Recovery Potential Metrics
Summary Form

Indicator Name: WATERSHED PERCENT FOREST

Type: Ecological Capacity

Rationale/Relevance to Recovery Potential: More watershed forest cover reduces risk of numerous impairment types, thus lessening the relative complexity of restoration of impaired waters from forested watersheds. Mollifying effects on runoff and recharge, temperature, and overland pollutant transport are associated with more forested watersheds and help ensure that several primary natural processes are or can become functional once stresses are removed.

How Measured: Percent of the total land area of a watershed mapped with a land cover classification of "forest" (i.e. deciduous forest, evergreen forest, mixed forest).

Data Source: Percent of the total land area of a watershed mapped with a land cover classification of "forest" (i.e. deciduous forest, evergreen forest, mixed forest). For land cover data, the National Land Cover Database (NLCD) for 2006, 2001 and 1992 is accessible at http://www.mrlc.gov/finddata.php; numerous statewide land cover mapping datasets are also available from state-specific sources. For watershed boundaries, numerous watershed scales have been delineated nationally as part of the Watershed Boundary Dataset (WBD) (See: http://datagateway.nrcs.usda.gov). Custom watershed boundary delineation can be done by aggregating NHDplus catchments (See: http://www.horizon-systems.com/nhdplus/) or WBD HUC12 watersheds. For relatively small study areas, it is possible to use aerial imagery to digitize the forest cover manually.

Indicator Status (check one or more)
_______ Developmental concept.
___x__ Plausible relationship to recovery.
_______ Single documentation in literature or practice.
___x__ Multiple documentation in literature or practice.
_______ Quantification.

Comments: Widespread applicability among watersheds in naturally-forested regions of the country.

Examples from Supporting Literature (abbrev. citations and points made):

- (Potter et al 2004) Regression analyses revealed that landscape variables explained up to 56% of the variance in measures of water quality condition.
- (Potter et al 2004)The resulting vulnerability models indicate that North Carolina watersheds with less forest cover are at most risk for degraded water quality and stream habitat conditions. Studies have found strong positive relationships between diverse assemblages of stream benthic macroinvertebrates that are intolerant of water quality degradation and watershed-wide forested land cover (Lenat and Crawford 1994, Stewart and others 2001, Weigel and others 2003) or forested land cover within riparian zones (Basnyat and others 1999, Sponseller and others 2001, Stewart and others 2001, Weigel and others 2003). Meanwhile, research has shown less diverse and more intolerant macrobenthic communities to be correlated with agricultural land cover (Lenat and Crawford 1994, Richards and others 1996, Weigel and others 2000, Genito and others 2002) and urban land use (Lenat and Crawford 1994, Morley and Karr 2002, Morse and others 2003, Roy and others 2003, Volstad and others 2003, Wang and Kanehl 2003).

- (Potter et al 2004) Two of the three watershed land cover variables — percent agricultural and percent forested — exhibited somewhat strong relationships. The percent of agriculture land cover at the watershed scale had a positive relationship with the indices, meaning that it was negatively correlated with aquatic ecological integrity. The percent of forest was correlated with better stream conditions. In our statewide analysis, the percent of forest cover at the watershed scale and in riparian zones were highly correlated enough (0.776) that the two have similar value as predictors of macroinvertebrate tolerance for water quality degradation. Forested land cover, at both the watershed and riparian scales, was a statistically significant predictor of benthic macroinvertebrate communities that are less tolerant of stream degradation, and that indicate a greater level of aquatic ecological integrity and better water quality. The opposite was the case for agricultural land cover at the watershed and riparian scales, and developed land cover in riparian zones.
- (wang 2001) The results shown in Table 5 indicate that the land-use components within the catchments could be major predictors for biotic integrity. The percentage of urban land was the second strongest predictor for both IBI and ICI. The negative signs of those coefficients indicate that as the intensity of human activities increase there is a tendency that the biological integrity of the rivers decreases. The percentage of wooded land was the third strongest predictor for IBI.
- (Iwata et al., 2003) In contrast to a scarcity of ecological studies, deforestation impacts on stream hydrology have been well investigated in tropical rain forests of Borneo (Douglas et al. 1992, Greer et al. 1995, Malmer 1996, Chappell et al. 1999, Fletcher and Muda 1999), as well as in other Southeast Asian regions (see reviews by Douglas et al. 1993, Douglas 1999). These studies have revealed that deforestation associated with logging operations or agricultural development greatly increases rates of soil erosion and sediment supply to streams (462).
- (Iwata et al., 2003) Ecological impacts of such sustained anthropogenic disturbance [deforestation/slash and burn agriculture] on stream communities can be more severe than our findings (Ryan 1991, Waters 1995, Harding et al. 1998), and a full recovery of the communities may require several decades (471).
- (Pringle 2001) However, their lower watersheds have largely been cleared for agriculture or urbanization. Deforestation has resulted in greater runoff, decreased infiltration rate and aquifer recharge, and increased erosion and sedimentation in rivers (Pringle and Scatena 1999) (992-993).
- (Pringle 2001) The high infiltration capacity of forested watersheds in the park helps to regulate surface water in the Sarapiqui and Puerto Viejo Rivers. Changes in land use in these protected areas could negatively affect lowland communities by causing increased flooding and decreased water quantity and quality (993).
- (Radwell and Kwak 2005) Reduced biotic integrity was found in other studies of midwestern United States lotic systems, with 36–84% of their watersheds in agricultural use (Roth and others 1996; Wang and others 1997). The watersheds in our study were much less disturbed, with forest cover ranging from 84% to 98% (808).
- (Gergel Lakes with f al., 2002) Forest-dominated catchments in the Minneapolis-St. Paul area were less eutrophic and had lower levels of chloride and lead than lakes in non-forest dominated catchments (Detenbeck et al., 1993) (120).
- (Ekness and Randhir 2007) Species richness has been shown to increase as vegetative density increases and with distance from developed areas (1470).
- (Gergel et al., 2002) For example, in a study of fish in Wisconsin streams, the health of fish communities was negatively correlated with the amount of upstream urban development (Wang et al., 1997). The health of fish communities was also positively correlated with amount of upstream forest and negatively correlated with amount of agriculture. This relationship exhibited a nonlinear, threshold response; declines in condition of the fish fauna occurred only after ~20% of the catchment was urbanized, and no impacts were attributed to agriculture until it occupied ~50% of the catchment (Wang et al., 1997) (120-121).

- (Grau et al., 2003) Recovery of forest structure is a key process for recovering ecosystem processes (e.g., hydrologic or biogeochemical cycles) and habitats (1161).
- (Grau et al., 2003) Trees determine the structure of forests by controlling the availability of resources and microhabitat for other organisms, such as different invertebrate groups. Therefore, the recovery of forest structure is expected to have strong effects on the diversity and composition of other organisms (Huston 1994) (1163).
- (Grau et al., 2003) Relatively small changes in the type of land cover could have major effects on rates of soil erosion. For example, if only the 5% of the watershed with the highest erosion rates (bare soil, agriculture on steep slopes) is transformed into closedcanopy forests, erosion in the watershed will decrease by 20%. If open woodlands are transformed through succession into closed-canopy forests, erosion will decrease by 7%. If instead the landscape is transformed into a mixture of pasture and agriculture, as it was during the first half of the 20th century, total basinwide erosion will increase between 33% (all pasture) and 103% (all agriculture) (1166).
- (Roy et al., 2007) Fish assemblages were correlated with urban, forest, and agriculture land cover variables, with the greatest number of strong relations with % forest and % urban in the catchment (eight strong models), and % forest and % agriculture in the 1-km riparian network (four strong models; Table 4). Cosmopolitan and lentic tolerant species were the only groups correlated with agriculture, with increased richness and abundance associated with agriculture at some spatial extents. For all except cosmopolitan species, the strongest relationships were with the largest spatial extents of land cover (catchment), followed by riparian land cover in the 1-km and 200-m reach, respectively. Endemic richness, endemic:cosmopolitan richness and abundance, insectivorous cyprinid richness and abundance, and fluvial specialist richness were all negatively correlated with % urban cover and positively correlated with % forest cover in the catchment (Table 4) (391-392).
- (Roy et al., 2007) Urbanization and the concomitant declines in forest land cover throughout catchments result in hydrologic alteration, increased bank erosion and sedimentation, altered in-stream habitat, and increased delivery of pollutants to streams, among other impacts (Paul and Meyer 2001). These changes, in turn, alter biotic assemblages, resulting in the observed linkages between catchment land cover and fish assemblages in this and other studies (e.g., Wang et al. 1997, 2001; Scott and Helfman 2001; Walters et al. 2003). Studies that incorporate a range of catchment land cover often demonstrate significant relationships between land cover and stream quality (see Table 1). This study had the greatest differences in %forest and%urban land cover (vs smaller ranges in % agriculture) across sites, and these variables were most important in predicting aspects of fish assemblage integrity (394).
- (Radwell and Kwak 2005) Our research revealed several insightful findings applicable to river ecology and management. First, we found that physical characteristics were more influential in ranking rivers in terms of ecological integrity, relative to biotic attributes. Among physical attributes, those at the watershed level, including land use, ownership, and road density, were the most influential components, playing a major role in discriminating among rivers. However, fish density, biomass, and occurrence of intolerant fishes were influential biotic factors, as well as invertebrate density and taxa richness (806).
- (Radwell and Kwak 2005) Fish density, number of intolerant fish species, and invertebrate density were important biotic variables responsible for the rankings. Contributing physical variables included riparian forest cover, nitrate concentration, turbidity, percentage of forested watershed, percentage of private land ownership, and road density both in the watershed and in a 100-m buffer (806).
- (Novotny et al., 2005) Instead of or in addition to an irreversible dominant surrogate stressor expressed, e.g., by percent imperviousness or percent urbanization, other stressors may be significant and more manageable. Obviously, for nonurban streams landscape features such as percent forested or agricultural area of the watershed (Wang et al., 2000; Van Sickle, 2003), riparian zone conditions and buffers, geology of the

watershed and morphology of the stream, ecoregional attributes (Omernik, 1987; Omernik and Gallant, 1989) or hydrologic stressors such as flow variability (Poff and Ward, 1989) are important. The other surrogates of stresses such as agricultural or forest land become important as the dominating effect of urbanization diminishes at low percentages of imperviousness but may have the same drawbacks as using percent imperviousness (189).

- (Norton and Fisher 2000) Riparian forest, forest on hydric soil, and upland forest all showed strong negative correlations with stream TN and NO3_ concentrations (Fig. 7) in the Choptank basin. Thus, stream TN and NO3_ concentrations in the Choptank basin were strongly related to both forest and cropland in the surrounding area (350).
- (Norton and Fisher 2000) In addition to cropland 100–300 m from streams, forest far from local streams (\500 m) was important in reducing TN and NO3 concentrations (Table 5). A much larger portion of the Choptank watershed (50–85%) influenced local stream concentrations compared to that in the Chester (351).
- (Norton and Fisher 2000) The basin zone analysis indicated that riparian forest in the Choptank may act as both a source and sink of TP. Forest directly adjacent to streams (0–100 m) was positively correlated to stream TP and forest in the 100–300 m zone was negatively correlated to stream TP in a multiple regression model (*r*2_0.41**). Forest in the 100–300 m zone with high redox conditions may have trapped and retained sediment-bound P while the riparian forest zone (0–100 m) with potentially low redox conditions may have contributed dissolved P from sediment as well as from the forest itself (organic P). Others have observed that forest acts not only as a sink for particulate-bound P but a source of dissolved, organic P (Peterjohn and Correll, 1984; Cooper et al., 1995) The riparian zone may have also contributed dissolved, inorganic P from trapped sediment if wet conditions in the forest created low redox conditions (Whigham et al., 1988) (358).