Selection of Minimally Disturbed Reference Sites Using the Landscape Development Intensity Index (LDI)

Brown and Vivas (2003) have developed a landscape development intensity index (LDI) to estimate the intensity of human land use based on nonrenewable energy flow. Application of the LDI is based on the ecological principle that the intensity of human dominated land uses in a landscape affect ecological processes of natural communities. The more intense the activity, the greater the effect on ecological processes. Natural landscapes with little or no agricultural or urban development will likely have intact ecological systems and processes. The intended use of the LDI was as an index of the human disturbance gradient.

The LDI is a land use based index of potential human disturbance calculated using coefficients corresponding to specific land use categories within drainage basins. The LDI coefficients were quantified using emergy use per unit area per time (Brown and Vivas, 2003). Emergy is energy that has been corrected for different qualities. Its unit 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 collected energy consumption data from billing records and literature sources, for energies such as electricity, fuels, fertilizers, pesticides, and water (both public water supply and irrigation). 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}. The LDI coefficients were calculated as the natural log of the empower densities normalized on a scale from 1 to 10. LDI coefficients for natural lands equal 1.0 and a LDI coefficient of 10.0 is associated with the highest intensity landuses (e.g., central business district or power plant).

The LDI is calculated as the area-weighted value of the land uses within an area of influence. Using the land use coefficients and the percent area occupied by each land use as determined by GIS landuse coverages, the LDI is calculated as follows:

$$LDI_{Total} = \Sigma\ (LDC_i * \%LU_i)$$

Where,

LDI_{Total} = Landscape Development Intensity Index for the area of influence

$\%LU_i$ = percent of total area of influence in landuse i

LDC_i = landscape development intensity coefficient for land use i

Brown and Vivas (2003) and Fore (2004) evaluated various methods for calculating the LDI, including distance weighting, and the area of influence. Brown and Vivas (2003) evaluated the differences in LDIs calculated using 100, 200, and 500 meter buffer differences around drainage basins for wetlands. They reported no significant difference between LDIs calculated using buffer distances of either 100 or 200 meters, however, LDIs calculated using a 500 meter buffer were different from those determined

using either the 100 or 200 meter distances in some cases. Additionally, they found that the LDIs determined using buffer distances of either a 100 or 200 meters were better able to predict the Wetland Biological Integrity [South Florida Water Management District's Wetland Rapid Assessment Procedure (WRAP)]. Brown and Vivas (2003) also compared distance-weighted and area-weighted LDIs. They found no significant difference between the two methods and concluded that, since the time to calculate an area-weighted LDI was considerably less, the area-weighted method was the most efficient method to calculate an LDI. Fore (2004) evaluated the effect of upstream catchment distance on the LDI for streams, in order to determine which spatial scale was a better predictor of site condition. She compared a LDI calculated as 100 m buffers around the streams both 10 km upstream of sampling points and for the entire upstream catchment area (watershed). The LDIs calculated using the two distances were both highly correlated with each other and equally correlated with Florida's Stream Condition Index (SCI) of stream macroinvertebrate biological integrity.

EPA (2000) guidance states that reference reaches are relatively undisturbed stream segments that can serve as examples of the natural biological integrity of a region. Because references reaches should be both minimally disturbed by anthropogenic influences and support valued ecologic attributes (healthy populations of flora and fauna), the metrics used to select reference reaches need to be correlated with both the degree of human disturbance influencing the reach as well the biological or ecological health of the system. As discussed above, the LDI was developed as a direct and objective measure of human disturbance. Additionally, it has been shown to be a reliable predicator of pollutant loading (Figure 1.) Furthermore, the LDI has been demonstrated in multiple cases and across multiple waterbody types to be an effective predictor of biological health.

Brown and Reiss (2006) suggested an LDI break point of less than or equal to 2.0 to identify minimally disturbed reference sites and an LDI of greater than 2.0 to designate areas with increasing levels of human disturbance based on an evaluation of diatom, macrophyte and macroinvertebrate assemblages [i.e., Florida Wetland Condition Index (FWCI)] in 193 depressional wetlands in Florida. The study divided wetlands into four groups for analysis (Group 1 – LDI = 1.0; Group 2 – $1.0 < LDI \leq 2.0$; Group 3 – $2.0 < LDI \leq 3.0$; and Group 4 – LDI > 3.0). Statistical comparisons (2-sample t-test and Fisher's one way multiple comparison) showed that there were no significant differences in diatom, macrophyte, or macroinvertebrate FWCI scores for LDI groups 1 and 2 (Table 1 and Figure 2). Additionally, groups 3 and 4 (LDI >2) were found to be significantly different from groups 1 and 2 (LDI $\leq$ 2). Brown and Reiss (2006) concluded that an LDI of 2.0 represented a very conservative break point between potentially disturbed sites and reference conditions.

The LDI has been also shown to be an effective predictor of stream macroinvertebrate biological integrity. Fore (2004) demonstrated a strong correlation (Spearman's $r=-0.60$, $p<0.01$) between the LDI the SCI (Figure 3). Furthermore, many of the 10 biological metrics that go into the SCI exhibit a strong correlation with the LDI. Percent sensitive taxa in particular shows a strong relationship with the LDI (Figure 4).

Another example of the relationship between LDI and biologic heath was provided by Niu (2004). Niu evaluated breakpoints in lake chlorophyll-a concentrations

relative to LDI within 547 Florida Lakes using change point analysis. He found statistically significant change points in median lake chlorophyll-a concentrations at LDI values of 1.9 and 6.3 (Figure 5).

As discussed above, the LDI was specially designed as a metric of human disturbance. LDI values of less than 2.0 are indicative of areas with very minimal levels of human disturbance. Although it would be ideal to incorporate direct measures of biological health into the selection of reference sites, this is not currently possible given the paucity of paired nutrient and biological data for the Lake Okeechobee Tributaries TMDL determined based on the selected analysis method. Since it has been demonstrated that the LDI is highly correlated with multiple measures of biological health, the use of the LDI alone is deemed appropriate and adequate for the selection of reference sites. Further, across multiple water body types and multiple trophic levels, a LDI of 2.0 has been shown to be a biologically significant break point that can be used to distinguish reference conditions from potentially disturbed areas. Therefore, a LDI of 2.0 or less is a conservative criterion that can appropriately and reliably be used to identify minimally disturbed reference sites.

Table 1. Comparison of Florida Wetland Condition Index (FWCI) scores using Fisher's one-way multiple comparison test for three separate species assemblages (diatoms, macrophytes, and macroinvertebrates) for depressional palustrine wetlands. From Brown and Reiss (2006).

LDI Group	Diatom FWCI		Macrophyte FWCI		Macroinvertebrate FWCI	
Group 1 LDI = 1.0	84.9 (15.2)	a	85.1 (9.1)	a	66.8 (17.1)	a
Group 2 1.0 < LDI ≤ 2.0	80.4 (17.8)	a	80.3 (13.4)	a	65.9 (18.0)	a
Group 3 2.0 < LDI ≤ 3.0	64.4 (18.9)	b	56.8 (20.3)	b	44.3 (22.1)	b
Group 4 LDI > 3.0	35.5 (25.9)	c	26.5 (21.7)	c	34.0 (18.4)	b

Group values represent mean (standard deviation).
Means in the same column followed by the same letter are not significantly different at $\alpha = 0.05$ using Fisher's LSD.

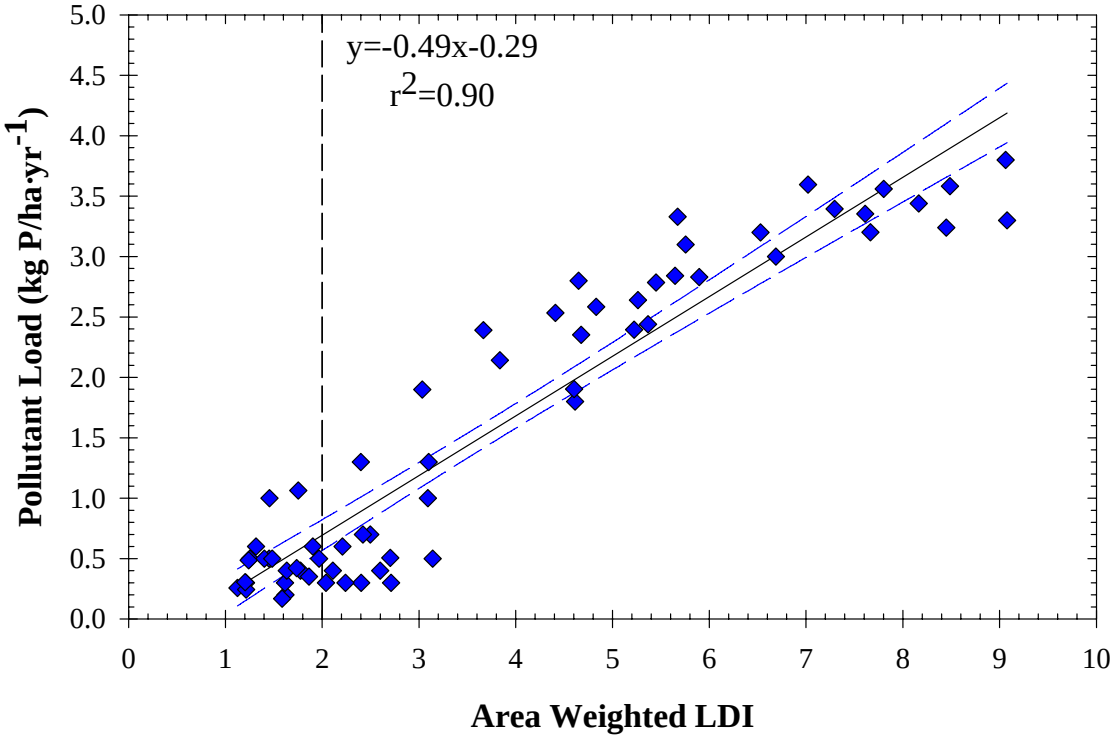

Figure 1. Area-weighted Landscape Development Intensity (LDI) index versus phosphorus pollutant load in 64 hydrologic units (sub-watersheds) of the St. Marks River watershed (recreated from Brown and Vivas, 2005).

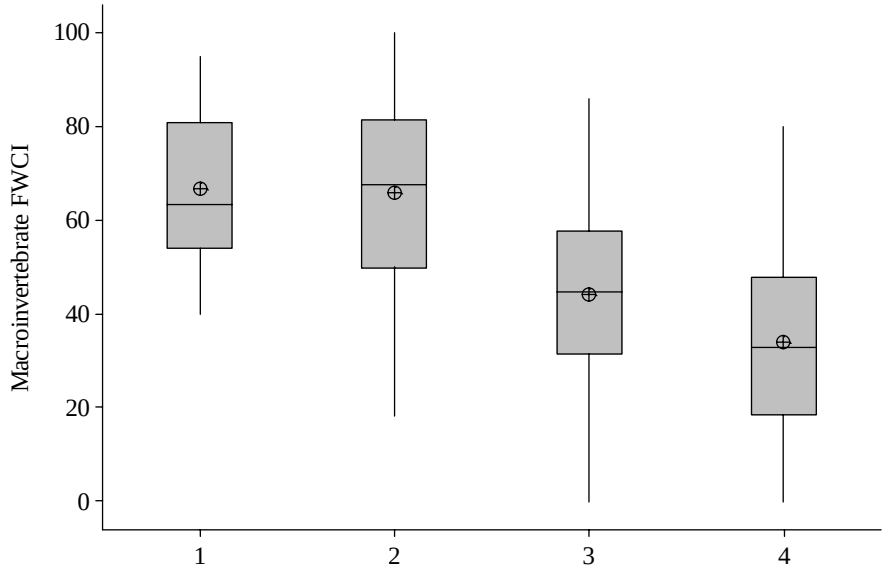

Figure 2. Box plot comparison of macroinvertebrate FWCI scores among LDI Groups, including Group 1 (LDI = 1.0), Group 2 (1.0 < LDI ≤ 2.0), Group 3 (2.0 < LDI ≤ 3.0), and Group 4 (LDI > 3.0). Boxes represent 25th – 75th quartile range, circles represent group mean values, horizontal lines represent median values (from Brown and Reiss, 2006).

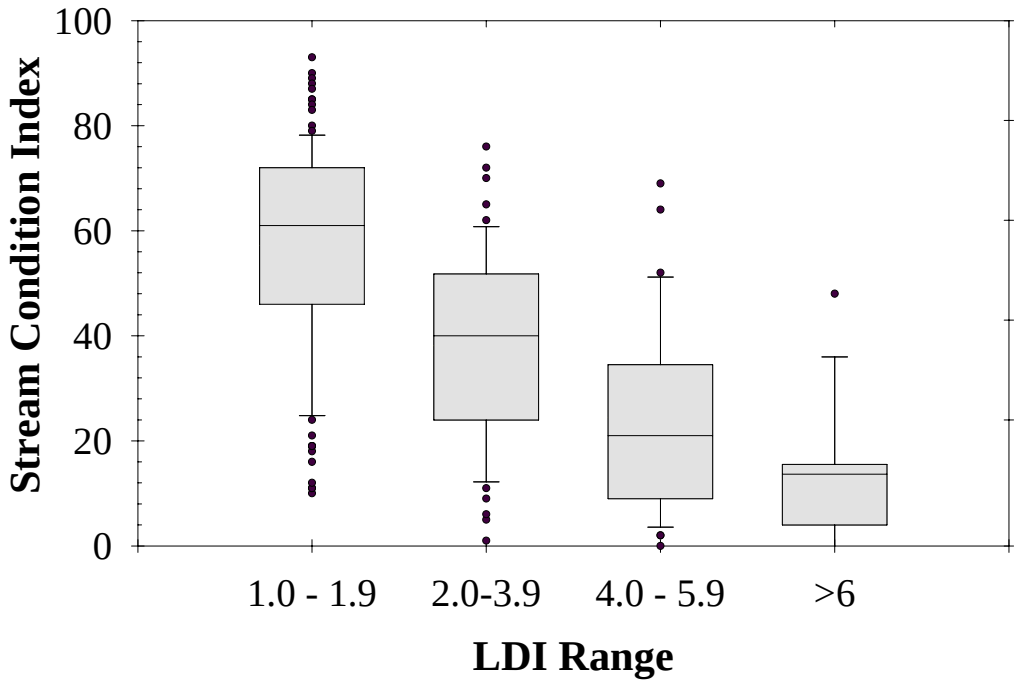

Figure 3. Box plot comparison of Stream Condition Index (SCI) scores and LDI values calculated based on a 100 m buffer area extending 10 km upstream of the sample point.

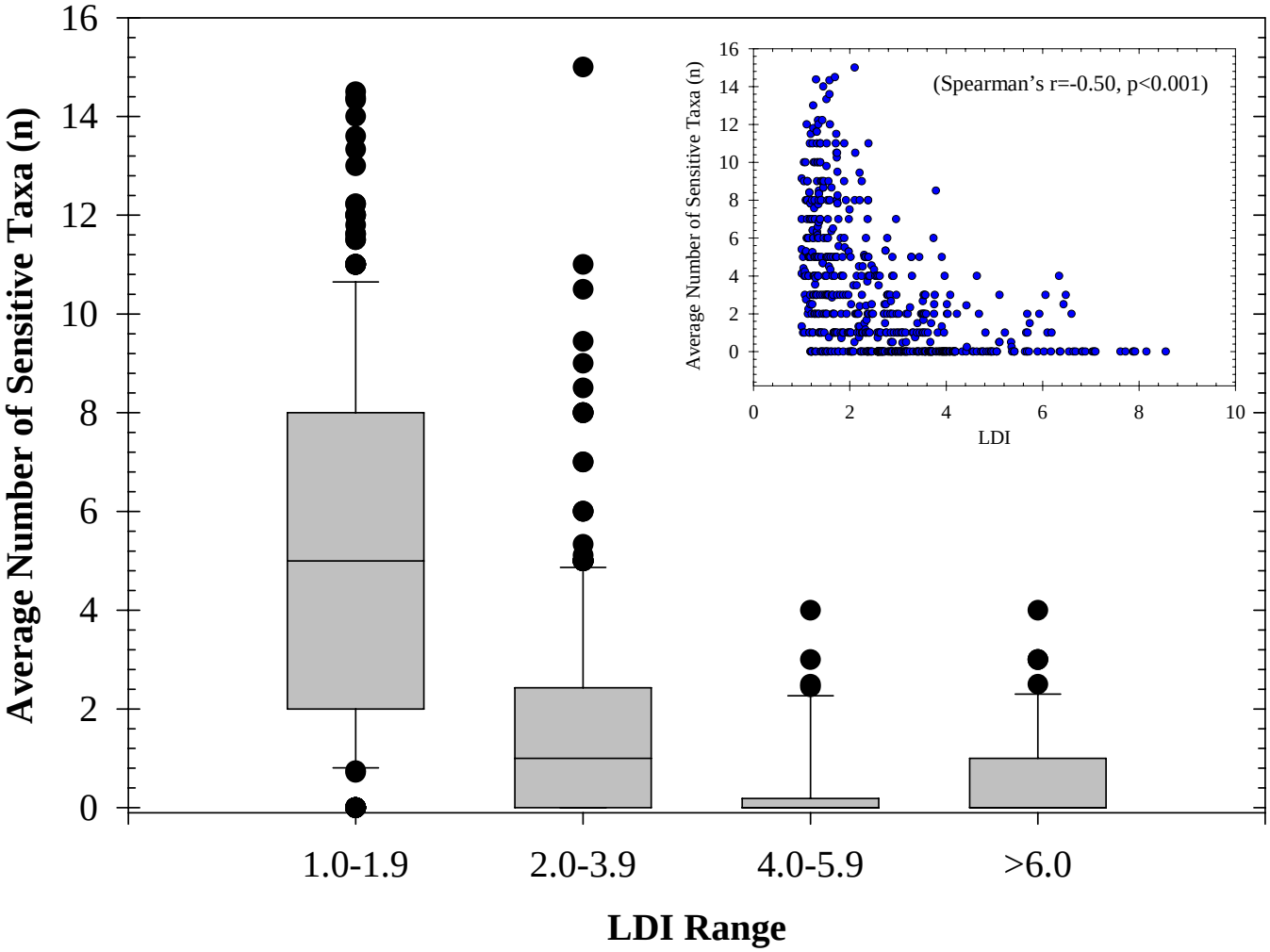

Figure 4. Comparison of average number of sensitive stream macroinvertebrate taxa for sites within different LDI groups. The number of sensitive taxa from streams with LDIs < 2.0 was significantly greater than for streams with higher LDIs (Kruskall-Wallis $p<0.0001$).

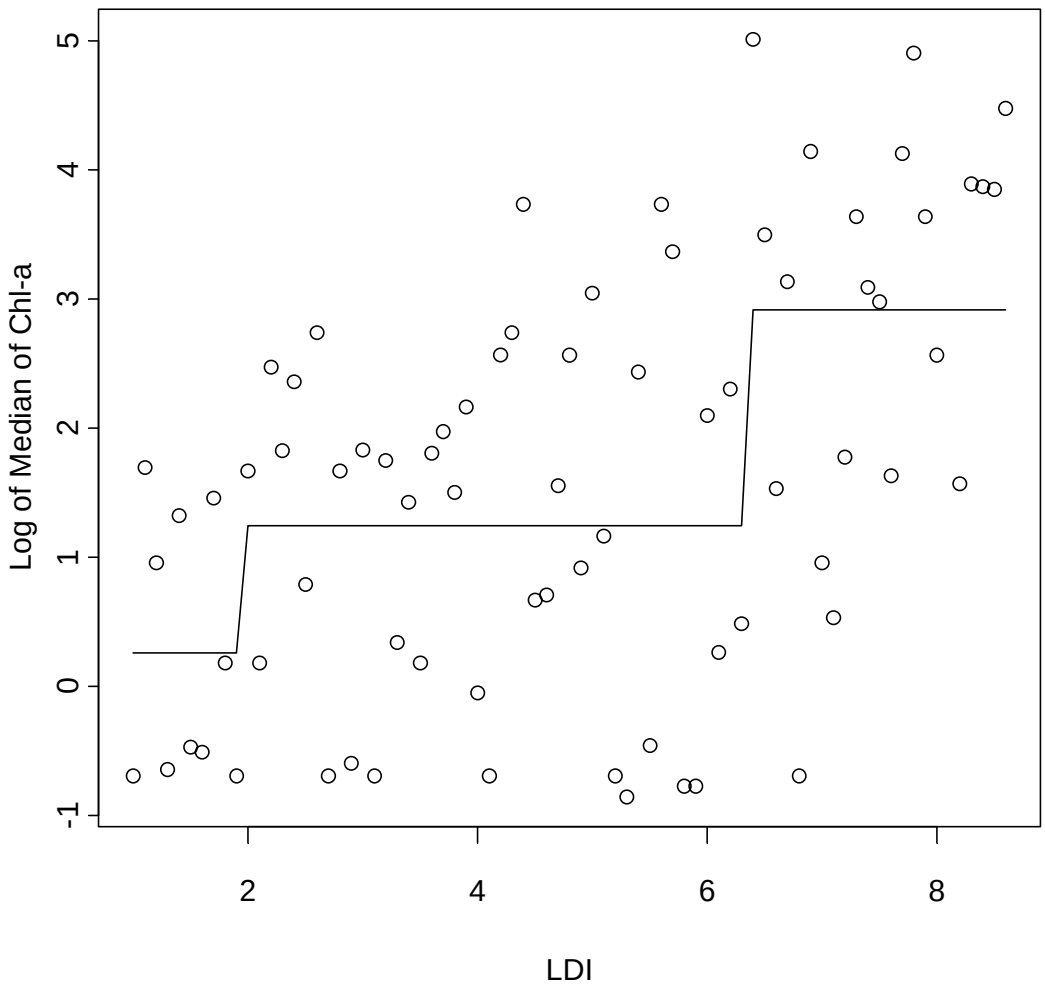

Figure 5. Log of lake median chlorophyll-a concentrations versus LDI. Two change points were detected. The first was detected at an LDI equal to 1.9 with about 80% confidence, and a second was detected at an LDI=6.3 with about 95% confidence.

Literature Cited

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