A Landscape Development Intensity Index

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ABSTRACT
The condition of landscapes and the ecological communities within them is strongly related to levels of human activity. Human-dominated land uses and especially the intensity of the uses can affect adjacent ecological communities through direct, secondary, and cumulative impacts. Recently much attention has been given to the relationships between land use and the quality of ecological communities (see for example; Allan et al., 1997; Beaulac and Reckhow, 1982; Crosbie and Chow-Fraser, 1999; Ehrenfeld, 1983; Galatowitsch et al., 2000; Kirkman et al., 1996; Richards et al., 1996; and Roth et al., 1996).

Using land use data and a development intensity measure derived from energy use per unit area, an index of Landscape Development Intensity (LDI) was calculated for watersheds of varying sizes to estimate the potential impacts from human-dominated activities that are experienced by ecological systems within those watersheds. The intended use of the LDI is as an index of the human disturbance gradient[1].

The following is a description of data needs and methods for calculating a Landscape Development Intensity index and several applications of the index as a land use based ranking scheme of the human disturbance gradient for watersheds. It 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, the LDI can be applied using available GIS land use/land cover data, aerial photographs, or field surveys.

INTRODUCTION

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. Consider, for instance, the two extremes of full development on the one hand and completely natural on the other. A fully developed landscape, dominated by high-energy land uses, may have few if any functional, natural ecological systems. At the other extreme, a natural landscape, one

[1] The human disturbance gradient is defined as the level of human induced impacts on the biological, chemical, and physical processes of surrounding lands or waters.

with no agricultural or urban development, would probably have intact ecological systems and processes. Landscapes in most regions of the globe fall somewhere between these two extremes in a gradient extending from completely natural to highly developed. They are composed of some developed areas but also have some natural ecological communities. The intensity of human uses may be an suitable metric for the disturbance gradient that results from increasing human use of landscapes.

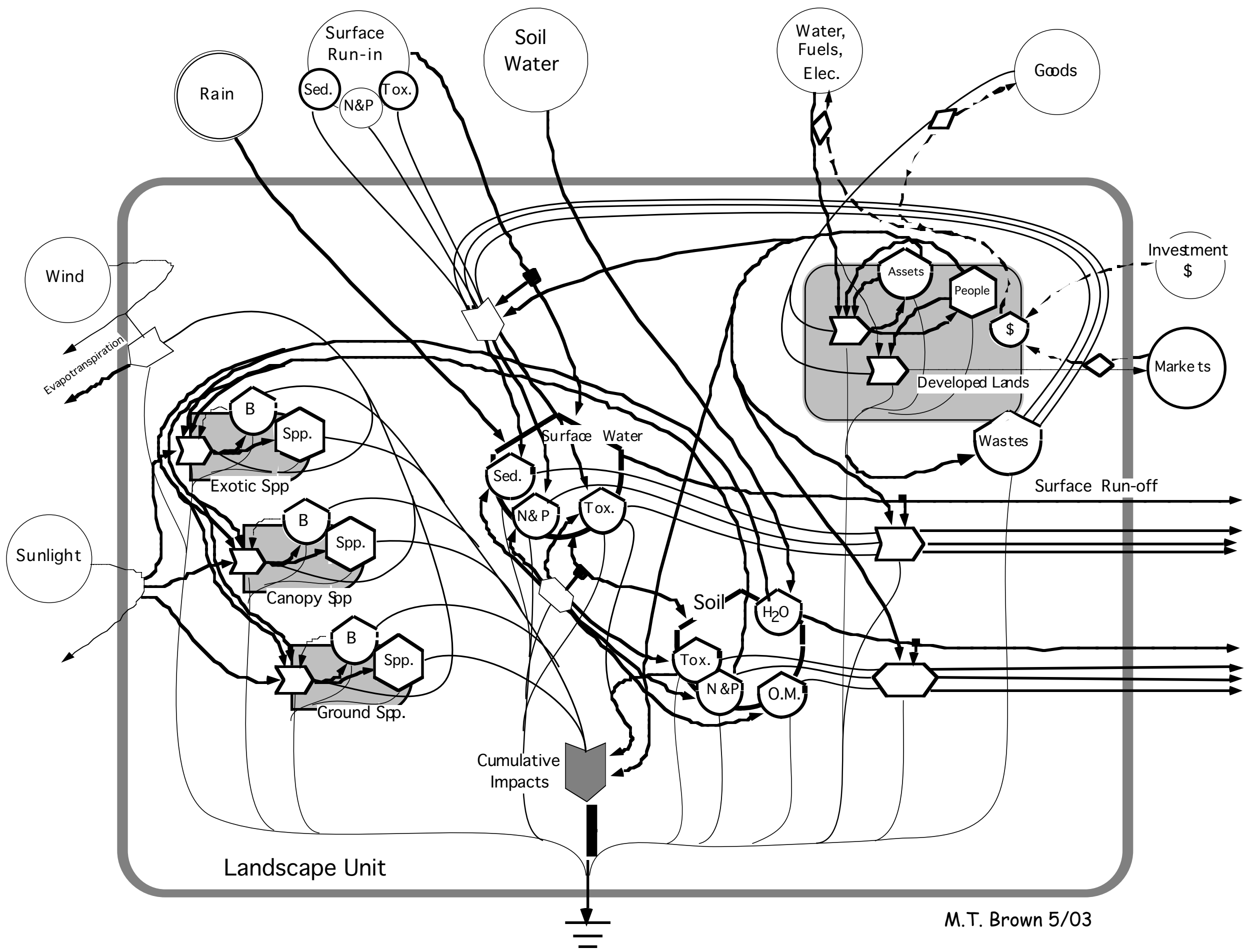

Figure 1. Systems diagram showing the effects of developed lands on wildlands. The more intense the development, the larger the effects.

Most landscapes are composed of patches of developed land and patches of wildlands[2], or undeveloped lands that remain within a developed landscape mosaic. While not directly

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[2] For convenience the term wildlands is used inclusively to mean all natural ecological systems, both terrestrial and aquatic, as well as marine ecosystems. Wildlands are areas of the landscape that are not developed.

converted, often wildlands experience cumulative secondary impacts that originate in developed areas and that spread outward into surrounding and adjacent undeveloped lands. The more developed a landscape, the greater the intensity of impacts. The systems diagram in Figure 1 illustrates some of the impacts originating in developed lands that are experienced by surrounding and adjacent wildlands. They come in the form of air- and water-born pollutants, physical damage, changes in the suite of environmental conditions (like changes in groundwater levels or increased flooding), or combinations of all of them. Pathways from the developed lands module on the right carry nutrients and toxins that affect surface and ground water which in turn negatively affect terrestrial and marine and aquatic systems. Other pathways interact directly with the biomass and species of wildlands decreasing viability and quantity of each. Pathways that affect the inflow and outflow of surface and groundwater may alter hydrologic conditions, which in turn, may negatively affect ecological systems.

Recently much attention has been given to developing classification systems for watersheds (Habersack, 2000; Hawkins, et al. 2000; Hawkins and Vinson, 2000), biological indicators of ecosystem health (Jones et al. 2001; Patil, 2001), and indices of biological integrity for streams (Barbour et al. 1996; Karr and Chu, 2000; Gerritsen and White. 1997). These efforts assume that human activities, which are tied to land uses, have affects on ecological functions, health, or integrity. Development of classification systems, indicators and indices often require the measurement of the human disturbance gradient or an index of the intensity of impacts from human dominated activities

METHODS

The LDI is a land use based index of potential human disturbance. It is calculated spatially based on coefficients applied to land uses within watersheds. These methods are based on the use of a Geographic Information System (GIS) and compatible land cover / land use digital data although the same analysis can be accomplished by hand using aerial photographs. While the analysis can be carried out by hand, GIS will be essential for large watersheds or a regional effort to characterize disturbance gradients for many ecological communities.

Delineation of Area of Influence

Land uses in the area "contributing" to a landscape unit[3] are first characterized and then an intensity factor assigned to each land use type. Development intensity factors are a function of the energy use per unit area of land use. A total area weighted development intensity is calculated for the area of influence.

The area of influence or extent of landscape that needs to be delineated depends on the type of landscape unit that is the subject of the evaluation. The area should include all lands that

[3] A landscape unit is the ecological community, drainage feature, or hydrologic system that is being studied. For instance, the study unit could be an individual ecological community such as a wetland, or a stream segment, or a sub-watershed drainage basin (HUC-6).

"contribute" to the landscape unit. In most cases, the watershed or drainage basin of the landscape unit is the most easily delineated. For large scale units such as rivers, streams, or lakes, delineated coverages of drainage basins often exist as part of GIS databases kept by various agencies of local, state, and federal government. For an individual wetland or forest patch, the area of influence is the surrounding landscape and could be delineated as the watershed of the ecosystem if topographic coverages are available. Experience in Florida's relatively flat terrain has shown however, that a characterization of the lands within a 100-meter buffer around an isolated wetland or forest patch is sufficient to "capture" the disturbance gradient. In the absence of any particular landscape feature such as a drainage structure that may direct stormwater into a wetland or water body, the 100-meter buffer was found to be quite adequate.

Characterization of Land Uses

The use of existing land use/ land cover GIS data from recent spatial data bases will save considerable time. If these data are not available, land uses can be delineated on aerial photographs. When existing GIS land use/ land cover data are used, it is important to update and verify land uses in the area of influence through ground truthing or verification using recent aerial photographs. Digital Orthophoto Quads (DOQ) have been used to good effect for ground truthing land use/land cover data from other sources. Newly obtained DOQ's are available for many parts of the country.

Land use/land cover classification schemes vary from region to region, and obviously in detail depending on scale of analysis. In Florida, the most used classification scheme is the Florida Land Use and Cover Classification System (FLUCCS), a hierarchical system of classification that begins with three broad classes: urban, agriculture and natural (FDOT, 1999). The classification system further subdivides each main class into finer and finer detail with each level of increasing resolution. Table 1 lists the classification scheme adopted for the LDI analysis. It is based on the FLUCCS categories, but differs slightly. The main concern was to keep the classes defined as closely to original classes used in developing the energy flow characteristics of land use types as possible and to make visual interpretation from aerial photographs relatively straight forward.

Table 1. Land Uses and Definitions

Land Use	FLUCCS[4]	Definition
Natural Land/Open Water	400 to 650*	Open water, upland, or wetland with very low manipulations (i.e. state parks, refuges, preserves and other protected lands).
Tree plantations	440	Land devoted to silviculture with varying stocking densities.
Unimproved Pastureland	213, 300	Native rangeland and woodland pasture with presence of livestock.
Low-intensity Open Land/Recreational	180, 190, 8146	Areas of natural vegetation in cities maintained as nature parks, and undeveloped land that may be

[4] FDOT. 1999.

		occupied by natural vegetation in an agricultural or urban landscape. Also includes access roads within conservation/protected lands.
Improved Pasture (no livestock)	211	Areas where the natural vegetation has been altered by drainage, irrigation, etc., for the grazing of domestic animals. Does not include livestock.
Low-intensity Pasture (with livestock)	211	Areas where the natural vegetation has been altered by drainage, irrigation, etc., for the grazing of domestic animals with a density of less than 1.2 animals/ha.
Citrus	221	Areas devoted to the production of oranges and citrus in general.
High-intensity Pasture (with livestock)	211	Areas where the natural vegetation has been altered by drainage, irrigation, etc., for the grazing of domestic animals with a density of more than 1.2 animals/ha.
General Agriculture	215, 222, 223, 224, 240	Applies to type of crop not known or crops other than citrus or row crops.
Medium-intensity Open Space/Recreational	181, 186, 189, 260, 510, 530, 740, 8145	Areas with grassy lawns in urban landscape including recreational land such as playgrounds, ball fields, and swimming beaches. Also applies to land that has been cleared and prepared for construction, dirt roads, barren land, and open areas surrounding power lines. Includes human-created water bodies (retention ponds, canals, reservoirs, etc).
Row crops	214	Areas devoted to the production of all types of vegetables usually grown in rows, whether producing or not.
Low-density Single Family Residential	110	Areas that are predominantly residential units with a density less than 10 units/ha.
High-intensity Open Land / Recreational	182, 187	Applies to stadiums not associated with institutions such as schools and universities, golf courses, and racetracks (horse, dog, car).
High-intensity Agriculture	230, 250	Dairy farms and large-scale cattle feed lots, chicken farms, and hog farms.
Med-density Single Family Residential	120	Areas that are predominantly residential units with a density between 10 and 20 units/ha.
High-density Single Family Residential	130	Areas that are predominantly residential units with a density of more than 20 units/ha.
Low-intensity Transportation	812, 8143-8144, 816	Paved road with 2 lanes (includes shoulders), railroads, and canals used for transportation.
Low-intensity Commercial	140	Commercial strip.
Institutional	143, 171-177	Schools, universities, religious, military, medical and professional facilities, and government buildings.
High-intensity Transportation	811, 812, 813, 8141-8142, 815	Paved road with more than 2 lanes (includes shoulders), airports, railroad terminals, bus and truck terminals, port facilities, and auto parking facilities when not directly related to other land use.
Industrial	150, 160, 820, 830,	Land uses include manufacturing, assembly or processing of materials/products and associated buildings and grounds. Also includes extractive areas and mining operations, water supply plants, and solid wastes disposal facilities.
Low-intensity Multi-family Residential	133	Areas that are predominantly multi-family residential units such as condominiums and apartment buildings up to 2 stories.
High-intensity Commercial	141,142, 145	Commercial mall with associated storage buildings and parking lots, hotels, convention centers, and theme

		parks.
High-intensity Multi-family Residential	134	Areas that are predominantly multi-family residential units such as condominiums and apartment buildings with 3 or more stories.
Low-intensity Central Business District	141	Central business districts with an average of 2 stories.
High-intensity Central Business District	141	Central business districts with an average of more than 2 stories.

* Does not include tree plantations (440) and reservoirs (530).

Quantifying Human Development Intensity by Land Use

The metric used for quantifying human activity is emergy[5] use per unit area per time. Emergy is energy that has been corrected for different qualities, and its unit of measure is the solar emergy joule (abbreviated sej). Thus the units for quantifying the intensity of human activity are sej/ha $*yr^{-1}$. Emergies used in calculating the LDI are all non-renewable energies including electricity, fuels, fertilizers, pesticides, and water (both public water supply and irrigation).

Referred to as "empower density," emergy use per area per time is calculated as average values for land use categories from previous studies (Brown, 1980; Whitfield, 1994; and Brandt-Williams, 2002). In these previous studies, energy consumption data were collected from actual billing records and from the literature and averaged on a per unit area basis for different land use types. Since the LDI is a measure of human activity, only non-renewable energies are used in the calculation. Included as an appendix are two tables that give details of the evaluation of land uses: 1) an evaluation of citrus agriculture and 2) an evaluation of low-density single family residential (1.5 units per hectare). Table 2 summarizes the non-renewable empower densities of the various land uses in the second column.

The last column in Table 2 is the LDI coefficient for each land use type. The LDI coefficient is calculated as the normalized natural log of the empower densities. First the natural log of the empower densities were calculated and then the resulting values were normalized on a scale from 1 to 10, with the LDI coefficient for natural lands equal to 1.0 and a LDI coefficient of 10.0 for the highest intensity land use (Central Business District).

Calculating an Area Weighted LDI

Land uses within the "area of influence" were assigned an LDI coefficient from Table 2, and then an overall LDI ranking was calculated as an area weighted average. Using the GIS, total area and percent of total area occupied by each of the land uses were determined and then the LDI was calculated as follows:

$$LDI_{Total} = \sum \%LU_i * LDI_i \quad (1)$$

[5] For a more complete description of emergy and methods for calculating the emergy of goods, services, and fuels, see Odum, (1996), Environmental Accounting.

where:

LDI_{total} = LDI ranking for landscape unit

$\%LU_i$ = percent of the total area of influence in land use i

LDI_I = landscape development intensity coefficient for land use i

Table 2. Land use classification, Non-Renewable Empower Density, and Resulting LDI Coefficients

Land Use	Non-Renewable Empower Density (E14 sej/ha/yr)	Ln Non-Renewable Empower Density	LDI Coefficients
Natural System	0.00		1.00
Natural Open water	0.00		1.00
Pine Plantation	5.10	1.63	1.58
Recreational / Open Space (Low-intensity)	6.55	1.88	1.83
Woodland Pasture (with livestock)	8.00	2.08	2.02
Pasture (without livestock)	17.20	2.84	2.77
Low Intensity Pasture (with livestock)	33.31	3.51	3.41
Citrus	44.00	3.78	3.68
High Intensity Pasture (with livestock)	46.74	3.84	3.74
Row crops	107.13	4.67	4.54
Single Family Residential (Low-density)	1,077.00	6.98	6.79
Recreational / Open Space (High-intensity)	1,230.00	7.11	6.92
High Intensity Agriculture (Dairy farm)	1,349.20	7.21	7.00
Single Family Residential (Med-density)	2,175.00	7.68	7.47
Single Family Residential (High-density)	2,371.80	7.77	7.55
Mobile Home (Medium density)	2,748.00	7.92	7.70
Highway (2 lane)	3,080.00	8.03	7.81
Low Intensity Commercial	3,758.00	8.23	8.00
Institutional	4,042.20	8.30	8.07
Highway (4 lane)	5,020.00	8.52	8.28
Mobile Home (High density)	5,087.00	8.53	8.29
Industrial	5,210.60	8.56	8.32
Multi-family Residential (Low rise)	7,391.50	8.91	8.66
High Intensity Commercial	12,661.00	9.45	9.18
Multi-family Residential (High rise)	12,825.00	9.46	9.19
Central Business District (Average 2 stories)	16,150.30	9.69	9.42
Central Business District (Average 4 stories)	29,401.30	10.29	10.00

RESULTS

Several aspects of calculating LDIs are given next. First the effect of the area of influence on LDI "scores" for isolated wetlands in Florida is discussed, and then two case studies are presented as examples of the use of LDI at a watershed scale and at the scale of individual isolated depressional wetlands.

Appropriate Area of Influence

We have tested various methods for calculating LDIs for the watershed of wetlands, including distance weighting, and several different areas of influence around wetlands. The effect of the area of influence was tested by calculating LDIs within increasing buffers surrounding wetlands. Figure 2 shows the results of LDI calculations for buffers of 100 meters and 200 meters for a set of 49 wetlands in Central Florida. There was no significant difference ($t_{(48)} = 0.44$, $p = 0.66$) between LDI's calculated using the 100-meter area of influence and the 200-meter area(Wilcoxon Signed Rank Test for differences, p= 0.726). We extended the buffer distance to as much as 500 meters and while there were differences in the mean LDIs calculated for each buffer difference, their power as a predictor of WRAP score (see below) declined.

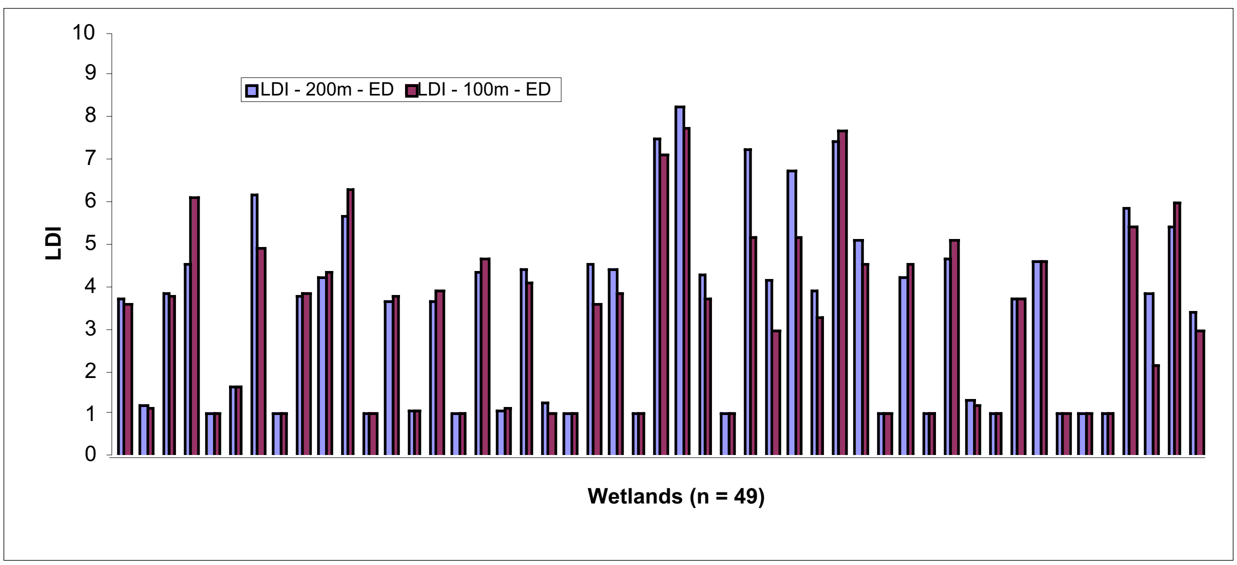


Figure 2. Graph of calculated LDIs for 49 wetlands in Central Florida, showing no significant differences between LDIs calculated using a 100 meter buffer and a 200 meter buffer.

The effect of distance weighting on LDI was tested using the 100 meter buffer distance for a sample of 36 wetlands from Central and South Florida. First the LDI was calculated, giving equal weight to the land use within the buffer regardless of the distance from the wetland. Then the LDI was calculated, assuming that the effect of development intensity on the landscape unit

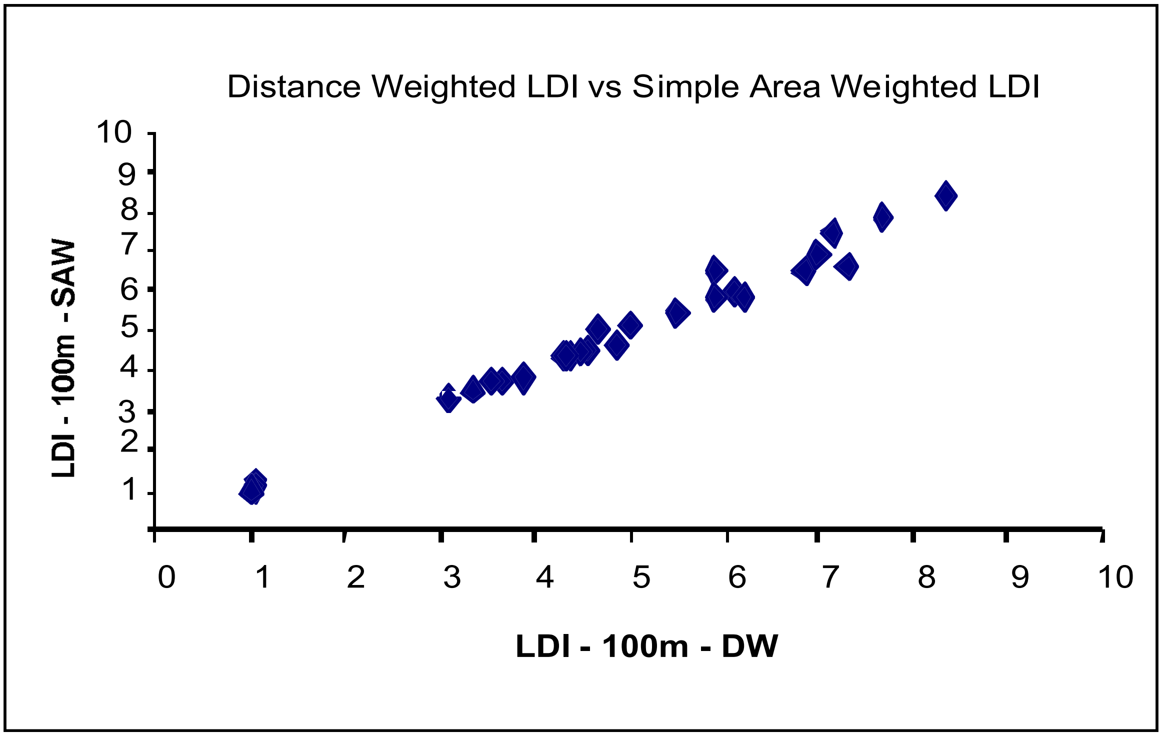


Figure 3. Graph of distance-weighted LDI (LDI-100m-DW) plotted against a simple area-weighted LDI (LDI-100m-SAW) for 36 wetlands in central Florida showing no significant difference between the two methods of calculating the index.

decreases linearly with distance. Figure 3 shows the results of comparison of the two methods. Essentially, there was no significant difference between the equal distance LDI (LDI-SAW) and the distance weighted LDI (LDI-DW).

In summary, it was found that a 100-meter area was sufficient to "capture" effects and that a distance-weighted method was no better than a simple area-weighted calculation. Since the amount of time required to calculate the distance-weighted LDI is significantly more than the area-weighted LDI, distance-weighting was considered not to be cost effective

Case Studies Using LDI

Presented next are two applications of LDI at different scales of analysis. In the first, LDI rankings were calculated at the watershed scale and related to total phosphorus loading. In the second application, LDI was related to a wetland assessment procedure developed in South

Florida (Wetland Rapid Assessment Procedure or WRAP), which was calculated for depressional herbaceous wetlands.

Watershed Scale Application of LDI

Parker (in Brown et al., 1998) calculated several different LDI's for 64 watersheds in the St. Marks River basin of the Florida Panhandle and related them to total phosphorus loading. Phosphorus loading was calculated using event mean concentration data within a GIS spatial model. The graph in Figure 4 uses Parker's data but recalculates LDI using Equation 1. LDI values of 1.0 – 2.0 correspond to watersheds that are nearly 100% natural lands; watersheds with LDI values between 2.0 and 5.0 are primarily agricultural while those greater than 5.0 are dominated by urban land uses. The variability in background concentrations of P evident in watersheds having low LDI scores (less than 3.0) is the result of subtle differences in relatively small development patterns of farms and rural roads in undeveloped watersheds. With increasing area and intensity of development, the modeled pollutant loads are highly correlated with the LDI values (r^2 = 0.877, p = 0.05).

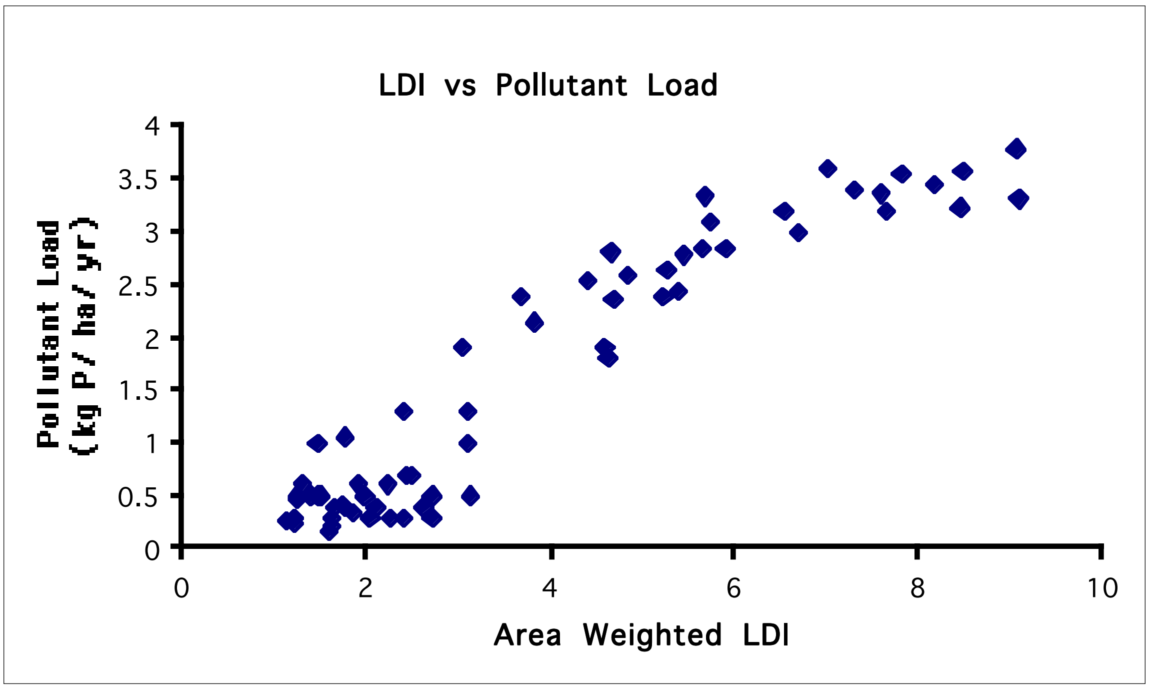


Figure 4. Area-weighted LDI verses phosphorus load in 64 hydrologic units (sub-watersheds) of the St. Marks River watershed

LDI Applied to Depressional Herbaceous Wetlands

In recent studies of depressional wetlands in Florida, an LDI has been used to characterize the human disturbance gradient as a means of developing biological indicators for wetlands (Brown et al. 2001, Brown et. al 2003, Lane 2003). Currently, data on three assemblages, (macrophytes, macro-invertebrates, and algae) collected from over 250 herbaceous and forested depressional wetlands are being used to develop a Wetland Index of Biological Integrity (WIBI) for Florida wetlands. Figure 5 is a graph of LDI verses the South Florida Water Management District's WRAP (Miller and Gonsalus, 1997) for 118 depressional forested wetlands in Florida. WRAP is a qualitative assessment of a wetland's functional capacity and is scored using six different variables: (1) wildlife utilization, (2) wetland overstory/shrub canopy, (3) wetland vegetative ground cover, (4) adjacent upland support/wetland buffer, (5) field indicators of wetland hydrology, and (6) water quality input and treatment systems. .

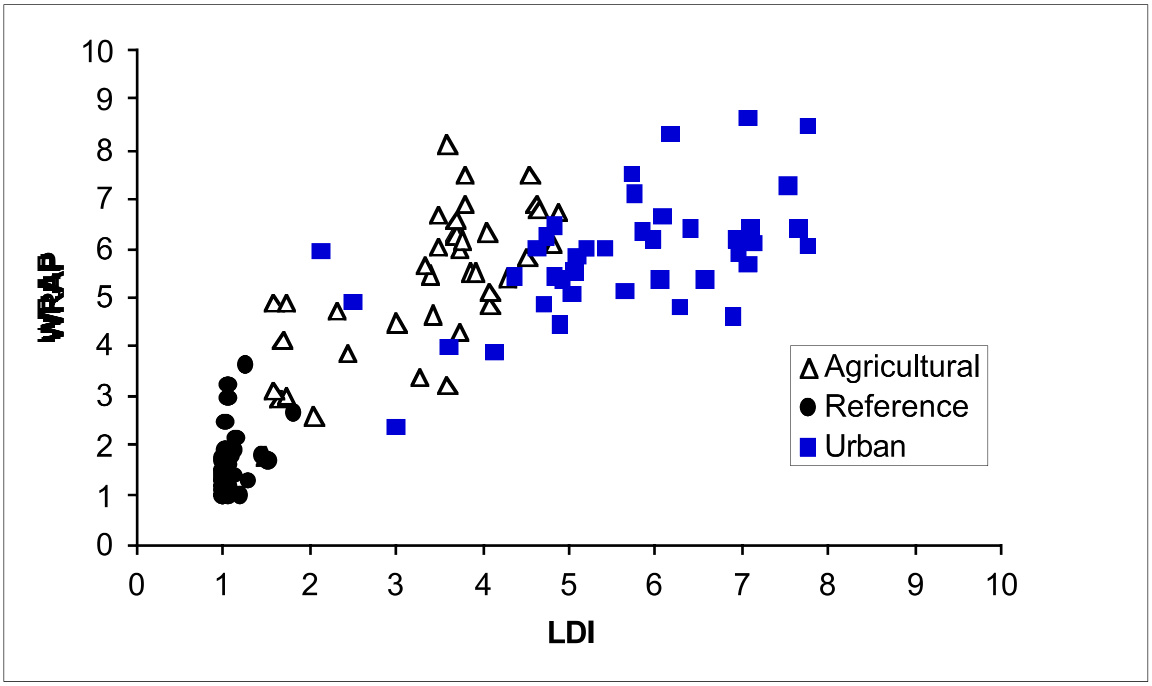
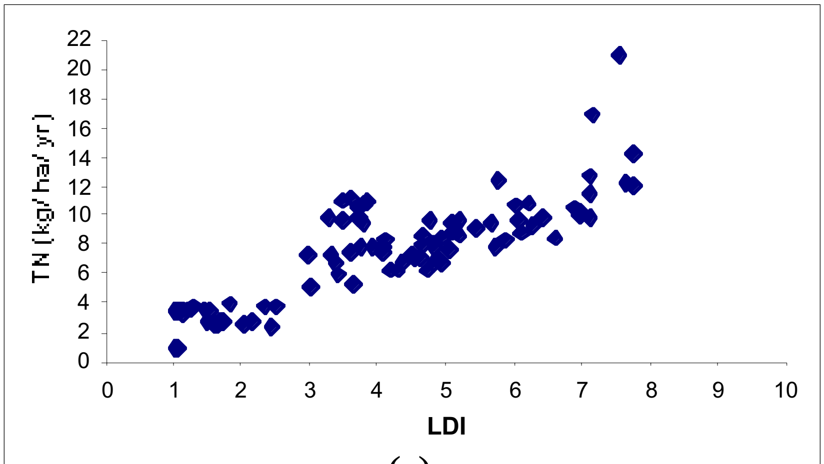


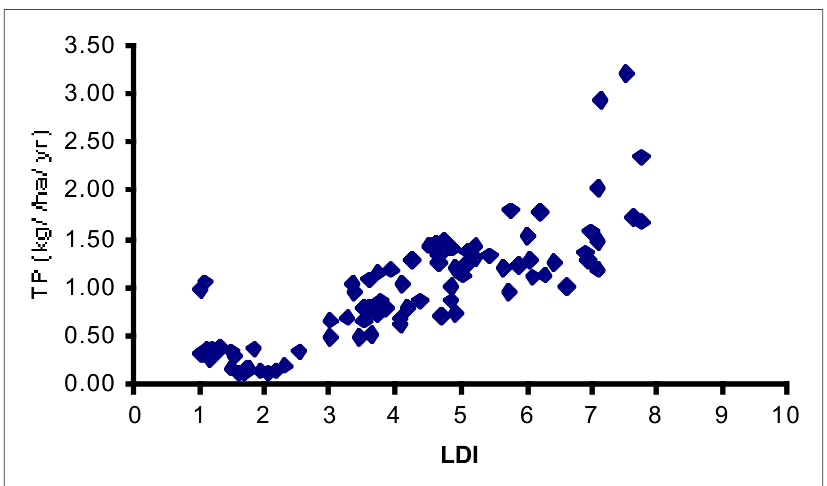
Figure 5. LDI versus Wetland Rapid Assessment Procedure Score. The WRAP score is generally on a scale of 0 – 3.0, with 3.0 as the best score. We have normalized the WRAP score to a scale of 1 - 10 (one being the best) for comparison with the LDI.

LDI shows a clear relationship ($r^2 = 0.71$, $p = 0.05$) to the WRAP qualitative assessment scores. Analysis of the Florida data set, from which these data have been extracted, is continuing with development of biological indicators of wetland ecosystem health for both depressional marsh and forested wetlands.

Using a GIS pollutant loading model and land use data for depressional wetlands in the Florida data set, we evaluated pollutant loads from a 100 meter buffer area surrounding each wetland. Figure 6 is a graph of modeled pollutant load (TP and TN) for 118 depressional wetlands. The relationship between modeled pollutant load and LDI is similar to that found for



(a)



(b)

Figure 6. LDI verses modeled total nitrogen load (a) and total phosphorus load (b) using 100 meter buffer around 118 depressional wetlands in Florida.

sub-watersheds with increasing pollutant loads correlated to increasing LDI scores (TN: $r^2 = 0.75$ and TP: $r^2 = 0.74$; $p= 0.05$)

CONCLUSIONS

The LDI Index is a quantitative measure of the intensity of human use of landscapes. It is based on the use of energy per unit area converted to energy of one type (solar emergy). LDI differs from other measures of land use intensity because it scales the intensity of activity based on non-renewable energy use, a characteristic common to all human dominated land uses. While it has been shown that percent impervious surface is a relatively good indicator of surface water pollution in watersheds, in agricultural watersheds where imperviousness may be relatively unimportant, the correlation between pollutant load and impervious surface declines. LDI, however, is a continuous index that ranks urban and agricultural land based on their empower density (emergy per unit area per unit time).

As a quantitative measure of the intensity of human use of landscapes, the LDI may be useful as a measure of the disturbance gradient in applications of bio-indicator development. At this point in the development of the LDI, we believe that because of the small area of influence around isolated depressional wetlands, distance weighting may not be important (and our early tests of distance weighting appear to suggest this). However, as we apply the LDI concept to larger watersheds, distance may be a far more important variable. Some preliminary analysis of spatial pattern of development suggests aggregate measures of landscape pattern combined with distance may be important modifiers for LDIs at the watershed scale.

We believe that the LDI can be applied in other areas with minimal data acquisition and changes in the LDI Land Use /Land Cover coefficients. Since the LDI coefficients are normalized between the most intense and least intense land uses, it may be possible to apply the LDI coefficients calculated for Florida at other locations with minor adjustments.

Research on the LDI continues, using the empower of land uses and water quality data from numerous watersheds throughout Florida. Several different methods of accounting for spatial influences of human activities within the area of influence are being tested as well. The use of LDI as an index of human disturbance is being tested at three landscape scales: the scale of individual wetlands, the scale of sub-watersheds (HUC-6), and at the larger scale of higher order basins (HUC -3) (Vivas, 2003). Spatial simulations of LDI have been evaluated as a means of determining buffer distances for set backs (buffer areas) between human dominated landscapes and sensitive wildlands (Brown, 2003).

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Appendix A-1.

Example emergy evaluations of two land use subsystems: 1) One hectare of citrus grove, and 2) one hectare of low density single family residential (1.5 units/hectare). The tables list annual emergy flows for the two subsystems that were used to calculate the empower densities in Table 2. Only the non-renewable emergies were summed to determine empower.

Table A-1 Emergy Evaluation of Oranges, per ha per year
(after Brandt-Williams, 2002)

Note	Item	Data (units/yr)	Unit	Unit Solar Emergy (sej/unit)	Solar Emergy (E13 sej/yr)
RENEWABLE INPUTS					
1	Sunlight	5.93E+13	J	1	6
2	Rain (chemical potential	6.25E+10	J	3.02E+04	189
3	Wind (kinetic energy)	2.36E+11	J	9.83E+02	23
NON-RENEWABLE STORAGES USED					
4	Net Topsoil Loss	6.33E+08	J	1.24E+05	8
PURCHASED INPUTS					
5	Fuel	2.28E+07	J	1.11E+05	0.3
6	Electricity	4.68E+08	J	2.69E+05	13
7	Potash	2.36E+05	g K	1.85E+09	44
8	Lime	2.40E+05	g	1.68E+09	40
9	Pesticides	1.79E+04	g	2.52E+10	45
10	Phosphate	1.12E+04	g P	3.70E+10	42
11	Nitrogen	3.01E+04	g N	4.05E+10	122
12	Labor	3.79E+08	J	1.36E+05	5
13	Services	3.01E+02	$	4.03E+12	121
	Sum of Non-renewable & Purchased Inputs				**440**

Notes to Table A-1

1 **Sunlight**

Annual energy = (Avg. Total Annual Insolation J/yr)(Area)(1-albedo)
Insolation = 6.90E+09 $J/m^2/y$ (NCDC, 2000)
Area = 1.00E+04 m^2
Albido = 0.14 (Odum 1986)
Annual energy = 5.93E+13

2 **Rain**

Annual energy = (in/yr)(Area)(0.0254 m/in)(1E6g/m3)(4.94J/g)(1 - runoff)
Rain (in/yr)= 54 (NCDC, 2000)
Area (m2)= 10000
Runoff coeff.= 7.70E-02 (AFSIRS estimate, Smajstrla, 1990)

Annual energy = 6.25E+10

3 **Wind kinetic energy**

Area = 1.00E+04 m^2

Density of Air = 1.30E+00 kg/m^3

Avg. annual wind velocity = 5.00E+00 mps (NCDC, 2000)

Geostrophic wind = 8.33E+00 mps

Drag Coeff. = 1.00E-03 (Miller, 1964 quoted by Kraus, 1972)

Energy (J) = (area)(air density)(drag coefficient)($velocity^3$)

= (_____m^2)(1.3 kg/m^3)(1.00 E-3)(______mps)(3.14 E7 s/yr)

Energy(J) = 2.36E+11 J/yr

4 **Net Topsoil Loss**

Erosion rate = 70 g/m^2/yr [Pimentel et al., 1995]

% organic in soil = 0.04 [Pimentel et al., 1995]

Energy cont./g organic = 5.40 kcal/g

Net loss of topsoil = (farmed area)(erosion rate)

O. M. in topsoil used up = (total mass of topsoil)(% organic)

Energy loss = (loss of organic matter)(5.4 kcal/g)(4186 J/kcal)

Annual energy = 6.33E+08

5 **Fuel** (includes diesel, gasoline, lubricants)

Annual energy = (gallons fuel) * (1.51E5 J/gal)

Gallons = 1.51E+02 FAECM data (Fluck, et al.1992)

Annual energy = 2.28E+07

6 **Electricity, J**

Annual energy = KWh*3.6E6 J/KWh

KWh = 1.30E+02 FAECM data (Fluck, et al.1992)

Annual energy = 4.68E+08

7 **Potash, g K per ha**

Annual consumption = (g fertilizer active ingredient)(78 gmol K/94 gmol K2O)

g = 2.84E+05 FAECM data (Fluck, et al.1992)

Annual consumption = 2.36E+05

8 **Lime, g per ha**

Annual consumption, g = 2.40E+05 FAECM data (Fluck, et al.1992)

9 **Pesticides, g per ha** (includes pesticides, fungicides, herbicides)

Annual consumption, g = 1.79E+04 FAECM data (Fluck, et al.1992)

10 **Phosphate, g P per ha**

(g fertilizer active ingredient)(31 gmol P/132 gmol DAP)

g = 4.79E+04 FAECM data (Fluck, et al.1992)

Annual consumption = 1.12E+04

11 **Nitrogen, g N per ha**

(g fertilizer active ingredient)(28 gmol N/132 gmol DAP)

g = 1.42E+05 FAECM data (Fluck, et al.1992)

Annual consumption = 3.01E+04

12 **Labor**

(pers-hr/ha/yr)*(3500 Cal/day)*(4186J/Cal) / (8 hr/day)

pers-hours = 2.07E+02 FAECM data (Fluck, et al.1992)

Annual energy = 3.79E+08

13 **Services, $ per ha**

$/yr = 3.01E+02 FAECM data (Fluck, et al.1992)

Annual emergy = ($ /yr)(sej/$)

Table A-2 Emergy Evaluation of Single Family residential unit
(After Brown, 1980)

Note	Item	Data (units/yr)	Unit	Unit Solar Emergy (sej/unit)	Solar Emergy (E13 sej/yr)	
RENEWABLE INPUTS						
1	Sunlight	5.93E+13	J	1	6	
2	Rain (chemical potential	2.71E+10	J	3.02E+04	82	
3	Wind (kinetic energy)	2.36E+11	J	9.83E+02	23	
NON-RENEWABLE STORAGES USED						
4	Net Topsoil Loss	4.52E+07	J	1.24E+05	1	
PURCHASED INPUTS						
5	Natural Gas	3.29E+10	J	1.11E+05	365	
6	Electricity	6.22E+09	J	2.69E+05	167	
7	Water	3.61E+09	gal	3.00E+05	108	
8	Food	4.19E+07	J	3.36E+06	14	
9	Goods	1.50E+04	$	1.10E+12	1650	
10	Pesticides	1.59E+04	g	2.52E+10	40	
11	Phosphate	8.44E+03	g P	3.70E+10	31	
12	Nitrogen	2.26E+04	g N	4.05E+10	91	
13	Construction materials	3.04E+07	g	1.55E+09	4712	(1.5 units/ha)
	Sum of Non-renewable & Purchased Inputs				**7180**	**10770**

Notes Table A-2

1 **Sunlight**

Annual energy = (Avg. Total Annual Insolation J/yr)(Area)(1-albedo)
Insolation = 6.90E+09 $J/m^2/y$ (NCDC, 2000)
Area = 1.00E+04 m^2
Albido = 0.14 (Odum 1987)
Annual energy = 5.93E+13

2 **Rain**

Annual energy = (in/yr)(Area)(0.0254 m/in)(1E6g/m3)(4.94J/g)(1 - runoff)
Rain (in/yr)= 54 (NCDC, 2000)
Area (m2)= 10000
Runoff coeff.= 6.00E-01 estimate
Annual energy = 2.71E+10

3 **Wind kenitic energy**

Area = 1.00E+04 m^2
Density of Air = 1.30E+00 kg/m^3
Avg. annual wind velocity = 5.00E+00 mps (NCDC, 2000)
Geostrophic wind = 8.33E+00 mps

Drag Coeff. = 1.00E-03 (Miller, 1964 quoted by Kraus, 1972)

Energy (J) = (area)(air density)(drag coefficient)(velocity^3)

= (_____m^2)(1.3 kg/m^3)(1.00 E-3)(______mps)(3.14 E7 s/yr)

Energy(J) = 2.36E+11 J/yr

4 **Net Topsoil Loss**

Erosion rate = 5 g/m^2/yr [Pimentel et al., 1995]

% organic in soil = 0.04 estimate

Energy cont./g organic = 5.40 kcal/g

Net loss of topsoil = (farmed area)(erosion rate)

O. M. in topsoil used up = (total mass of topsoil)(% organic)

Energy loss = (loss of organic matter)(5.4 kcal/g)(4186 J/kcal)

Annual energy = 4.52E+07

5 **Natural Gas**

Annual energy = (therms) * (1.055 E8 J/therm)

Therms = 3.12E+02 (Gainesville Regional Utilities, 2002)

Annual energy = 3.29E+10

6 **Electricity, J**

Annual energy = KWh*3.6E6 J/KWh

KWh = 1.73E+03 (Gainesville Regional Utilities, 2002)

Annual energy = 6.22E+09

7 **Water**

Annual consumption = (gallons)(3785 cm3)(1 g/cm3)(4.94J/g)

gal = 1.93E+05 (Gainesville Regional Utilities, 2002)

Annual consumption = 3.61E+09

8 **Food**

Annual consumption = (2500Cal/day)(4187 J/Cal)(4 per/household)

Annual consumption, g = 4.19E+07

9 **Goods**

Annual Consumption = $15,000

10 **Pesticides, g per ha** (includes pesticides, fungicides, herbicides)

Annual consumption, g = 1.59E+04 estimate

11 **Phosphate, g P per ha**

(g fertilizer active ingredient)(31 gmol P/132 gmol DAP)

g = 3.59E+04 estimate

Annual consumption = 8.44E+03

12 **Nitrogen, g N per ha**

(g fertilizer active ingredient)(28 gmol N/132 gmol DAP)

g = 1.07E+05 estimate

Annual consumption = 2.26E+04

13 **Construction Materials**

mass (g) = (total weight)/(50 years)

Total weight = 1.52E+09 (Haukoos, 1994)

mass (g) = 3.04E+07

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