The Landscape Development Intensity Index (LDI)

The intensity and aerial extent of human activities in a landscape may adversely affect the ecological processes of natural communities (Brown and Vivas 2003, 2005). By incorporating non-renewable energy input expenditures, the Landscape Development Intensity Index (LDI) functions as an objective measure of how human disturbance affects biological, chemical, and physical processes of aquatic systems. The LDI can be used at the scale of river, stream, or lake watersheds, or at the smaller scale of individual isolated wetland watersheds. Based on land uses and land cover, the LDI can be applied using available GIS land use/land cover data, aerial photographs, or field surveys (Brown and Vivas 2003, 2005).

Land use within a buffer area (size of buffer areas can differ, depending on the scale of the watershed) is summarized using a series of LDI coefficients correlated with the intensity of human activities, corresponding to specific land use categories within drainage basins. The LDI coefficients were quantified as “emergy” use per unit area per time. Since emergy (energy that has been corrected for different qualities) is expressed as the solar emergy joule (sej), the units for quantifying the intensity of human activity are therefore sej/ha·yr-1 (empower density). Brown and colleagues utilized energy consumption data from a variety of sources, and included the “cost” of electricity, fuels, fertilizers, pesticides, and water (both public water supply and irrigation) in their calculations. Because the LDI was meant to be a measure of human disturbance, only non-renewable energies were used in the calculation. Natural systems were assigned a non-renewable empowerment density of 0 sej/ha·yr-1 (Brown and Vivas 2003, 2005). The landscape development intensity (LDI) index is calculated as the percentage area within the catchment of a particular type of land use multiplied by the coefficient of energy use associated with that land use, summed over all land use types found in the catchment (Table 1).

$$LDI = \sum \left(LDI_i * \%LU_i \right).$$

Where,

LDI_i = the nonrenewable energy land use for land use *i*, and

$\%LU_i$ = the percentage of land area in the catchment with land use *i*.

Table 1. Description of land use and the coefficient value used to calculate the LDI. Higher values indicate greater intensity of human land use.

Land use	LDI value
Natural Open water	1.00
Pine Plantation	1.58
Woodland Pasture	2.02
Pasture	2.77
Recreational / Open Space (Low-intensity)	2.77
Low Intensity Pasture (with livestock)	3.41
Citrus	3.68
High Intensity Pasture (with livestock)	3.74
Row crops	4.54
Single Family Residential (Low-density)	6.79
Recreational / Open Space (High-intensity)	6.92
High Intensity Agriculture	7.00
Single Family Residential (Med-density)	7.47
Single Family Residential (High-density)	7.55
Low Intensity Highway	7.81
Low Intensity Commercial	8.00
Institutional	8.07

High Intensity Highway	8.28
Industrial	8.32
Low Intensity Multi-family residential	8.66
High intensity commercial	9.18
High Intensity Multi-family residential	9.19
Low Intensity Central Business District	9.42
High Intensity Central Business District	10.00

The Florida Department of Environmental Protection (DEP) uses the LDI as a tool to estimate potential land use impacts on streams, lakes, and wetlands. For streams and rivers, DEP typically uses a LDI calculated for the 100 m buffer of the waterbody for 10 km upstream of the point of interest. For lakes and isolated wetlands, DEP typically uses a LDI calculated for the 100 m buffer around the waterbody. LDI values less than two (≤2) can be considered minimally disturbed (see discussion in section 7.2.1 of FDEP 2009).

Human Disturbance Gradient (HDG)

The Human Disturbance Gradient (HDG) is both a conceptual model and semi-quantitative method for measuring how humans alter and degrade waterbodies (streams, rivers, lakes, wetlands, and potentially estuaries). The Florida Department of Environmental Protection (DEP) has used an HDG to develop biological tools, including the Stream Condition Index (SCI), Bioreconnaisance (BioRecon), and the Lake Vegetation Index (LVI). In the development of these tools, candidate metrics were tested for correlation with HDG, and metrics with the highest correlation were chosen for the indices (Fore *et al.* 2007a, Fore *et al.* 2007b).

The concept of the HDG was introduced by Karr and colleagues, who described five factors to summarize the ways in which humans alter and degrade rivers and streams (Karr *et al.* 1986; Karr *et al.* 2000): flow regime, physical habitat structure, water quality, energy source, and biological interactions. First, the natural flow regime of a stream may be altered by dams, water removal, or water return. In extreme cases, changes in water volume or flow timing can result in flooding or dry channels. Second, stream macroinvertebrates depend on a variety of physical habitat types for food, shelter, and reproduction. A greater diversity of substrate size, types of vegetation, and bank architecture translates into a greater variety of organisms. Third, water quality may be evaluated in terms of turbidity, conductivity, nutrient concentrations, or the presence of other chemicals or metals. Fourth, energy source describes the seasonal availability, type of organic material, and size and shape of material available as food. Fifth, the introduction of exotic species or disease and the harvest of fish and shellfish for sport, commercial, and subsistence uses can alter biological interactions such as competition or predation within the natural assemblage.

Quantifying Human Disturbance for Florida Streams and Rivers

Four of the five factors were incorporated in DEP's HDG tool for Florida rivers and streams (Fore *et al.* 2007a). DEP biologists developed a hydrologic scoring system based on their knowledge of water removal, patterns of drought, and hydrographs for the sites (Table 2). To measure habitat condition, the Stream and River Habitat Assessment was used. The index evaluates substrate condition and availability, water velocity, habitat smothering (e.g., by sand and silt), channelization, bank stability, and the width and condition of riparian vegetation. Ammonia (NH_3) was selected to summarize water quality because it was the most consistently associated with the other water quality measures, had the most complete record of data, and can be attributed to human sources to a greater degree than other nutrients. The fourth element of the stream and river HDG was the **Landscape Development Intensity Index** (LDI) **(link to above)**. To define the HDG, DEP converted the four measures of human disturbance to unitless scores and summed the scores to create HDG values for each stream site, where 0 indicated minimal human disturbance and 9 indicated extreme disturbance.

Table 2. Hydrologic condition of stream site, scoring range for hydrologic index, and description of human influences. The high or low values within each condition class were assigned at the discretion of the biologist based on the extent of disturbance. These changes were associated with human disturbances, not natural events such as hurricanes or extreme droughts.

Condition	Score	Description
Excellent	1–2	Flow regime as it naturally occurs (slow and fairly continual release of water after rains), few impervious surfaces; high connectivity with ground water and surface features delivering water (e.g., sandhills, wetlands; no ditches or berms)
Good	3–4	Flow regime minimally changed; some water withdrawals; some wetland drainage, some impervious surfaces, some ditching
Moderate	5–6	Flow regime moderately altered; hydrograph moderately flashy (scouring after rain events with subsequent reductions in flow), ground water pumping evident; much wetland drainage, topographic alterations reduce natural water input; more impervious surfaces, dams/control structures change normal water delivery schedule

Poor 7–8
Flow regime highly altered; hydrograph very flashy (scouring after rain events with subsequent reductions in flow, leading to stagnant or dry conditions related to large amounts of impervious surfaces and/or ditching); water withdrawals and impoundments or control structures severely alter flows; large areas of impervious surfaces

Very poor 9–10
Flow regime entirely human controlled; hydrograph very flashy (scouring after rain events with subsequent reductions in flow, leading to stagnant or dry conditions related to impervious surfaces and ditching); intensity of water withdrawals and impoundments fundamentally alter the nature of the ecosystem

Quantifying Human Disturbance for Florida Lakes

To quantify human disturbance for Florida lakes, four of Karr's five factors (Karr *et al.* 1986; Karr *et al.* 2000): water quality, physical habitat structure, flow regime, and energy (LDI) (Fore *et al.* 2007b).

For the water quality component, DEP used a unit-less water quality (WQ) index composed of specific conductance, total Kjeldahl nitrogen (TKN), nitrites/nitrates (NO_{2+3}), total phosphorus (TP), and algal growth potential (AGP). To convert to unit-less scores, DEP used the percentiles from a statewide data set (Integrated Water Resource Monitoring [IWRM] Cycle 1, 2000-2003) to define expectations. The DEP Lake Habitat Assessment scores were used for the habitat component of the lake HDG. The Lake Habitat Assessment rates vegetation quality, stormwater inputs, bottom substrate, lakeside human alterations, upland buffer zone, and watershed land use (DEP SOP FT 3200). For hydrologic condition, each lake was assigned a score of 0 if no hydrologic modification was observed or 1 if the lake was impounded or its hydrology artificially controlled (Fore *et al.* 2007b).

To define the human disturbance gradient (HDG), we converted the four measures of human disturbance (the water quality index, the habitat index, the measure of hydrologic condition, and the LDI) to unit-less scores and summed the scores to define HDG values for each lake-visit. HDG ranged from the minimum value of 0 to the maximum of 7 for the 95 lakes in the development data set (Fore *et al.* 2007b).

Biological Condition Gradient (BCG)

The Biological Condition Gradient (BCG) is a conceptual model that relates biological response to increasing levels of stressors. The model describes how ten attributes of aquatic ecosystems (see below) change in response to increasing levels of stressors. The attributes include several aspects of community structure, organism condition, ecosystem function, and spatial and temporal attributes of stream size and connectivity. The BCG is divided into six tiers of biological condition along the stressor-response curve (Figure 1 and described below), ranging from observable biological conditions found at no or low levels of stress (a natural condition) to those found at high levels of stressors (severely changed). The model provides a common framework for interpreting biological information regardless of methodology or geography. It is based in fundamental ecological principles and has been extensively verified by aquatic biologists throughout the United States (U.S. E.P.A. 2010, Fore *et al.* 2007a, FDEP 2007).

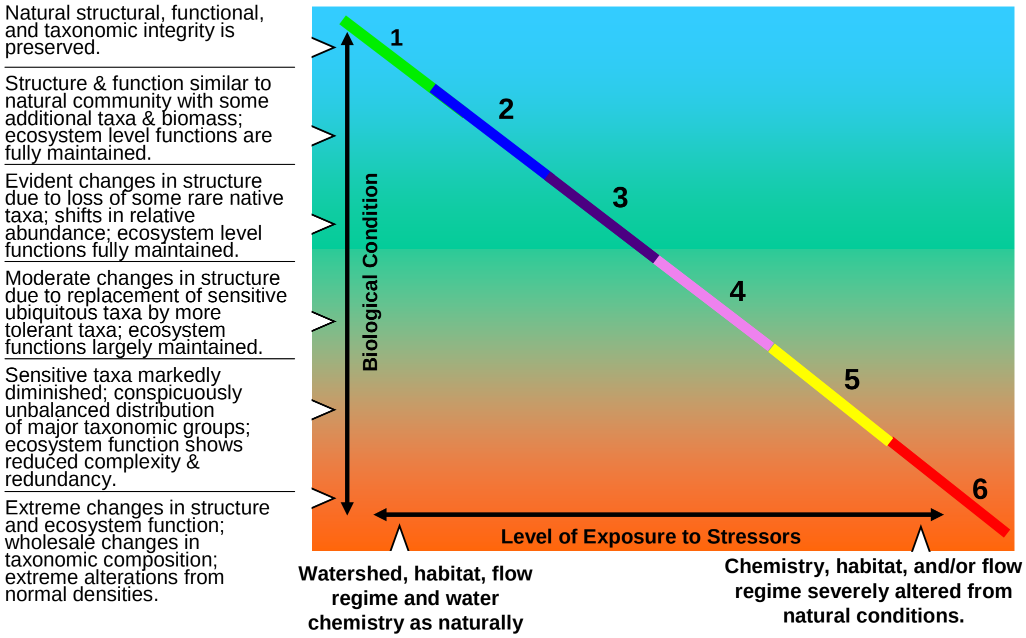

Figure 1. The Biological Condition Gradient Model (from Davies and Jackson 2006).

The BCG utilizes biological attributes of aquatic systems that predictably respond to increasing pollution and human disturbance. While these attributes are measurable, some are not routinely quantified in monitoring programs (*e.g.*, rate measurements such as productivity), but may be inferred via the community composition data (*e.g.*, abundance of taxa indicative of organic enrichment).

The biological attributes considered in the BCG are:

1) Historically documented, sensitive, long-lived or regionally endemic taxa
2) Sensitive and rare taxa
3) Sensitive but ubiquitous taxa
4) Taxa of intermediate tolerance
5) Tolerant taxa
6) Non-native taxa
7) Organism condition
8) Ecosystem functions
9) Spatial and temporal extent of detrimental effects
10) Ecosystem connectance

The gradient represented by the BCG has been divided into six levels (tiers) of condition that were defined via a consensus process (Davies and Jackson 2006) using experienced aquatic biologists from across the U.S., including Florida representatives. The six tiers are:

1) Native structural, functional, and taxonomic integrity is preserved; ecosystem function is preserved within range of natural variability;
2) Virtually all native taxa are maintained with some changes in biomass and/or abundance; ecosystem functions are fully maintained within range of natural variability;
3) Some changes in structure due to loss of some rare native taxa; shifts in relative abundance of taxa but sensitive–ubiquitous taxa are common and abundant; ecosystem functions are fully maintained through redundant attributes of the system;
4) Moderate changes in structure due to replacement of some sensitive–ubiquitous taxa by more tolerant taxa, but reproducing populations of some sensitive taxa are maintained; overall balanced distribution of all expected major groups; ecosystem functions largely maintained through redundant attributes;
5) Sensitive taxa are markedly diminished; conspicuously unbalanced distribution of major groups from that expected; organism condition shows signs of physiological stress; system function shows reduced complexity and redundancy; increased buildup or export of unused materials; and
6) Extreme changes in structure; wholesale changes in taxonomic composition; extreme alterations from normal densities and distributions; organism conditioning is often poor; ecosystem functions are severely altered.

The six levels described above are used to correlate biological index scores with biological condition, as part of calibrating the index. Once the correlation is well established, a determination is made as to which biological condition represents attainment of the Clean Water Act (CWA) goal according to paragraph 101(a)(2) related to aquatic life use support, “protection and propagation of fish, shellfish, and wildlife.”

During the development of the BCG model at National BCG Workshops, each of the break-out groups independently reported that the ecological characteristics conceptually described by tiers 1–4 corresponded to how they interpret attainment of the CWA’s interim goal for protection and propagation of aquatic life (Davies and Jackson 2006). As described in subsequent sections, two panels of Florida experts (one for the Stream Condition Index, and one for the Lake Vegetation Index) independently arrived at the same conclusions as did the national expert groups. Additionally, the State of Maine has adopted a policy that aquatic communities conceptually aligned with BCG Category 4 meets the CWA’s interim goal for protection and propagation of aquatic life, and this was subsequently approved by EPA.

Application of the Biological Condition Gradient to Florida Bioassessment Tools

DEP conducted BCG exercises to calibrate scores for the Stream Condition Index (SCI) and the Lake Vegetation Index (LVI). For the SCI, twenty-two experts examined taxa lists from 30 stream sites throughout Florida, 10 in each stream ecoregion, that spanned the range of SCI scores. Without any knowledge of the SCI scores, they reviewed the data and assigned each macroinvertebrate community a BCG score from 1 to 6, where 1 represents natural or native condition and 6 represents a condition severely altered in structure and function from a natural condition. Experts independently assigned a BCG score to each site, and then were able to discuss their scores and rationale, and could opt to change their scores based on arguments from other participants. At the conclusion of the workshop, DEP regressed the mean BCG score given to each stream against the SCI score for that site (Figure 2) (Frydenborg and Miller 2007).

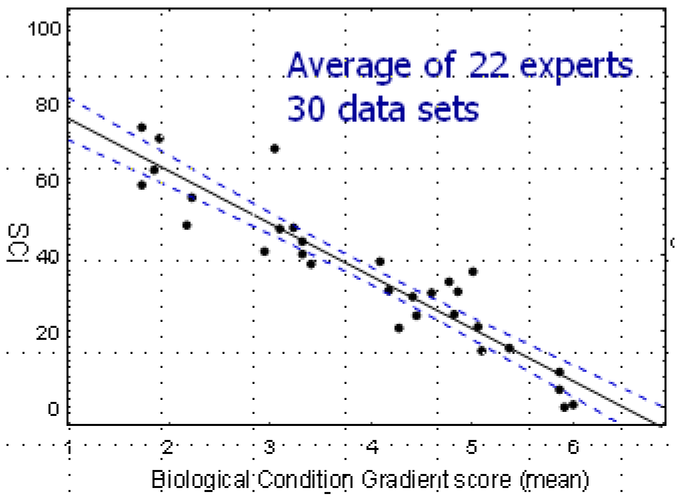

Figure 2. Regression line with 90% confidence interval showing the relationship between the mean BCG score and SCI score. The median BCG value the expert group considered meeting a healthy, well balanced community corresponded to a BCG tier of 4 and an SCI score of 34 (this subsequently changed based upon a proportional odds analysis). The "exceptional" threshold was established at 64 and above, based on the score associated with a BCG 2.

The experts were also asked to identify the lowest BCG level that still provided for the propagation and maintenance of a healthy, well-balanced aquatic community (the interim goal of the Clean Water Act) and the BCG category (and higher) that represented exceptional conditions (the ultimate goal of the Clean Water Act, also referred to as "biological integrity"). All of 22 participants thought category 2 SCI scores should be considered exceptional, which corresponds to an SCI score of 64. Eleven of 22 participants thought SCI scores associated with category 5 should be impaired, while nine participants thought category 4 represented an impaired ecological condition and two experts thought that category 4 was the lowest acceptable condition (Frydenborg and Miller 2007).

In a process analogous to that for the SCI BCG calibration, 20 Florida plant ecologists, botanists, and lake managers, all with at least five years of experience, were involved in BCG calibration of the LVI. The experts examined taxa lists from 30 lakes throughout Florida that spanned the range of LVI scores. Without any knowledge of the LVI scores, they reviewed the plant data and assigned each plant community a BCG score from 1 to 6, where 1 represents natural or native condition and 6 represents a condition severely altered in structure and function from a natural condition. Experts independently assigned a BCG score to each lake, and then were able to discuss their scores and rationale, and could opt to change their scores based on arguments from other participants. At the conclusion of the workshop, DEP regressed the mean BCG score given to each lake against the LVI score for that lake (Figure 3) (Appendix 7 in Fore *et al.* 2007b).

As in the SCI exercise, the experts were also asked to identify the lowest BCG level that still provided for the propagation and maintenance a healthy, well-balanced aquatic community and the BCG category that represented exceptional conditions. Thirteen of 19 participants thought category 2 LVI scores should be considered exceptional and one expert did not provide an opinion. Twelve of 20 participants thought LVI scores associated with category 5 should be impaired, while 5 participants thought category 4 represented an impaired ecological condition. Although DEP originally proposed that the LVI impairment threshold be established at the BCG line of 4.6 (Appendix 7 in Fore *et al.* 2007b), DEP decided, in conjunction with EPA, to establish the LVI impairment threshold based primarily on the benchmark distribution. This analysis suggests that scores of 45 and below should represent impairment, and scores of 78 and above should represent exceptional (see FDEP 2009).

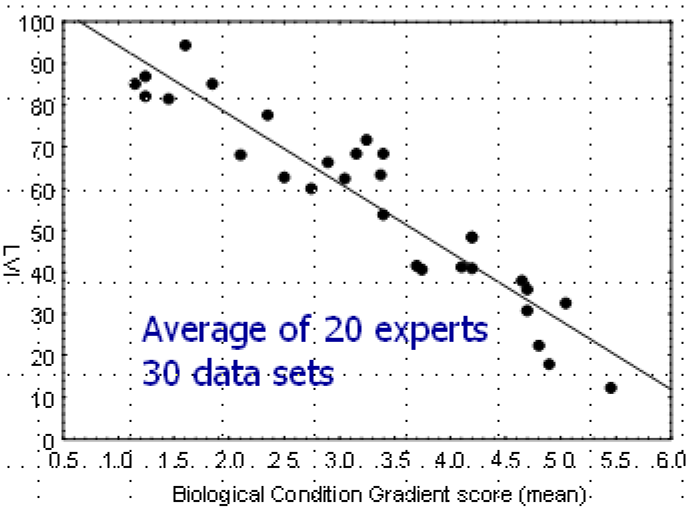

Figure 3. LVI scores regressed against the BCG scores developed "blindly" by a panel of lake experts. The median BCG value the expert group considered meeting a healthy, well balanced community corresponded to a BCG tier of 4 and an LVI score of 45. The "exceptional" threshold was established at 78 and above, based on the score associated with a BCG 2.

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