# Evaluating Endemic Ecosystem with the Aid of Optical Remote Sensing and Geographical Information Systems (GIS) Techniques

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**Key words**: anthropogenic, endemic ecosystems, eco-regions, soil moisture regime.

## SUMMARY

The availability of satellite image archives ─ especially those on platforms with fine temporal resolution ─ has facilitated change detection within aquatic and terrestrial ecosystems. With increased anthropogenic activities, tremendous pressures have been placed on these ecosystems. Within this study, we used a series of remote sensing and land classification data in deriving various simulated and transformed data in assessing and evaluating the different eco-regions within the study area. As such, a series of descriptive analysis was performed on the transformed and simulated data in an attempt to understand, but more importantly, to evaluate and show the causality between the soil moisture regime, and the vegetative distribution within endemic ecosystems such as the Long Island Central Pine Barrens (LICPB) study region are attainable. The results obtained showed where the changing soil moisture regime within this particular ecosystem affects the region overall health. Soil moisture calculations which were derived from standard volumetric applications, was further substantiated by a series of indices such as the Moisture Stress Index (MSI) and the Wetness Index. The volumetric surface soil moisture ($\theta_{v\ (0\text{-}5cm)}$) values obtained, also depicted where there were significant correlation between the various textural classes, terrestrial resources, wetlands, and aquatic resources to be found within the LICPB. The results further indicated where the upper soil moisture regime within the LICPB was temporally and spatially diverse, but demonstrated marked differences between the various eco-regions within the study area itself. The data set, coupled with various graphical applications, and Geographical Information Systems (GIS) Techniques, further indicated a variance in vegetative indices, but more importantly, justified future concerns for the severely stressed LICPB ecosystem.

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## 1. INTRODUCTION:

Endemic ecosystems such as Pine Barrens, represents some of the most rare and fragile ecosystems within the continental United States. Ecologically speaking, "Barrens" is often used as a phrase to describe a region that is nutrient-poor and, basically supports vegetative species that are adapted to fire and climatic invariability, and as such, these ecosystems represents environmentally diverse regions that are mainly endemic to harsh conditions ─ dry ─ and mainly driven by fire (Keener, 1983). As such, the literature has shown where Pine Barrens eco-regions are among some of the most diverse habitats, supporting a wide variety of endangered plant and animal species (Henderson et al., 1998). Predominantly, "Barrens" have been noted to exhibit scant vegetation cover due to a variety of influences, which includes soil moisture, soil texture, and substrate chemistry (Bliss, 1997).

Vegetation categories such as pine, oak, and heath, have also been used to classify particular types of "barrens". However, "Barrens" have been shown to occur within climatic regions that support distinct vegetation types. Regions such as the Canadian polar barrens or "Polar Desert", the gravel barrens found in Japan, and the serpentine barrens found in Cuba, are some of the different types of barrens that have been noted to exist within diverse climatic regions (Beurton, 198; Matsuo 1989).

The evaluation of Pine Barren ecosystems with the aid of instrumentations and methodology such as soil moisture assessment, *in situ* measurements, and applications such as microclimate, soil association evaluation, and vegetative cover analysis, have proved quite challenging and time consuming. With the aid of active and passive remote sensing techniques, the task of monitoring these rare ecosystems on a micro and macro scale has shown interesting results. Unfortunately, previous studies have shown where there is still a greater need for a rapid response time in the evaluation and protection of these regions (Arabas, 2000; Buchholz, 1983; Robichaud et al., 2000).

## 2. METHODS

### 2.1. Study Area:

The LICPB is situated on the northeastern coastal plain of New York state (40° 53′N, 72° 39′W) (Fig.1.0). Formed as a result of glacial retreat and deposition, the study region has noticeable and distinguishing features such as low to moderate relief, tidal wetlands, forested wetlands, isolated pockets of woody wetlands, palustrine emergent wetland, palustrine forested wetland and emergent herbaceous wetland regions. These regions are often defined as transitional zones or areas between terrestrial and aquatic systems ─ where the water table is usually at, or near the surface (Cowardin, 1979). The study area also contains identifiable features such as kettle holes, vernal pools, mounds and till deposits of glacial composition (Kames and knobs), sandy and feldspatic nutrient-poor soil composites, but more importantly, rare dwarf pitch pine which averages only 1.44 to 1.83 meters (4 to 6 feet) when fully grown (U. S. Fish and Wildlife Service 1991).

Land use pattern within the LICPB is structured around two core regions ─ the Compatible Growth Area (47,500 acres or 192.2 km$^2$) and the Core Preservation Area (50,000 acres or 202.35 km$^2$). However, anthropogenic activities such as residential and commercial development, fragmentation, and encroachment, have since reduced the LICPB to its present size of some 102,500 acres (41278 hectares or 414.8 km$^2$) (Alden et al. 1999). As such, the largest concentration of vegetation within the LICPB is located within its central and eastern sections, which encompasses the Terryville outwash plain and portions of the Ronkonkoma Moraine. Based on the anthropogenic activities that have occured within the LICPB, it has been estimated that eco-regions such as the dwarf pitch pine plains, pitch pine-scrub oak woodland, heath, pitch pine, heath and scrub oak regions have declined by some 46% (Jordan et al., 2003) (Fig.1.1).

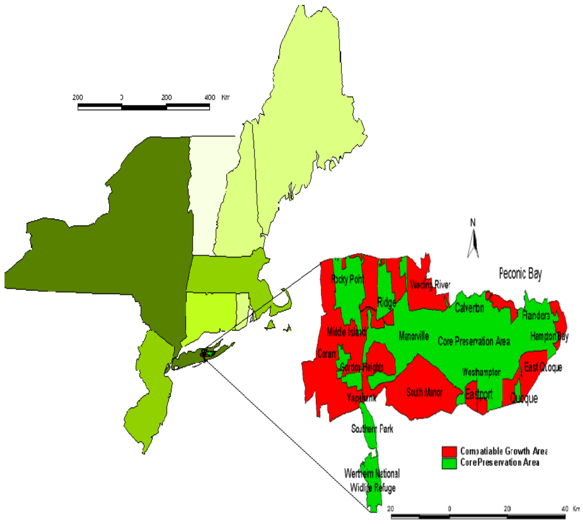


**Fig.1.0.** Map depicting the Long Island Central Pine Barrens (Study Area)

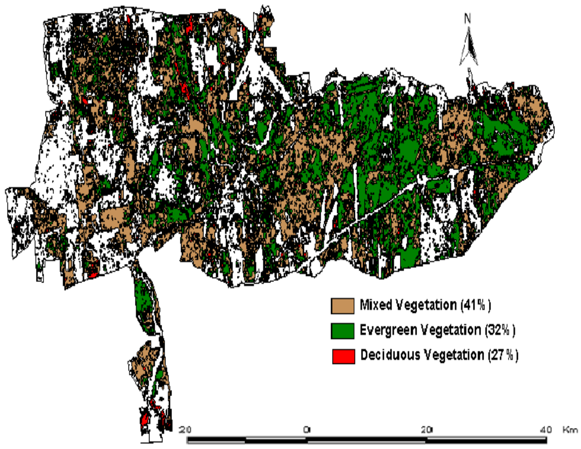


**Fig.1.1.** Map depicting areas and percent count of mixed, evergreen, and deciduous vegetation within the LICPB [Source: National Land Cover Data – 1992]

### 2.2.Soil Moisture Retrieval Methods:

Within the LICPB, the availability of soil moisture varies from very dry upland sites (excessively well-drained sandy soil, Dwarf Pine Plains Region), through wet sites (tidal regions, Carman's River Region), to aquatic sites (lakes, bogs, kettle holes and rivers)

(Fig.2.0). As such, the different ecoregions within the LICPB have evolved in such a manner in which the availability of soil moisture plays an integral role in the survival of each component of this rare ecosystem.

Field data was collected within the study region from November 22, 2003 to January 20, 2004, and on April 17, 2004. A grid system was developed to acquire desirable spacing between each site (Fig. 2.1), and as such, thirty one sampling sites (n=31), representative of the soil and vegetation data found within the LICPB were used for analysis. Data on soil texture and composition were recorded based on the United States Department of Agriculture (USDA) soil survey laboratory methods and procedures (Reynolds, S.G, 1970a). Land use and land cover data within the immediate and general sample sites were documented for comparison with satellite imagery and classification data. Laboratory preparation incorporated weighing the soil samples that were collected within ± 0.02 g of each other, which was considered to be constant. The samples were then dried in an oven (Thelco Precision Scientific, Model # 27, Serial # 21-AC-3) at 100 °C (212˚F) for 24 hours, cooled and then re-weighed (Reynolds, 1970a; 1970b, Hillel, 1980).The final weight and identification of each soil sample was then recorded.

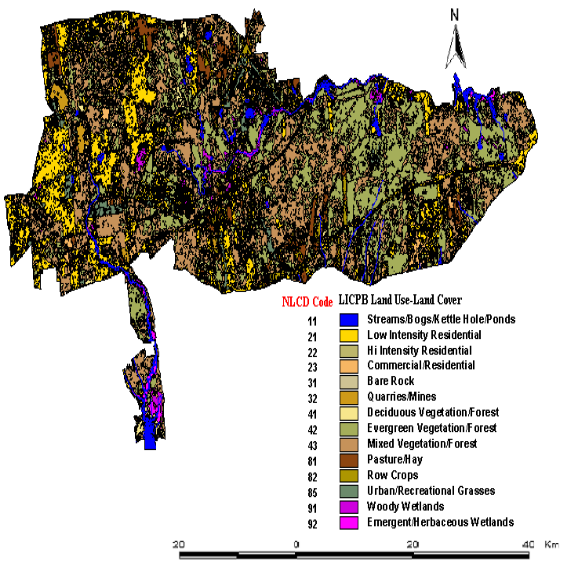


**Fig.2.0.** Land Use and Land Cover within the Long Island Central Pine Barrens [Source: National Land Cover Data (NLCD) 1992]

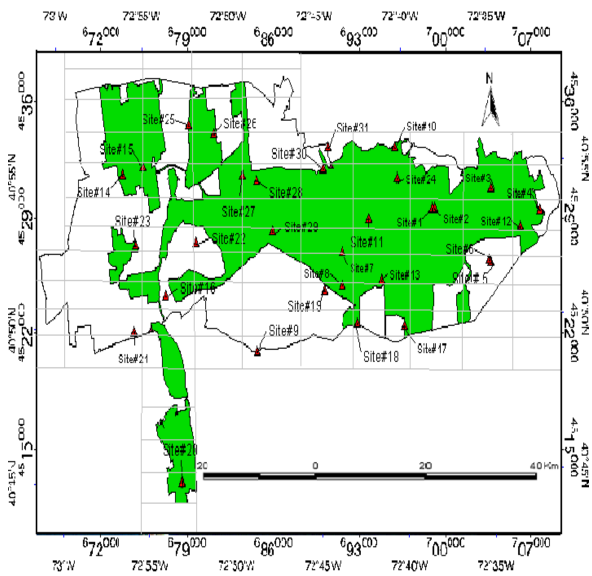


**Fig.2.1.** Map of the LICPB depicting grid pattern that was used to divide the study region, and also the different soil sampling sites (n=31), and ground control points that were used in the assessment and evaluation of the study region's ecosystem.

## 2.3. Volumetric Soil Moisture Measurements and Processing

Volumetric soil moisture ($\theta_v$) which is often defined as the ratio between the volume of water present within a sample and the total volume of the sample itself, was calculated based on the gravimetric soil moisture (***w***) or the initial mass of water (**$M_{H2O1}$**) within each soil sample and was obtained with the use of the following (1);

$$w = \frac{M_{w1} - M_{d1}}{M_{d1}} \quad \textbf{(1)}$$

where **$M_{w1}$** is the original mass of wet sample, and **$M_{d1}$** is the original mass of oven dry sample. Also, an important criterion in determining soil moisture measurements is bulk density (Munkholm, and Kay, 2002). As such, the bulk density measurements incorporated a smaller sample of oven dried soil (**$M_{d2}$**) and the volume of a smaller dried sample of soil (**$V_{d2}$**) that was obtained by means of the following (2);

$$V_{d2} = (V particles + V pores) \quad \textbf{(2)}$$

where *Vparticles* represents the volume of soil particles, and *Vpores* represents the volume of soil pores. Subsequently, the bulk density was calculated using the following (3);

$$(\rho_b) = \frac{M_{d2}}{V_{d2}} \quad \textbf{(3)}$$

where $\rho_b$, soil bulk density, **$M_{d2}$** mass of smaller oven dry sample (g), and **$V_{d2}$** is the volume of dry soil sample (ml). As such, the volumetric soil moisture ($\theta_v$) measurement for the LICPB was calculated based on the initial mass of water (***w***), which was divided by the density of water (1.0 g $cm^{-3}$) and is expressed as (4);

$$\frac{M_{H2O1}}{\rho H2O} \quad \textbf{(4)}$$

where $M_{H2O1}$ represents the initial mass of water, and $\rho$H2O represents the density of water (1.0 g $cm^{-3}$). From equation (4) the volume of water (**$V_{H2O1}$**) in the original sample of wet soil was derived. As a result, the results from equations (1) and (4) were used in calculating the volumetric soil moisture content, and is expressed as (5);

$$\theta_v = \frac{v_{H201}}{v_{w1}} \quad \textbf{(5)}$$

where (**$V_{H2O1}$**) the original sample of wet soil volume of water, and (**$V_{w1}$**) represents the initial volume of water (**$V_{w1}$**) from the larger soil sample.

## 2.4. Image Processing

Soil moisture evaluation within some ecosystems has been noted to produce fast and comprehensible classification. Field scale measurement and assessment of soil moisture parameters has shown to involve sophisticated techniques which can be time consuming and costly (Albertson and Kiely, 2001). As a result, alternative techniques such as remote sensing have been showed to produce results that are timely, agreeable, but more importantly, cost effective. As a result, one of the major advantages of remote sensing is it permits a large area to be observed very quickly, but also on a regular basis.

Remote sensing information that was dereived for the LICPB ecosystem, incorporated the use of various simulated LandSat Enhanced Thematic Mapper plus (ETM+) data. A series of vegetation maps, along with moisture indices maps which included Moisture Stress Index (MSI) maps, and Global Vegetation Moisture Index (GVMI) maps of the upper soil surface (0-5cm) within the LICPB ecosystem was created. Classification and image processing were performed using the Environment for Visualizing Images (ENVI 4.0) software. Vegetation cover and soil data assessment was tabulated using Arc View GIS 3.2 software (Environmental Systems Research Institute, Inc. Redlands, CA, U.S.A). Vector data used within this study were converted from the standard geographic datum transformation NAD83 (North American Datum of 1983) to NYS State Plane, LI Zone NAD27 (North American Datum of 1927). Further data and measurements that were generated of the study region were used to produce contour images and maps. These maps were developed using the ArcView GIS 3.2 software.

## 3. RESULTS

The measured soil moisture data for the LICPB ecosystem, showed where the values ranged from 0.08 to 0.53 (Fig.4). The results also showed where the upper soil moisture regime (0-5cm) within the study area fluctuated based on the temporal and spatial distribution of variables associated with the study region, such as soil composition (quartz and feldspatic deposits), dry upland sites (excessively well-drained sandy soil, Dwarf Pine Plains Region), wet sites (tidal regions, Carman's River Region), and aquatic sites (lakes, bogs, kettle holes and rivers) (Fig.2.0) (Van Pelt and Wierenga, 2001).

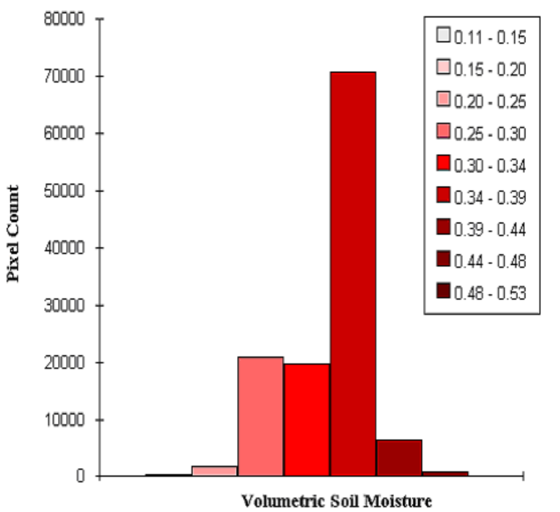


**Fig.3**. Distribution of measured volumetric soil moisture values within the LICPB

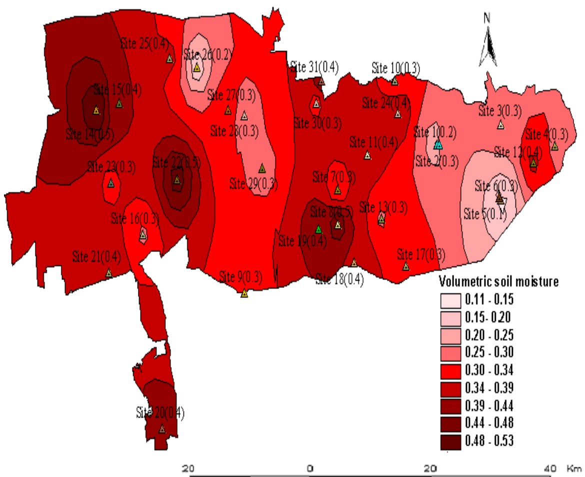


**Fig.4.** Contour map of the LICPB depicting Volumetric Soil Moisture ($\theta_v$) measurements at field scale between November 22, 2003 and April 17, 2004.

The upper surface soil moisture (0-5cm) values also depicted marked spatial predictability that ranged in order of 0.08 to 0.29 for sandy soils and 0.3 to 0.53 for clay and loamy soils (Fig.4). As such, it was noted where seventy four percent (74%) of the LICPB exhibited soil moisture values ranging from 0.34 to 0.39(Fig.3). Further analysis showed where those regions with high soil moisture values were located within the central and western sections of the study area (Fig.4).

### 3.1. Moisture Stress Index (MSI) Analysis

The evaluation of the LICPB ecosystem incorporated transformed and simulated values that were derived from indices such as Moisture Stress Index (MSI). MSI has been shown to be an important index in the assessment of water content within vegetation canopy (Moghaddam and Saatchi, 1999). Summarily, MSI is often used as a ratio based on reflectance values in characterizing the surface moisture conditions. The MSI values derived incorporated the following (6):

$$MSI = \frac{MIR}{NIR} \qquad \textbf{(6)}$$

where *NIR* is represented as LandSat ETM+ band 4,and *MIR* is represented as LandSat ETM+ band 5. The MSI data derived for the LICPB ecosystem, showed where the surface moisture conditions ranged from 1.0 to 2.8 ($p<0.0001$) (Fig.5). As such, it was noted where the MSI values derived for the LICPB ecosystem were appreciable low. Contoured MSI data was derived for the LICPB ecosystem in an attempt to establish patterns of congruity between the measured volumetric soil moisture ($\theta_v$) (Fig.6.).

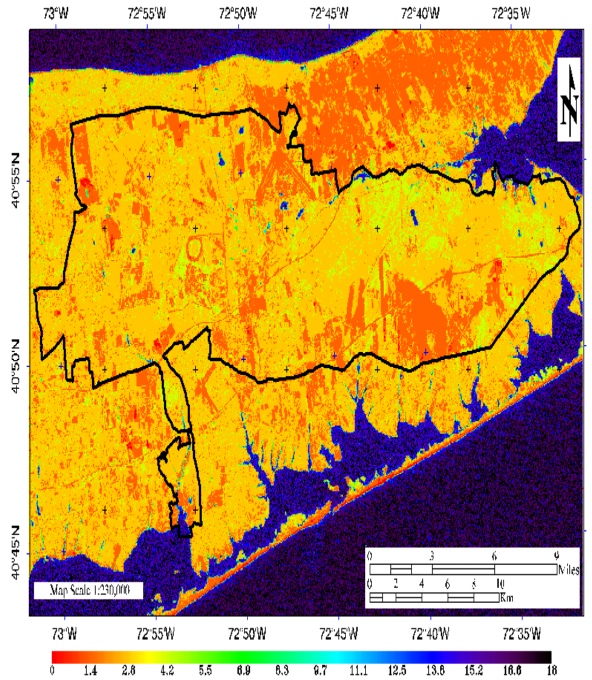


**Fig.5**. Simulated LandSat Moisture Stress Index (MSI) map of the LICPB ecosystem.

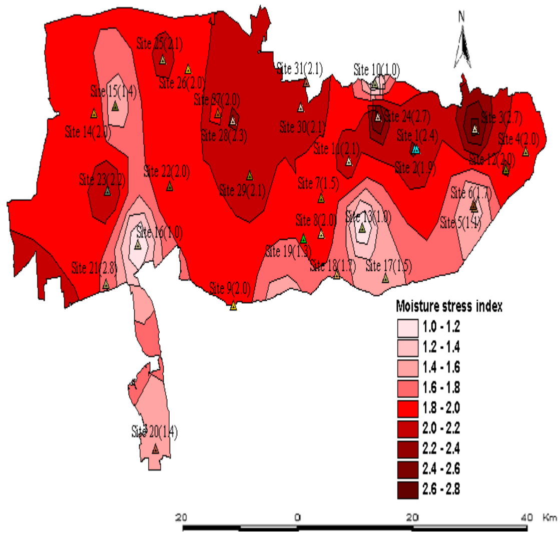


**Fig.6**. Contoured map depicting the Moisture Stress Index (MSI) estimates for the LICPB.

marked variability in soil type and composition, but more importantly, the soil moisture regime within these regions were noted to be spatially heterogeneous due to factors such as fire-influencing landscape features, soil composition, and precipitation variability (Entin et al., 2000). With volumetric soil moisture ($\theta_v$) values that ranged between 0.29 and 0.35, it was noted where these particular regions exhibited similar surface moisture values. However, low correlation ($r^2 = 0.3$) values were noted between the measured volumetric soil moisture ($\theta_v$) and the MSI values at these sites. Importantly, eco-regions within the LICPB that depicted high MSI values (1.62 to 1.82) were more pronounced at or between elevations of 6 to 30m.

### 3.2. Wetness Index (WI) Analysis

Soil moisture is often determined by variables such as plant transpiration, infiltration, plant uptake, and soil evaporation (Guswa et al., 2002). As such, a soil Wetness Index (WI) analysis based on the above variables, was conducted within the LICPB study region. The WI was derived using the following:

$$\mathbf{WI} = 0.1446(ETM{+}1) + 0.1761(ETM{+}2) + 0.3322(ETM{+}3) + 0.3396(ETM{+}4) - 0.6210(ETM{+}5) - 0.4186(ETM{+}7), \quad \mathbf{(7)}$$

where ETM+1 represents the LandSat (*Blue-green*) band1, ETM+2 represents the LandSat (*Green*) band 2, ETM+3 represents the LandSat (*Red*) band 3, ETM+ 4 represents the LandSat (*NIR*) band 4, ETM+5 represents the LandSat (*Mid-infrared (MIR*) band 5, and ETM+7 represents the LandSat (*MIR*) band 7 (Price et al. 2002).

The WI values derived depicted a range of –18.8 to 17.8 (<0.0001). However, Fig.7 showed where the lowest WI values (–18.8 to 1.5) represented regions within the LICPB ecosystem where the soil profile was particularly sandy and very dry, and as a result, the drainage pattern and the infiltration rate within these sections of the study area was at its highest. Interestingly, the simulated WI values also depicted areas within the LICPB with relatively high surface soil moisture concentration (10.0 to 17.8) (Fig.8.). These areas represented soil profiles with course silt to clay association.

From Fig. 8, it was also noted where the lowest WI values were found within the southern section of the study area (Sites 13 and 17), in which, substantially low surface soil moisture ($\theta_v$) values were also detected (Fig.4.). Some measure of agreeable correlation was noted between the MSI and WI values ($r^2$ = 0.72). However, further analysis of the WI dataset (Fig.8.) showed where ecoregions that experienced moderate to low soil moisture were located within the most active fire-prone areas of the LICPB. As such, the soil series within these particular ecoregions are often dry and droughty, and have been shown to possess a great degree of soil sorting. Form the literature, it was also noted where the level of soil sorting within these particular ecoregion, displayed characteristics that adversely impact the porosity and permeability, but are important factors that dictates the interaction between returning fire regime and soil texture, and as a result, these regions are often referred to as "fire climax ecosystems" (Olsvig et al., 1979).

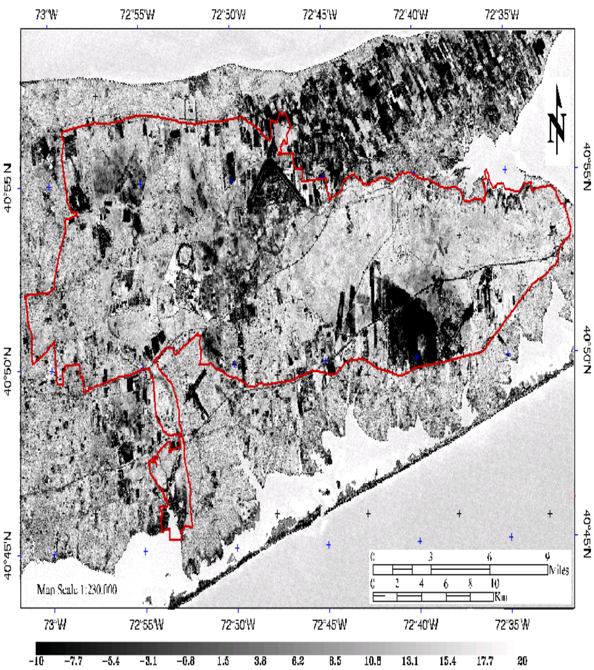


Fig.7. Simulated LandSat Wetness Index (WI) Map of the LICPB ecosystem.

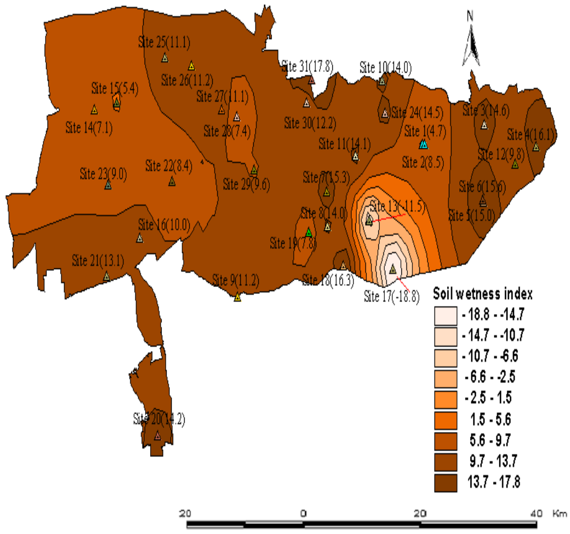


Fig.8. LICPB Contoured Wetness Index (WI) Map

### 3.3. Global Vegetation Moisture Index (GVMI)

It has been noted from the literature where the Global Vegetation Moisture Index (GVMI) is more suitable for the retrieval of vegetation water content (*EWT canopy*) (Ceccato, 2001). Furthermore, the GVMI estimates vegetation water content at canopy level and is a good estimator of vegetation stress, but more importantly, is independent of vegetation type and composition (Toomey and Vierling, 2005). As such, the following (8) was used to derive the GVMI for the LICPB;

$$GVMI = \frac{\left(NIR + 0.1\right) - \left(SWIR + 0.02\right)}{\left(NIR + 0.1\right) + \left(SWIR + 0.02\right)} \qquad \textbf{(8)}$$

where *NIR* represents the LandSat ETM+ band 4, and *SWIR* represents the LandSat ETM+ band 5.

The simulated GVMI values were noted to range between 0.0001 and 0.3 (Fig.9.). The simulated GVMI values also showed where averagely, most of the LICPB GMVI values had a range that fell between 0.18 and 0.22. This represented 59% of the normal distributed GVMI value to be found within the LICPB (Fig.10.). Interestingly, the GMVI values also depicted marked similarities when compared to volumetric soil moisture ($\theta_v$) data (Fig.4.). Averagely, both depicted values within the same range, but even more importantly, the data further showed how inversely, both surface soil moisture (0-5cm) and vegetation water content (*EWT canopy*) do play an important role in the health and viability of the flora and fauna to be found within the LICPB. However, on a more serious note, the results further showed where the moisture content within the canopy level is severely low, an indicator of severe vegetation stress within the LICPB ecosystem.

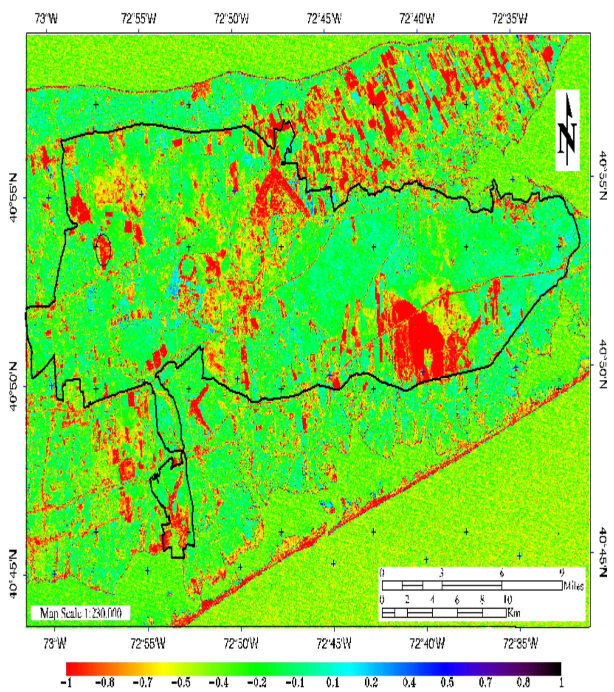


**Fig.9.** Simulated Global Vegetation Moisture Index (GMVI) map of the LICPB Ecosystem.

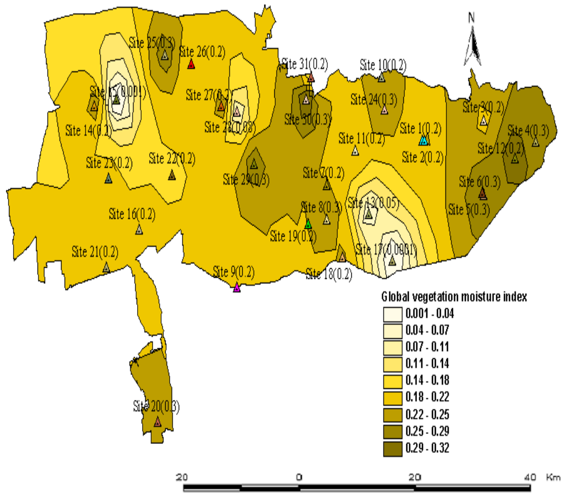


**Fig.10.** Contoured Global Vegetation Moisture Index (GVMI) for the LICPB Ecosystem.

With the aid of field measurements and a series of simulated remote sensing transformations, the evaluation of the LICPB ecosystem through its vegetative properties and upper soil moisture profile (0-5cm) proved insightful. The results derived from the simulated dataset, provided an invaluable tool in which a comparative analysis could be performed in evaluating the LICPB ecosystem. More importantly, it should be noted that the above paper in no way justifies any final format in the assessment of Endemic Ecosystems such as the LICPB. As such, future research should incorporate the use of Synthetic Aperture Radar (SAR) assessment as well as a more defined trend analysis for the above ecosystems in question.

From the analysis of the MSI dataset it was noted where 60% of the LICPB ecosystem had moisture stress values of 1.8 to 2.0. Although the MSI values showed no distinct correlation with the measured soil moisture values ($r^2$ = 0.30), especially within known vegetative regions of the study area, the data showed where extremely low MSI values were more pronounced within the southern sections of the LICPB ecosystem, regions where fire dynamics were a recurrent theme.

With noticeable correlation ($r^2$ = 0.7) between the WI and the MSI data, further analysis of the data showed where the lowest WI values (-18.8 to 1.5) represented those eco-regions within the LICPB that had some of the driest soil association (Plymouth series, Riverhead series, Carver series), while those with the highest values (10.0 to 17.8), were noted to be located within those areas with the wettest soil association (Haven Series, Bridgehampton series). However, the WI data further showed where the lowest moisture values, both within the vegetation and the soil profile, were found within the fire-scared ecoregions of the LICPB (Sites 13 and 17). The highest moisture values were detected within the northern sections of the study region, areas of appreciable vegetation.

Simulated GVMI measurements as mentioned earlier, have been shown to be an important parameter as it relates to the assessment of soil moisture parameters from both an optical and active remote sensing perspective. Global Vegetation Moisture Index data for the LICPB was noted to be within a range 0.32 and a mean of 0.20 (Fig. 4.11). In addition, the GVMI measurements showed a positive correlation ($r^2$ = 0.7) to WI data. It was also noted where the soil moisture simulations within the LICPB ecosystem have a high spatial variability and as such, field data was shown to correlate loosely with some types of analyses better than others. However, it has been noted from the simulated transformations and verification from the *in situ* measurements, that the LICPB ecosystem is very much under intense pressure from hydrological and anthropogenic variables.

While it was further noted where the Global Vegetation Moisture Index (GVMI) data depicted a range of 0.32 and a mean of 0.20, the data further showed where there was a positive correlation ($r^2$ = 0.7) with the simulated WI values for the LICPB. The simulated GVMI values further showed where the vegetation measurements within the different ecoregions of the LICPB were important factors in the assessment of soil moisture parameters from both an optical and active remote sensing perspective. The evaluation further showed where the soil moisture found within the various ecoregions depicted high spatial variability, but more importantly, the derieve field data correlate loosely with some types of analyses better than others. As such, it was noted whwere the LICPB ecosystem is under intense pressure from hydrological and anthropogenic variables.

Without a doubt, the LICPB is one of the last natural ecological resources of the northeastern United States. Vegetative decline within the LICPB have been noted to be greatest within the scrub oak-shrub (84%) and pitch pine-scrub oak woodland areas (72%). This rare natural resource and ecosystem will become a memory, if increased anthropogenic encroachment goes unchecked, but more importantly, without proper conservation measures.

## REFERENCES

**Albertson, J.D., and G. Kiely. 2001.** On the structure of soil moisture time series in the context of land surface models. J. Hydrology.243: 101–119

**Alden, O., Cassie, B., Kahl, J., Oches, E., Zirlin, H., and Zomlefer, W. 1999**. *Audubon Society Field Guide to the Mid-Atlantic Region.* Alfred A. Knopf, New York, New York.

**Arabas, K.B. 2000.** Spatial and temporal relationships among fire frequency, vegetation, and soil depth in an eastern North American serpentine barren. J. Tor. Bot. Soc. (127):51-65

**Barbour, M.G., Burk, J.H., and Pitts, W.D. 1980**. Terrestrial plant ecology. Menlo Park, CA: Benjamin/Cummings. pp.604

**Beurton, C. 1986.** Phyllode-producing *Zanthoxylum* taxa in Cuba. *Feddes Repert* 97:29 41.

**Bliss, L.C. 1997.** Arctic Ecosystems of North America. In: Polar and Alpine Tundra. F.E. Wielgolaski, ed. Elsevier, Amsterdam. pp.551-684

**Buchholz, K. 1983.** Initial responses of pine and oak to wildfire in the New Jersey Pine Barren Plains. Bull. Torrey Bot. Club (110):91-96

**Buermann, W., Wang, Y., Dong, J., Zhou, L., Zeng, X., Dickinson, R. E., Potter, C. S., and Myneni, R. B.** 2002, Analysis of a multiyear global vegetation leaf area index data set, Journal of Geophysical. Res., 107(D22), 4646, doi:10.1029/2001JD000975,

**Ceccato, Pietro, 2001**, Estimation of Vegetation Water Content Using Remote Sensing for the Assessment of Fire Risk Occurrence and Burning Efficiency, *Degree of Doctor of Philosophy*, University of Greenwich.

**Central Pine Barrens Comprehensive Land Use Plan**, Volume 2: Version of 6/28/95, Existing Conditions, Reprinted 8/96

**Cowardin, L.M., 1979**, as referenced in *Coastal Wetlands of the United States. National Oceanic and Atmospheric Administration, February 1991.*

**Crow, Wade T., and Wood, Eric F. 2002**, The Value of Coarse-Scale Soil Moisture Observations for Regional Surface Energy Balance Modeling, Journal of Hydrometeorology, 3: pp 467-482

**Entin, J. K., Robock, A., Vinnikov, K.Y., Hollinger, S.E., Liu, S., and Namkhai, A.**, 2000, Temporal and spatial scales of observed soil moisture variations in the extratropics. J. Geophys. Res., 105, 11,865-11,877,

**Guswa, A. J., Celia, M. A., and Rodriguez-Iturbe, I.,** Models of soil moisture dynamics in ecohydrology: A comparative study, *Water Resources Research*, 38(9), 1166, doi: 10.1029/2001WR000826, 2002.

**Henderson, F.M., Hart Jr., T.F., Heaton, B., and Chasan, R., 1998**, "Spectral Separability and Composition of Coastal Wetlands Using SAR and Fused Optical-SAR Data Sets", *Proceedings of IEEE International Geoscience and Remote Sensing Symposium*, Seattle, WA, IEEE, Houston,TX.

**Hillel, D, 1980.** Introduction to Soil Physics, *Academic Press,* San Diego, CA.

**Hillel, D. 1998.** Environmental Soil Physics, Academic Press, San Diego, CA.

**Hunt, R. E., and B.N. Rock. 1989**. Detection of changes in leaf-water content using near-and middle infrared reflectances. Remote Sensing of Environment (30): pp., 43-54.

**Jacobs, Jennifer M., Mohanty, Binayak P., Hsu, En-Ching., Miller, Douglas, 2004,** SMEX02: Field scale variability, time stability and similarity of soil moisture, Remote Sensing of Environment 92:pp. 436–446

**Keener, C. S. 1983.** Distribution and biohistory of the Mid-Appalachian shale barrens. *Botanical Review* 49:65-115.

**Jordan, M. J, Patterson III, W. A, and Windisch, A.G, 2003,** Conceptual ecological models for the Long Island pitch pine barrens: implications for managing rare plant communities, Forest Ecology and Management 185: pp., 151–168

**Lobell, David B., and Asner, Gregory P.** 2002, Moisture Effects on Soil Reflectance, Soil Science Society of America Journal (66): 722-727.

**Matsuo, K. 1989.** Biosystematic studies on the genus *Plantago*: 1. Variations in *Plantago japonica* and its related species, with special reference to it identity. *ACTA Phytotaxon Geobot,* 40:37-60.

**Melloh, R., Anfang, R., and LaPotin, N. 1987**. An elevation stratified land cover evaluation in the Devil's Lake Basin, North Dakota. Proceedings U. S. Army Corps of Engineers Sixth Remote Sensing Symposium, Galveston, TX. pp. 119-133.

**Olsvig, L. S., J. F. Cryan, and R. H. Whittaker, 1979**, "Vegetational gradients of the pine plains and barrens of Long Island, New York." In *Pine Barrens: Ecosystem and Landscape,* edited by R. T. T. Forman,. New York: Academic Press, pp., 265-282

**Price, K.P., Guo, X., and Stiles, J M. 2002,** Optimal Landsat TM band combinations and vegetation indices for discrimination of six grassland types in eastern Kansas, *International Journal of Remote Sensing*, pg 1–12

**Reynolds, S.G, 1970a.** The gravimetric method of soil mo isture determination, part I. A study of equipment, and methodological problems. *Journal of Hydrology*, 11:258-273.

**Robichaud, Peter R., Beyers, Jan L., Neary , Daniel G. 2000**, Evaluating the Effectiveness of Postfire Rehabilitation Treatments, USDA Forest Service General Technical Report RMRS-GTR-63:1-89

**Soil Conservation Service**. Soil survey laboratory methods and procedures for collecting soil samples. Washington, DC: United States Department of Agriculture; 1967

**Soren, Julian., and Simmons, Dale L., 1987**. "Thickness and Hydrogeology of Aquifers and Confining Units Below the Upper Glacial Aquifer on Long Island, New York." *U.*S. Geological Survey Water-Resources Investigations Report 86-4175.

**Stoll, J., Bong, S., and Lunetta. R. 1987**. GOES satellite data and GIS technology have a future in habitat analysis. Proceedings U. S. Army Corps of Engineers Sixth Remote Sensing Symposium, Galveston, TX. pp. 161-179.

**Szilagyi, Jozsef, 2002.** Vegetation Indices to Aid Areal Evapotranspiration Estimations, ***Journal of Hydrologic Engineering***, Vol. 7, No. 5,p.368-372.

**Toomey, M., and Vierling, Lee A., 2005,** Multispectral remote sensing of landscape level foliar moisture: techniques and applications for forest ecosystem monitoring, Can. J. For. Res. 35: 1087–1097

**Ulaby, F. T., and E1-Rayes, M. A. 1987**, "Microwave Dielectric Spectrum of Vegetation. Part II: Dual- Dispersion Model", IEEE Transaction on Geoscience and Remote Sensing, vol.25, no.5, pp.550-557.

**U. S. Fish and Wildlife Service, 1991**. Northeast coastal areas study: significant coastal habitats of southern New England and portions of Long Island, New York. Prepared by the Southern New England-New York Bight Coastal Ecosystems Program, U.S. Fish and Wildlife Service, Charlestown, RI.

**Van Pelt, R.S., and Wierenga. P.J. 2001.** Temporal stability of spatially measured soil matric potential probability density function. Soil. Sci. Soc. Am. J. 65:668–677.

**Wagenet, R.J., and Rao, P.S.C. 1985**. "Basic concepts of modeling pesticide fate in the crop root zone," *Weed Science*, 33 (suppl. 2): pp. 25-32.

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