provide very low ecosystem services (Brabec et al. 2002, Arnold et al. 1996)

Targets and Thresholds:

Process	Target impervious cover	Finding	Location	Citation
Water quality	<10% of watershed	Impervious areas should be kept at or below 10% of a watershed in order to effectively mitigate the impacts of urbanization and development on watersheds.	Washington	Booth 2000
Water quality	<25%	Impervious cover should be maintained at or below 25% in heavily urbanizing watersheds	Multiple	Leitao et al. 2006; Brabec et al. 2002; Arnold et al. 1996

Agricultural and Other Land Use Cover

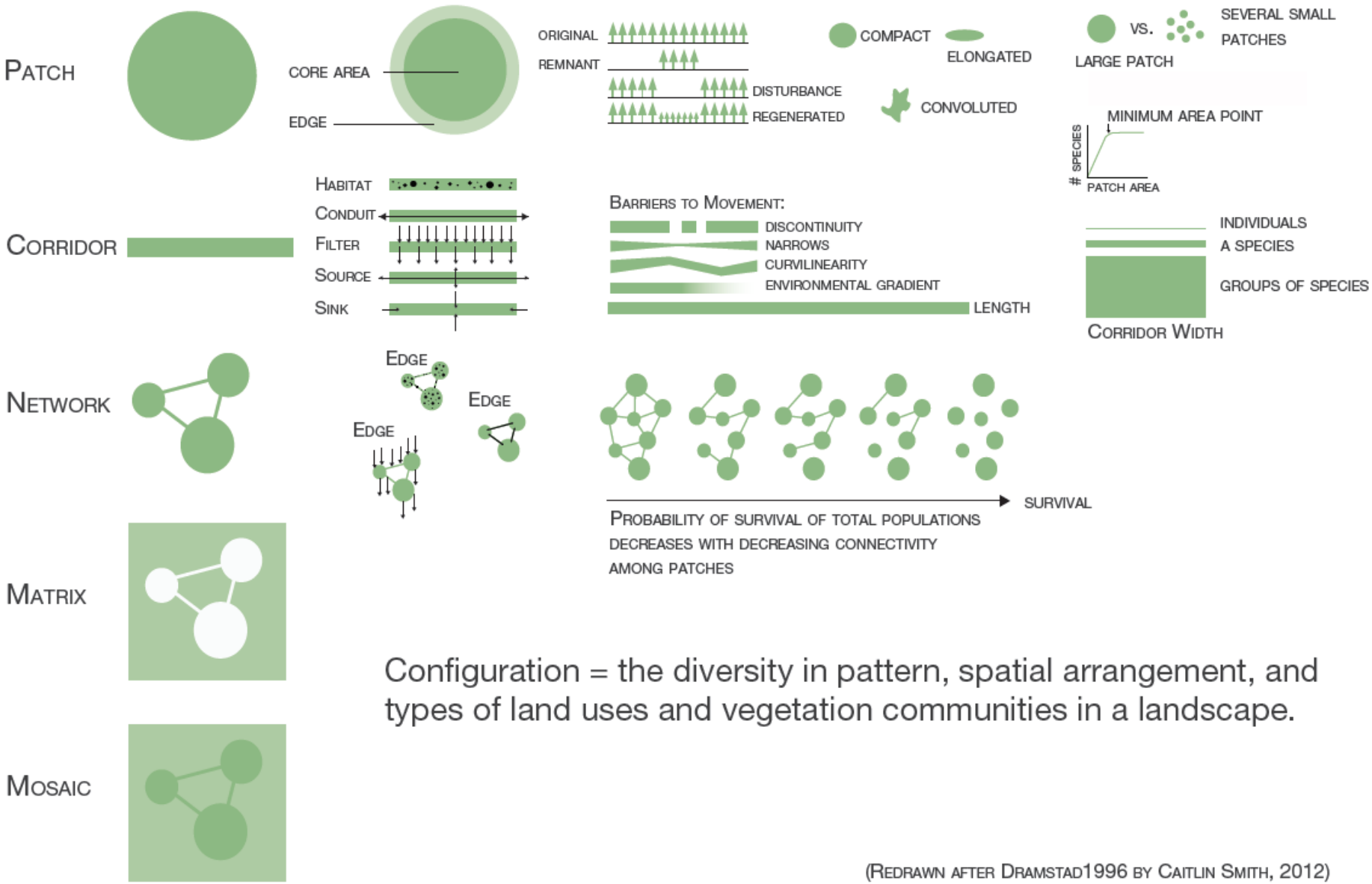
Significant Findings:

- Biotic integrity is negatively correlated with the extent and proportion of agricultural land cover (Roth et al. 1996, Moyle and Randall 1998, Haug and Oliphant 1990)
- Rates of pollination by native bees increase with the amount and proximity of nearby natural habitat (Kremen 2002, Morandin 2007)
- The amount, distribution, and intensity of agricultural land use correlates negatively with water quality and stream health (Lorenz et al. 2008, Houlahan and Findlay 2004, Freeman et al. 2008
- Upstream land uses are the primary determinant of downstream water quality (Roth et al. 1996)

Targets and Thresholds:

Taxa or Process	Target cover/other measure	Finding	Location	Citation
Pollination	>30% uncultivated	Yield and profit could be maximized with 30% of land uncultivated within 750 m of field edges.	Northern Alberta	Morandin 2006
Birds	<50% upland landscape in tilled agriculture	Numerous wetland bird species were more likely to inhabit wetlands in landscapes where <50% of the upland matrix was tilled.	South Dakota	Naugle et al. 2001

Landscape Configuration Indicators



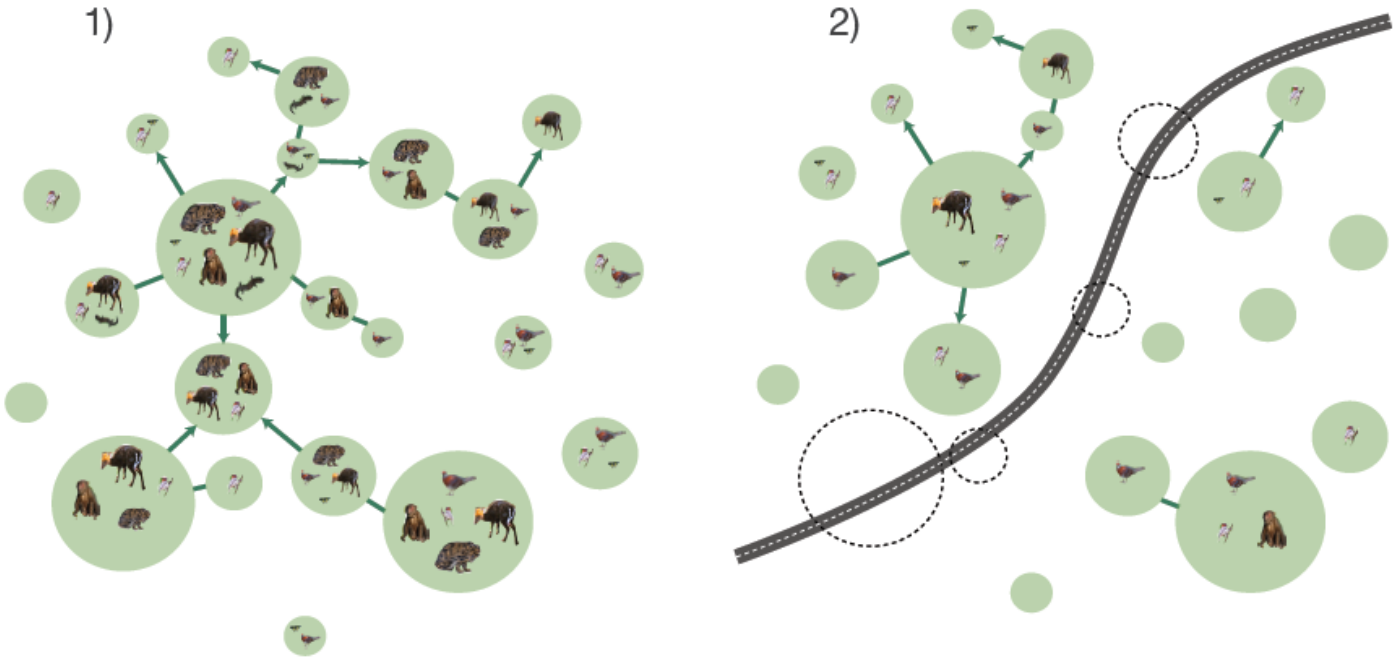
Configuration = the diversity in pattern, spatial arrangement, and types of land uses and vegetation communities in a landscape.

(Redrawn after Dramstad1996 by Caitlin Smith, 2012)

Fragmentation and Connectivity

Fragmentation: the degree to which vegetation communities are broken apart into smaller isolated sections within a landscape. Often works in tandem with habitat loss.

Connectivity: a contiguity condition in which patch elements flow uninterrupted across a landscape.



(Image by Caitlin Smith, 2012)

1) Landscape with high patch connectivity

2) Landscape fragmented by road; reducing connectivity

Fragmentation and Connectivity

Significant Findings:

- Landscape fragmentation results in demographic changes in plant and animal populations, as well as the possible risk of extinction (Jules 1998, Hargis et al, 1999, Connelly et al. 2004, Stewart et al. 2001)

- Small streams, and the water quality provisioning ecosystem services they provide, are most vulnerable to fragmentation via diversion, channelization, and elimination in fragmented urban and agricultural environments (Peterson 2001)

Targets and Thresholds:

Taxa or Process	Connectivity index	Findings	Location	Citation
Mammals (American Martens)	<100m gaps; <25% open	Forested landscapes were unsuitable for martens when the average nearest-neighbor distance between open, non-forested patches was <100m. Timber harvests and natural openings should not constitute more than 25% of a landscape greater than 9km^2 to ensure marten population persistence.	Northern Utah	Hargis et al. 1999
Birds	Movement confined within 75m of forest edge	Chickadee flocks moved parallel to forest boundaries within up to 75m of forest edge	Northern Alberta	Desrochers and Fortin 2000
Birds	<50 m gaps	Forest dwelling birds are reluctant to cross gaps in forest cover greater than 50 meters.	Quebec	Desrochers and Hannon 1997

Corridor Systems

- Riparian Corridors
- Shelterbelts
- Linear distrubances

Roads

(Photo Credit: AENV Watershed Indicators for Southern Alberta 2008)

Shelter Belts

(Photo Credit: www.aftaweb.org)

Riparian Corridor

(Photo Credit: www.epa.gov)

Riparian Corridors/Stream Buffers

Significant Findings:

- Buffers less than 5-10m provide little protection of aquatic resources under most conditions (Castelle and Connolly 1994)
- Continuous riparian buffers correlate with higher overall watershed water quality and aquatic diversity (Stewart et al. 2001, Schlosser and Karr 1981, Kennedy et al. 2003, Weller et al. 1998)
- Riparian buffers play an important role in managing nitrogen uptake in watersheds (Mayer et al. 2007)

Targets and Thresholds:

Taxa or Process	Target buffer width	Findings	Location	Citation
Fish habitat/ aquatic health	30m	High percentages of forest cover within a 30m riparian buffer were related to healthy fish communities and water quality. Fish density increased with increase in the average length of riparian vegetation without gaps (>30m).	Wisconsin	Stewart et al. 2001
Water quality	>50m	Wide buffers (>50 m) more consistently removed significant portions of nitrogen entering a riparian zone than narrow buffers (0-25 m).	World-wide (literature review)	Mayer et al. 2007

Shelter Belts

Significant Findings:

- Shelterbelts can be effective in controlling erosion and filtering odors at both the farm and landscape scale as a means of safeguarding regional air (Brandle et al. 2004, Leuty 2004, Tyndall and Colletti 2007)

- For erosion control, the area completely protected by windbreaks is assumed to be a distance 10 times the height of the barrier downwind from the barrier along the prevailing wind direction (Ticknor et al. 1988)

- Shelterbelts of 6-10 meters high serve as an adequate buffer to reduce odors from nearby animal operations (Tyndall and Colletti 2007).

Targets and Thresholds:

Taxa or Process	Shelter belt dimension	Findings	Location	Citation
Air quality	6-10m high	Shelterbelts of 6-10 meters high serve as an adequate buffer to reduce odors from nearby animal operations	North America	Tyndall and Colletti 2007
Erosion protection	Area protected = distance 10 times the height trees	Erosion protection is thought to extend to a distance 10 times the height of the tree species used as a windbreak	North America	Ticknor 1988
Erosion protection	Single row	Single row plantings are common and are as effective and use less land than multiple row plantings.	North America	Tibke 1988

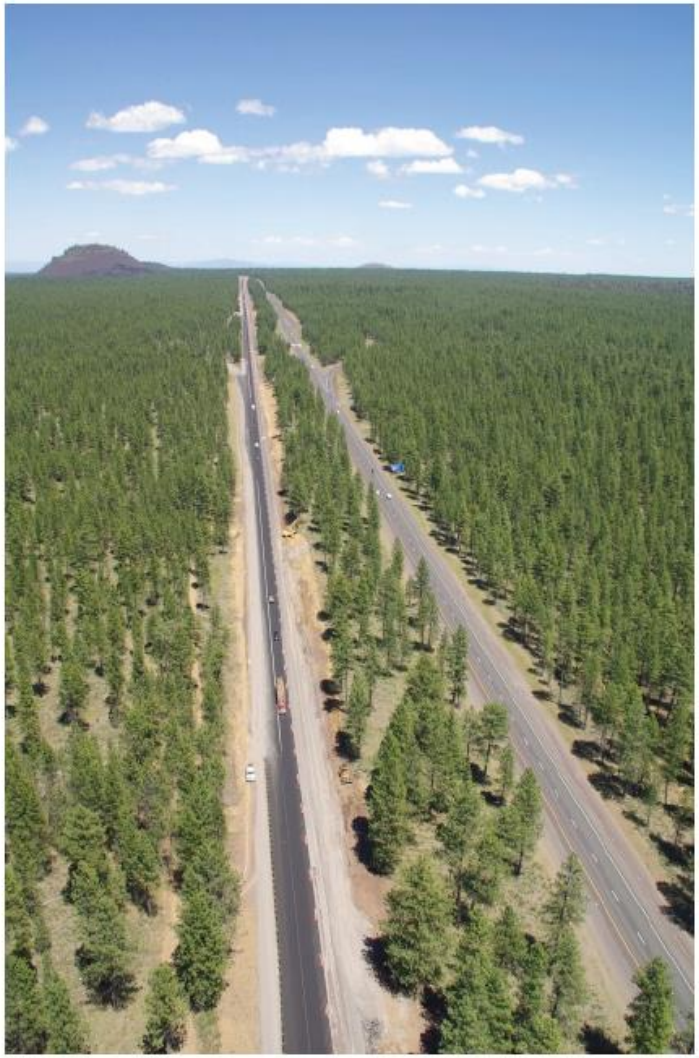
Linear Disturbances

Significant Findings:

- In general, most mammals, fish, and birds are significantly negatively affected by increasing road density in a given landscape (Clevenger et al. 2003, Rowland et al. 2000, AESRD 2012, Kissner 2004, Lorenz et al. 2008)

- Bird abundance and breeding success tends to decrease with increasing noise associated with road and energy development disturbances (Bayne et al. 2005, Habib et al. 2007, Kaseloo 2005)

- Birds are more vulnerable to roadkill than mammals on divided highways with forested medians due to their willingness to cross narrow gaps (Clevenger et al. 2003)



Lava Butte, Oregon (Photo Credit: greenroads.org)

Linear Disturbances

Significant Findings:

- Roads can serve as vectors for the spread of invasive plant species, especially up to 1000m from the road (Gelbard and Belnap 2003)

- Roads can affect male and female members of a species differentially, having cascading implications for the survival of populations when females of a species are disproportionately impacted (Proctor et al. 2012, Leblond et al. 2007)

- Road construction can increase turbidity and suspended sediment loads in nearby streams (Fowler et al. 1988)

(Photo Credit: flickr.com)

Linear Disturbances

Targets and Thresholds for Road Density:

Taxa or Process	Target density	Findings	Location	Citation
Elk	1.5 km/km²	Road density threshold at which elk could still occur in high numbers: 1.5 km/km²	Oregon	Rowland et al. 2000
Elk	0.62 km/km²	Road density threshold for elk in Alberta: 0.62 km/km²	Alberta	AESRD 2012
Snakes (Prairie rattlesnake)	1.6km per 1/4 section	Road densities greater than 1.6 km per 1/4 section are unsuitable for prairie rattle snakes	Alberta	Kissner 2004
Grizzly bears	0.4 km/km²	Road density threshold for grizzly bears in Alberta: 0.4 km/km²	Alberta	AESRD 2012

Targets and Thresholds for Road Avoidance:

Taxa or Process	Buffer width	Findings	Location	Citation
Birds	1,500 m for >10,000 vehicles/day; 2,800 m for >60,000 vehicles/day	In a study of grassland birds (bobolinks and meadowlarks), effect distances ranged from 50-1,500 m at 10,000 vehicles/day and increased to 70-2,800 m at 60,000 vehicles/day. Similar effect distances were found for woodland species.	Netherlands; Boston USA	Kaseloo 2005
Species dwelling near roads	1,000m	Species occupancy near roads is severely affected at a threshold traffic volume of 30,000 vehicles per day. Avoidance zones extend up to 1000 m from the road. Roads with 50,000 vehicles per day can result in an average effect-distance of 800 m for woodland species and more than 900 m for grassland species.	Multiple (literature review)	Kociolek and Clevenger 2011

Patch Size

Significant Findings:

- Ideal patch size varies depending on the taxonomic group and associated dispersal patterns in question (Bender et al. 1998, McGarigal and Cushman 2002, Herkert 1994, Soule 1991
- In general, species with smaller dispersal ranges, such as plants and invertebrates, require smaller patches of <10 ha (McGarigal and Cushman 2002)
- Large vertebrates, wide-ranging predators, and area-sensitive birds require larger patches of >2,500 ha (Trine 1998, Mattson 1990, and Beier 1993)

Targets and Thresholds:

Taxa	Target Patch Size	Finding	Location	Citation
Birds	5-55ha	Area-sensitive bird species required patches of suitable habitat at least 5-55 ha in size, and regularly avoided smaller grassland fragments even when they were composed of suitable habitat	Illinois	Herkert 1994
Birds	50 ha	Minimum habitat requirements for birds ranges from 1 to 2,500 hectares, however most studies cited area requirements under 50 hectares (Kennedy et al. 2003).	USA	Kennedy et al. 2003
Birds	>6.5 ha, 15.4-32.6 ha	Black tern required 6.5 ha in heterogeneous landscapes, but required 15.4-32.6 ha in homogenous landscapes	South Dakota	Naugle et al. 1999

Core Area and Edge

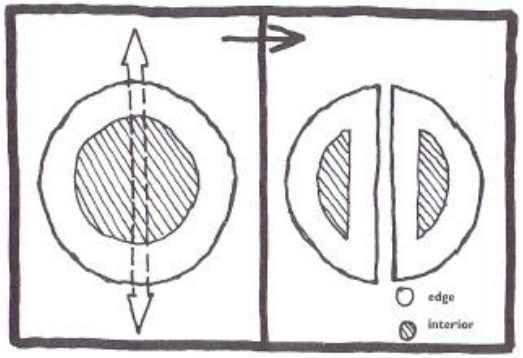
Significant Findings:

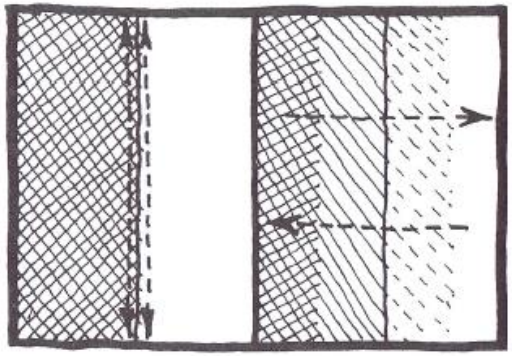
- Species diversity is generally higher in patches with greater percentages of interior core area (Knutson et al. 1999, Kennedy et al. 2003)

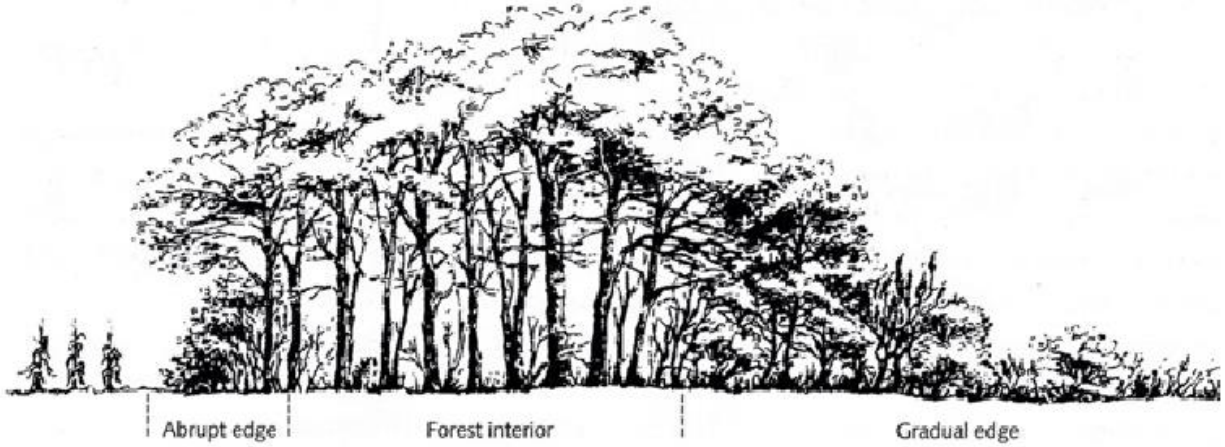
- Larger core areas have less interaction with the surrounding matrix, resulting in reduced probability of exotic species invasion (Gelbard and Belnap 2003).

- The shape of edges facilitate different movement patterns among mammals and birds, either directing movement parallel to hard edges of promoting passage through softer curvilinear edges (Dramstad et al. 1996, Desrochers and Fortin 2000)

- Predation rates may be greater at habitat edges (Soule 1991, Patten et al. 2006)







(Images From Dramstad1996)

Core Area and Edge

Targets and Thresholds:

Taxa or Process	Target Edge Length	Finding	Location	Citation
Water quality	2250m for N and P; 4000m for sediment P	Water nitrogen and phosphorous levels were negatively correlated with forest cover at 2250 meters from the wetland edge. Sediment phosphorous levels were negatively correlated with wetland size and forest cover at 4000 meters from the wetland edge, and positively correlated with the proportion of land within 4000 meters of the wetland.	Ontario	Houlahan and Findley 2004
Amphibian species richness	2000m	Species richness increases with the percentage of forest within 2000m of a wetland	Iowa and Wisconsin	Knutson et al. 1999
Flora	65m	Trillium populations in forest remnants within 65m of forest clear-cut edges have almost no recruitment of young plants	Oregon	Jules 1998

Landscape Heterogeneity

Significant Findings:

- Landscape heterogeneity decreases the abundance of rare interior species, increases the abundance of edge species and animals requiring two or more landscape elements, and enhances potential species coexistence (Kennedy et al. 2003)

- The flows of energy and biomass across boundaries separating the patches, corridors and matrix of a landscape increase with increasing landscape heterogeneity (Kennedy et al. 2003)

- The flows of energy and biomass across boundaries separating the patches, corridors and matrix of a landscape increase with increasing landscape heterogeneity (Kennedy et al. 2003)

- When undisturbed, horizontal landscape structure tends progressively toward homogeneity; moderate disturbance rapidly increases heterogeneity, and severe disturbance may increase or decrease heterogeneity (Kennedy et al. 2003)

Conclusions

"There are certain indispensable patterns in the landscape that, if protected, will conserve the majority of important ecological functions" (Forman 1995).

- Cover and configuration are related. The relative importance fluctuates at certain thresholds of landscape cover
- Proportion of native land cover in a landscape is a good indicator or environmental quality, species diversity, riparian and watershed health
- Proportion of impervious surface and agricultural land cover are inverse indicators of environmental quality, species diversity, riparian and watershed health
- Large patches of forest or other natural vegetation provide ecological services that cannot be duplicated by other elements
- Linear corridors of vegetation can provide habitat connectivity and erosion control in an otherwise fragmented landscpe

02 PLANNING + DESIGN