Thresholds for Regional Vulnerability Analysis

Prepared For:

Elizabeth Smith
Regional Vulnerability Assessment Program
National Exposure Research Laboratory
U.S. EPA (E243-05)
109 T.W. Alexander Drive
Research Triangle Park, NC 27711

Prepared By:

Jennifer Hendricks
Jackie Little
TN & Associates, Inc.
124 S. Jefferson Circle
Oak Ridge, TN 37830

Contract No. 68-C-98-187

June 20, 2003

Thresholds for Regional Vulnerability Assessment: A Literature Review

Abstract:

This report provides a literature review of ecological variables and their threshold values. The objective was to find studies done with a defined ecological threshold value in the Mid-Atlantic region. Not many studies have been done in this region so the search was expanded to include the United States as well as other countries. The article is a summary of references on ecological threshold values and their impact on the environment. The references come from various articles, reports, and web pages as well as different agencies in the United States and foreign countries.

Introduction:

The Environmental Protection Agency's (EPA) Office of Research and Development developed the Regional Vulnerability Assessment (ReVA), to conduct ecological assessments on the regional level. TN&A was awarded a contract from EPA to provide continued support to ReVA. The support included a literature search on different ecological variables focused on the Mid-Atlantic region. The search was to identify thresholds, if any that have been defined for a particular variable. Threshold values indicate how far the environment can be impaired before it incurs significant damage. Some stressor variable values are known and have standard guidelines. For example, EPA has strict guidelines when it came to Ozone, Pesticides and Herbicides. For others like Imperviousness, many studies have been done but, there are no EPA guidelines to follow. A list of variables was given as a focal point to begin the search.

In the past, studies focused on one variable's impact on the environment. Today, many variables are impacting the environment. Any change in the landscape can have multiple effects. Many disagree on the percentage of continuous, supportive land needed for suitable habitat. Jannson and Angelstam (1999) did a study on long-tailed tit's habitat. Their model showed 30% of land for suitable habitat, below this level populations decline. Studies done by With and Crist (1995) indicated 45%. Others like Robinson (1996), James and Saunders (2001), and Andren (1999) suggest between 70-80% is needed before the habitat breaks into fragmented patches. Once fragmented, some species might decline. There is no clearly defined threshold.

Methods:

The background search was done in Fall 1991 to Spring 1992. The search began with articles provided by the EPA. An initial search was then done on the Internet. After reviewing the initial results, it was determined that the search had to expand outside the Mid-Atlantic region because there were not enough studies done. The second search was done in Fall 1992 to Spring 1993 using the final ReVA variable list (Table I).

Table I. Final List of Variables and Variables' Description

Variable Name	Variable Description	Units
AGSL	Agriculture land on steep slopes	%
CROPSL	Crop land on steep slopes	%
DAMS	Impoundment density	dams/1000km
FUNGICIDE	Annual Fungicide loadings	lbs/acre
HARDCHIPMIL	Chip mill capacity for hardwoods	tons
HARDWOODINV	Index values for hardwood inventory	index values
HARDWOODREM	Index values for hardwood removals	index values
HERBICIDE	Annual atrazine loadings 1990-93	lbs/acre
IMPLCPCT	Percent impervious land cover	%
INSECTICIDE	Annual O-P insecticides loadings 1990-93	lbs/acre
MIGSCENARIO	Migratory scenarios that use area	# of scenarios
NO3DEPMODEL	Nitrate wet deposition - modeled	kg/ha
OZONE8HR	Ozone - 8 hr max	ppm-hrs
POPDENS	Population density - 1995	people/sq. mile
PSOIL	Soil loss potential	%
RDDENS	Road density	m/ha.
RIPAG	Agriculture land cover along streams	%
RIPFOR	Forest land cover along streams	%
SO4DEPMODEL	Sulfate wet deposition - modeled	kg/ha
SOFTCHIPMIL	Chip mill capacity for softwoods	tons
SOFTWOODINV	Index values for softwood inventory	index values
SOFTWOODREM	Index values for softwood removals.	index values
STRD	Roads crossing streams	%
SUM06	Ozone - sum 06	ppb
UINDEX	Human use index	%
UVB	Mean annual UV-B irradiance	IRRADIANCE (J/sq. mi)
DISSOLVEDP	Dissolved phosphorus	kg/ha/yr
TOTALN	Nitrogen in surface water	kg/ha/yr
EDGE2	Forest edge habitat at the 2 HA scale	%
EDGE65	Forest edge habitat at the 65 HA scale	%
INT2	Forest interior habitat at the 2 HA scale	%
INT65	Forest interior habitat at the 65 HA scale	%
WETLNDSPCT	Percent wetlands land cover	%
NONCLIMAXPCT	Percent coverage with FOREST but the species aren't the climax listed by Kuchler. These may be planted or successional vegetation.	%
NATCOVERPCT	Percent coverage with FOREST that matches potential vegetation in Kuchler.	%
AQUAEXOTIC	Exotic aquatic species	#
AQUANATIVE	Native aquatic species	#
AQUATE	Threatened and endangered aquatic species	#
TERREXOTIC	Exotic terrestrial species	#
TERRNATIVE	Native terrestrial species	#
TERRTE	Threatened and endangered terrestrial species	#

Variable Name	Variable Description	Units
FORCOVDEFOL	Pct forest cover defoliated as pct of existing forest cover	%

Once the searches were compiled, the next step was again to review the various studies. Information that was not pertinent to our search was discarded. The studies that provided useful information were compiled into a reference table (table II). Comments have additional information. Additional cited references are attached at the end of the table.

Table II. Ecological Threshold Value References

Type of Variable	Value (* indicates primary source)	Citation	Comments
Landscape	<2,000 acres (for local scale species ex. rare species, invertebrates, plants, fens, bogs, streams, less than 10 river miles) 1,000-50,000 acres (for intermediate-scale species ex. amphibians, wetlands, medium lakes 20,000-1,000,000 acres (for coarse scale species ex. fox, badgers, longleaf pines, spruce-fir forests, Finger Lakes, Great Lakes) >1,000,000 acres (for regional-scale ex. migratory birds, bats, insects and animals like wolves, grizzlies, caribou	Functional Landscapes and the Conservation of Biodiversity Poiani K. & B. Richter, The Nature Conservancy http://www.conserveonline.org/2000/11/b/en/WP1.pdf	Local scale: occurrences of small patch communities Intermediate scale: single large patch or several different kinds of habitats. Coarse scale: dominant or historically dominant terrestrial habitat between the patches. Regional scale: vast areas including natural and semi-natural terrestrial matrix, associated patches, connecting corridors. Framework has been tested at variety of conservation areas, landscape breakdowns for best conservation. Larger manuscript can be found in BioScience.
Landscape	368,000 hectares-threshold resulted in 455 of the conterminous US being categorized as large-area counties. 75% of endangered species associated with water found in Southern Appalachians region.	Threatened and endangered species geography: characteristics of hot spots in the conterminous United States. Flather, C.H. May, 1998. Bioscience. http://www.findarticles.com/cf_0/m1042/n5_v48/20924869/print.jhtml	United States Threatened and endangered species are concentrated in distinct geographic regions – because many endangered plants exhibit restricted distributions (Falk 1992), plants make up on average, 365 of endemics in these hot spots. Endangered species in Eastern and western coast hot spots are associated with forest ecosystems.
Landscape – Habitat	Preferred habitat occupied <40% of landscape (habitat specialists exhibited aggregated populations) Suitable habitat <35% of landscape (habitat generalists with good dispersal abilities occurred as aggregated populations) Preferred habitat was a minor (20%) of habitat (habitat generalists with limited dispersal only formed patchy distributions) Good dispersers, which can move ≥ 5% of landscape, are likely to form patchy distributions when their preferred habitat comprises a minor proportion (<35-40%) of landscape. This threshold of aggregation is modified by habitat	Critical Thresholds in Species' Response to Landscape Structure. With, K. A. & T. O. Crist. 1995. Ecology. 76(8): 2446-2459. http://www.ksu.edu/withlab/publications/With&Crist1995.pdf	Simulation model The landscape becomes disconnected when the "backbone" of percolating cluster is broken by removing critical habitat cells along the spine and separating the cluster into two separate habitat patches. Habitat specialists occurred as aggregated populations even when the preferred habitat comprised nearly half (45%) of landscape; unlikely to leave once the patch was encountered. Species with dispersal ranges encompassing 3-20% of landscape shifted from a random to aggregated distribution when preferred habitat occupied < 40% of landscape For habitat generalists, a threshold occurred when preferred habitat comprised ~35% of landscape for species with dispersal ranges varying from 5-20%.

Type of Variable	Value (* indicates primary source)	Citation	Comments
	specificity, however.		
Landscape – Habitat	7,000 contiguous acres (deep woodland protection) patches at 20 acres	Greenway Guide: Connected Habitats. http://www.dutchessny.gov/connectedhabitats.pdf	New York Requirements for selected animals of >20 acres (cottontail, skunk), 20-99 acres (whitetail deer, wild turkey, chickadee), and 100-900 acres (red tail hawk, red fox).
Landscape – Habitat EDGE	240 m (wetlands buffer), Total Suspended Sediment conc. below 25 milligrams/liter should result in lower turbidity and fewer harmful effects on stream and its biota 35% forest cover at scale of 10,000 ha 200 ha (patch size) support 80% of expected forest bird species. 500 m (forest edge buffer) 30 m (stream buffer) <75% vegetation cover stream degradation occurs.	How Much Habitat is Enough? Great Lakes Fact Sheet © Environment Canada 1998. http://www.on.ec.gc.ca/wildlife/factsheets/fs_habitat-e.html	Canada 10% or watershed, 6% of subwatershed should be comprised of wetlands. Waterfowl nest w/in 240 meters of marsh, turtles within 275 meters, make swamps large as possible but 20 meters the least; sediments below 25mg/l to control harmful effects on water, small forest have interior of at least 200 meters, minimum width 500 meters to support interior birds, 30% forest cover, and corridors 100 meters wide.
Landscape – Habitat	70-80% One should not use threshold 10-30% of original habitat as general value in landscape management or conservation of threatened species (Monkkonen and Reunanen, 1999).	Habitat fragmentation, the random sample hypothesis and critical thresholds. Andren, H. 1999. Oikos. 84(2): 206-308.	Hypothesis Loss of species was low at beginning of habitat loss but increased as proportion of lost habitat was above 70-80% depending on species pool. Difference appears only at a high degree of habitat loss that might represent a critical threshold.
Landscape – Habitat Roads INT RDDENS	Semlitsch (1998) recommended for several species of Ambystoma salamanders that buffers around breeding ponds extend to over 160 m (500 ft) and suggested that these areas provide for foraging, growth, maturation, and maintenance. About 40,000 ha (100,000 acres) of bottomlands, in largely forested condition, are needed to support a population of between 50 and 200 bears, depending on the quality of the habitat (Rudis and Tansey 1995). By the same criteria, a population of about 1,000 black bears would require between	Chapter 4: Effects of Forest Management on Terrestrial Ecosystems Baker, J.C. & W.C. Hunter. 2002. In Wear, D.N. & J.G. Greis (eds) Southern Forest Resource Assessment Gen. Tech. Rep. SRS-53. Asheville, NC: US Department of Agriculture, Forest Service. http://www.srs.fs.fed.us/sustain/report/pdf/chapter_04e.pdf	Southeastern United States Where forest cover falls below 70%, these and other data suggest that populations may not be sustainable, but large forest patches within a more fragmented landscape may still be able to support healthy populations (Robinson 1996) (deMaynadier and Hunter 2000), frogs and toads were not inhibited from crossing either narrow (5 m) or wide (12 m) roads in forested landscape: salamanders were inhibited form crossing the wider roads. Some effective restoration probably is possible for red spruce but would require the conversion of existing northern hardwood stands to either spruce or spruce-hardwood mixtures. Some 50,000 acres of such treatment would be needed to reach preharvested forest conditions.

Type of Variable	Value (* indicates primary source)	Citation	Comments
	140,000 ha (350,000 acres) and 1,600,000 ha (4,000,000 acres). These areas could include substantial agricultural acreage. Land planted in grain crops is extensively used by black bears as long as escape cover is nearby.		High stocking rates (700 to 1000 seedings per acre), increasing use of fertilizers and herbicides for maximizing pine growth and reduction of fire as a management changes, essentially have eliminated many of the benefits for early successional species of wildlife that were provided formerly in pine plantations.
Landscape – Habitat <u>INT</u> <u>EDGE</u>	Suitability was considered 'low' if % was less than 10%, 'medium' if % was between 10% and 25%, and 'high' otherwise	Assessing Habitat Suitability at Multiple Scales: A Landscape-Level Approach Ritters, K.H., R.V. O'Neill, & K.B. Jones Biological Conservation. 1997. 81: 191-202.	Chesapeake Bay, US Chesapeake Bay Watershed would approach a woody-cover dominated condition without human influence. A window with 90% or more woody vegetation was considered to be suitable for woodland archetypic species, a window with 90% or more herbaceous vegetation for the herbaceous/field species, and a window of 11% or more of the edges between woody and non-woody for the woodland-edge species.
Landscape – patch size <u>EDGE</u>	*Table II: Patch and/or landscape effects on presence and abundance of animal taxa.* (arachnids, amphibians, reptiles, birds, mammals, insects)	Patch characteristics and landscape context as predictors of species presence and abundance: A review. Mazerolle, M.J., M-A. Villard. 1999. Ecoscience. 6(1): 117-124.	Two out of three mammal studies (scrub, suburban landscape) showed significant landscape effects. Significant effects of landscape context were reported in all five amphibian studies from agricultural, scrub, or suburban landscapes, and both reptile studies (from scrub or suburban landscapes).
Landscape – patch size <u>NATCOVERPCT</u> <u>INT</u> <u>EDGE</u>	More than 70% cover of original native vegetation-rangeland pastoral, extensive forestry, large reserve; patch size at least 10 km² (1000 ha). Between 30 and 70% cover of original native vegetation-livestock grazing; patch size no smaller than 5 km² (500 ha) preferably with connections to other patches, or no more than 1 km gaps across clear land. Between 10 and 30% cover of original native vegetation-cropping and grazing; patch size of least 20 ha minimum to support some woodland birds as long as not to far apart, some at least 200 ha	A Framework for Terrestrial Biodiversity Targets: Murray-Darling Basin. Part 1.6. Framework Explanation. James, C. D. & D. A. Saunders. 2001. CSIRO Sustainable Ecosystems and Murray-Darling Basin Commission, Canberra. http://www.mdbc.gov.au/whatson/FDF/BiodiversityTargetReport.pdf	Australia *Figure 7,8, 9: Decision tree for assigning priorities to each biodiversity attribute for landscapes with more than 70% (fig. 7), 30-70% (fig. 8), and 10-30% (fig. 9) native vegetation cover.* Landscapes 30-70% native cover, short linear strips be useful for connecting patches Patches should be made in a shape that long axis is less than 5 times the length of short axis to minimize edge effect.

Type of Variable	Value (* indicates primary source)	Citation	Comments
	need for many woodland birds that are declining, few patches of 500 ha are recommended. Less than 10% cover of original native vegetation-cropping		
Landscape – patch size NATCOVERPCT INT EDGE	Thresholds are 30% cleared of natural vegetation (70% remains natural) (McIntrye & Hobbs, 1997) *Table B1: Diagnosis of landscapes as classified in this Framework.* small patch 20 ha 30 kms (patch separation) >30% leads to extinction debt Figure of 30% is a minimum value for vegetation communities and landsystems as surrogates for biodiversity retention, and for retention of ecosystem function.	A Framework for Terrestrial Biodiversity Targets: Murray-Darling Basin. Part 2. Background Section. James, C. D & D. A. Saunders. 2001 CSIRO Sustainable Ecosystems and Murray-Darling Basin Commission, Canberra. http://www.cazr.csiro.au/biodiversitytargets/bck_attributes.htm	Australia Landscape thresholds for farming, urban, and natural areas with different selected scales for patch size, habitats, and watershed scales. From between 70 & 60% cover and below, suitable habitat begins to form discrete patches (instead of continuous) and the inter-patch distance increases. Threat and Context analysis section gives a threshold criteria for different situations such as rareness; size and extent; isolation; population; etc.
Landscape – patch size	5% suitable habitat 100 m (distance between patches for long-tailed tit (*Aegithalos caudatus*))	Threshold levels of habitat composition for the presence of the long-tailed tit (*Aegithalos caudatus*) in a boreal landscape Jansson, G. & P Angelstam, 1999. Landscape Ecology 14: 283-290. http://147.46.94.112/e_journals/pdf_full/journal_l/l04_99_140306.pdf	Sweden Used models to show that 30% of habitat suitable for populations, below population declines due to isolation. Threshold effect at 5% suitable habitat, probability of presence when patches are about 100 m apart
Landscape – forests – patch size Roads INT RDDENS	375-500 ha (forest patch size) 300 m x 3km, 35% crown closure, canopy height, 12 meters (connectivity) 200 pieces/acre (wood debris) 10-12/acre (snags) < 0.58 km/km^2 (roads)	Forest Management Guidelines to Protect Native Biodiversity in the Fundy Model Forest –Executive Summary Biodiversity Guidelines Greater Fundy Ecosystem Research Project, UNB Faculty of Forestry and Environmental Management http://www.unb.ca/departs/forestry/centers/cwru/execsum.htm	New Brunswick, Canada Forests patch size 375-500 acres with 35% closed crown cover, mature-overmature forests greater than 500 acres and 60% crown closure. Ten to 12 dead standing and12-15 live for feeding and nesting. Use of Aspen, beech maple or yellow birch good.
Bird habitat – forest Regional level Local level	7,500acres (3,000 ha)(contiguous forest tracts at regional level) areas of at least 250 acres (100 ha) are needed to maintain some	Forest Habitat Maryland Partners in Flight, 1998. Land Management Guidelines for the	Maryland Regional and local criteria for birds including forest edge habitat and management recommendations.

Type of Variable	Value (* indicates primary source)	Citation	Comments
INT EDGE	forest-interior bird communities >25 acres (10 ha)(contiguous forest tracts at local level >100 m (330 ft) (safe forest buffer distance)	Benefit of Land Birds in Maryland. http://www.mdbirds.org/mdpif/forest.html	Keep road widths less than 25 ft (7.6 m) to discourage cowbirds and predators from gaining access to the forest interior.
Bird habitat – scrub Local level INT EDGE	30 ft (10 m)(scrub habitat at forest edge) 100 m (300 ft)(wildlife corridors)	Scrub Habitat Maryland Partners in Flight, 1998. Land Management Guidelines for the Benefit of Land Birds in Maryland. http://www.mdbirds.org/mdpif/scrub.html	Maryland Shrub habitat dominated by low growing shrubs, young, less than 20 ft tall Ex. Golden winged warbler habitat of 25 acres (10 ha) in size. States that corridors should be as wide as possible with the limitation being safe distance to wires.
Bird habitat – grassland Local level INT EDGE	100 acres (40 ha) but preferably 250 acres (100 ha) or larger <0.5 mi(1 km) (distance between grasslands that are 25 – 100 acres in size)	Grassland Habitat Maryland Partners in Flight, 1998. Land Management Guidelines for the Benefit of Land Birds in Maryland. http://www.mdbirds.org/mdpif/grass.html	Maryland Grasslands should be close to each other, less than 0.5 mile (1 km) with threshold of 25 acres (10 ha) in size. Gives management recommendations.
Land birds – habitat INT EDGE	Gives name of bird, status to places can find bird in MD; habitat they occupy	List of Landbirds and their generalized habitats in Maryland (excludes species that rarely occur in the State) Appendix A Maryland Partners in Flight, 1998. Land Management Guidelines for the Benefit of Land Birds in Maryland. http://www.mdbirds.org/mdpif/appendix_a.html	Maryland *Good table of information.*
Birds – habitat INT EDGE	No less than 25 acres (10ha) along streams (forests) 50 - 160 ft buffer for (closed canopy), 320 ft(100m) where canopy is open 20 ft (open buffer along waterways) No less than 50 acres (20ha) (grasslands) for least sensitive to habitat fragmentation 6-8 ha (patch size located within a mi of each other) 70% (canopy closure for forest-interior birds)	The Importance of Corps of Engineers Lands to Migrating and Breeding Birds Fisher, R. A. & H. R. Hamilton. July 2001. Technical Note, Ecosystem Management & Restoration Research Program, ERDC TN-EMRRP-SI-20 http://www.wes.army.mil/el/emrrp/pdf/si20.pdf	United States Corps manage many waterways where birds stop during migration or live. Gives a lowest level for them to survive no less than 25-50 acres with buffers to protect along water ways. Texas alone gets 450-640 different species of birds that reside along coasts. Many area-sensitive species will not use habitat blocks less than their required size even if suitable habitat is present (Hagen and Johnston 1992).

Type of Variable	Value (* indicates primary source)	Citation	Comments
	Effects of edges can extend from 150-300 ft (45-90 m) into forest edge (Rosenberg et al 1999)		
Birds – habitat urbanization INT EDGE UINDEX	>100 m from forest edge (interior habitat), 8-20 area sensitive species (low urbanization) 5-16 area sensitive species (moderately urbanized) 2-10 area sensitive species (high urbanization) American crows detected roughly constant across all urbanization categories	Effects of Urbanization on the Distribution of Area-Sensitive Forest Birds in Prince George's County, Maryland. Dawson D., C. Robbins & L. Darr, 2001. Conservation of Biological Diversity, Conference Proceedings http://www.biodiversitynet.org/conservation/eud.html	Maryland Area sensitive birds prefer low urbanization, expected to have 8-10 species. Low urbanization categorized as portion of land within 300 m in urban land uses <0.33. Moderately urbanized, categorized as portion urban land uses <0.33-0.66. High urbanization categorized as portion of land urban land uses >0.66 Differences in expected number of area-sensitive species among forests in the 3 urbanization categories is greatest for forests smaller than 30 HA
Birds – habitat INT EDGE	Habitat, food, breeding	Illinois Birds http://www.inhs.uiuc.edu/chf/pub/ifwis/birds/index.html 01/02/02; 01/03/02	Selected a few birds to be found endangered or threatened in the Mid-Atlantic states. Give habitat (forest, grassland) food (vegetation) and breeding grounds. Examples of piping plover, short-eared owl, loggerhead shrike, falcon, bald eagle, bachman's sparrow, and swainson's warbler.
Habitat – critical Birds and mammals INT EDGE	Between 10 and 60% of original habitat 10 and 30% of suitable habitat	On Critical thresholds in landscape connectivity: a management perspective. Monkkonen, M., & P. Reunanen. 1999. Oikos. 84(2): 302-305.	Hypothetical 10-60%: neutral landscape modeling and models based on empirical data (Gardner, et al 1987, With and Crist 1995, With 1997, Lamberson et al 1992) 10-30%: below this level of habitat availability the loss of species decline in population size with greater than expected from habitat loss alone (Andren 1994) Existing data suggest that 10-30% threshold in habitat availability for birds and mammals is quite possible an understatement for other species
Fishes – habitat	Temp. not exceed 25°C(coldwater fish), 36°C(warm water fish) low turbidity (less than 20 NTU) <3 ppm dissolved oxygen (warm water streams) <5 dissolved oxygen (cold water streams) > 20 ppm $CaCO_3$ (pH buffering)	Habitat requirements for Freshwater Fishes Morrow J. & C. Fischenich, May 2000. Ecosystem Management & Restoration Research Program, ERDC TN-EMRRP-SR-06 http://www.wes.army.mil/el/emrrp/pdf/sr06.pdf	United States General criteria for maintaining freshwater fishes. *Table 3: Temperature Requirements and Preferences for Select Fish Species*.
Habitat – reptiles and amphibians	>50 m, (buffer width) (Dickson, 1989)	Riparian Habitat Management for Reptiles and Amphibians on Corps of Engineers	United States Abundance of amphibians and reptiles increases in

Type of Variable	Value (* indicates primary source)	Citation	Comments
RIPFOR		Projects Dickerson D., August 2001. Ecosystem Management & Restoration Research Program, ERDC TN-EMRRP-SI-22 http://www.wes.army.mil/el/emrrp/pdf/si22.pdf	streamside zones associated with a closed canopy and leaf litter ground cover (Dickson 1989, Rudolph and Dickson 1990). Both macrohabitat components and microhabitat components should be considered in riparian habitat management for reptiles and amphibians.
Habitat – wildlife INT EDGE UINDEX RIPAG RIPFOR	Forest size supporting diversity in wild: 10 acres/300 ft minimum width (tree species); 50 acres (forest dwelling birds); 600-1,000 acres (falcons, owls) large contiguous >1000 acres for large mammals (Burghardt, 1976; Rogers and Allen, 1987) 100 meters wide(wooded area for deep forest habitat) 50-150 ft (wetland buffer) 35 acres (forest edge & farmland species) (Whitcomb et al., 1981) 600-1,000 acres (raptors) (Fryer-Murza, 1990) 6-30 units/acre high density nodes go long way to alleviate environmental stress	Sustainable Development Patterns: The Chesapeake Bay Region. Rogers J. W., 1992 Water Science Technology, 26(12): 2711-2721.	Chesapeake Bay, US Forests to small for breeding populations, scientists predict many species will last less than 50 years. Woodlands with buffer 150 ft wider remove 89% phosphate and 90% of nitrates. Areas less than 35 acres have fewer species where over 175 acres have more species (Whitcomb et al 1981). Fixed stream corridors range in width from 25-300 ft. Stream corridor widths in suburban areas should range from 65-150 ft. Vegetation in rural stream corridors should be from 50-300 ft wide on either side of the stream.
Habitat – wildlife Fragmentation UINDEX	100 m (disturbance produces islands in habitat) 200 m (habitat is fragmented) >300 m (little habitat avoidance) >15 m (flushing distance for elk, & waterbirds) (Schultz & Bailer, 1978; Cassirer et al., 1992; Rodgers & Smith, 1995) 40 m (flushing distance for grassland raptors) (Holmes et al., 1993) 100 -300m (flushing distance for mule deer) (Ward et al, 1980; Freddy et al., 1986) 1 unit/13 ha (gray fox) (Harrison, 1997) avoid suitable habitat	Estimating the cumulative effects of development on wildlife habitat. Theobald D., J. Miller & T. Hobbs, 1997. Landscape and Urban Planning. 39: 25-36.	Species avoid humans >15 meters depending on the species, except those with history of coexistence with humans (mice, raccoons), deer as far as 1 km. Impacts of habitat near a house or road (10 m) are greater than those further away.
Habitat – mammals	Critical Reserve: Gray wolf - 3606	Edge Effects and the Extinction of	Wide-ranging carnivores are more likely to become

Type of Variable	Value (* indicates primary source)	Citation	Comments
EDGE INT	km²; Black bear - 36 km²; Brown bear - 3981 km²; lion – 291 km²; tiger – 135 km²	Populations Inside Protected Areas. Woodroffe, R. & J. Ginsberg. 1998. Science. 280: 2126-2128.	extinct than those with smaller home ranges, irrespective of population density. Critical reserve size derived using logistic regression models to predict area at which populations persisted with a probability of 50%. This measure is analogous to the LD50 of a drug. Tables show results of logistic regressions on the presence and absence of large carnivores in protected areas falling within their historic ranges all species more likely to disappear from small reserves than larger ones.
Habitat – corridor / edge effects EDGE	200 m (critical distance between 2 woodlands)	Canada Validation Standards ©Environment Canada, 2001. http://www.qc.ec.gc.ca/faune/corridors_verts/html/criteria%20_validation.html *Note: The webpage no longer exists. It is now part of a larger work "A Framework for Guiding Habitat Rehabilitation"	Canada Edge effects can extend into interior 300m, on average.1:1 ratio of edge habitat to forest interior, 900 m is desirable for long-term viability of forest corridors. Research found that 97% of censused species could be found within 400 m of forest edge.
Habitat EDGE INT RIPAG RIPFOR IMPLCPCT	Wetlands – 240 m width of adjacent habitat on each side Riparian – 30 m wide vegetated buffers on each side Forest – 200 ha patch size, 2 km to adjacent patches, corridors should be minimum 100 m wide >15 % imperviousness	A Framework for Guiding Habitat Rehabilitation ©Environment Canada http://www.on.ec.gc.ca/wildlife/docs/framework-e.html.	Document put together as a suggested guideline to habitat protection. Good source of information and method of measuring data. Wetlands should be as large as possible. Vegetation <30 m adjacent to lands *Table 4. wildlife use of various size habitats.* Below 10 % imperviousness to protect land Have 30% should have forest cover <30 ha not support birds
Habitat edge / gap effects EDGE	>50 m (gaps) (*Desrochers & Hannon, 1997) >25 m (edge affect on chickadees)	Winter Responses of Forest Birds to Habitat Corridors and Gaps St. Clair C., M. Belisle, A. Desrochers & S. Hannon, 1998. Conservation Ecology [online] 2(2):13. http://139.142.203.66/pub/www/Journal/vol12/iss2/art13/main.html	Alberta, Canada Study of Chickadees Chickadees not willing to cross open gaps greater than 50 m but under forest, willing to travel up to 200 m. Not venture from forest edge more than 25 m.
Edge effects – birds EDGE	≤50 m from edge	The Effect of Edge on Avian Nest Success: How Strong is the Evidence? Paton P., 1993. Conservation Biology. 8(1):17-26, 1994.	Edge effects occur within 50 meters of an edge. Cowbirds more likely to parasitize nests in open habitat (>40% open canopy w/in 200 m of nests) compared to contiguous forest habitats (<20% open). (Brittingham and Temple, 1983). Correlation between patch size and nest success.
Edge effects – forests	Changes in the percent cover of	Edge Effects in the Mixed Hardwood	North Carolina

Type of Variable	Value (* indicates primary source)	Citation	Comments
EDGE	individual species, the relative cover of exotic species, and species richness indicated that edge effects penetrate deeper on south-facing edges (to 60 m) than on north-facing edges (to 20 m). edge effects could be detected to 50 m on south facing edges and 10-30 m on north-facing edges. Graphic – 1 ha/94% edge; 10 ha/42% edge; 100 ha/14% edge; 1000 ha/5% edge	Forests of the Roanoke River Basin, North Carolina. Fraver, S. 1994. Master of Science Thesis submitted http://www4.ncsu.edu/unity/users/s/shear/public/fraver.htm	Objective of study was to estimate how far the effects of agriculturally maintained edges penetrate the mixed hardwood forests. Mid-day air temperatures were higher and relative humidities were lower near the edge than in the interior, with temperatures stabilizing at 20 m inside the forest and relative humidities at 10 m for both north and south orientations. Analyses of species responses to the edges showed a number of species to be edge oriented; however, no species were found to be interior oriented.
Edge effects – Pines EDGE	A 30 m buffer zone around the north-facing edges or red and jack pine plantation fragments would maintain a forest interior environment, which is required for maintenance of interior understory plant species. Furthermore, south, east, or west facing edges may have a greater depth-of-edge influence than north-facing edges indicating that a buffer of 30 m may not be adequate for an edge of different orientation. *Table 4; info summary of previous selected studies on understory plant species.*	Effects of edges on plant communities in a managed landscape in northern Wisconsin. Euskirchen, E.S., J. Chen, R. Bi. 2001. Forest Ecology and Management. 148: 93-108.	Wisconsin The distance of 120 m was selected as a maximum since it is at least twice the length at which edge effects is the understory of temperate forests in the eastern US have been noted (Palik & Murphy 1990; Fraver 1994; Matlack 1994) 5 species in jack pine stand showed irreversible shift in abundance directly at the edge The largest depth-of-edge influence for an edge-forest species was 30 m into the clearcut for Epigea repens at the jack pines. The largest depth-to-edge influence for an edge-clearcut species was 30 m into the forest interior for Comptonia peregrina at the red pine sites. Edge effects in terms of an increase in exotic species was minimal, suggesting that these younger, relatively isolated, north-facing forest fragmentation are better able to resist exotic invasion.
Edge effects – habitat – patch size EDGE	20,000 ha may be required for northern spotted owls, 60% of which should contain suitable contiguous habitat (Lamberson et al. 1994) microclimatic edge influences can extend 200 m or more into forested patch, a minimum patch width of 600 m should supply a 200 m wide section of interior habitat. Certain size threshold, compact patch shapes should protect interior habitat against detrimental edge effects because these forms	Biodiversity and Interior Habitats: The Need to Minimize Edge Effects. Part 6 or 7. Bannerman, S. June 1998. Extension Note 21. . British Columbia Ministry of Forests Research Program. http://www.for.gov.bc.ca/hfd/pubs/Docs/En/En21.pdf	British Columbia, Canada Trees adjacent to edges may grow more quickly, and regeneration of species such as Douglas-fir and western hemlock can increase, in the first 30-60 m of edge. Tree mortality also increases along edges of newly exposed clearcuts. Franklin (1992)-various patch sizes and % of interior habitat available given a 240 m wide section of edge influence : 10 ha (100%), 20 ha (95%), 40 ha (67%), 80 ha (48%), 160 ha (33%); patch sizes of 50 ha or more will be required to provide significant amounts of unmodified interior forest. Long "hard" edges facing southwest create more pronounced edge effects and result in a greater

Type of Variable	Value (* indicates primary source)	Citation	Comments
	have low edge-to-interior ratios.		penetration of microclimatic influences into adjacent intact forests. Edge-related predation may extend as far as 600 m into the forest patch (Wilcove 1987)
Habitat fragmentation	10 hypothetical organisms per cell, threshold at 7x7 cell patch	Numerically Exploring Habitat Fragmentation Effects on Populations Using Cell-Based Coupled Map Lattices Bevers, M & C.H. Flather, 1999. Theoretical Population Biology 55, 61-76. http://147.46.94.112/e_journals/pdf_full/journal_t/t16_9955105.pdf	Model theory Model theory on habitat fragmentation on population capacity. No exact value to give, just hypothetical.
Habitat fragmentation – birds	45 km (distance for percolation transition for Mexican spotted owl (*Strix occidentalis lucida*))	Detecting Critical Scales in Fragmented Landscapes Keitt, T.H., D.L. Urban & B.T Milne, 1997. Conservation Ecology [online] 1(1): 4. http://www.consecol.org/Journal/vol1/iss1/art4	Southwestern United States Data for suitable nesting habitat for Mexican spotted owls (*Strix occidentalis lucida*). Perceive habitat as large interconnected cluster, travel 45 km over inhospitable habitat, regional transition from connected to disconnected
Habitat fragmentation – birds	40-45 km (*Keitt 1997) Army ant followers disappeared even in fragments as large as 100 ha.	Implications of scale in the study of fragmentation and it effects. PAMS Department, University of Canterbury, Christchurch, New Zealand http://www.cybermagic.co.nz/resources/content/20010810.htm	Southwestern United States Habitat patches at critical distance of between 40-45 km, the regional connectivity transitioned between disconnected and connected phases.
Forest fragmentation – birds	Combination of timber harvests & natural openings comprise <25% of landscapes ≥9km² in size Forest landscapes unsuitable when nearest-neighbour distance between open (non-forested) patches was <100 m; distance between open areas <100 m had no marten captures.	The influence of forest fragmentation and landscape pattern of American martens. Hargis, C. D., J. A. Bissonette, & D. L. Turner. 1999. Journal of Applied Ecology. 36(1): 157-172.	American martens Canopy cover ranged from 28% to 55% and lower limit of 30% is suitable (Koehler & Hornocker, 1977; Spencer, Barrett & Zielinski, 1983). Not detected in sites with >25% open areas, even though forest connectivity was still present.
Habitat fragmentation – insects	*Table 1: Hypotheses and empirical data on the effects of habitat fragmentation on plant and insect communities of calcareous grasslands.*	Insect communities and biotic interactions on fragmented calcareous grasslands – a mini review. Steffan-Dewenter, I. and T. Tscharntke Biological Conservation. 2002. 104: 275-	Europe Connected patches showed slower rates of extinctions and higher species richness than disconnected patches.

Type of Variable	Value (* indicates primary source)	Citation	Comments
		284.	
Forest fragmentation EDGE	500 – 1,000 m (0.5 – 1.0 km) buffer zone needed to accommodate all edge effects (Laurance 1997). Estimated fragments of forests up to 10 km^2 will be composed entirely of edge-affected habitat (Gascon et al. 2000).	Fragmentation – a Serious Threat to Ancient Forests: Summary of Current Scientific Knowledge GRL Technical Note 10/2001 Greenpeace Research Laboratories. http://archive.greenspace.org/~forests/forests_new/html/content/reports/fragmentation.pdf	Edge effects include light, temperature, soil moisture content and wind turbulence. Seed crossing was found to be higher when edge vegetation was thinned and penetrated deeper into the interior of the ancient forest.
Riparian areas – buffers RIPAG RIPFOR	100-ft buffer (general; University of New Hampshire Cooperative Extension); larger buffer recommended for sensitive wetlands 300-1,000 ft on each side of stream for interior forests (Wenger, 1999) US Fish and Wildlife published habitat suitability index 10-350 ft on each side of stream (for birds, mammals, reptiles, amphibians; Castelle, et al., 1994.) 50 ft flat ground then increase additional 4 ft for every 1% increase in slope (Maryland Dept of Natural Resources); Schueler recommends adding 4 ft for every 1% increase of slope above 5%. road crossings less than 2 crossings per km (2 per 0.62 miles) of stream length (May et al., 1997)	Riparian Methodology: A Methodology for Defining and Assessing Riparian Areas in the Raritan River Basin. Newcomb, D. and D. Van Abs. June 2000. http://www.raritanbasin.org/Publications/Methodolgies/Riparian_Methodology.pdf	New Jersey MA Dept. of Fisheries, Wildlife and Environmental Law Enforcement recommends riparian forests be at least 330 ft wide to provide some nesting habitat for neotropical-nearctic songbird migrants. .
Riparian forest buffers RIPAG RIPFOR	Forests of mature trees (30 – 75 years old) are known to effectively reduce nonpoint pollution from agricultural fields 500 ha forest tracks (songbirds) Buffers 100 meters (50-100ft) (for sediments, pesticides, pollutants, habitat help) 2mm of silt deposition caused 100% mortality in white perch eggs and 0.5-1 mm sediment caused	Chesapeake Bay Riparian Handbook: A Guide for Establishing and Maintaining Riparian Forest Buffers Palone, R. S. and A. H. Todd (Eds.) Revised 1998. USDA Forest Service Northeastern Area State and Private Forestry. NA-TP-02-97.	Mid-Atlantic Region, US 3-Zone concept. Zone 1: near stream, improve habitat, greatest impact along smaller streams where canopy completely covers the water surface providing maximum control over light and temperature conditions, trees aid in filtering surface runoff and in some landscapes help remove nutrients carried in groundwater. Zone 2: upslope from zone 1, primary function to remove, transform, or store nutrients, sediments and other pollutants flowing over the surface and through groundwater.

Type of Variable	Value (* indicates primary source)	Citation	Comments
	50% mortality in adults Recommend canopy density be kept at least 80% coverage. Concludes that the maximum shading ability is reached within a width of 80 ft, with 90% of maximum reaches within 55 ft. For forest practices in MD, 50 ft buffer width is modified for slope adding 4 ft for each % of slope Only vegetation within 25 ft of stream channel will provide a powerful role in stabilization. Riparian areas used by reptiles, amphibians, mammals, birds as preferred habitat.	http://www.chesapeakebay.net/pubs/subcommittee/nsc/forest/handbook.htm	Can remove 50-80% of sediment in runoff from upland fields. Zone 3: contains grass filter strips to help slow runoff *Table 3-2: Wildlife Food Plants showing plant species and wildlife species using plants for food.* *Table 5-2: Relative Potential for Sediment Filtering of Surface Runoff According to Riparian Conditions.* *Figure 6-3: Range of minimum widths for meeting specific buffer objectives.* *Table 11-1: Benefits of Urban Riparian Forest Buffers.*
Riparian Forest Buffers RIPAG RIPFOR	50-100 ft (for sediment trapping; Palone & Todd, 1997) 300-400 (to trap clay particles; Wilson, 1967; Cooper et al. 1987) Rudolph and Dickson (1990) a wide variety of reptiles and amphibians used SMZs greater than 98 ft but were scarce in SMZs less than 83 ft wide. Riparian forests less than 328 ft wide were dominated by short-distance migrants while buffers wider than 328 ft had more neotropical migrant species and these continued to increase in numbers much more gradually in forests wider than 656 ft. 25 ft (for edge species; Croonquist & Brooks, 1991; Keller et al., 1993) 100 – 300 ft (to support , large animals and some birds 80-110 ft (for cold water fish; Dosskey et al., 1997; O'Laughlin & Belt, 1995, Palone & Todd, 1997)	Function, Design, and Establishment of Riparian Forest Buffers: A Review. Klapproth, J. C. 1999. http://scholar.lib.vt.edu/theses/available/etd-041399-091320/unrestricted/klapproth1.pdf	Virginia SMZ-Streamside Management Zones More detail than the Chesapeake Bay Riparian handbook with more studies and examples done. Gives buffer width criteria for sediments, pollutants as well as habitats for wildlife. *Table 3.1: Wildlife which prefer riparian area habitat.* Some species not live in buffers unless they are very wide (300 ft or more) 75-100 ft buffer per side to produce water quality and wildlife benefits (Palone and Todd, 1997). Table 5.4: Herbicides for Invasive Plant Control.
Riparian areas – buffers RIPAG	15-200 ft (nutrient removal) 30-300 ft (sediment control) 25-55 ft (streambank stabil.) 25-200 ft (flood control)	Understanding the Science Behind Riparian Forest Buffers: Planning, Establishment, and Maintenance. Table 2.	Virginia Range of minimum widths for meeting buffer objectives.

Type of Variable	Value (* indicates primary source)	Citation	Comments
RIPFOR	23-300 ft (wildlife habitat) 60-110 ft (aquatic habitat) 50-110 ft (water temp. moderation).	Klapproth, J. C. 2001. http://www.ext.vt.edu/pubs/forestry/420-155/table2.html	
Riparian buffers RIPAG RIPFOR	>130 m (reptiles and amphibians) >50 m (mammals) >30 m (invertebrates and fishes) >100 m (birds) 30 m (water quality) 30 -500 m+ (habitat) 20 m (stream)	Design Recommendations for Riparian Corridors and Vegetated Buffer Strips Fischer R. & C. Fischenich, April 2000. Ecosystem Management & Restoration Research Program, ERDC TN-EMRRP-SR-24 http://www.wes.army.mil/el/emrrp/pdf/sr24.pdf	United States Buffers greater than 10 m help reduce sedimentation, nitrates, phosphorus Help benefit reptiles, amphibians, mammals, fish, birds with habitat nestings and breedings, as well provide food and shelter Streams - enhances stability reducing erosion Vegetation - help have impact of low, medium, and high on sedimentation, habitat, water quality. *Table 1: Recommended Widths of Buffer Zones and Corridors for Water Quality.* *Table 2: Recommended Widths for Corridors and Vegetated Buffer Strips for Vegetation, Reptiles and Amphibians, Mammals, Fish, and Invertebrates.* Gives author, state, width, and benefit. *Table 3: Recommended Minimum Widths of Riparian Buffer Strips and Corridors for Birds.* Gives author, location, width, and benefit.
Riparian buffers-birds RIPAG RIPFOR	Corridor widths of 150-175 m were necessary to include 90 – 95% of bird species.	Width of Riparian Zones for Birds Fischer, R. A. January 2000. Ecosystem Management & Restoration Research Program, ERDC TN-EMRRP-SI-09 http://www.wes.army.mil/el/emrrp/pdf/si09.pdf	United States Retaining vegetation helps reduce erosion, sedimentation that could hurt birds, provides nesting, habitat and food Gives table of recommended minimum widths of riparian buffer strips and corridors for birds in various locations Recommended widths for ecological concern in buffer strips, typically wider than those recommended for water quality concerns (Fischer et al., 1999, Fischer, 2000.)
Buffer zone RIPAG	Width up to 100 ft or more necessary on steeper slopes and less-permeable soils to obtain sufficient capacity for infiltration of runoff and vegetation and microbial uptake of nutrients and pesticides. Width up to 100 feet in trees may be needed for adequate shade and water temperature control for cold water fisheries in warm climate	How to Design a Riparian Buffer for Agricultural Land. Dosskey, M., D. Schultz, T. Isenhart. Agroforestry Notes 4. USDA Forest Service, Rocky Mountain Station. http://waterhome.brc.tamus.edu/projects/afnote4.htm	*Table 1: Relative effectiveness of different vegetation types for providing specific benefits* For slopes less than 155, most sediment settling occurs within a 25-30 ft wide buffer of grass
Buffer zone	A general, multi-purpose, riparian buffer design consists of a 50 ft-	A Riparian Buffer Design for Cropland.	Trees and shrubs near the waterway stabilize the bank, improve and protect the aquatic environment,

Type of Variable	Value (* indicates primary source)	Citation	Comments
RIPAG	wide strip of grass, shrubs, and trees between the normal bank-full water level and cropland. Trees spaced 6-10 ft apart occupy the first 20 ft nearest the stream, shrubs spaced 3-6 ft apart dominate the next 10 ft, and grass extends 20 ft further out to the edge of the crop field. This design can be thought of as consisting of 2 rows of trees, 2 rows of shrubs, and 20 ft of grass. Planting trees and shrubs in well-spaced rows make maintenance activities, such as mowing or mulching, easier to do. This design requires 6 acres per mile of bank (12 acres per mile of stream if installed on both sides of the stream).	Dosskey, M., D. Schultz, T. Isenhart. Agroforestry Notes. USDA Forest Service, Rocky Mountain Station. http://waterhome.brc.tamus.edu/projects/afnote5.htm	and protect cropland from flood erosion and debris damage. Grass disperses and slows the flow of runoff from adjacent crop fields which promotes settling of sediment and infiltration of nutrients and pesticides, while vigorously growing vegetation and soil microbes take up nutrients and some pesticides. Perennial vegetation provides wildlife habitat and visual diversity to a cropland landscape. This design may provide only limited control of dissolved nutrients and pesticides in cropland runoff; and be ineffective for stabilizing serious streambank erosion. For wildlife habitat, installation of this buffer design along both sides of a small stream provides an effective width of 100 ft.
Bird physiographic regions MIGSCENARIO TERRNATIVE TERRTE	Priority Bird Populations and Habitats for Physiographic regions (10. Mid-Atlantic Piedmont; 12 Mid-Atlantic Ridge and Valley; 17 Northern Ridge and Valley; 22 Ohio Hills; 24 Allegheny Plateau; and 44 Mid-Atlantic Coastal Plain)	Partners in Flight Physiographic Areas Plans Partners in Flight. http://www.blm.gov/wildlife/pifplans.htm	United States Audubon uses these plans. Also give executive summary and conservation recommendations and needs. Area 44 is only complete available plan to view.
Bird Important Bird Areas TERRNATIVE TERRTE	Watch list of selected birds to conserve of high priority.	National Audubon Society Important Bird Area Programs: State-based Projects Saving Birds and their Habitats http://www.audubon.org/bird/iba	Watch list for PA, MD, DE, WV, VA and some have maps of specific areas within state. Audubon uses PIF physiographic area plans.
Migratory flyways MIGSCENARIO	4 major North American flyways that have been named: the Atlantic, the Mississippi, the Central, and the Pacific. Atlantic: importance to migratory waterfowl and other birds some of which are flocks of Canvasbacks, Redheads and Lesser Scaups that winter on the waters and marshes of Delaware Bay. Coastal route follows the shore line. Many birds that breed east of the Allegheny	North American Migration Flyways. http://www.birdnature.com/flyways.html 1/15/03	Mississippi: longest migration route of any in Western Hemisphere. Not even a ridge of hills on the entire route is high enough to interfere with movements of migratory birds, and greatest elevation about sea level is less than 2000 ft. Well timbered and watered, the entire region affords ideal conditions. Used by # of ducks, geese, shorebirds, blackbirds, sparrows, warbler and thrushes Central: encompasses all of that vast region lying between valley of Mississippi River and Rocky Mtns. Pacific: most of waterfowl that travel the US section of this route come from AK and Mackenzie Valley.

Type of Variable	Value (* indicates primary source)	Citation	Comments
	Mountains parallel to seacoast, move southward in fall.		Closely parallels the eastern foothills of the Rocky Mountains
TERRNATIVE	*Table of Birds of Deciduous/Mixed Forests and Breeding/Nest Facts*	Eastern Forests: Deciduous/Mixed http://www.birdnature.com/deciduous.html	Eastern United States From Delaware to the Carolinas, the loblolly pine is the major tree.
Habitats – migratory birds MIGSCENARIO TERRNATIVE	The diverse habitats of this internationally important flyway include mixed pine and hardwood forest, wax myrtle thickets, beaches, dunes, croplands, open fields, salt marshes, fresh water and brackish ponds and the near shore waters of the Chesapeake Bay and Atlantic Ocean	Location and Habitats Kiptopeke State Park, Eastern Shore of Virginia N.W.R, Fisherman Island N.W.R. Coastal Virginia Wildlife Observatory http://www.cvwo.org/NewFiles/lochab.html	Virginia This small area has yielded significant insights into the volume, timing, distribution and species diversity of bird and insect migration. It ranks as one of the most significant migration areas in North America, a vital link in the Canada-to-South America flyway.
Fish – sedimentation Temperatures RIPAG SEDIMENT	Temp 65° F. Sedimentation 200 ppm	The Effects of Livestock Grazing on Riparian and Stream Ecosystems Armore, C., D. Duff, & W. Elmore. 1991. Fisheries. 16(1): 7-11.	Ungrazed stream zones have better fish habitat, and fish are typically more successful and more numerous than in heavily grazed zones with degraded habitat. When vegetation is removed, summer temp. can reach 85°F or higher. Fish cannot survive if prolonged temps exceeds 65°F. High temps can be acutely lethal, promote disease because of induced stress, adversely impact spawning and reproductive success. Mortality for rainbow trout can exceed 75% (Peters 1962) when sediments elevate to 200 ppm. For steelhead trout, when sediment approximates 30% of the substrate, less than 25 % of eggs develop to emergent fry stage compared to and excess of 75% emergence when sediments are less than 20& (Bjornn 1973).
Forest land	Minimum area 0.4 ha (USNRCS, USDA, USGS) Minimum crown cover: 60% (USNPS) 25% (USNRCS) 10% (USDA) 20% (USGS) Minimum tree height: 6m (USFWS) 5m (USNPS) 4m (USNRCS) 4m (USDA) 2m (USGS)	Forest Extent and Change World Resources Institute. 2000. World Resources 2000-2001 People and Ecosystems: The Fraying Web of Life http://www.wri.org/wr2000/pdf/page_forests_006_extent.pdf	Tables on major forests of the world; Types of forests in the world and threshold values used for defining forest lands from selected countries and organizations. USFWS-US Fish & Wildlife USNPS-US National Park Service USNRCS-US National Resource Conservation Service USDA-USDA Forest Service USGS-US Geological Survey

Type of Variable	Value (* indicates primary source)	Citation	Comments
Forests – trees	Unspaced - threshold diameter at 26m height Spaced – 500 trees per hectare for threshold diameter at 18 m height	Spacing to Increase Diversity within Stands Stand Density Management Diagram http://www.for.gov.bc.ca/hfp/pubs/standman/Sp_Div.pdf	British Columbia, Canada Structural diversity of trees covering structure, crowns, and canopy.
Trees	15 trees/ha density (Rose & Muir, 1996).	Response of Forest Vegetation to Varying Levels and Patterns of Green-tree Retention: An overview of a Long-term Experiment. Halpern, C., S. Evans, C. Nelson, D. McKenzie, D. Liguori, D. Hibbs, and & M. Halaj. 1999. Northwest Science. 73: 27-44. Special Issue.	Oregon. Regional comparisons of 70- to 110-yr-old stands with and without older (>200 yr) residual trees suggest that above a threshold density (ca. 15 trees/ha), residuals can affect the composition of younger cohorts and reduce their basal area growth (Rose & Muir, 1996). *Table 3: Hypothesized short-term (5-10yr) responses of forest overstory and understory communities to varying levels and patterns of green-tree retention.*
Wetlands WETLNDSPCT	Most recognize both OBL (obligate wetland) and FACW (facultative wetland) as hydrophytic and indicators of wetlands because they are more often associated with wetlands. Plants as indicators (vegetation characteristic or soil property essentially unique to wetlands.)	Using Plants as Indicators of Wetland Tiner R., 1993. Proceedings of the Academy of Natural Sciences of Philadelphia. 144:240-253.	Criteria of plants, soils that make up wetlands. OBL >99% of time, FACW 67-99% of the time (estimated probability of occurrence in wetlands) Certain FACU species have adapted to wetland environments Table 6: Recommend list of primary indicators for US Wetlands.
Wetlands WETLNDSPCT	Smaller than 1.2 hectares (USACE proposed new protection threshold) were removed, their loss would dramatically increase the nearest-wetland distance from 471 meters to 666 meters loss of all wetlands smaller than the current Corps protection thresholds (4.0 hectares) translates to an increase in distance to 1,633 meters-beyond, for example, the maximum dispersal of wood frogs.	Size Does Matter: The Value of Small Isolated Wetlands. Semlitsch, R. D. The National Wetlands Newsletter. Jan.-Feb. 2000. p. 5-6, 13. http://www.biosci.missouri.edu/semlitsch/Documents/Ray/PDFSEMLITSCH.PDF	Carolina Bay, US For example, a 1.0-hectare wetland isolated by 500-1,000 meters may have more biological value than a 1.0-hectare wetland with neighboring wetlands just 50-100 meters away Wetland regulations should protect wetlands as small as 0.2 hectares-the lower limit of detection by most remote sensing-until additional data are available to directly compare diversity across a range of wetland sizes.
Habitat – Invasive plants TERREXOTIC	Herbaceous; Shrubs; Vines; Trees	Invasive Non-native Plants that Threaten Native Species and Native Habitats in Maryland Appendix B Maryland Partners in Flight, 1998. Land Management Guidelines for the	Maryland *List of invasive non-native plants that threaten native species and natural habitat in MD.*

Type of Variable	Value (* indicates primary source)	Citation	Comments
		Benefit of Land Birds in Maryland. http://www.mdbirds.org/mdpif/appendix_b.html	
Invasive habitat Roads Edge effects urbanization TERRNATIVE TERREXOTIC TERRTE RDDENS INT EDGE UINDEX	Red imported fire ants are most abundant in open habitats with disturbed soil, where sunlight can reach the soil surface (Stiles and Jones 1998) Gaps of 250 ft or more produced isolation characteristics for some songbirds in small forest fragments created by power lines and roads (Robbins & others 1989). A 10 acre woodlot without any nearby houses had greater species richness and higher abundance of neotropical migrant species than did a 60 acre urbanized woodlot, indicating that the diversity and abundance of neotropical migrant birds decreased with increased urban development (Friesen & others 1995) Urban woodlots of 20 acres or more can support dense and diverse populations of breeding birds, provided that they have adequate shrub understory, mature and dead standing trees, and vegetative edge types of sufficient width and proper quality (Linehan and others 1967) The threshold for avoidance of residential areas by gray foxes is between 130 and 325 residences per square mile (Harrison 1997).	Chapter 3: Human Influences on Forest Wildlife Habitat Graham, K.L. 2002. In Wear, D.N. & J.G. Greis (eds) Southern Forest Resource Assessment Gen. Tech. Rep. SRS-53. Asheville, NC: US Department of Agriculture, Forest Service. http://www.srs.fs.fed.us/sustain/report/pdf/chapter_03e.pdf	Southeastern United States Linear corridors, such as roads and power lines, can exclude sensitive forest wildlife from the adjoining habitat for distances ranging up to 330 ft or more. Many other invasives, such as kudzu, mimosa tree, or princess tree, are less adapt at colonizing deeply shaded, mature forests except along edges, in natural or artificial forest canopy openings, or in disturbed of fragmented forests. *Table 3-3: Some southeastern forest bird species and their sensitivities to urban and suburban development.* Starlings are common in urban and agricultural woods but seldom found in densely forested areas (Ingold & Densmore 1992). House sparrows are found mainly in urban and agricultural areas and seldom found in predominantly forested areas (James & Neal 1986). Most studies found that nesting success decreased near edges as a result of increasing nest predation and parasitism rates. The strongest effects appeared to occur within about 125 ft of the edge. Burrowing owls benefit from light levels of urban development and reach their highest densities in areas 55 to 65 % developed. Even in heavily forested landscapes, ovenbirds showed reduced densities of breeding territories and reduced pairing success within 500 ft of forest roads (Ortega & Capen 1999).
Invasive species? – beetle FORCOVDEFOL	Beetle kill on forest trees – edge density 0.45 km^2 Bark beetle killed patches were relatively more eastern, southern, and southwestern slopes, and at below median elevation (1000m).	Plant-pest interactions in time and space: A Douglas-fir bark beetle outbreak as a case study. Powers, J., P. Sollins, M. Harmon, J. Jones. 1999.	Oregon 14 landscape structure layers at 2 spatial scales: window size of 20 ha (0.45 km^2) and 123 ha (1.11 km^2). These sizes were chosen to bridge 1km, a distance at which point pattern analysis showed significant clustering of patches of beetle kill. Beetle kill occurred in larger patches, more frequent in patches with higher than average edge density at

Type of Variable	Value (* indicates primary source)	Citation	Comments
		Landscape Ecology. 14(2): 105-120.	the 0.45 km² scale. Like mature conifer forest *Table 2: distribution of beetle kill (all size patches) with respect to vegetation cover types defined by a classified TM image*
Biotic/invasive species FORCOVDEFOL	Forest communities have remained resistant to plant invaders as long as the canopy remained intact (Corlett, 1992). Australian paperbark tree which at one time increased its range in south FL by >20 ha per day, replaces cypress, sawgrass and other native species. Covers about 160,000 ha, dense and exclude virtually all other vegetation	Biotic Invasions: Causes, Epidemiology, Global Consequences, and Control Mack, R. N., D. Simberloff, W. M. Lonsdale, H. Evans, M. Clout, & F. A. Bazzaz 2000. Ecological Applications, 10(3): 689-710	1) Animal invaders can cause extinctions of vulnerable native species through predation, grazing, competition & habitat alteration. 2) plant invaders can completely alter the fire regime, nutrient cycling, hydrology, & energy budgets in a native ecosystem & greatly diminish the abundance or survival of native species. 3) in agriculture, principal pests of temperate crops are nonindigenous, and the combined expenses of pest control & crop losses constitute an onerous "tax" on food, fiber, & forage production.
Invasive species – migration Fragmentation TERREXOTIC	Schwartz (1992) found an order of magnitude reduction in migration rate when suitable habitat for colonization occupies only 20% of landscape. Malanson and Cairns (1997) found a threshold in migration rate occurs when suitable habitat is reduced to <33% of landscape. Collingham et al (1996) found that migration rates are little affected by fragmentation until <10% of landscape represents habitat suitable for colonization. Landscape structure affects migration rates only when suitable habitat falls below 10-25%, depending on the pattern of fragmentation (Collingham & Huntley 2000)	The Landscape Ecology of Invasive Spread With, K. A. 2002. Conservation Biology. 16(5): 1192-1203.	If disturbances are small and localized, so as to create a more fragmented pattern of disturbed habitat, the spread of this species will be confined to a small portion of landscape until about 70% of landscape is disturbed, at which point it is able to percolate across entire map. If disturbances are large and concentrated, however, this species would be able to percolate across a landscape in which as little as 30% of habitat had been disturbed. Occurrence of non-native plants is greater along edges of forest fragments (woodlots) in agriculturally dominated landscapes in mid-western US (Brothers & Spingam 1992)
Non-indigenous species: plants, mammals, birds, amphibians & reptiles AQUAEXOTIC TERREXOTIC	700,000 ha/yr-weeds spreading and invading habitat (Babbitt 1998); 115,000 ha/yr-loosestrife spreading and invading wetlands (Thompson et al 1987) 1 rat/5 chicken on poultry farms (D. Pimentel, unpublished; Smith 1984) 5 birds killed per feral cat/year-	Environmental and Economic Costs Associated with Non-Indigenous Species in the United States Pimentel, D., L. Lach, R. Zuniga, and D. Morrison. 1999. Cornell University.	United States Approximately 50,000 foreign species and about 42% of species of threatened or endangered species are at risk because of non-indigenous species. An estimated 5000 introduced species exist (Morse et al. 1995) compared to total 17,000 native species plants (Morin 1995) Center for disease control estimates medical treatment for dog bites costs $165 million/yr, and

Type of Variable	Value (* indicates primary source)	Citation	Comments
	based on WI and VA data – total damage to US bird pop. approx. $14 billion/yr 1 pigeon/ha in urban areas or 0.5 pigeons/person and using potential control costs as suggogate for losses, cause an estimated $1.1 billion/yr in damages (Johnston &Janiga 1995) 700,000/m² mussel densities in some areas (Griffiths et al 1991) and observed completely covering native mussels, clams and snails $24 billion/yr of crop losses due to introduced weeds. European starlings estimated to occur at densities of more than 1per ha in agricultural regions (Moore 1980)-capable of destroying as much as $2,000 worth of cherries per ha; grain fields consume $6/ha of grain (Feare 1980) Costs of hospitalization for a single outbreak of influenza, like type A, can exceed $300 million/yr (Chapman et al 1992)	http://www.news.cornell.edu/releases/Jan99/species_cost.html	indirect costs, such as lost work, increase total costs of dog bites to $250 million/yr (Colburn 1999; Quinlan and Sacks, 1999) Single most serious pest bird in US is exotic common pigeon Guam-introduction of brown tree snake reached densities 100/ha; of 13 native forest birds, 3 still exist; 12 native lizards, 3 have survived (Rodda et al 1997) Introduced balsam woolly adelgid destroyed up to 95% of fraser firs in southern Appalachian with loss of 2 native bird species and invasion by 3 other bird species as result of adelgid-mediated forest death (Alsop & Laughlin 1991) Pest insects destroy about 13% of potential crop production representing a value of about $33 billion in US crops (USBC 1998) Spend about $11 million annually on gypsy moth control In forests, more than 20 non-indigenous species of plant pathogens attack woody plants (Liebold et al 1995). *Table 1: Estimated annual cost associated with some non-indigenous species introduction in US*
Endangered Species <u>AQUATE</u> <u>TERRTE</u>	48% of plants and 40% of arthropods are restricted to single counties. This index suggests that birds and then herptiles provide the best indicators for any particular area.	Geographic Distribution of Endangered Species in the United States Dobson, A. P., J. P. Rodriguez, W. M. Roberts, and D.S. Wilcove. 1997. Science. 275: 550-553. http://geography.uoregon.edu/whitlock/geog423/readings/pdfs/dobsonetal.pdf	United States US map broken down by counties showing endangered species of plants, birds, fish, and mollusks. Table suggests that the counties that contain a complete set of endangered plant species will contain the greatest number of other endangered species. Agriculture activity is the key variable for plants, mammals, birds, and reptiles. water use and human population density are also significant predictors of the density of endangered reptiles.
Turtles <u>TERRNATIVE</u>	0.176 ha (males) and 0.066 ha (females) home ranges In MD, they typically inhabit wet meadows formed by subclimax communities of grasses and	The Distribution, Ecology and Conservation Needs of Bog Turtles, with Special Emphasis on Maryland. Lee, D.S. & A.W. Norden	Maryland Since bog turtles occur in variety of open wetlands lacking a canopy layer and over a relatively broad latitudinal span (34ºN to 44ºN), it is difficult to explain their fragmented geographic distribution based on

Type of Variable	Value (* indicates primary source)	Citation	Comments
	sedges. Sites usually located in level and low gradient (3-8% slopes) spring fed areas that have modest amounts of permanent running water. Most sites occupied are small, 0.40 to 2.0 ha, and the characteristic open sedge meadows are easily swamped by invading woody vegetation.	http://www.tortoisereserve.org/Research/Lee_Norton_Body2.html	habitat availability. Herman (1991) noted that in the Blue Ridge between Virginia and Georgia, bog turtles prefer spring-fed wetlands that contain highly organic mucky soils. Chase et al (1989) found that the greater the index of population density, the more likely the colony site was to be located in a circular basin with spring-fed pockets of shallow water, a bottom substrate of soft mud and rock with interspersed wet and dry pockets, and dominant vegetation of low grasses and sedges.
Forest Defoliation – Gypsy moth FORCOVDEFOL	664 km^2 (aspen-birch) 10,884 km^2 (nonforest) 25,750 km^2 (maple-birch-beech) 62,812 km^2 (oak-hickory) 2,200 km^2 (oak-pine) 380 km^2 (pine)	Landscape Characterization of Forest Susceptibility to Gypsy Moth Defoliation. Liebold A. M., G. A. Elmes, J. A. Halverson & J. Quimby, 1994. Forest Science. 40(1): 18-29.	Pennsylvania Acres of defoliation for six major forest type groups. Pine, oak-pine, and oak-hickory most susceptible, maple-birch-beech, aspen-beech, nonforest –types least susceptible. Susceptibilty to the Gypsy moth decreased at elevations lower than 200 m. 30% defoliation is considered the lower threshold for detection from the air.
Forest – Hemlock	Provides critical winter habitat for moose, white-tailed deer, ruffed grouse, turkey, songbirds, and other wildlife Most common from 1,000 to 3,000 ft in mid-atlantic states (42%), codominant role with number of northern coniferous species, to dominant role in pure stands	Composition, Structure, and Sustainability of Hemlock Ecosystems in Eastern North America McWilliams, W. H. & T.L. Schmidt. 1999. Proceedings: Symposium on Sustainable Management of Hemlock Ecosystems in Eastern North America. June 22-24, 1999. Durham, New Hampshire http://www.fs.fed.us/na/morgantown/hemlock_proceedings/p5.pdf.	United States The overall rate of hemlock mortality across its natural range is 0.26% and among lowest of tree species in states within hemlock's natural range. Of total volume of hemlock that is used, 60% for pulp and paper, 40 % for lumber. Mid-Atlantic states contain 42% of the hemlock inventory, followed by New England (37%) the Lake States (14%) and Southern Appalachian States (8%).
Forest – Hemlock FORCOVDEFOL	100% defoliation (for severe damage in hemlock) Trees completely (100%) defoliated, 74% of canopy hemlock were dead within 1 yr. In contrast, only 28% of white pine understory trees were dead within 5 yrs of the defoliation.	Overview of Hemlock Health Douto, D.R. & K.S. Shields. 1999. Proceedings: Symposium on Sustainable Management of Hemlock Ecosystems in Eastern North America. June 22-24, 1999. Durham, New Hampshire http://www.fs.fed.us/na/morgantown/hemlock_proceedings/p76.pdf	United States. Hemlock trees dies within 1 yr and most of these were dominant or codominant trees. In contrast, many fewer white pine trees died and the trees that did die succumbed slowly-within 5 yrs. Hemlock Stressors: dry sites with exposed ledge; wet, poorly drained sites; close to water; partial harvesting; two defoliations or insects. Map of native range of eastern hemlock and hemlock distribution 1998.
Forest – Hemlock habitats	96 bird and 47 mammal species associated with hemlock	Wildlife Habitat Associations in Eastern Hemlock-Birds, Smaller Mammals, and Forest Carnivores. Yamasaki, M., R. M. DeGraaf, and J. W.	United States

Type of Variable	Value (* indicates primary source)	Citation	Comments
		Lanier. 1994. Proceedings: Symposium on Sustainable Management of Hemlock Ecosystems in Eastern North America. June 22-24, 1999. Durham, New Hampshire http://www.fs.fed.us/na/morgantown/hemlock_proceedings/p135.pdf	
Road density RDDENS	1.8mi/mi^2 0.5-1mi/mi^2 (USFS Forest Plan Standards & Guidelines)	Total Maximum Daily Load Assessment Box Canyon Creek Montezuma County, Colorado. 2002. http://www.cdphe.state.co.us/wq/Assessment/TMDL/pdf/tmdl/BOXTMDLfnl.pdf	Colorado Water quality target -road densities of 1.8 mi/mi^2 throughout watershed. USFS has developed Forest Plan Standards and Guidelines which identify road density standards for various land uses.
Road density RDDENS	Road Density < 1 mi/ mi ^{2} (low) 2-3 mi/ mi ^{2} (moderate) > 3 mi/ mi ^{2} (high)	Appendix N Watershed Sensitivity and Condition Analysis for the Herger-Feinstein QLG Act Pilot Project Area http://www.r5.fs.fed.us/hfqlg/archives/feis/Appendix/App_N.htm	Continues with rating for land use, % of basin in slopes. What they consider impact on watershed.
Road density RDDENS	1 mi/ mi ^{2} (Lyon, 1983; Hornocker, 1981; Naney, 1991; Britell, et al., 1989)	Analysis of Road Densities in Selected Grizzly Bear Management Units in the Northern Rockies. Bechtold, T, D. Havlick, & K. Stockman, 1996. 1996 ESRI International Conference. Palm Springs, CA. May 20-24, 1996. http://gis.esri.com/library/userconf/proc96/TO450/PAP413/P413.htm	Northern Rockies, US Road densities greater than 1 mi/sq mi. reduce habitat and increase mortality for range of mammals including elk, bears, wolverines, and lynx and forest fragmentation for smaller species such as reptiles, rodents, and amphibians, increased encroachment of alien plants in areas of soil disturbance Effects reptiles, amphibians, mammals. US Fish and Wildlife identified 0.5 mi buffers for grizzly habitat. 489 mi ^{2}avg. home range.
Road density RDDENS	1mi/ mi ^{2} <0.6 km/ km^2	Spatial Models as an Emerging Foundation of Road System Ecology and a Handle for Transportation Planning and Policy. Forman, R.T.T. http://www11.myflorida.com/emo/sched/SpatialModels.pdf	Road densities less than 1 mi/sq mi, wolves, mountain lions thrive. Used 8 models.
Road density – traffic effect zone RDDEBS	305 meters for 10,000 vehicles/day in woodlands, 365 m for 10,000 vehicles/day in grassland, 810 m for 50,000 vehicles/day in natural ecosystems in urban areas	Estimate of the Area Affected Ecologically by the Road System in the United States (Abstract of paper) Forman, R. T. T. http://www.magicalliance.org/Fragmentatio	Outer limits of ecological effects along a road calculated as two times the effect distances for the most sensitive bird species highlighted in Dutch studies by Reijnen et al. (1995, 1996)

Type of Variable	Value (* indicates primary source)	Citation	Comments
	(Forman & Deblinger 1999).	n/area_affected_by_roads.htm	
Road density RDDENS	1 mi/ mi ^{2} (elk in Oregon) 0.93 mi/ mi ^{2} (wolves in Wisconsin) 0.8 mi/ mi ^{2} (black bears in Southern Appalachians)	The Ecological Effects of Roads or The Road to Destruction Noss, R. http://www.wildrockies.org/WildCPR/reports/ECO-EFFECTS-ROADS.html	Utah Wolves, grizzlies, black bears survive when less than 1 mi/sq mi. results in 25% reduction in elk habitat. Study shows small mammals rarely venture out when distance between road clearance exceeded 20 meters. Invasive weedy plants invade treefall gaps up to 5 km from forest edge, cowbird penetrate forests at least 200 meters from edge.
Road Density RDDENS	Noise level at which population densities of all woodland birds began to decline averaged 42 decibels (dB), 48 dB for grassland species. <10-20 m but may extend to 200 m downwind. (road dust as sediment transfer may directly damage vegetation, provide nutrients for plant growth, or change the pH and vegetation. (Santelman and Gorham 1988) 1-2 km of wetland –species richness of wetland plants amphibians/reptiles, and birds correlated negatively with road density, southeastern Ontario (Findlay and Houlahan 1997). 2-3 km/km² – increased peak flow in streams (Jones and Grant 1996)	Roads and Their Major Ecological Effects. Forman, R.T.T & L.E. Alexander. 1998. Annu. Rev. Ecol. Syst. 29: 207-31.	US-road density is 1.2 km/km², and drive their cars for about 1 h/day. Plants-few documented cases known of species that have successfully spread more than 1 km because of roads Roads by wetlands and ponds commonly have the highest roadkill rates, even though amphibians may tend to avoid roads (Fahrig, et al 1995). Large and mid-sized mammals especially susceptible on two-lane, high-speed roads, and birds and small mammals on wider, high-speed highways (Evink et al 1996; Oxley et al 1974; Romin and Bissonette 1996). Based on road-effect zones, an estimated 15-20% of the US is ecologically impacted by roads. *Figure 2: Road-effect zone defined by ecological effects extending different distances from a road*.
Road density RDDENS	5 m – disturbed or polluted zone from road (Angold 1997a) 100 m – detectable impact on ecological communities from road (Angold 1997b)	Effects of roads on wildlife in an intensively modified landscape. Underhill, J.E. & P.G. Angold. 2000. Environmental Research. 8: 21-39. http://www.nrc.ca/cisti/journals/sample/a00-003.pdf	United Kingdom *Table 1: A summary of the ecological impacts of extant roads upon local biota* (pollution, change in hydrology, disturbance effects, physical barriers) Molluscs avoid pathways which lack vegetation cover (Oggier 1997) Table on impacts on roads at 3 different size ha on sites. A study of badgers undertaken by Clarke et al (1998) revealed than an increase in badger mortality was proportional to increase in traffic density up to a certain traffic threshold above which badgers resisted crossing the road & consequently the proportional mortality rate fell.
Roads	Shannon wavelet – canopy cover	Vegetation responses to landscape	Wisconsin

Type of Variable	Value (* indicates primary source)	Citation	Comments
Forest canopy RDDENS NATCOVERPCT?	patterns also appeared to be dominated by the 700 m scale, suggesting that canopy cover might be useful variable for predicting plant dominance in the landscape. Roads have been found to affect composition up to 200 m away (Angold 1997) and to decrease plant species richness up to 1 km away (Findlay & Houlahan 1997)	structure at multiple scales across a Northern Wisconsin, USA, pine barrens landscape. Brosofske, K.D., J. Chen, T.R. Crow, & S.C. Saunders. 1999. Plant Ecology. 143: 203-218.	Road near meter 1600 was farther from edges between adjacent patches than the others and seemed to be associated with a very distinct low diversity area. It has been shown that species diversity increases (and composition changes) near closed-open canopy edges (Brothers & Spingarn 1992; Fraver 1994; Matlack 1994).
Roads – turtles RIPFOR	275 m buffer zone around wetlands where no development occurs is necessary to ensure the integrity of turtle communities (Burke & Gibbons 1995) 100 m nesting migration of small turtles (Burke & Gibbons 1995); 5 km nesting migration of larger bodied turtles (Obbard & Brooks 1980)	The effect of road mortality on aquatic turtle populations. Steen, D. The Roosevelt Wild Life Station Conservation and Education Research. http://www.esf.edu/resorg/rooseveltwildlife/Research/turtle%20mort/turtleMort.htm	New York Even without expanding the road base, the current road density and traffic volume is predicted to be high enough to lead to a population decline in several turtle species in many areas across state and may be effective at limiting population growth in rare species, such as spotted and blanding's turtles.
Road stream crossing STRD	Road Stream Crossing Density: < 1 mi/ mi^2 (low) 1-2- mi/ mi^2 (moderate) > 2 mi/ mi^2 (high)	Appendix N Watershed Sensitivity and Condition Analysis for the Herger-Feinstein QLG Act Pilot Project Area http://www.r5.fs.fed.us/hfqlg/archives/feis/Appendix/App_N.htm	California Gives rating for road and road stream crossing, low being less than 1 mi/sq mi.
Road crossings Imperviousness STRD IMPLCPCT	limit stream crossings by roads and utility lines to less than 2 per km of stream length. 10% - stream ecosystem impairment begins	Effects of Urbanization on Small Streams in the Puget Sound Ecoregion. May, C.W, R. R. Horner, J.R. Karr, B.W. Mar, E.B. Welch. 1997. Watershed Protection Techniques. 2(4): 483-494. editors Thomas R. Schueler and Heather K. Holland, published 2000 by the Center for Watershed Protection, Ellicott City, MD http://www.stormwatercenter.net	Pacific Northwest, US Sediment, zinc and lead indicated a relationship with urbanization showing the highest concentrations in the most developed basins.
Imperviousness IMPLCPCT	10% sensitive 15% stressed (Galli, 1993; Gibson et al., 1993; Plafkin et al., 1989)	The Importance of Imperviousness. Schuler, T. R. 1994 Watershed Protection Techniques. 1(3):	Imperviousness 10%-beyond and urban steam habitat quality is classified as poor. Several fish studies show that habitat is poor when imperviousness is 10-15% as estimated from

Type of Variable	Value (* indicates primary source)	Citation	Comments
	Table Review of Key Findings of Urban Stream Studies.	100-111. editors Thomas R. Schueler and Heather K. Holland, published 2000 by the Center for Watershed Protection, Ellicott City, MD http://http://www.stormwatercenter.net	population density that exceeds 4 persons/acre. Table 2 gives ref., year, location, biological parameter and key finding.
Imperviousness IMPLCPCT	0-10% (unimpacted) 11-25% (somewhat impacted) 26%+ (heavily impacted) 8-15% (Maxted et al., 1997; Delaware)	Watershed Characteristics and Aquatic Ecological Integrity: A Literature Review. FitzHugh, T. http://www.freshwaters.org/pub_docs/litrev.pdf	Gives Appendix of article summaries and references to articles summarized.
Imperviousness IMPLCPCT	10-15% all wetlands with more than 20% local drainage basin imperviousness were moderately to severely impaired, primarily due to poor habitat.	The Impact of Urban Stormwater Runoff on Freshwater Wetlands and the Role of Aquatic Invertebrate Bioassessment. Hicks, A. & J.Larson, 1996. Effects of Watershed Development and Management on Aquatic Ecosystems. p 386-401.	Degradation on aquatic ecosystems at 10-20%, habitat impacted >15%. Severe problems after 30%. (Pitt, et al. 1995)
Imperviousness IMPLCPCT	10-25%	Impervious Cover as a Urban Stream Indicator and a Watershed Management Tool. Schueler T. & R. Claytor, 1996. Effects of Watershed Development and Management on Aquatic Ecosystems. p. 513-529.	Impact sensitive streams 10%, shift to poor between 11 & 25% Non-supporting after 25%. Nearly all research used has been preformed in mid-Atlantic and Puget Sound eco-regions.
Imperviousness IMPLCPCT	10 - 20% sites with high levels (≥80%) of forest land use consistently had good IBI and habitat scores.	Influences of Watershed Land Use on Habitat Quality and Biotic Integrity in Wisconsin Streams. Wang, L., J. Lvons, P. Kanehl, & R. Gatti. 1997. Fisheries. 22(6): 6-12.	Wisconsin Threshold value of urbanization between 10% and 20% beyond which IBI scores were consistently low. sharp threshold between 10% and 20% urban land use across which IBI scores declined dramatically Found little influence of agriculture on habitat quality or biotic integrity in watersheds with less than 50% agriculture. This suggests that there may be a threshold level at which agricultural impacts begin to manifest themselves.
Imperviousness Pesticides IMPLCPCT PESTICIDE	ISC=10-20% - hydrologic and geomorphic (Booth & Jackson 1997), biological (Klein 1979, Yoder et al 1999) Urban use accounts for more than 136,000 kg, which is a third of US	Streams in the Urban Landscape Paul, M.J. and J.L. Meyer. 2001. Annu. Rev. Ecol. Syst. 32: 333-65.	*Table 1: Effects of impervious surface cover (ISC) resulting from urbanization on various physical and biological stream variables.* Pesticide application rates on golf courses (including herbicides, insecticides, and fungicides) exceed 35 pounds/acre/year, whereas corn/soybean rotations

Type of Variable	Value (* indicates primary source)	Citation	Comments
	pesticide use. Invertebrate measures declined significantly with increasing ISC until they indicated maximum degradation at 17% ISC Above 45% ISC, all streams were degraded, regardless of riparian status. Fish response to increasing urbanization: urban land use: 0-5%-sensitive species lost; 5-15%-habitat degradation occurs and functional feeding groups lost; above 15%-toxicity and organic enrichment result from severe degradation (Yoder 1999)		receive less than 6 pounds/acre year (Schueler 1994) In one study on Long Island urban streams had mean summer temps 5-8° C warmer and winter temps 1.5-3°C cooler than forested streams.
Urbanization UINDEX	>60% (threshold of watershed urbanization beyond which attainment of warm water habitat is unlikely)	Using Biological Criteria to Assess and Classify Urban Streams and Develop Improved Landscape Indicators. Yoder, C. O. & R. J. Miltner, and D. White http://www.epa.gov/ORD/WebPubs/nctuw/Yoder.pdf	Ohio Habitat IBI scores used. The upper threshold of urbanization which corresponded to a loss of warmwater habitat attainment was in the 25-30% range. Quality and extent of riparian zone ceased to be effective above 45-60% impervious land cover
Urbanization UINDEX	2.53 housing unites/hectare continuous negative response to increasing urbanization = <5% urban land use loss of sensitive fish and macroinvertebrate species due to substrate degradation, disruption within the aquatic food web at intermediate levels of development, and response to toxicity, organic enrichment, or both at higher levels of development (>15% urban land use	Assessing the Status of Aquatic Life Designated Uses in Urban and Suburban Watersheds Yoder, C. O. & R. J. Miltner, and D. White. 1999. National Conference on Retrofit Opportunities for Water Resource Protection in Urban Environments. Proceedings Chicago, IL. Feb. 9-12, 1998. http://www.epa.gov/ORD/NRMRL/Pubs/1999/625K99002.pdf	Cuyahoga River Basin, OH Housing density identified a threshold level of urbanization, coinciding with 2.53 housing units per hectare, beyond which IBI or ICI scores will increasingly fail to attain the biological criteria for the warmwater habitat use designation. Mean IBI scores from streams with less than 3% urban land use were significantly higher than those with greater than 33% urban land use
Imperviousness – population density POPDENS	4 persons/acre	Fish Dynamics in Urban Streams Near Atlanta, Georgia Couch, C et al., 1997. Technical Note 94. Watershed Protection Techniques. 2(4): 507-510. editors Thomas	Georgia Watershed population density exceeds 4 persons/acre, streams rated poor. Used results of 3 studies in GA to make this determination.

Type of Variable	Value (* indicates primary source)	Citation	Comments
		R. Schueler and Heather K. Holland, published 2000 by the Center for Watershed Protection, Ellicott City, MD http://http://www.stormwatercenter.net	
Population, housing density & urban land use UINDEX POPDENS	8% urban land use (Yoder et al., 1999; Cuyahaoga River watershed) 33% urban land use (Yoder, et al.; Columbus watershed) 15% urban land use (Yoder, et al.; drainage areas of less than 100 mi^2) poor IBI exist at 2.5-4 persons/acre (Jones and Clark 1987; Couch et al 1997; Dreher 1997; Yoder et al 1999).	Watershed Characteristics and Aquatic Ecological Integrity: A Literature Review. FitzHugh, T. http://www.freshwaters.org/pub_docs/litrev.pdf	Gives Appendix of article summaries reviewed on imperviousness and housing density effects on watersheds. 10% sensitive, 15% stressed for streams. Myers et al (1997) found that in Puget Sound area, a road density of 3.5 km/km² corresponded to 10% impervious cover, and 5.5 km/km² corresponded to 25% impervious cover.
Housing density Urban land use UINDEX POPDENS	0.5-1.5 person/acre 15-33% urban land use *Table Comparison of different land use indicators.*	Housing Density and Urban Land Use as Indicators of Stream Quality. Ken Brown. Technical Note 116. Watershed Protection Techniques. 2(4): 735-739. editors Thomas R. Schueler and Heather K. Holland, published 2000 by the Center for Watershed Protection, Ellicott City, MD http://www.stormwatercenter.net	Midwest, US Fish IBI dropped when watersheds exceeded 33% urban land use, 15% in another study where watershed size was < 100 sq mi. 0.5-1.5 persons/acre was fair with 1.5 and above had significant degradation.
Population density – timber POPDENS	Population density between 20 and 70 people per square mile- transition between rural and urban land use. Population effects reduce commercial inventories between 30 and 49% in the study area. For each 20% increment in population, timberland area drops by roughly 4%.	The effects of population growth on timber management and inventories in Virginia. Wear, D.N., R. Liu, M. Foreman, R.M. Sheffield. 1999. Forest Ecology and Management. 118: 107-115. http://www.srs.fs.fed.us/pubs/rpc/1999-06/rpc_99jun_46.pdf	Virginia The probability declines as population density increases and approaches zero as density reaches ca. 150 people per square mile (psm). The odds of being commercial forest land are roughly 50:50 at a population density of 45 people psm and the probability of commercial forestry is >0.75 at ca 20 people psm. At 70 psm there is a 25% chance of commercial forestry.
Population – animals POPDENS	Franklin (1980) has suggested that, simply to maintain short-term fitness, the minimum effective population size (in the genetic sense) should be around 50. He further recommended that to maintain sufficient genetic	Minimum Population Sizes for Species Conservation Shaffer, M.L. BioScience. 1981. 31(2): 131-134.	Short-term fitness (i.e., prevent serious in-breeding and its deleterious effects)

Type of Variable	Value (* indicates primary source)	Citation	Comments
	variability for adaptation to changing environmental conditions, the minimum effective pop. size should be around 500.		
UV radiation UVB	4.6 – 77 Gy (LD_{50} for woody plants) (*Sarapul'tsev & Geras'kin, 1989) 4.6-16.0 Gy (LD_{50} for conifers) (*Sarapul'tsev & Geras'kin, 1989) 5x10-4 Gy/day (dose intensity) (Shevchenko et al., 1992) UHF irradiation with wave length λ=3 cm, energy flux density of 150-200 mW/cm², and exposure for 1-25 min caused a lethal effect in many insects as well as mammals (mice, rats, rabbits, sheep).	Estimation of Effects of Physical Factors on Natural and Agricultural Ecological Systems. Geras'kin J. A. & G. V. Koz'min, 1995. Russian Journal of Ecology. 26(6): 389-393.	Woody plant are least radio resistant (conifers) and being most sensitive, marked suppression of growth and dying off of needles observed at doses 1.2-2.5 Gy (*Aleksakhin, 1982). Aquatic microorganisms most sensitive. Ryegrass, wheat, and oaks very resistant. Mosses, lichens, and soil fungi are more resistant to radiation in comparison to woody and herbaceous plants.
Acid deposition – nitrate NO_3DEP	10kg N/ha-y (forests)>5-10 kg/ha (watersheds in the East) 15-20 kg N/ha/yr (forest and chaparral watersheds surrounding the Los Angeles Basin)	Acid Deposition: The Ecological Response. A Workshop Report March 1-3, 1999 Washington, DC. The Ecological Society of America http://esa.sdsc.edu/aciddep.htm	Above the threshold shows leaching loses of nitrate
Acid deposition – nitrate Sulfate NO_3DEP SO_4DEP	3-10 kg N/ha/y (forests; Fox et al., 1989) <3kgN/ha/y (desert, shrub, or forest) <3 kg S/ha/y (forests; Fox et al., 1989) 2.7-6.7 kg S/ha/y (for oligotrophic lakes and streams) by Canadians	National Park Service Atmospheric Deposition http://www.aqd.nps.gov/ard/pubs/ColoPlat.Review/chap1_14.html	Colorado Plateau NADP protocols do not assess dry deposition rates. Acid deposition for areas of concern across the Colorado Plateau Gives maps of 1990-1994 Average Nitrate/Sulfate Deposition.
Acid deposition – nitrate NO_3DEP	Order of sensitivity using a broad vegetation classification would be: Acid grassland/bog > conifer forest > deciduous forest > cultivated/fertile areas. Table of critical loads ranges from literature (Grennfelt & Thornelof 1992; Hornung et al. 1995) for application to different sensitivity classes based on vegetation type. Class 1: 40-100 kg N/ha/yr. Class 2: 15-30 kg N/ha/yr. Class 3: 10-20 kg N/ha/yr. Class 4: 5-15 kg N/ha/yr.	Critical loads for nitrogen deposition and their exceedance at European scales. Kuylenstierna, J., W. Hicks, S. Cinderby, H. Cambridge. 1998. Environmental Pollution. 102(S1): 591-598.	Europe *Table 1: vegetation types range from Class 1 (least sensitive) to Class 4 (most sensitive) in their sensitivity to impacts of nitrogen deposition.* Example Class 1: vineyards, soft fruits, mixed orchards, citrus fruits, nuts. Class 2: birch, beech, various oaks. Class 3: dwarf birch, spruce and/or fir, mixed conifers, pine/spruce with birch. Class 4: tundra/rock/ice, peat bog, swamp marsh.

Type of Variable	Value (* indicates primary source)	Citation	Comments
Acid deposition – sulfate Acid neutralizing capacity SO_4DEP ANCWTAVG	<200μeq/L (ANC) and >10kg/ha (sulfate deposition) (Schindler, 1988)	Descriptive Risk Assessment of the Effects of Acidic Deposition on Rocky Mountain Amphibians. Corn P. & F. Vertucci, 1992. Journal of Hepetology, 26(4): 61-369.	Rocky Mountains, US Sulfate range 10-25 kg/ha pose a risk of acidification to sensitive watersheds, habitats with ANC<200μeq/L and sulfate deposition >10 kg/ha considered to be at risk of acidification.
Acidification – pH value	pH 6.5 Sensitive pH 5.5 (sensitive organisms)	Environmental impacts on freshwaters: acidification as a global problem. Psenner R., 1994. The Science of the Total Environment. 143: 53-61. 1/02	Europe Biological effects of acidification start early (pH 6.5), sensitive organisms the threshold is pH 5.5. Mollusks, crustaceans, and fishes pH 5.5 represents endpoint rather than beginning of acidification
Acidification – pH value	Ph decreases to 5.5, species richness in phytoplankton, zooplankton, and benthic invertebrate communities decreases (Baker et al, NAPAP SOS/T 13 1990; Locke, 1983). Direct foliar damage can occur from precipitation with extremely low ph levels (i.e. 3.0-3.6 and below)	Benefits and Costs of the Clear Air Act. Appendix E: Ecological Effects of Criteria Pollutants US EPA http://www.epa.gov/oar/sect812/appen_e.pdf	United States Biological affects of pH on fishes Table Summary of Biological Changes with surface water acidification at different pH levels -6.0 to 5.5 – loss of sensitive species, decrease in species richness 5.5 to 5.0 – loss of sport species including lake trout, walleye, rainbow trout and smallmouth bass 5.0 to 4.5 – loss of most species. NAPAP defines acidic conditions as occurring when the acid neutralizing capacity (ANC) is below 0 μeq/L.
Acid neutralizing capacity Acid deposition – sulfate ANCWTAVG SO_4DEP	25μeq/L 0 μeq/L SSWC Model: 19 kg SO_4 ha^{-1} yr^{-1} (Adirondacks) 18 kg SO_4 ha^{-1} yr^{-1} (Maine) 18 kg SO_4 ha^{-1} yr^{-1} (S. New Engla nd) Magic Model: 19 kg SO_4 ha^{-1} yr^{-1} (Adirondacks) 18 kg SO_4 ha^{-1} yr^{-1} (Maine) 18 kg SO_4 ha^{-1} yr^{-1} (S. New England)	Sensitivity of Critical Load Estimates for Surface Waters to Model Selection and Regionalization Schemes. Holden Jr.G. R., T. Strickland, P. W. Shaffer, P. F. Ryon, P. L. Lingold, R. S. Turner. J. Environ. Qual. 22: 279-289, 1993.	Europe Used 25μeq/l and 0 μeq/L for ANC value. 25μeq/L value corresponds to a pH of between 5.8 and 6.0. Aquatic ecosystems undergo measurable degradation when chronic pH levels fall below 6.0 (Schindler, 1988,; Baker et al., 1991) 0 μeq/L value corresponds to a surface water pH of about 5.3 used to define acidic surface water. Models suggest that deposition changes on the order of 9"2 kg SO_4 ha^{-1} yr^{-1} are sufficient to affect steady state surface water ANC values from 25μeq/L to 0 μeq/L
Acid neutralizing capacity ANCWTAVG	Base flow sensitive #50 μeq/L^{-1} (Schindler, 1988)	The Effects of Acidic Deposition on Streams in the Appalachian Mountain and Piedmont Region of the Mid-Atlantic United States.	Mid-Atlantic region, US Most low acidic streams located in small (<20 km²) upland forests, Many fish species not found when pH is in range 5-5.5. Has tables of population estimates of acidic and low

Type of Variable	Value (* indicates primary source)	Citation	Comments
		Herlihy A., P. Kaufmann, M. Church, Wigington, Jr P., J. Webb & M. Sale, 1993. Water Resources Research. 29(8): 2687-2703.	ANC Streams resources in the mid-Atlantic Highlands; estimates of stream acid base status within physiographic provinces; physical and chemical characteristics of acidic and nonacidic NSS upstream reach ends, population estimates of the number and proportion of mid-Appalachian acidic reaches based on index conditions and worst case episodic conditions using the two-component mixing model of Eshleman (1988) and snyopic stream chemistry surveys in the mid-Atlantic Highlands region.
Acid Deposition Eutrophication Ozone – plant Sulfur dioxide (SO2) Nitrogen oxides (Nox) ANCWTAVG SUM06 SO_4DEP NO_3DEP	ad: Sulphur – 3 kg/ha/yr (forest soils) e: between 3 and 20 kg N/ha per year terrestrial ecosystems; 2-5 kg/ha per year "natural" forests o: AOT40 value of 3000 ppb-hours for crops (regarded as an "acceptable" loss in yield), semi-natural plant communities; AOT40 value of 10,000 ppb-hours for forest trees has been proposed SO2: 10-20 µg/m³ (forest ecosystems and natural vegetation), 30 µg/m³ (crops) both as annual mean and half-year mean; 10 µg/m³ (lichens) NO2: 30 µg/m³ *Table 1 and 2 info on critical loads of sulphur and nitrogen*	Critical Loads Environmental factsheet published by the Swedish NGO Secretariat on Acid Rain. Updated May 1998. http://www.acidrain.org/cl_fact.htm	Sweden Proposed critical load figures have always tended to be set successively lower as research methods improve and more data becomes available. In terrestrial ecosystems the critical loads for nitrogen defined with reference to forest soils, the intention being to preserve ecosystem stability in long run 40 ppb referred to as AOT40, accumulated exposure over a threshold of 40 ppb The impact of ozone on organic materials, such as rubber, pigments, and various polymers, a provisional critical level of 20 ppb chosen. European ecosystems can at most withstand a deposition of 200 acid equivalents per hectare per year (eq/ha/yr). In terms of sulphur, that amounts to 3.2 kg S/ha/yr.
Acid deposition Sulfur dioxide Nitrogen SO_4DEP NO_3DEP	Sulfur-20 mg m-3 or .007 ppm (Stockholm Environment Institute, pg. 196-197) Nitrogen 1-3 kg N/ha	Acid Rain http://www1.ldc.lu.se/iiiee/IMPACTS/ACID_RAIN/ACIDRAIN_HOME.HTML	Sweden Sensitivity is first evident at levels above 30 mg m-3. Some vulnerable species of trees, mosses, lichens, and bushy and grassland vegetation begin to show physiological damage at 20 mg m-3 Nitrogen- critical load is lowest for low-productivity forest land and for virgin forest, whereas in productive spruce forest it can be as high as 10-20 kg N/ha Lower the pH levels, the higher the mercury concentration found in fish
Impairment Waters 303(d) list	Mid-Atlantic selected states. Impairment on selected watersheds	EPA's Total Maximum Daily Load (TMDL) Program.	United States Each state gives list by waterbody type or watershed name then search further to view % of impairment

Type of Variable	Value (* indicates primary source)	Citation	Comments
		National 1998 Section 303(d) List Fact Sheet. http://oaspub.epa.gov/waters/national_rept.control?p_cycle=1998	damage. Gives also impairment reported, impairment priorities, and approved TMDLs by pollutant.
Water Quality – nitrogen Soil loss	The greater the average slope gradient, the greater the soil loss, ranging from a total of 6.8 tons per acre lost when the slope gradient was 1%, to 19.4 tons per acre at 4%, to 32.3 tons per acre at 6%, to 33.7 tons per acre at 7% (Beasley and others 1984). Dissolved oxygen concentrations of 8 mg per L are considered optimal for aquatic organism health (Chapman and Mcleod 1987; USEPA 1986)	Chapter 21: Forest Impacts on Water Quality Fulton, S. & B. West. 2002. In Wear, D.N. & J.G. Greis (eds) Southern Forest Resource Assessment Gen. Tech. Rep. SRS-53. Asheville, NC: US Department of Agriculture, Forest Service. http://www.srs.fs.fed.us/sustain/report/pdf/chapter_21e.pdf	Southeastern United States Beschta and others (1987) found that retaining canopy cover generally keeps temperature increases to less than 2ºC. 10 mg/L is appropriate for water bodies whose designated uses include municipal drinking water. However, aquatic communities respond to much lower levels of inorganic nitrogen. Very little studies done on insecticides. No studies identified adverse affects on aquatic biota from phosphorus and nitrogen.
Water quality – nitrogen and phosphorus	10mg/L (N) (*EPA, 1976) 0.10 ug/L (P) (*EPA, 1976)	National Strategy for the Development of Regional Nutrient Criteria EPA Fact Sheet, EPA Office of Water. June 1998. http://www.epa.gov/OST/standards/nutsi.html	United States Nitrate criteria to protect human and animal health, phosphorus criteria to protect marine and estuarine waters.
Water quality – nitrogen and phosphorus	Low, medium, high for steams and shallow ground water - no exact number	National findings and their implications for water policies and strategies. USGS Geological Survey Circular 1225. http://Water.usgs.gov/pubs/circ/circ1225/html/national.html	Table of relative level of contamination in steams and groundwater of nitrogen, phosphorus, herbicides, insecticides.
Water quality – Nitrate Phosphate Pesticides	Maximum Allowable Concentration: Nitrate – 50 mg N/l Phosphate – 5000 μg P/l Pesticides – individually: 0.1 μg/l, total: 0.5 μg/l	The Impact of Agriculture on Water Quality Cartwright, N., L. Clark, & P. Bird. 1991. Outlook on Agriculture. 20(3): 145-152.	United Kingdom From Europe Community Drinking Water Directive guidelines which should not be exceeded is based on World Health Organization. Pesticides may be more firm (more stingent than the 0.1μg/1 MAC) because some pesticides may be highly toxic to aquatic life.
Nitrogen	0.1 mg/L (P) (*USEPA)	Nutrients are a potential concern for aquatic life USGS Geological Survey Circular 1225 http://Water.usgs.gov/pubs/circ/circ1225/html/aquatic.html	No criteria for nitrogen for steams.
Nitrogen	53.6 million lbs/y	Nutrient Inputs to Mainstream and Tributory	Maryland

Type of Variable	Value (* indicates primary source)	Citation	Comments
		Waters. Maryland's Environmental Indicators Status Report, 1998. http://www.mde.state.md.us/enpa/2000_enpa/envi_indicators/wq_eco04.html	MD goal of nutrient input for Chesapeake Bay.
Nitrate	10 ppm	Nitrate Concentrations in Forested Watershed Map. The State of the Nation's Ecosystems http://www.us-ecosystems.org/forests/essential_chemicals/detailview3.html	United States EPA drinking water standard for nitrate.
N :P ratio	Koerselman and Meuleman have generalized that under conditions where either N or P limits plant growth, an N : P ratio >16 indicates P limitation on a community level, while an N : P ration <15 indicates N limitation. At N : P ratios between 14 and 16, either N or P can be limiting, for plant growth is limited by N and P together.	Impact of environmental nutrient loading on the structure and functioning of terrestrial ecosystems. Singh, K.P. & S.K. Tripathi. 2000. Current Science. 79(3): 316-323. http://tejas.serc.iisc.ernet.in/~currsci/aug102000/ra43.pdf.	In many terrestrial ecosystems, N deposition rates range from 2.5 to 20 N/ha/yr. Several other ecosystems increased N deposition levels (30-64 kg N /ha/yr) have been reported to cause imbalances in mineral nutrition. Tilman and Pecala have concluded that peak diversity is obtained in habitats with soils of low to intermediate levels of nutrient supply.
Phosphorus	3.74 million lbs/y	Nutrient Inputs to Mainstream and Tributory Waters. Maryland's Environmental Indicators Status Report, 1998. http://www.mde.state.md.us/enpa/2000_enpa/envi_indicators/wq_eco/wq_eco04.html	Maryland MD goal of nutrient input for Chesapeake Bay.
Phosphorus	0.001 ppm (marine and estuarine water Parry 1998) >0.05 ppm (streams entering lakes and reservoirs) >0.025 ppm (within lakes or reservoirs) >0.10 ppm (prevention of plant nuisances in streams or other flowing water not discharging to lakes or impoundments)	Managing Phosphorus: Agronomic and Environmental Concerns Voss, R. 1999. Illinois Fertilizer Conference Proceedings, January 25-27, 1999. http://frec.cropsci.uiuc.edu/1999/report1/	The critical concentration of P associated with accelerated aquatic growth is very low, 0.01 ppm, but a range from 0.01 to 0.03 ppm seems to be accepted (NCR 1993) A dissolved p concentration of 1 ppm is the limit required of sewage-treatment output and on advocated by some as critical flow-weighted-mean-annual concentration for agricultural runoff. The dutch have designated a critical P saturation value of 25 % (Van der Molen et al. 1998) Studies in US have generally found low concentration of DP in tile drainage, but

Type of Variable	Value (* indicates primary source)	Citation	Comments
			concentrations frequently exceed the projected critical value of 0.01 ppm of P for algae growth (Baker et al. 1975)
Phosphorus	USEPA (1986) recommended a limit for controlling eutrophication of 0.05 ppm for total phosphorus in streams that enter lakes and 0.1 ppm for total phosphorus in flowing streams.	Phosphorus, Agriculture & The Environment. Mullins, G. Virginia Cooperative Extension. Pub. No. 424-029. 2001. Virginia Tech. http://www.ext.vt.edu/pubs/grains/424-029/424-029.html	Virginia In Virginia, the critical value for maximizing crop yields is 55 ppm of Mehlich I extractable phosphorus. However, Mehlich I phosphorus levels in excess of 300 ppm have been observed in VA soils with a history of poultry litter and/or other manure application.
Ozone – plant SUM06	0.06 ppm	Ozone –It's Formation & Impacts on People and Plants Southern Research Station, Forest Service http://webcam.srs.fs.fed.us/ozone.htm	Vegetation exposure to ozone in western North Carolina.
Ozone – plant SUM06	60 ppb	Chapter 2. Overview of Ozone Effects on Vegetation NPS Technical Information in support of the Interior's Request for Rule the to Request for Restore & Protect Air Quality Related Values. http://www.aqd.nps.gov/ard/epa	Foliar injury, reductions in leaf and root biomass when ozone constant over 60 ppb. Heck and Cowling (1997) recommended 3-month, 8:00 a.m. to 8:00 p.m., SUM 06 effects endpoints for natural vegetation, i.e. 8 to 12 ppm-hrs for foliar injury to natural ecosystems and 10 to 15 ppm-hrs for growth effects on tree seedlings in natural forest stands.
Ozone – plant SUM06	40 ppb (AOTA40; *Ashmore, M.R. & Wilson, R.B., 1994) 60 ppb (1 hr exposure) 16 ppb (8 hr exposure)	Chapter 12. Effects of ozone on vegetation: critical levels Air Quality Guidelines for Europe. 2000. http://www.who.nl.aqg/12-ozonelevel.pdf	Europe To protect vegetation from reductions in shoot growth and seed production, long-term effects and yield losses of 5% or 10%, forest tree species from long term effects and growth reductions before deterioration.
Ozone – plant SUM06	35-60 ppb (*Legge et al., 1995)	The Importance of High-Level Versus All Levels of Hourly Average Concentrations for Affecting Vegetation © A. S. Lefohn http://www.asl-associates.com/peaks.htm	Mid level concentrations more important than hourly average, but agree 35-60 ppb is best level, Ex. levels >.087 ppb for US crops.
Ozone – plants SUM06	Ozone – 0.06 ppm	Benefits and Costs of the Clear Air Act. Appendix F: Effects of Criteria Pollutants on Agriculture. US EPA http://www.epa.gov/oar/sect812/1990-	United States SUM06 threshold (0.06 ppm) was selected to conform with recent EPA ozone NAAQS (Abt Associates, 1998) and may correlate more closely to crop damage (Lefohn et al. 1988).

Type of Variable	Value (* indicates primary source)	Citation	Comments
		2010/ch_apf.pdf	
Ozone – human OZONE8HR	1 hr – 125 ppb 8 hr – 85 ppb	TX Natural Resource Conservation Commission - NAAQS http://www.tnrcc.state.tx.us/air/monops/naaqs.html	Texas Ozone level to protect the public
Ozone – human OZONE8HR	1 hr – 0.15 ppm 8 hr – 0.08 ppm	EPA National Ambient Air Quality Standards (NAAQS) http://www.epa.gov/airs/criteria.html	United States Ozone level to protect the public including sensitive populations
Ozone – human / plant OZONE8HR SUM06	Human – 0.08 ppm Plants – 0.06 ppm	Science, Uncertainty, and EPA's New Ozone Standards Lefohn, A. 1997. Environmental Science & Technology. 31(6): 280A-284A, 1997.	EPA standard to protect humans and plants. Ozone induced health effects, including decreased lung function, increased respiratory symptoms, hospital admissions and emergency room visits for respiratory causes, and inflammations of the lung. EPA predicted that 50% of species and cultivars tested would exhibit a yield loss of 10-20% across the range of SUM06 index of 25-38 ppm-h (US EPA 1996).
Ozone – human / plant Particle matter OZONR8HR SUM06	There is an 8.5% increase in hospital emergency departments visits per 10 ppb increase of ambient ozone levels (SAD) and a high correlation between high tropospheric ozone levels and worker absenteeism (Dockery 1993) CEPA reference level for ground ozone is considered 15 ppb (as 1 hour daily maximum) and 25/15 µg/m³ for PM 10/2.5 (24 hour average) 60 ppb –ozone causes injury to foliage, increases susceptibility to diseases and other stresses in plants and tree species, reduces yields in sensitive crops (CWS). According to the most recent Science Assessment Document, ozone is linked to detrimental effects in the respiratory systems of animals, such as lung haemorrhages in birds (SAD)	Particulate Matter, Ground-Level Ozone, and the Canada-Wide Standards Regulatory Process. Hancey, C. December 1999. http://www.sierraclub.ca/national/climate/ground-level-ozone.html Note: This paper was undertaken as part of a student term project at Dalhousie University.	Canada Over 40 studies have concluded similar results: there is no threshold under which human and environmental effects (arguably intricately interwoven) do not occur, and the health and environment damage relationship to these pollutants is linear. Background levels are said to be the "natural" levels at which the pollutants occur in the atmosphere. Recorded background levels range from 25-40 ppb over a 1 hour averaging period for ground level ozone, and from 4-11 µg/m³ for PM 10 and 1-5 µg/m³ for PM 2.5 over a 24 hour averaging period. PM has long been associated with chronic bronchitis and asthma, but has never been established as a causal agent, only an aggravate
Ozone – human Particle Matter	PM 2.5 – 30 µg/m³	Ontario and the Canada-Wide Standards for particulate matter and ground-level	Ontario, Canada Canada-Wide standard for PM is more than 50%

Type of Variable	Value (* indicates primary source)	Citation	Comments
OZONE8HR	Ozone – 65 ppb (average 8 hours)	ozone Ontario Ministry of the Environment programs and initiatives. Dec. 1999. http://www.ene.gov.on.ca/programs/3924.pdf.	more stringent than the US limit. Canada-Wide standard for ozone is about 20% more stringent than the US target. Receives pollution from US.
Pollutants – ozone Sulphur dioxide, nitrogen oxide SUM06	SO2 – 250 ppb Ozone – 80 ppb NO2 – 1000 ppb	Air Pollution and Agriculture Ashmore, M. 1991. Outlook on Agriculture. 20(3): 139-144.	Summary of major air pollutants. Concentration is approximate threshold for visible injury on sensitive crops after exposure for less than one day. Sensitive crops barley, tobacco, bean, pea, maize Gives threshold for hydrogen fluoride (100 ppb) and ammonia (5000 ppb). 4 major ways in which air pollutants may damage agricultural production: 1) Direct visible injury, usually to leaf tissue, 2) direct effects on growth and yields, 3) effects on crop quality, 4) indirect effects.
Organic compounds Sulphur dioxide, particle matter, cabon monoxide, nitrogen dioxide, VOCs	0.5 tonne/yr-Organic metals and chromium (VI) compounds 20 tonnes/yr-sulphur dioxide, PM, carbon monoxide, NO2; consistent with most US jurisdictions (target 90% capture of Ontario point source emissions) 10 tonnes/yr-VOCs (target for a grater than 90% capture of Ontario emissions) 100,000 tonnes/yr-CO2; consistent with US jurisdictions 5,000 tonnes/yr-methane (capture emissions from large landfills) 5 kilograms-methyl mercury to harmonize with NPRI alternate reporting threshold	Rationale for Development of Reporting Thresholds. Ontario Ministry of the Environment http://www.ene.gov.on.ca/envision/env_reg/er/documents/2001/ra00e0016e.pdf.	Ontario, Canada The 268 NPRI (National Pollutant Release Inventory) share common reporting thresholds including 10 employees or more, 10 tonnes of substances manufactured, processed or otherwise used (MPO) or more, and lowere alternate thresholds for polycyclic aromatic hydrocarbons (PAH), polychlorinated dibenzodioxins (PCDD) and polychlorinated dibenzofurans (PCDF), hexachlorobenzene and mercury. In addition, the MOE (Ministry of the Environment) has developed lower MPO thresholds for 79 contaminants not on the NPRI list.
Atrazine-frogs HERBICIDE	0.1 ppb (Hayes)	Pesticide blames for sexual mutation in frogs. Associated Press, 2002. CNN.com http://www.cnn.com/2002/TECH/science/04/16/frog.mutations.ap/index.html	Berkeley research team found that amounts as small as 0.1ppb affect frogs. EPA permits 3 ppb, Find full study in Proceedings of the National Academy of Science.
Atrazine HERBICIDE	Atrazine – 3 ug/L Alachlor - 2 ug/L Simazine – 4 ug/L	Pesticides in Surface Water of the Mid-Atlantic Region.	Mid-Atlantic Region, US Atrazine is most widely applied herbicide, chlorpyrifos and chlorothalonil are most widely used

Type of Variable	Value (* indicates primary source)	Citation	Comments
		Ferrari, M.J., S.W. Ator, J.D. Blomquist, J.E. Dysart Water Resources Investigations Report 97-4280. http://dg33dmdtws.er.usgs.gov/maia/97-4280	insecticide and fungicide, respectively. MCL and Health Advisories established by USEPA pertain to finished drinking water, they do provide values with which ambient concentrations can be compared.
Atrazine HERBICIDE	0.5 ppb, the behavior of goldfish was affected: more "burst swimming", a sudden spurt of no-directed movement, followed by immobilization of the fish. Variety of studies have documented effects at or below 20 ppb: researchers from University of Ulm, Germany, showed 2 ppb of atrazine decreased photosynthesis of a water moss to about 10% of that in unexposed plants (Hofmann & Winkler 1990), biologist from University of Sydney, Australia, found 10 ppb of atrazine caused a decrease in photosynthesis of seagrass (Ralph 2000), Smithsonian Institute scientists measured 50% mortality and reduced reproduction of wild celery exposed to 12 ppb of atrazine (Correll & Wu 1982). Danish researchers found soil from a freshwater wetland was unable to completely break down atrazine (Larsen et al 2001). Because of it's long persistence in wetlands, USDA and Clemson University scientists calculated a wetland buffer would have to be at least 100 m (325 ft) wide in order to mitigate atrazine-contaminated runoff (Lavy, et al 1996).	Atrazine: Environmental Contamination and Ecological Effects. Cox, C. Herbicide Factsheet. Journal of Pesticide Reform. 2001. 21(3): 12-20. http://www.pesticide.org/atrazineEnv.pdf.	Can damage natural communities. Low concentration of 0.04 ppb reduced the release of a sex hormone from testes cells in Atlantic salmon and reduced their milt (sperm) production by about 50% (Moore and Waring 1998) Stress (measured by an increase in blood protein) occurred in rainbow trout at a concentration of 3 ppb (Davies, et al 1994). At 5 ppb, goldfishes grouping behavior decreased (Saglio & Trijasse 1998), swimming behavior of zebrafish was altered (Steinberg et al 1995), and kidney damage occurred in rainbow trout (Fischer-Scherl 1991). At 10 ppb, the ability of shiners to withstand warmwater decreased (Messaad et al 2000). Concentrations of 20 ppb caused dramatic declines in the abundance and diversity of plant-eating insects in experimental ponds conducted at the University of Kansas. Study conducted by EPA researchers in MN wetlands found that algae exposed to 15 ppb were less productive than algae in untreated wetlands.
Atrazine HERBICIDE	Hayes saw no hermaphroditic frogs in locations where atrazine was absent, while sites with at least 0.2 parts per billion in water all had	Herbicide Scrambles Frogs' Sex Organs. Atrazine feminizes the amphibians. Marcus, A.	Report found on latest findings appears in Nature.

Type of Variable	Value (* indicates primary source)	Citation	Comments
	such creatures.	University of Maryland Medicine. 30-Oct-2002. http://www.umm.edu/natnews/509952.html	
Pesticide - Insects	*Current recommended Economic Thresholds for Insect Pests - insect crop economic threshold (Pest Management Unit of Sustainable Production Branch)* Stands that show patches of thinning, stunting, or dying off, may be the first indication of an infestation, as they are usually visible from a distance.	Economic thresholds of insect pests Saskatchewan Agriculture, Food and Rural Revitalization http://www.agr.gov.sk.ca/DOCS/crops/integrated_pest_management/insects/thresholds.asp	Saskatchewan, Canada An economic threshold is the insect's population level or extent of crop damage at which the value of the crop destroyed exceeds the cost of controlling the pest., expressed in variety of ways including number of insects per plant per square mile, the amount of leaf surface damage, etc. Economic thresholds serve merely as a guideline to the producer Crop monitoring techniques are given as well as cultural control of insect pest.
Pesticide	1% loss of 1 lb./acre pesticide application can contaminate all of the drainage from a field in a normal year at 5 parts per billion (ppb.) This level can be of concern if the drainage water enters drinking water supplies. Iowa Dept. of Natural Resources study of pesticides in spring rainwater commonly detected alachlor and atrazine in concentrations approaching 1ppb.	Understanding and reducing pesticide losses. PM 1495. Revised Feb. 1999. Iowa State University University Extension. http://www.extension.iastate.edu/Publications/PM1495.pdf	Atrazine is more likely to be found in both surface water and groundwater. Application and postapplication losses to the atmosphere may far exceed those moving in water. Crop rotation tends to reduce the need for pesticides, thereby eliminating or reducing their use. Some studies suggest that as much as 50% of some pesticides is washed off the residue by a light, 1/2 – inch of rain.
Pesticides	Pesticides have potential to accumulate in sediment and aquatic biota if they had (1) a water solubility less than 1 milligram per liter (mg/L) or an octanol-water partition coefficient (Kow) greater than 1,000 and (2) a soil half-life greater than 30 days.	Pesticides in Stream Sediment and Aquatic Biota. Current Understanding of Distribution and Major Influences USGS http://www2q-city.com/shelbayreports/sediments/pesticides_in_stream_sediment.pdf	Fish was the most common type of aquatic biota sampled, followed by mollusks and other invertebrates. Kow is an indirect measure of lipid solubility, so that hydrophobic compounds tend to have a high Kow and low water solubility.
Pesticides	Acute lethal doses (LD50) for the mallard duck showed that 16 of 20 organophosphates were acutely toxic at doses less than 20 milligrams per kilogram (mg/kg) of body weight and the most toxic had an LD50 over twenty times smaller (Porter 1991).	Pesticides and Birds: From DDT to Today's Poisons Cox, C. Journal of Pesticide Reform. 1991. 11(4): 2-6.	Dinoseb, a dinitrophenol herbicide that interferes with the basic energy metabolism in both plant and animal cells (USEPA 1986), kills wild birds at doses of 7 mg/kg (NIOSH 1991) and is acutely toxic to birds as some of the most toxic insecticides. Herbicides can indirectly cause birds' starvation or force them to leave treated areas because the herbicides destroy habitat used by the birds' prey.

Type of Variable	Value (* indicates primary source)	Citation	Comments
	Some nestings died after being fed paraquat at 10 mg/kd, which is one-third of the LD50 for humans (Hoffman et al 1985).	http://www.pesticide.org/birds.pdf	
Sedimentation SEDIMENT	<63 µm in size are most important fraction for contaminant adsorption and transport, due to relatively large surface area and geochemical composition (Stone & Droppo 1994). Well-sorted grains (0.2-0.5 mm) have the lowest threshold velocity and critical bed shear. Benthic insectivores and herbivores declined as did lithophilous/gravel spawners, as the volume of <62.5-µm sediment increased within the bed.	Biological Effects of Fine Sediment in the Lotic Enviornment. Wood, P.J. and P.D. Armitage. 1997. Environmental Management. 21(2): 203-217.	Lewis (1963) found tat suspended cola particles seriously damanged the aquatic moss, *Eurhynchium riparioides.* Deleterious abrasion of the plant leave was evident within 3 weeks at a sediment concentration of 100 mg/L and the development of new side shoots only occurred at concentrations below 500 mg/L. *Table 3: Ecological impact and cause of an increase in suspended sediment and sedimentation in rivers and streams.* Impact, cause and author.
Soils – Salinity PSOIL	0-2 Ece(dS/m) (mostly negligible) 2-4 Ece(dS/m) (sensitive restricted) 4-8 Ece(dS/m) (tolerant only) >16 Ece(dS/m) (only a few very tolerant)	Salinity and Plant Tolerance. Kotuby-Amacher, J., R. Koenig, B. Kitchen. http://extension.usu.edu/publica/agpubs/agso03.pdf	Utah High soil salinity may lead to leaf burn and defoliation. Fruits, vegetables and ornamentals are more sensitive than field crops. Above the threshold, associated with expected yield losses of 10%, 25% and 50% are indicated. 2Ece is general overall level before yield-reducing effects begin. Gives threshold for variety of different crops.
Soils – Erosion PSOIL	2-5 tons/acre/y	T value (or T level) US House Committee on Agriculture http://agriculture.house.gov/secgloss/tu.htm	United States Average soil loss that will permit current production levels to be maintained economically.
Soils – Erosion PSOIL	1 t/ha	Soil Erosion Assessment by Means of LANDSAT-TM and Ancillary Digital Data in Relation to Water Quality. Jürgens C. & M. Fander, 1993. Soil Technology. 6: 215-223.	Germany Values greater than 1 t/ha have negative impact on water quality, with lowest tolerable soil erosion threshold on shallow soils. Vineyards and crop-land show medium to high rates.
Soils – Erosion PSOIL	13 ton/ha/y (= 1mm/year)	Criteria and Instruments to Control Soil Erosion Poesen, J. http://www.desertification.it/doc/AlgheroWEB/Poesen.htm	Mediterranean environment / Europe 13 ton/ha/y accepted for deep medium-texture soils under temperate humid conditions. Instruments to control soil erosion (soil conservation techniques), gives good examples.
Soils – Erosion	2-11 tons/ha/y (*Larson et al.,	Erosion	Arizona

Type of Variable	Value (* indicates primary source)	Citation	Comments
PSOIL	1984)	Orr, B. 2002. Office of Arid Lands Studies, The University of Arizona http://ag/arizona.edu/agnic/erosion.html	Soil Conservation considers threshold of 2-11 tons/ha/y depending on soil characteristics.
Soils – Erosion slopes PSOIL		Environmental Guidelines Appendix E Erodible Soils List http://www.ci.rockville.md.us/cityprojects/envguide/egappendD.html	Maryland List of soils classified as highly erodible from Natural Resources Conservation Service in MD, give soils and slope %.
Erosion - slope	Slope gradient 3-5° (*Ebisemiju, 1988)	Slope Gradient and Soil Erosion http://www.cs.uwindsor.ca/gully/Erosion/Inclination_of_slope.htm	Threshold limit of slope erosion in laterite terrain in Guyana -length 225 m and slope gradient of 3-5°. Moderate (3-20°) - active erosion. Very steep (>20°) – mass movement. Gives graphs to support different slope thresholds.
Erosion - Slope buffers	0-30% slope, 3-8 m (next to pastures; Johnson & Ryba, 1992), 0-70% slope, 8-46 m (near logging; Johnson & Ryba, 1992) 2-6% slope, 23-92 m (livestock feedlots; Johnson & Ryba, 1992)	Riparian Buffer Widths at Rocky Mountain Resorts. Brown E. W., J. E. Jones, J. K. Clary & J. M. Kelly, 1996. Effects of Watershed Development and Management on Aquatic Ecosystems. p. 278-294.	Rocky Mountains, US Buffer for erosion potential. Gives additional info from Johnson & Ryba, 1992 on buffers on water quality (30-120 m), sediment (30-38 m), habitat (67-92 m for small mammals, 75-200 m for birds, 100 m or larger mammals), and 30 m for benthic).

Additional References

Abensperg-Traun, M., G. T. Smith, G. W. Arnold, D. E. Steven. 1996. The effects of grazing on animal communities in remnants of gimlet *Eucalyptus salubris* woodland in the Western Australian wheatbelt. I. Anthropods. Journal of Applied Ecology 33: 1281-1301.

Abt Associates. 1998. Agricultural Benefits Using AGSIM for the NOx SIP Call. Prepared for U.S. Environmental Protection Agency (US EPA)/OAQPS.

Aleksakhin, R. M. 1982. Yadernaya Energiya I Biosfera (Nuclear Energy and the Biosphere). Moscow: Energoatomizdat.

Alsop, F. J. and T. F. Laughlin. 1991. Changes in spruce-fir avifauna of Mt. Guyot, Tennessee, 1967-1985. Journal of the Tennessee Academy of Sciences 66(4): 207-209.

Andren, H. 1994. Effects of habitat fragmentation on birds and mammals in landscapes with different proportions of suitable habitat: a review. Oikos 71: 355-366.

Angold, P. G. 1997 . The impact of a road upon adjacent heathland vegetation: effects on plant species composition. Journal of Applied Ecology 34: 409-417.

Ashmore, M. R. and R. B. Wilson, eds. 1994. Critical levels for air pollutants in Europe. London, Dept. of the Environment.

Askins, R. A., M. J. Philbrick, D. S. Sugeno. 1987. Relationship between the regional abundance of forest and the composition of forest bird communities. Biological Conservation 39: 129-152.

Babbitt, B. 1998. Statement by Secretary of the Interior on invasive alien species. Proceedings, National Weed Symposium, BLM Weed Page. April 8-10, 1998.

Baker, J. L., K. L. Campbell, H. P. Johnson, J. J. Hanway. 1975. Nitrate, phosphorus, and sulfate in subsurface drainage water. Journal of Environmental Quality 4: 406-12.

Baker, J. P., D. P. Bernard, S. W. Christensen, M. J. Sale, J. Freda, K. Heltcher, D. Marmorek, L. Rowe, P. Scanlon, G. Suter, W. Warren-Hicks, P. Welbourn. 1990. Biological effects of changes in surface water acid-base chemistry. NAPAP SOS/T Report 13. In: Acidic Deposition: State of Science and Technology, Volume II, National Acid Precipitation Assessment Program. Washington, D.C.

Baker, L. A., A. T. Herlihy, P. R. Kaufmann J. M. Eilers. 1991. Acidic lakes and streams in the United States: The role of acid deposition. Science 252: 1151−1154.

Beasley, R. S., E. L. Miller, S. C. Gough. 1984. Forest road erosion in the Ouachita Mountains: pp. 203-212. In: P. A. Peters and J. Luchok (eds.) Proceedings of the mountain logging symposium. Charleston, WV: West Virginia University.

Bellamy, P. E., S. A. Hinsley, I. Newton. 1996. Factors influencing bird species numbers in small woods in south-east England. Journal of Applied Ecology 33: 249-262.

Benke, A., E. Willeke, F. Parrish, D. Stites. 1981. Effects of Urbanization on Stream Ecosystems. Completion Report Project No. A-055-GA. Office of Water Research and Technology. US Dept. of Interior.

Beschta, R. L., R. E. Bilby, G. W. Brown [and others]. 1987. Stream temperature and aquatic habitat: fisheries and forestry interactions: pp. 191-232. In: E. O. Salo and T. W. Cundy (eds.) Streamside management: forestry and fishery interactions. Contrib. 57. Seattle: University of Washington, College of Forest Resources.

Bjornn, T. C. 1973. Survival and emergence of salmon and trout embryos and fry in gravel-sand mixtures. Idaho Cooperative Fisheries Research Unit, University of Idaho, Moscow.

Black and Veatch. 1994. Longwell Branch Restoration-Feasibility Study. Vol. 1. Carrol County, MD Office of Environmental Services. 220 pp.

Blake, J. G. and J. R. Karr. 1987. Breeding birds in isolated woodlots: Area and habitat relationships. Ecology 68: 1724-1734.

Booth, D. B. and C. R. Jackson. 1997. Urbanization of aquatic systems: degradation thresholds, stormwater detection, and the limits of mitigation. Journal of American Water Reosource Association 33: 1077-90.

Booth, D. 1991. Urbanization and the Natural Drainage System-Impacts, Solutions and Prognoses. Northwest Environmental Journal 7(1): 93-118.

Britell, J. D., R. J. Toelker, S. J. Sweeney, G. M. Koehler. 1989. Native cats of Washington. Washington Dept. of Wildlife, Olympia, WA.

Brittingham, M. C. and S. A. Temple. 1983. Have cowbirds caused forest songbirds to decline? Bioscience 33: 31-35.

Brönmark, C. 1985. Freshwater snail diversity: Effects of pond area, habitat heterogeneity and isolation. Oecologia 67: 127-131.

Brown, A. L. and J. A. Litvaitis. 1995. Habitat features associated with predation of New England cottontails: What scale is appropriate? Canadian Journal of Zoology 73: 1005-1011.

Brosofske, K. D., J. Chen, T. R. Crow, S. C. Saunders. 1999. Plant diversity at multiple scales across a northern Wisconsin pine barren landscape. Plant Ecology 143: 203-218.

Brosofske, K. D., J. Chen, R. J. Naiman, J. F. Franklin. 1997. Harvesting effects on microclimate gradients from small streams to uplands in western Washington. Ecological Applications 7: 1188-1200.

Brothers, T. S. and A. Spingam. 1992. Forest fragmentation and alien plant invasions on central Indiana old-growth forests. Conservation Biology 6: 91-100.

Buhlmann, K. A. 1998. Ecology, terrestrial habitat use, and conservation of a freshwater turtle assemblage inhabiting a seasonally fluctuating wetland with emphasis on the life history of *Deirochelys reticulaira*. Ph.D. diss., University of Georgia.

Burbrink, F. T., C. A. Phillips, E. J. Heske. 1998. A riparian zone in southern Illinois as a potential dispersal corridor for reptiles and amphibians. Biological Conservation 86: 107-115.

Burke, V. and J. W. Gibbons. 1995. Terrestrial buffer zones and wetland conservation: A case study of freshwater turtles in a Carolina bay. Conservation Biology 9:1365-1369.

Cassirer, E. F., D. J. Freddy, E. D. Ables. 1992. Elk response to disturbance by cross-country skiers in Yellowstone National Park. Wildlife Society Bulletin 20: 375−381.

Castelle, A. J., A. W. Johnson, C. Connolly. 1994. Wetland and stream buffer size requirements – A Review. Journal of Environmental Quality 23: 878−882.

Chapman, D. W. and K. P. McLeod. 1987. Development of criteria for fine sediment in the Northern Rockies ecoregion. US EPA Water Div. Rep. 910/9-87-162. Seattle: US Environmental Protection Agency.

Chapman, L. E., M. A. Tipple, L. M. Schmeltz, S. E. Good, H. L. Regenery, A. P. Kendal, H. E. Gary, N. J. Cox. 1992. Influenza–United States, 1989-90 and 1990-91 seasons. Mortality and Morbidity Weekly Report Surveillance Summaries 41(SS-3): 35-46.

Chase, J. D., K. R. Dixon, J. E. Gates, D. Jacobs, G. T. Taylor. 1989. Habitat characteristics, population size and home range of the bog turtle, *Clemmys mahlenbergi*, in Maryland. Journal of Herpetology 23(4): 356-362.

Chen, J., J. F. Franklin, T. A. Spies. 1992. Vegetation responses to edge environments in old growth Douglas-fir forests. Ecological Applications 2: 387-396.

Clarke, P. G., P. C. White, S. Harris. 1998. Effects of roads of badger, *Meles meles* populations in south-west England. Biology Conservation 86: 117-124

Coker, D. R. and D. E. Caspen. 1995. Landscape-level habitat use by brown-headed cowbirds in Vermont. Journal of Wildlife Management 59: 631-637.

Colburn, D. 1999. Dogs take a big bite out of health care costs. The Washington Post, February 2, 1999. Page z5.

Collingham, Y. C. and B. Huntley. 2000. Impacts of habitat fragmentation and patch size upon migration rates. Ecological Applications 10: 131-144.

Collingham, Y. C., M. O. Hill, B. Huntley. 1996. The migration of sessile organisms: a simulation model with measurable parameters. Journal of Vegetation Sciences 7: 831-846.

Cooper, J. R., J. W. William, R. B. Daniels, W. P. Robarge. 1987. Riparian areas as filters for agricultural sediments. Soil. Sci. Soc. Am. J. 51: 416−420.

Corlett, R. T. 1992. The ecological transformation of Singapore, 1819-1990. Journal of Biogeography 19: 411-420.

Correll, D. L. and T. L. Wu. 1982. Atrazine toxicity to submersed vascular plants in simulated estuarine mesocosms. Aquatic Botany 1982: 151-158.

Couch, C. et al. 1997. Fish Dynamics in Urban Streams Near Atlanta, Georgia. Technical Note 94. Watershed Protection Techniques 2(4): 511−514.

Cronquist, M. J. and R. P. Brooks. 1991. Use of avian and mammalian guides as indicators of cumulative impacts in riparian-wetland areas. Environmental Management 15: 701−714.

CWS Development Committee (DC) for PM and Ozone. May 1999. Discussion Paper on Particulate Matter (PM) and Ozone: CWS Scenarios for Consultation.

Darveau, M., P. Beauchesne, L. Belanger, J. Huot, P. Larue. 1995. Riparian forest strips as habitat for breeding birds in boreal forest. Journal of Wildlife Management 59: 67-78.

Davies, P. E., L. S. J. Cook, D. Goenarso. 1994. Sublethal responses to pesticides of several species of Australian freshwater fish and crustaceans and rainbow trout. Environmetal Toxicology and Chemistry 13: 1341-1354.

Defenders of Wildlife. http://www.defenders.org

DeMaynadier, P. G. and M. L. Hunter, Jr. 2000. Road effects on amphibian movements in a forested landscape. Natural Areas Journal 20: 56-65.

Desrochers, A. and S. J. Hannon. 1997. Gap crossing decisions by forest songbirds during the post fledging period. Conservation Biology 11: 1204−1210.

de Vries, H. H., P. J. den Boer, Th. S. van Dijk. 1996. Ground beetle species in heathland fragments in relation to survivial, dispersal, and habitat preference. Oecologia 107: 332-342.

Dickman, C. R. 1987. Habitat fragmentation and vertebrate species richness in an urban environment. Journal of Applied Ecology 24: 337-351.

Dickman, C. R. and C. P. Doncaster. 1987. The ecology of small mammals in urban habitats. I. Populations in a patchy environment. Journal of Animal Ecology 56: 629-640.

Dickson, J. G. 1989. Streamside zones and wildlife in southern U. S. forests. Practical Approaches to Riparian Resource Management: An Educational Workshop. R. G. Gresswell, B. A. Barton and J. L. Kershner, eds. U.S. Bureau of Land Management, Billings, MT. 131−133.

Dockery, D. W. et al. 1993. An Association between Air Pollution and Mortality in Six US Cities. The New England Journal of Medicine 329(24): 1753-1759.

Dosskey, M. G., R. C. Shultz, T. M. Isenhart. 1997. How to design a riparian buffer for agricultural land. National Agroforestry Center. Agroforestry Notes AF Note-4. USDA Forest Service/National Resources Conservation Service, Lincoln, NE.

Dreher, D. W. 1997. Watershed urbanization impacts on stream quality indicators in Northeastern Illinois: pp. 129-135. In: D. Murray and R. Kirschner, eds, Assessing the Cumulative Impacts of Watershed Development on Aquatic Ecosystems and Water Quality. Northeastern Illinois Planning Commission, Chicago, IL.

Ebisemiju, F. S. 1988. Gully morphometric controls in a laterite terrain, Guyana. Geo. Eco. Trop. 12(1-4): 41−59.

Enoksson, B., P. Angelstam, K. Larsson. 1995. Deciduous forest and resident birds: The problem of fragmentation within a coniferous forest landscape. Landscape Ecology 10: 267-275.

Erman, D. C., J. C. Newbold, K. B. Roby. 1977. Evaluation of streamside buffer strips for protecting aquatic organisms. Tech Completion Report, Contrib. 165. California Water Resource Center, University of California-Davis.

Eshleman, K. N. 1988. Predicting regional episodic acidification of surface waters using empirical techniques. Water Resources Research 24: 1118−1126.

Esseen, P. and K. Renhorn. 1998. Edge effects on an epiphytic lichen in fragmented forests. Conservation Biology 12: 1307-1317.

Evink, G. L., P. Garret, D. Zeigler, J. Berry., eds. 1996. Trends in Addressing Transportation Related Wildlife Mortality. No. FL-ER-58-96. Florida Dep. Transp. Tallahassee, FL. 395 pp.

Fahrig, L., J. H. Pedlar, S. E. Pope, P. D. Taylor, J. F. Wegner. 1995. Effect of road traffic on amphibian density. Biology Conservation 73: 177-82.

Falk, D. A. 1992. From conservation biology to conservation practice: strategies for protecting plant diversity: pp. 397-431. In: P. L. Fiedler, S. K. Jain and K. Subodh, eds. Conservation Biology: The Theory and Practice of Nature Conservation, Preservation, an Management. New York: Chapman & Hall.

Feare, C. J. 1980. The economics of starling damage: pp. 39-55. In: E. N. Wright, I. R. Inglis and C. J. Feare eds. Bird Problems in Agriculture. Croydon, UK: the British Crop Protection Council.

Findlay, C. S. and J. Houlahan. 1997. Anthropogenic correlates of species richness in southeastern Ontario wetlands. Conservation Biology 11: 1000-9.

Fischer, R. A. 2000. Width of riparian zones for birds. EMRRP Technical Note Series, TN-EMRRP-SI-09, U.S. Army Engineer Research and Development Center, Vicksburg, MS. http://www.wes.army.mil/el/emrrp/pdf/si09.pdf

Fischer, R. A., C. O. Martin, D. Q. Barry, K. Hoffman, K. L. Dickson, E. G. Zimmerman, D. A. Elrod. 1999. Corridors and vegetated buffer zones: A preliminary assessment and study design. Technical Report EL-99-3, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS. http://www.wes.army.mil/el/elpubs/pdf/tre/99-3.pdf

Fischer-Scherl, T. et al. 1991. Morphological effects of acute and chronic atrazine exposure in rainbow trout (*Oncorhynchus mykiss*). Archives of Environmental Contamination and Toxicology 20: 454-461.

Fitzgibbon, C. D. 1997. Small mammals in farm woodlots: The effects of habitat, isolation and surrounding land-use patterns. Journal of Applied Ecology 34: 530-539.

Forman, R. T. T. and R. D. Deblinger. 1999. The ecological road effect zone for a Massachusetts (USA) suburban highway. Conservation Biology 14: 36−46.

Fox, D. G., A. M. Bartuska, J. G. Byrne, E. Cawling, R. Fisher, G. E. Litkens, S. E. Lindberg, R. A. Linthcrest, J. Messer, D. S. Nichols. A screening procedure to evaluate air pollution on class 1 wilderness areas. USDA Forest Service General Technical Report RM-168, Fort Collins, CO.

Franklin, I. R. 1980. Evolutionary change in small populations: pp. 135-150. In: M. E. Soule and B. A. Wilcox (eds.) Conservation Biology: An Evolutionary-Ecological Perspective. Sinauer, Sunderland, MA.

Franklin, J. F. 1992. Scientific basis for new perspectives in forests and streams: pp. 25-72. In: R. J. Naiman (ed.) Watershed management: balancing sustainability and environmental change. Springer-Verlag, New York.

Fraver, S. 1994. Vegetation responses along edge-to-interior gradients in the mixed hardwood forests of the Roanoke River Basin, North Carolina. Conservation Biology 8: 822-832.

Freddy, D. J., W. M. Bronaugh, M. C. Fowler. 1986. Responses of mule deer to disturbance by persons afoot and in snowmobiles. Wildlife Society Bulletin 14: 63−68.

Friesen, L. E., P. F. Eagles, R. J. MacKay. 1995. Effects of residential development on forest-dwelling neotropical migrant songbirds. Conservation Biology 9(6): 1408-1414.

Fryer-Nurza, J. 1990. New Jersey Threatened and Endangered Species Program. Trenton, NJ. Interview.

Gaines, D. 1974. Review of the status of the Yellow-billed Cuckoo in California: Sacremento Valley populations. Condor 76: 204-09.

Galli, J. 1993. Rapid Stream Assessment Technique. Metropolitan Washington Council of Governments. Washington, D.C.

Gardner, R. H., B. T. Milne, M. G. Turner, R. V. O'Neill. 1987. Neutral models for the analysis of broad-scale landscape pattern. Landscape Ecology 1: 19-28.

Gari, H. and A. McIntosh. 1986. Distribution of Benthic Macroinvertebrates in Streams Exposed to Urban Runoff. Water Resources Bulletin 22: 447-458.

Gascon, C., G. B. Williamson, G. A. B. da Fonseca. 2000. Receding forest edges and vanishing reserves. Science 288: 1356-1358.

Gibson, G. M., M. Barbour, J. Stribling, J. Karr. 1993. Biological Criteria: Technical Guidance for Streams and Small Rivers. US EPA Assessment and Watershed Protection Division, Washington, D.C.

Greenfelt, P. and E. Thornelof, eds. 1992. Critical Loads of Nitrogen – A Workshop Report. Report Nord 1992, 41, Nordic Council of Ministers, Copenhagen.

Greenfelt, P. and J. Nilsson (Ed) 1988. Critical loads for sulphur and nitrogen – report from a workshop held at Skokloster, Sweden, March 19-24, 1988. The Nordic Council of Ministers. Report 1988: 15, Copenhagen, Denmark. ISNB 87-7303-248-4

Griffiths, D. W., D. W. Schloesser, J. H. Leach, W. P. Koalak. 1991. Distribution and dispersal of the zebra mussel (*Dreissena polymorpha*) in the Great Lakes Region. Canandian Journal of Fishery and Aquatic Science 48: 1381-1388.

Gutzwiller, K. J. and S. H. Anderson. 1992. Interception of moving organisms: Influences of patch shape, size and orientation on community structure. Landscape Ecology 6: 293-303.

Gutzwiller, K. J. and S. H. Anderson. 1987. Multiscale associations between cavity-nesting birds and features of Wyoming streamside woodlots. Condor 89: 534-548.

Hagar, J. C. 1999. Influence of riparian buffer width on bird assemblages in Western Oregon. Journal of Wildlife Management 63: 484-96.

Hagen, J. M. III and D. W. Johnston, eds. 1992. Ecology and conservation of neotropical landbirds. Smithsonian Institute Press. Washington, D C.

Harper, K. A. 1999. Variability in forest structure and composition along edge-to-interior gradients from lakeshore and clearcut edges and in riparian buffers in the aspen-dominated mixed wood boreal forest. Doctoral thesis, University of Alberta, Edmonton, Canada.

Harrison, R. L. 1997. A comparison of Gray Fox ecology between residential and undeveloped rural landscapes. The Journal Of Wildlife Management 61(1): 112-122.

Heck, W. W. and E. B. Cowling. 1997. The need for a long-term cumulative secondary ozone standard –an ecological perspective. Environmental Management. January:23−33.

Hecnar, S. J. 1997. Amphibian pond communities in southwestern Ontario. In: D. M. Green (ed.) Amphibians in decline: Canadian studies of a global problem. Herpetological Conservation 1: 1-15.

Hodges, M. F. and D. G. Krementz. 1996. Neotropical migratory breeding bird communities in riparian forests of different widths along the Altamaha River, Georgia. Wilson Bulletin 108: 496-506.

Hoffman, D. J., J. C. Franson, O. H. Pattee, C. M. Bunck. 1985. Survival, growth, and histopathological effects of paraquat ingestion in nesting American kestrels. Archives of Environmental Contamination and Toxicology 14: 495-500.

Hofmann, A. and S. Winkler. 1990. Effects of atrazine in environmentally relevant concentrations on submersed macrophytes. Arch. Hydrobiol 118: 69-70.

Holmes, T. L., R. L. Knight, L. Stegall, G. R. Craig. 1993. Responses of wintering grassland raptors to human disturbance. Wildlife Society Bulletin 21: 461-468.

Hornocker, M. G. and H. S. Hash. 1981. Ecology of the wolverine in northwestern Montana. Canadian Journal of Zoology 59: 1286−1301.

Hornung, M. A., M. A. Sutton, R. B. Wilson eds. 1995. Mapping and Modeling of Critical Loads of Nitrogen. Report of a workshop held at Grange-over-Sands, Cumbria, U.K., under the auspices of the UN/ECE Convention on Long-range Transboundary Air Pollution, Working Group for Effects, October 24−26, 1994. Institute of Terrestrial Ecology, Penicuik, U.K.

Howe, R. W. 1984. Local dynamics of bird assemblages in small forest habitat islands in Australia and North America. Ecology 65: 1585-1601.

Huhta, E., T. Mappes, J. Jokimäki. 1996. Predation on artificial ground-nests in relation to forest fragmentation, agricultural land and habitat structure. Ecography 19: 85-91.

Ingold, D. J. and R. J. Densmore. 1992. Competiton between European starlings and native woodpeckers for nest cavities in Ohio. Sialia 14(2): 43-48, 54.

James, D. A. and J. C. Neal. 1986. Arkansas birds, their distribution and abundance. Fayetteville, AR: University of Arkansas Press.

Johnson, Allan W. and Diane M. Ryba. 1992. A Literature Review of Recommended Buffer Widths to Maintain Various Functions of Stream Riparian Areas. Prepared for King County Surface Water Management Division. February.

Johnston, R. F. and M. Janiga. 1995. Feral Pigeons. New York: Oxford University Press.

Jones, R. and C.Clark. 1987. Impact of Watershed Urbanization on Stream Insect Communities. American Water Resources Association 15(4).

Jules, E. S., E. J. Frost, L. S. Mills, D. A. Tallmon. 1999. Ecological consequences of forest fragmentation in the Klamath Region. Natl. Areas J 19: 368-378.

Keitt, T. H., D. L. Urban, B. T. Mine. 1997. Detecting critical scales in fragmented landscapes. Conservation Ecology 1: 4.

Keller, C. M. E., C. S. Robbins, J. S. Hatfield. 1993. Avian communities in riparian forests of different widths in Maryland and Delaware. Wetlands 13(2): 137−144.

Kilgo, J. C., R. A. Sargent, B. R. Chapman, K. V. Miller. 1998. Effect of stand width and adjacent habitat on breeding bird communities in bottomland hardwoods. Journal of Wildlife Management 62: 72-83.

Klein, R. D. 1979. Urbanization and stream quality impairment. Water Resources Bulletin 15 (4): 948-63.

Koehler, G. M. and M. G. Hornocker. 1997. Fire effects on marten habitat in the Selway-Bitterroot Wilderness. Journal of Wildlife Management 41: 500−505.

Koerselman, W. and A. F. M. Meuleman. Ibid, 1141-1150.

Laan, R. and B. Verboom. 1990. Effects of pool size and isolation on amphibian communities. Biological Conservation 54: 251-262.

Lamberson, R. H., B. R. Noon, C. Voss, K. S. McKelvey. 1994. Reserve design for territorial species: the effects of patch size and spacing on the viability of the northern spotted owl. Conservation Biology 8(1): 185-95.

Lamberson, R. H., R. McKelvey, B. R. Noon, C. Voss. 1992. A dynamic analysis of northern spotted owl viability in a fragmented forest landscape. Conservation Biology 6: 505-512.

Larsen, L., C. Jorgensen, J. Aamand. 2001. Potential mineralization of four herbicides in a ground water-fed wetland area. Journal of Environmental Quality 30: 24-30.

Larson, W. E., F. J. Pierce, R. H. Dowdy. 1984. Loss in long-term productivity from soil erosion in the United States. In: J. A. El-Swaify, W. C. Moldenhauer, A. Lo, eds. Soil Erosion and Conservation. Soil Conservation Society of America. Ankeny, IA.

Laurance, W. F. 1997. Introduction, Section II: Physical Processes and Edge Effects: pp. 29-32. In: W. F. Laurance and R. O Bierregaard (eds.) Tropical Forest Remnants: Ecology, Management and Conservation of Fragmented Communities. University of Chicago Press, Chicago.

Lavy, T. L. et al. 1996. Long-term in situ leaching and degradation of six herbicides aged in subsoils. Journal of Environmental Quality 25: 1268-1279.

Lefohn, Allen S. et al. 1988. A comparison of indices that describe the relationship between exposure to ozone and reduction in the yield of agricultural crops. Atmospheric Environment 22: 1229−1240.

Legge, A. H., L. Gruenhage , M. Nosal, H., -J. Jaeger, S. V. Krupa. 1995. Ambient and adverse crop response: An evaluation of North American and European data as they relate to exposure indices and critical levels. Angew. Bot 69: 192−205.

LeVeen, E. P. and W. R. Z. Willey. 1983. A political economic analysis of urban pest management: pp. 19-40. In: Frankie, G. W. and C. S. Kohler, eds. Urban Entomology: Interdisciplinary Perspectives. New York: Praeger.

Lewis, K. 1973. The effect of suspended coal particles on the life forms of the aquatic moss, *Eurhynchium riparioides* (Hedw). I. The gametophyte plant. Freshwater Biology 3: 251-257.

Liebold, A. M., W. L. MacDonald, D. Bergdahl, V. C. Mastro. 1995. Invasion by exotic forest pests: a threat to forest ecosystem. Forest Science 41(2): 1-49.

Limburg, K. and R. Schimdt. 1990. Patterns of Fish Spawning in Hudson River Tributaries-Response to an Urban Gradient? Ecology 71(4): 1231-1245.

Linehan, J. T., R. E. Jones, J. R. Longcore. 1967. Breeding-bird populations on Delaware's urban woodlots. Audubon Field Notes 21: 641-646.

Locke, A. 1993. Factors influencing community structure along stress gradients: zooplankton responses to acidification. Ecology 73: 903−909.

Luchetti, G. and R. Fuersteburg. 1993. Relative Fish Use in Urban and Non-Urban Streams. Proceedings Conference on Wild Salmon. Vancouver, British Columbia.

Lynch, J. F. and D. F. Whigham. 1984. Effects of forest fragmentation on breeding bird communities in Maryland, USA. Biological Conservation 28: 287-324.

Lyon, L. J. 1983. Road density models describing habitat effectiveness for elk. Journal of Forestry 81: 592−595, 613.

Malanson, G. P. and D. M. Cairns. 1997. Effects of dispersal, population delays, and forest fragmentation on tree migration rates. Plant Ecology 131: 67-79.

Maryland Department of Natural Resources. http://www.dnr.state.md.us.

Matlack, G. R. 1994. Vegetation dynamics of the forest edge: trends in space and successional time. Journal of Ecology 82: 113-123.

Maxted, G. et al. 1997. Habitat and Biological Impairment in Delaware Headwater Streams. Technical Note 72. Watershed Protection Techniques 2(2): 358−360.

May, C. W., R. R. Horner, J. R. Karr, B. W. Mar, E. B. Welch. 1997. Effects of Urbanization on Small Streams in the Puget Sound Lowland Ecoregion. Watershed Protection Techniques 2 (4).

McCollin, D. 1993. Avian distribution patterns in a fragmented wooded landscape (North Humberside, U.K.): The role of between-patch and within-patch structure. Global Ecology and Biogeography Letters 3: 48-62.

McCoy, E. D. and H. R. Mushinsky. 1994. Effects of fragmentation on the richness of vertebrates in the Florida scrub habitat. Ecology 75: 446-457.

McIntyre J. and R. Hobbs. 1997. A framework for conceptualizing human effects on landscapes and its relevance to management and research models. Conservation Biology 13: 1282−1292.

McIntyre, N. E. 1995. Effects of forest patch size on avian diversity. Landscape Ecology 10: 85-99.

Messaad, I. A., E. J. Peters, L. Young. 2000. Thermal tolerance of red shiner (*Cyprinella lutrenis*) after exposure to atrazine, terbufos, and their mixtures. Bull. Environ. Contam. Toxicol 64: 748-754.

Mitchell, F. 1996. Vegetated buffers for wetlands and surface waters: Guidance for New Hampshire municipalities. Wetlands Journal 8: 4-8.

Monkkonen, M. and P. Reunanen, 1999. On critical thresholds in landscape connectivity: management perspective. Oikos 84: 302−305

Moore, A. and C. P. Waring. 1998. Mechanistic effects of a triazine pesticide on reproductive endocrine function in mature male Atlantic salmon (*Salmo salar L.*) parr. Pest. Biochem. Physiol 62: 41-50.

Moore, N. W. 1980. How many wild birds should farmland support?: pp. 2-6. In: E. N. Wright, I. R. Inglis and C. J. Feare, eds. Bird Problems in Agriculture. Croydon, UK: The British Crop Protection Council.

Morin, N. 1995. Vascular plants in the United States: pp. 200-205. In: E. T. LaRoe, G. S. Farris, C. E. Puckett, P. D. Doran and M. J. Mac, eds. Our Living Resources: a Report to the Nation on the Distribution, Abundance, and Health of US Plants, Animals and Ecosystems. Washington DC: US Department of the Interior, National Biological Service.

Moring. J. R. 1982. Decrease in stream gravel permeability after clear-cut logging: An indication of intragravel conditions for developing salmonid eggs and alevins. Hydrobiologia 88: 295-298.

Morse, L. E., J. T. Kartesz, L. S. Kutner. 1995. Native vascular plants: pp. 205-209. In: E. T. LaRoe, G. S. Farris, C. E. Puckett, P. D. Doran and M. J. Mac, eds. Our Living Resources: a Report to the Nation on the Distribution, Abundance, and Health of US Plants, Animals and Ecosystems. Washington DC: US Department of the Interior, National Biological Service.

Naney, R. 1991. USDA Forest Service Region 1. Lynx, Fisher and Wolverine Coordination Meeting.

National Institute for Occupational Safety and Health (NIOSH). 1991. Registry of toxic effects of chemical substances. Microfiche edition. D.V. Sweet, ed. Cincinnati, OH

The Nature Conservancy. http://nature.org

O'Laughlin, J. and G. H. Belt. 1995. Functional approaches to riparian buffer strip design. Journal of Forestry 93(2): 29−32.

Obbard, M. E. and R. J. Brooks. 1980. Nesting migrations of the snapping turtle (*Chelydra serpentina*). Herpetologica 36: 158-162.

Oggier, P. 1997. Roads as barriers to the dispersal of the endangered land snail *Helicella itala*. In: Habitat fragmentation and infrastructure: Proceedings of the international conference on habitat fragmentation, infrastructure and the role of ecological engineering. MECC, Maastricht, 18-21 September 1995. Edited by K. Canters. Ministry of Transport, Public Works and Waste Management, Delft, the Netherlands.

Opdam, P., G. Rijsdijk, F. Hustings. 1985. Bird communities in small woods in an agricultural landscape: Effects of area and isolation. Biological Conservation 34: 333-352.

Opdam, P., D. van Dorp, J. F. ter Braak. 1984. The effect of isolation on the number of woodland birds in small woods in the Netherlands. Journal of Biogeography 11: 473-478.

Ortega, Y. K. and D. E. Capen. 1999. Effects of forest roads on habitat quality for ovenbirds in a forested landscape. The Auk 116(4): 937-946.

Oxley, D. J., M. B. Fenton, G. R. Carmody. 1974. The effects of roads on populations of small mammals. Journal of Applied Ecology 11: 51-59.

Palik, B. J. and P. G. Murphy. 1990. Disturbance versus edge effects in sugar-maple/beech forest fragments. Forest Ecology Management 32: 187-202.

Palone, R. S. and A. H. Dodd, eds. 1997. Chesapeake Bay Riparian Handbook: A guide for establishing and maintaining riparian forest buffers. USDA Forest Service Northeastern Area State and Private Forestry. NA-TP-02-97. Radnor, PA.

Parry, R. 1998. Agricultural phosphorus and water quality: U.S. Environmental Protection Agency perspective. Journal of Environmental Quality 27: 258-261.

Pedersen, E. and M. Perkins. 1986. The Use of Benthic Invertebrate Data for Evaluating Impacts of Urban Runoff. Hydrobiologia 139: 13-22.

Pest Management Unit of Sustainable Production Branch, Saskatchewan Agriculture and Food. Crop Protection Agency. Pest Identification, Threshold Information. 125-3085 Albert St. Regina, Saskatchewan. S4S 0B1 306.787.8130

Peters, J. C. 1962. The effects of stream sedimentation on trout embryo survival. pp. 275−279. In C. M. Tarwell, ed. Biological problems in water pollution. U. S. Public Health Service, Cincinnati, OH.

Pitt, R., R. Field, M. Lalor, M. Brown. 1995. Urban Stormwater Toxic Pollutants: Assessment, Sources, and Treatability. Water Environment Research 67(3): 260−275.

Plafkin, J., M. Barbour, K. Porter, S. Gross, R. Hughes. 1989. Rapid Bioassessment Protocols for Use in Streams in Rivers: Benthic Macroinvertebrates and Fish. USEPA Office of Water. EPA-444(440)/4-3901. Washington, D.C.

Porter, S. L. 1991. Pesticide poisoning in birds of prey. Unpublished manuscript. Weyer's Cave, VA: Wildlife Center of Virginia.

Pyle, C. and J. Chen. 1998. Edge effects on understory species and their relation to microclimate, disturbance, and species ecology in an old-growth Douglas-fir forest. Unpublished manuscript.

Quinlan, K. P. and J. J. Sacks. 1999. Hospitalizations for Dog Bite Injuries. Centers for Disease Control website. http://www.cdc.gov/ncipc/duip/hospital.htm (23 February 1999).

Ralph, P. J. 2000. Herbicide toxicity of *Halophila ovalis* assessed by chlorophyll a fluorescence. Aquatic Botany 66: 141-152.

Reed, R. A., J. Johnson-Barnard, W. L. Baker. 1996. Contribution of roads to forest fragmentation in the Rocky Mountains. Conservation Biology 10: 1098-1106.

Reijnen, R., R. Foppen, H. Meeuwsen. 1996. The effects of car traffic on the density of breeding birds in Dutch agricultural grasslands. Biological Conservation 75: 255−260.

Reijnen, R., R. Foppen, C. ter Braak, J. Thissen. 1995. The effects of car traffic on breeding bird populations in Woodland III. Reduction of density in relation to the proximity of main roads. Journal of Applied Ecology 32: 187−202.

Renhorn, K. E., P. A. Essen, K. Palmqvist, B. Sundberg. 1997. Growth and vitality of epiphytic lichens. Oecologia 109: 1-9.

Robbins, C. S., D. K. Dawson, B. A. Dowell. 1989. Habitat area requirements of breeding forest birds on the Middle Atlantic States. Wildlife Monographs 103. 34 p.

Robinson, S. K. 1996. Threats to breeding neotropical migratory birds in the Midwest: pp. 1-21. In: E. R. Thompson III (ed.) Management of Midwestern landscapes for the conservation of neotropical migratory birds. Gen. Tech. Rep. NC-187. St. Paul, MN: US Department of Agriculture, Forest Service.

Rodda, G. H., T. H. Fritts, D. Chiszar. 1997. The disappearance of Guam's wildlife. BioScience 47(9): 565-574.

Rodgers, J. A., Jr., and H. T. Smith. 1995. Set-back disturbance to protect nesting birds colonies from human disturbances in Florida. Conservation Biology 9: 89−99.

Rogers, L. L. and A. W. Allen. 1987. Habitat suitability index models black bear, Upper Great Lakes Region. Biol. Rep. 82. U.S. Fish and Wildlife Service. Washington, D.C. 50pp.

Roland, J. and P. D. Taylor. 1997. Insect parasitoid species respond to forest structure at different spatial scales. Nature 386: 710-713.

Romin, L. A. and J. A. Bissionette. 1996. Temporal and spatial distribution of highway mortality of mule deer on newly constructed roads at Jordanelle Reservior, Utah. Gt. Basin Nat.56: 1-11

Rose, C. R. and P. S. Muir. 1996. Green-tree retention: consequences for timber production in forests of the western Cascades, Oregon. Ecological Applications 7: 209−217.

Rosenberg, K. V., R. W. Rohrbaugh, S. E. Baker Jr., J. D. Lowe, R. S. Hames, A. A. Dhondt. 1999. A land managers guide to improving habitat for scarlet tanagers and other forest-interior birds. The Cornell Lab of Ornithology, NY.

Roth, N. E., J. D. Allen, D. L. Erickson. 1996. Landscape influences on stream biotic integrity assessed at multiple spatial scales. Landscape Ecology 11: 141-156.

Rudis, V. A. and J. B. Tansey. 1995. Regional assessment of remote forests and black bear habitat from forest resource surveys. Journal of Wildlife Management 59: 170-180.

Rudolph, D. C. and J. G. Dickson. 1990. Streamside zone width and amphibian and reptile abundance. Southwestern Naturalist 35: 472-476.

Saglio, P. and S. Trijasse. 1998. Behavioral responses to atrazine and diuron in goldfish. Archives of Environmental Contamination and Toxicology 35: 484-491.

Santelman, M. V. and E. V. Gorham. 1988. The influence of airborne road dust on the chemistry of Sphagnum mosses. Journal of Ecology 76: 1219-31.

Sarapul'tsev B. I. and S. A. Geras'kin. 1989. Specie-specific radioresistance and the phylogeny of higher plants. Radiobiologiya 29(1): 100−107.

Schindler, D. W. 1988. The effects of acid rain on freshwater ecosystems. Science 239: 149−157.

Schueler, T. 1995. The Architecture of Stream Buffers from Watershed Protection Techniques Volume 1, Number 4. Summer 1995.

Schueler, T. R. 1994. Minimizing the impact of golf courses on streams. Watershed Protection Techniques 1: 73-75.

Schueler, T. and J. Galli. 1992. Environmental Impacts on Stromwater Ponds. In: Watershed Restoration SourceBook. Anacostia Restoration Team. Metropolitan Washington Council of Governments. Washington, D.C. 242 pp.

Schultz, T. D. and J. A. Bailer. 1978. Responses of National Park elk to human activity. The Journal Of Wildlife Management 42: 91−100.

Schwartz, M. W. 1992. Modelling effects of habitat fragmentation on the ability of trees to respond to climatic warming. Biodiversity and Conservation 2: 51-61.

Science Assessment Document (SAD). Feb. 1999. Ground-Level Ozone. Federal-Provincial Working Group on Air Quality Objectives and Guidelines for the Canada-Wide Standards (CWS) process.

Semlitsch, R. A. 1998. Biological delineation of terrestrial buffer zones for pond-breeding salamanders. Conservation Biology 12: 1113-1119.

Shaver, E., J. Maxted, G. Curtis, D. Carter. 1995. Watershed Protection Using and Integrated Approach. In: Stormwater NPDES Related Monitoring Needs. Engineering Foundation. American Society of Civil Engineers. Crested Butte, CO. August 7-13, 1994.

Sheperd, B. F. and R. K. Swihart. 1995. Spatial dynamics of fox squirrels (*Sciurus niger*) in fragmented landscapes. Canadian Journal of Zoology 73: 2098-2105.

Shevchenko, V. A., V. L. Pechkurenkov and V. I. Ambramov. 1992. Radiaysionnaya Genetika Prirodnykh Populyatsii (Radiation Genetics of Natural Populations). Moscow: Nauka.

Smith, G. T., G. W. Arnold, S. Sarre, M. Abensperg-Traun, D. E. Steven. 1996. The effect of habitat fragmentation and livestock grazing on animal communities in remnants of gimlet Eucalyptus salubris in woodland in the Western Australia wheatbelt. II. Lizards. Journal of Applied Ecology 33: 1302-1310.

Smith, R. 1984. Producers need not pay startling “rodent tax” losses. Feedstuffs 56(22): 13-14.

Spackman, S. C. and J. W. Hughes. 1995. Assessment of minimum stream corridor width for biological conservation: Species richness and distribution along mid-order streams in Vermont, USA. Biological Conservation 71: 325-332.

Spencer, W. D., R. H. Barrettand W. J. Zielinski. 1983. Marten habitat preferences in the northern Sierra Nevada. Journal of Wildlife Management 47: 1181−1186.

Steedman, R. J. 1988. Modification and Assessment of an Index of Biotic Integrity to Quantify Stream Quality in Southern Ontario. Canadian Journal of Fisheries and Aquatic Sciences 45: 492-501.

Steinberg, C. E. W., R. Lorenz, O. H. Spieser. 1995. Effects of atrazine on swimming behavior of zebrafish, *Brachydanio rerio*. Water Research 29: 981-985.

Steward, C. 1983. Salmonid Populations in an Urban Environment–Kelsey Creek, Washington. Masters Thesis. University of Washington.

Stiles, J. H. and R. H. Jones. 1998. Distribution of the red imported fire ant, *Solenopsis invicta*, in road and powerline habitats. Landscape Ecology 335: 335-346.

Stone, M. and I. G. Droppo. 1994. In-channel surficial fine-grained sediment laminae. Part II: Chemical characteristics and implications for contaminant transport in fluvial systems. Hydrological Processes 8: 113-124.

Tassone, J. 1981. Utility of hardwood leave strips for breeding birds in Virginia’s central Piedmont. M.S. thesis, Virginia Polytechnic Institute and State University, Blacksburg.

Taylor, B. L. 1993. The Influences of Wetland and Watershed Morphological Characteristics and Relationships to Wetland Vegetation Communities. Masters Thesis. Dept. of Civil Engineering, University of Washington.

Thompson, D. G., R. L. Stuckley, E. B. Thompson. 1987. Spread, impact, and control of purple loosestrife (*Lythrum salicaria*) in North American wetland. Washington, DC: US Fish and Wildlife Service, Fish and Wildlife Research 2.

Tilman, D. and S. Pecala. 1993. Pp. 13-25. In: R. E Richlefs and D. Shluter (Eds.) Species Diversity in Ecological Communities. University of Chicago Press, Illinois.

Triquet, A. M., G. A. McPeek, W. C. McComb. 1990. Songbird diversity in clearcuts with and without a riparian buffer strip. Journal of Soil and Water Conservation 45: 500-503.

Turchi, G. M., P. L. Kennedy, D. Urban, D. Hein. 1995. Bird species richness in relation to isolation of aspen habitats. Wilson Bulletin 107: 463-474.

UN ECE CLRTAP. 1996. Manual on methodologies and criteria for mapping critical levels/loads and geographical areas where they are exceeded. Produced by the UN ECE CLRTAP Task Force on Mapping and the CCE. Published by Umweltbundesamt, Berlin, Germany. http://www.oekodata.com/icpmapping/html/body_manual.html

USBC. 1998. Statistical Abstract of the United States 1996. 200th ed. Washington, DC: US Bureau of the Census, US Government Printing Office.

US EPA. 1996. Fed. Regist. Dec. 13, 1996. 61(24l): 65716-50.Washington, D.C.

US EPA. 1990. National Ambient Air Quality Standards (NAAQS). http://www.epa.gov/airs/criteria.html

US EPA. 1986. Office of Pesticides and Toxic Substances. Office of Pesticides Programs. Pesticide fact sheet (dinoseb). No. 130. Washington, DC.

US EPA. 1986. Quality criteria for water: 1986. Washington DC: US Environmental Protection Agency, Office of Water Regulations and Standards. 402 p.

US EPA. 1976. Quality Criteria for Water. Washington, D.C. 207 p.

US EPA. Mid-Atlantic Integrated Assessment (MAIA). http://www.epa.gov/maia/html/reports.html

Vander Haegen, M. W. and R. M. DeGraaf. 1996. Predation on artificial nests in forested riparian buffer strips. Journal of Wildlife Management 60: 542-550.

Van der Molen, D. T., A. Breeuwsma, P. C. M. Boers. 1998. Agricultural nutrient losses to surface water in the Netherlands: impact, strategies, and perspective. Journal of Environmental Quality 27: 4-11.

Verboom, B. and R. van Apeldoorn. 1990. Effects of habitat fragmentation on the red squirrel, Sciurus vulgaris L. Landscape Ecology 4: 171-176.

Villard, M. –A., G. Merriam, B. A. Maurer. 1995. Dynamics in subdivided populations of Neotropical migratory birds in a fragmented temperate forest. Ecology 76: 27-40.

Virginia Cooperative Extension. Educational Program and Resources on Agriculture and Natural Resources. http://www.ext.vt.edu/resources

Vos, C. C. and J. P. Chardon. 1998. Effects of habitat fragmentation and road density on the distribution pattern of the moor frog *Rana arvalis*. Journal of Applied Ecology 35: 44-56.

Vos, C. C. and A. H. P. Stumpel. 1995. Comparison of habitat-isolation parameters of North American shrub steepe birds: The effects of spatial scale. Oikos 48: 132-147.

Ward, A. L., N. E. Fornwalt, S. E. Henry, R. A. Hodorff. 1980. Effects of highway operation practices and facilities on elk, mule deer, and pronghorn antelope. Federal Highway Office Research and Development Report FHWA-RD-79-143.

Welsch, D. J. Maryland Department of Natural Resources Forest Service. Riparian Forest Buffers. Function and Design for Protection and Enhancement of Water Resources. http://www.na.fs.fed.us/spfo/pubs/n_resource/riparianforests

Wenger, Seth. 1999. A Review of the Scientific Literature on Riparian Buffer Width, Extent, and Vegetation. Office of Public Service and Outreach, Institute of Ecology, University of Georgia. http://outreach.ecology.uga.edu/tools/buffers/lit_review.pdf

Whitaker, D. M. and W. A. Montevecchi. 1999. Breeding bird assemblages inhabiting riparian buffer strips in Newfoundland, Canada. Journal of Wildlife Management 63: 167-79.

Whitcomb, R. F., C. S. Robbins, J. F. Lunch, B. L. Whitcomb, M. K. Klimkiewiczand D. Bystrak. 1981. Effects of forest fragmentation on avifauana of the eastern deciduous forest. p. 123−205. In: R. L. Burgess and D. M. Sharpe,eds., Forest island in man-dominated landscapes. Spinger-Verlag. New York, NY.

Wilcove, D. S. 1987. From fragmentation to extinction. Natural Areas Journal 7(1): 23-29.

Wilson, L. G. 1967. Sediment removal from flood water by grass filtration. Trans. Am. Soc. Agric. Eng 10: 35−37.

With, K. A., R. H. Gardner, M. G. Turner. 1997. Landscape connectivity and population distributions in heterogeneous environments. Oikos 78: 151-169.

With, K. A. and T. O Crist. 1995. Critical thresholds in species' responses to landscape structure. Ecology 76: 2446-2459.

Yoder, C. O., R. Miltner, D. White. 1999. Assessing the Status of Aquatic Life Designated Uses in Urban and Suburban Watersheds, pp. 16−28 In R. Kirschner, ed. National Conference on Retrofit Opportunities for Water Resources Protection in Urban Environments. EPA/6325/R-99/002.

Yoder, C. 1991. The Integrated Biosurvey as a Tool for Evaluation of Aquatic Life Use Attainment and Impairment in Ohio Surface Waters. In: Biological Criteria: Research and Regulation.