# Pattern metrics and the early detection of ecosystem degradation in the ridge-slough landscape

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## Introduction

- Pattern metrics are quantitative tools to describe spatial heterogeneity and enumerate landscape condition. They are integral to successfully monitoring large landscapes.
- Indicators of condition need to meet the following criteria: 1) sensitive 2) specific 3) easy to measure
- What is the timing of landscape metrics vs. landscape condition change; are they leading or lagging?

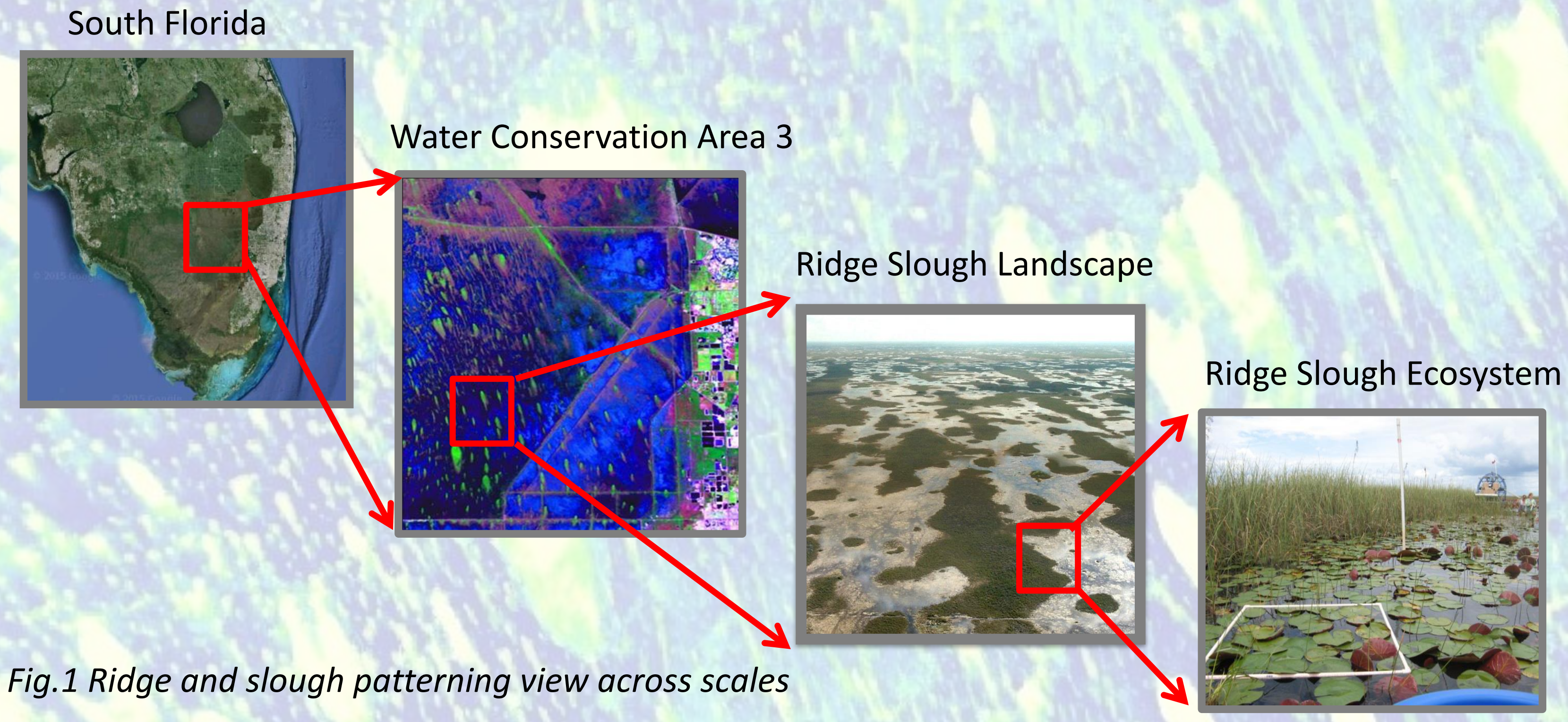
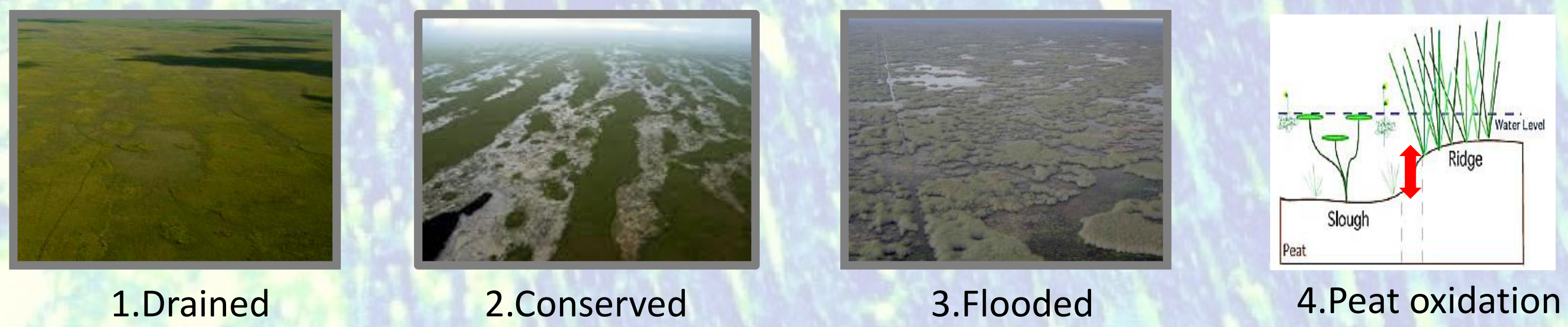


*Fig.1 Ridge and slough patterning view across scales*

### Ridge and slough regular patterning background

- Two distinct vegetation patches: ridges (sawgrass) at higher elevation within a matrix of slough (water lily, bladderwort). Patches are elongated parallel to historical flow.
- Patterning is decoupled from underlying limestone and suggesting genesis from autogenic and self-organized processes.
- The loss of patterning happens in two dimensions: 1) Blurring of the disctinctive, directional pattern (Fig.2-1, 2-2 and 2-3) and 2) flattening of the landscape (Fig. 2-4) .
- Changing soil elevation patterns (high variation, bimodal) is a crucial signal of landscape degradation.



1.Drained 2.Conserved 3.Flooded 4.Peat oxidation

*Fig.2 Ridge and slough landscape condition and changes*

## Methods

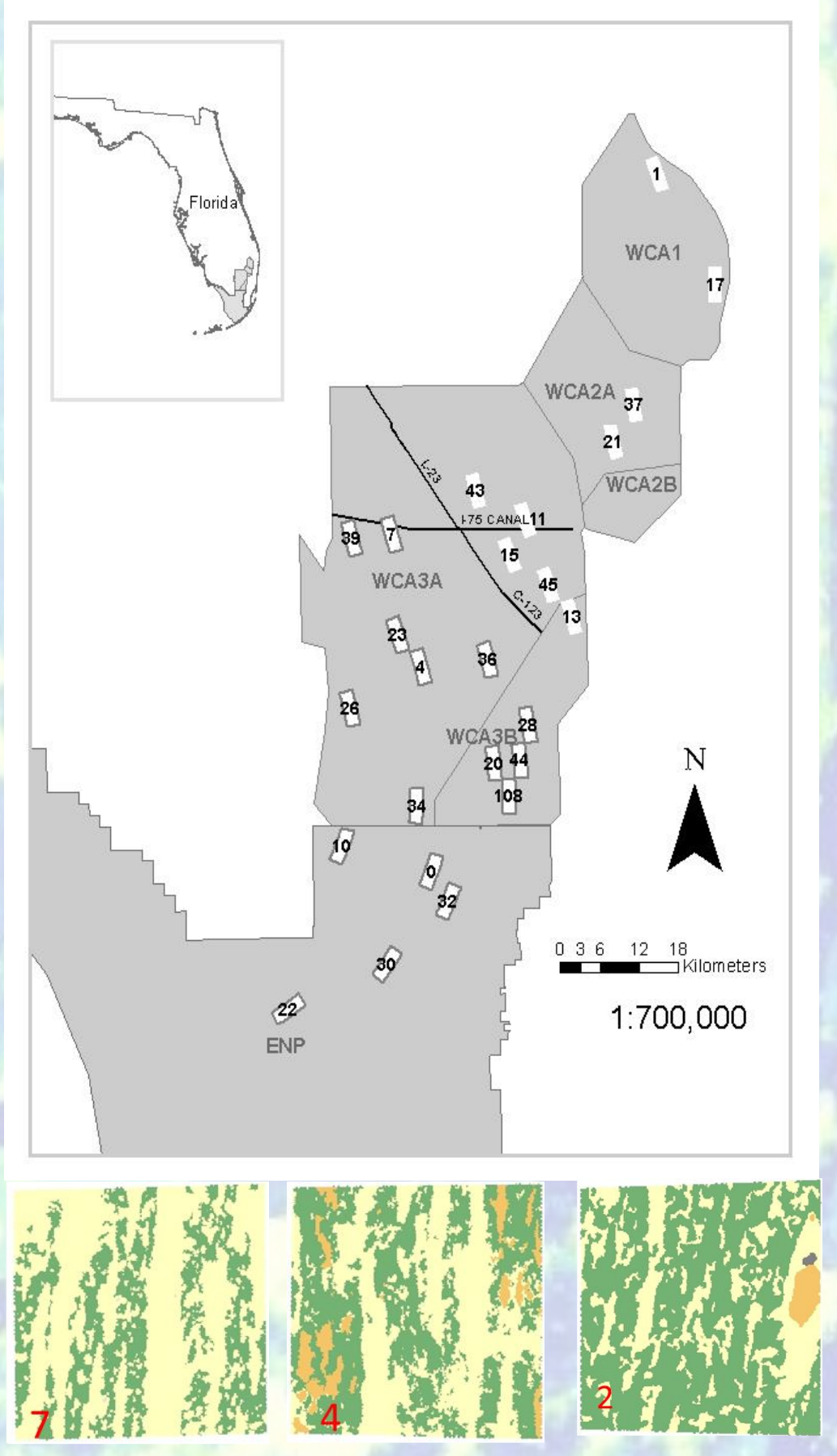
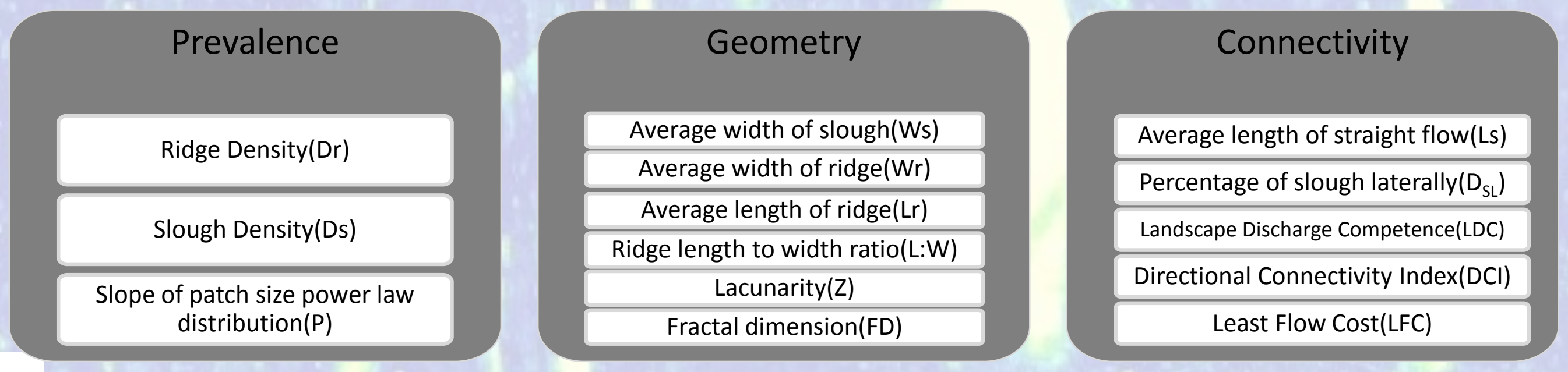


*Fig.3 Research location and 2X2 km binary vegetation map. Green denotes ridge, yellow denotes slough*

- **Vegetation maps for pattern metrics**
  - 25 2 X 2 km Primary Sampling Units(PSU) vegetation maps were categorized into binary maps. Ridge = sawgrass, spikerush-sawgrass marsh, swamp forest, swamp shrubland and swamp scrub; Slough = waterlily marsh, spikerush marsh, panicgrass marsh. All other vegetation types (e.g., cattails, cypress swamps, upland shrubs) were excluded from our analyses.
  - Subset of 13 PSUs consists only of sites south of I-75
- **Ridge and slough condition from soil elevation**
  - Soil elevation were derived from water elevation (EDEN) by subtracting local water depth measurements from water elevation. Each PSU consist 80 randomly located water depth sampling sites.
  - Two measures were extracted from peat elevations for each PSU: 1) bi-modality based on the comparative fit of a single vs. two normal distributions. Bimodality of soil elevation ($BI_{SE}$) has a value of 1 where soil elevations are fit by two normal distributions, and 0 for where a unimodal fit was better. 2) the standard deviation of soil elevation ($SD_{SE}$), which provides a measure of elevation variation and divergence



Prevalence
- Ridge Density(Dr)
- Slough Density(Ds)
- Slope of patch size power law distribution(P)

Geometry
- Average width of slough(Ws)
- Average width of ridge(Wr)
- Average length of ridge(Lr)
- Ridge length to width ratio(L:W)
- Lacunarity(Z)
- Fractal dimension(FD)

Connectivity
- Average length of straight flow(Ls)
- Percentage of slough laterally($D_{SL}$)
- Landscape Discharge Competence(LDC)
- Directional Connectivity Index(DCI)
- Least Flow Cost(LFC)

*Fig.4 Pattern metrics and its abbrevation*

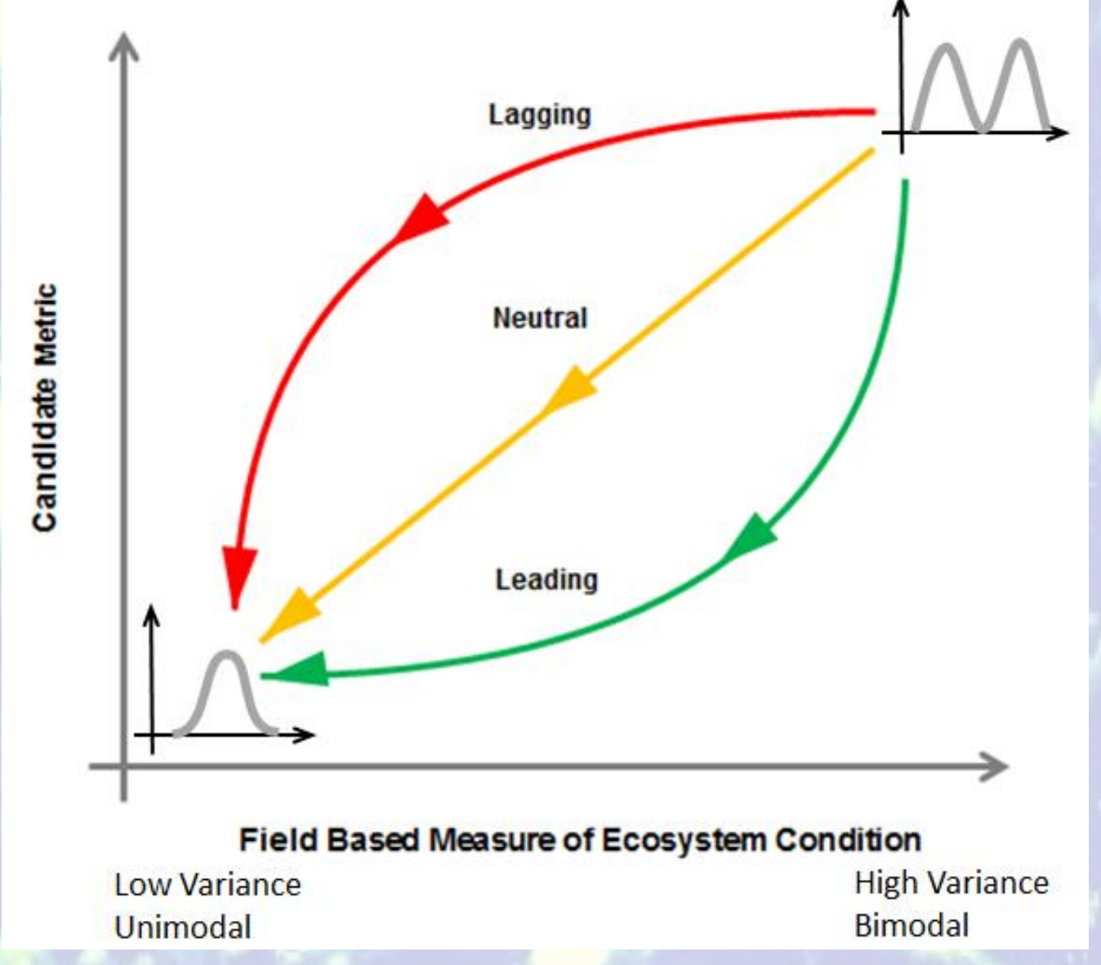


*Fig5 Schematic of pattern metrics selection*

- **Pattern metrics**

Previous research (Wu et al. 2006, Nungesser 2011, Larsen et al. 2012, Yuan et al. accepted) provided a critical foundation for selecting pattern metrics. Metrics were based at the block level (e.g., $D_r$ and $D_s$) and patch level (e.g., $W_s$ ,$W_r$, L:W calculated for each patch and averaged for block)

- **Pattern metrics vs. soil elevation condition**
  - Logistic regression was used to fit each metrics with $BI_{SE}$
  - Power function. $y = ax^b$, where x is $SD_{SE}$ for each PSU, and y is the value of each pattern metric. The sign of *a* indicates the direction of relation, and value of b indicates curvature. A leading indicator is one where $|b|>1$. A contemporary indicator is where $|b|=1$, and lagging indicators have $|b|<1$.

## Results and Conclusion I

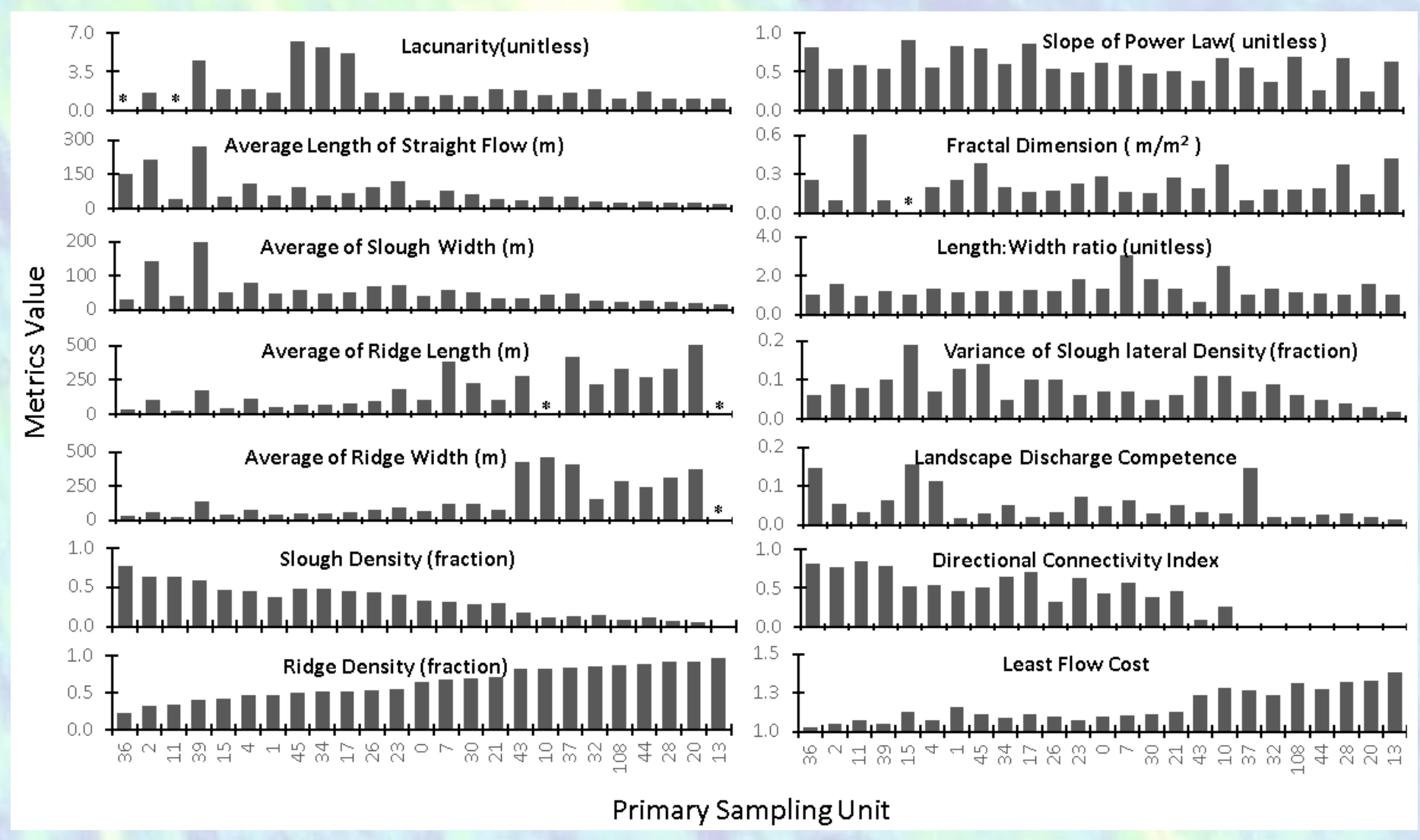


*Fig. 6 Metrics value for each PSU*

| | Dr | Ds | Wr | Lr | Ws | Ls | Z | FD | L:W | $D_{SL}$ | P | DCI | LFC | LDC |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Dr** | | -1 | 0.8 | 0.8 | -0.5 | -0.9 | | | | | | -0.9 | 0.9 | -0.8 |
| **Ds** | -1.0 | | -0.8 | -0.8 | | 0.9 | | | | | | 0.9 | -0.9 | 0.8 |
| **Wr** | 0.8 | -0.8 | | 0.9 | | -0.6 | | | | | | -0.7 | 0.9 | -0.6 |
| **Lr** | 0.8 | -0.8 | 0.8 | | | -0.6 | -0.6 | | | -0.5 | | -0.6 | 0.8 | -0.5 |
| **Ws** | -0.6 | 0.5 | -0.4 | | | 0.6 | | | | | | 0.6 | -0.7 | |
| **Ls** | -0.7 | 0.7 | -0.5 | -0.4 | 0.7 | | | | | | | 0.8 | -0.8 | 0.9 |
| **Z** | -0.5 | 0.5 | | -0.6 | | | | | | | | | | |
| **FD** | | | | | | | | | | | | | | |
| **L:W** | | | | | | | | | | | | | | |
| **$D_{SL}$** | -0.4 | | | -0.5 | | | 0.6 | | | | | | | |
| **P** | -0.5 | 0.4 | | -0.6 | | | | | | 0.5 | | | | |
| **DCI** | -0.9 | 0.9 | -0.8 | -0.7 | 0.6 | 0.7 | | | | | 0.4 | | -0.9 | 0.7 |
| **LFC** | 0.9 | -0.9 | 0.8 | 0.7 | -0.7 | -0.7 | -0.5 | | | | | -0.9 | | -0.7 |
| **LDC** | -0.6 | 0.6 | -0.4 | | | 0.6 | 0.5 | | | | | 0.5 | -0.5 | |

Subset
Global

Color ramp
-1.0 strong negative
-0.8
-0.5
0.5
0.8
1.0 strong postive

*Table 1* Correlation matrix. Correlation is significant at a=0.05 level were colored. Insignificant were not shown.

- Composition metrics ($D_R$, $D_S$) are strongly related to connectivity metrics (DCI, LFC, LDC) but weakly related to the geometry metrics.
- Connectivity metrics (DCI, LFC and LDC) are strongly correlated.
- Four metrics (Z, FD, L:W, P) have low correlation with any other metrics.

## Results and Conclusion II

*Table2 Logistic model fitting of metrics against soil elevation bimodality $BI_{SE}$*

| | | Global | | | | | Subset | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| No. | Metrics | SD | B | exp(B*SD) | Sig. | Psudo $R^2$ | SD | B | exp(B*SD) | Sig. | Psudo $R^2$ |
| 1 | $D_R$ | 0.22 | -4.24 | 0.40 | **0.08** | 0.20 | 0.22 | -6.91 | 0.22 | **0.05** | 0.41 |
| 2 | $D_S$ | 0.21 | 4.45 | 2.56 | **0.07** | 0.20 | 0.22 | 6.01 | 3.82 | 0.07 | 0.34 |
| 3 | P | 0.17 | -0.51 | 0.92 | 0.84 | 0.00 | 0.15 | 0.18 | 1.03 | 0.96 | 0.00 |
| 4 | $W_R$ | 140.51 | -0.01 | 0.25 | 0.11 | 0.25 | 128.75 | -0.02 | 0.13 | 0.13 | 0.40 |
| 5 | $L_R$ | 148.11 | -0.01 | 0.35 | 0.18 | 0.13 | 149.93 | -0.01 | 0.16 | 0.09 | 0.38 |
| 6 | $W_S$ | 17.04 | 0.09 | 4.71 | 0.04 | 0.38 | 19.93 | 0.13 | 12.69 | 0.06 | 0.64 |
| 7 | $L_S$ | 33.91 | 0.02 | 2.11 | 0.14 | 0.15 | 40.23 | 0.02 | 2.60 | 0.15 | 0.22 |
| 8 | L:W | 0.28 | 3.82 | 2.88 | 0.07 | 0.24 | 0.27 | -0.99 | 0.77 | 0.34 | 0.09 |
| 9 | FD | 0.12 | -7.04 | 0.41 | 0.19 | 0.13 | 0.08 | -7.91 | 0.52 | 0.32 | 0.10 |
| 10 | Z | 0.30 | 2.60 | 2.20 | 0.19 | 0.14 | 0.30 | 3.40 | 2.75 | 0.16 | 0.23 |
| 11 | $D_{SL}$ | 0.04 | 1.35 | 1.05 | 0.91 | 0.00 | 0.02 | 45.73 | 2.91 | **0.10** | 0.26 |
| 12 | DCI | 0.29 | 3.95 | 3.12 | **0.05** | 0.27 | 0.31 | 4.24 | 3.64 | **0.07** | 0.32 |
| 13 | LFC | 0.10 | -21.5 | 0.11 | 0.06 | 0.43 | 0.11 | -22.19 | 0.08 | 0.13 | 0.51 |
| 14 | LDC | 0.04 | 8.85 | 1.40 | 0.43 | 0.04 | 0.04 | 17.01 | 1.81 | 0.30 | 0.10 |

- **Pattern Metrics and Soil Elevation Bimodality Distribution ($BI_{SE}$ )**

Logistic regression between pattern metrics and soil elevation bimodality distribution
  - Global data, slough width ($W_S$ ) and DCI are the only two significant predictors ($p \leq 0.05$)
  - Subset data, only ridge density ($D_R$) is significant at $p < 0.05$. However, at $p < 0.1$, slough density ($D_S$), ridge length ($L_R$), slough width ($W_S$), lateral slough density ($D_{SL}$), and directional connectivity index (DCI) are significant.

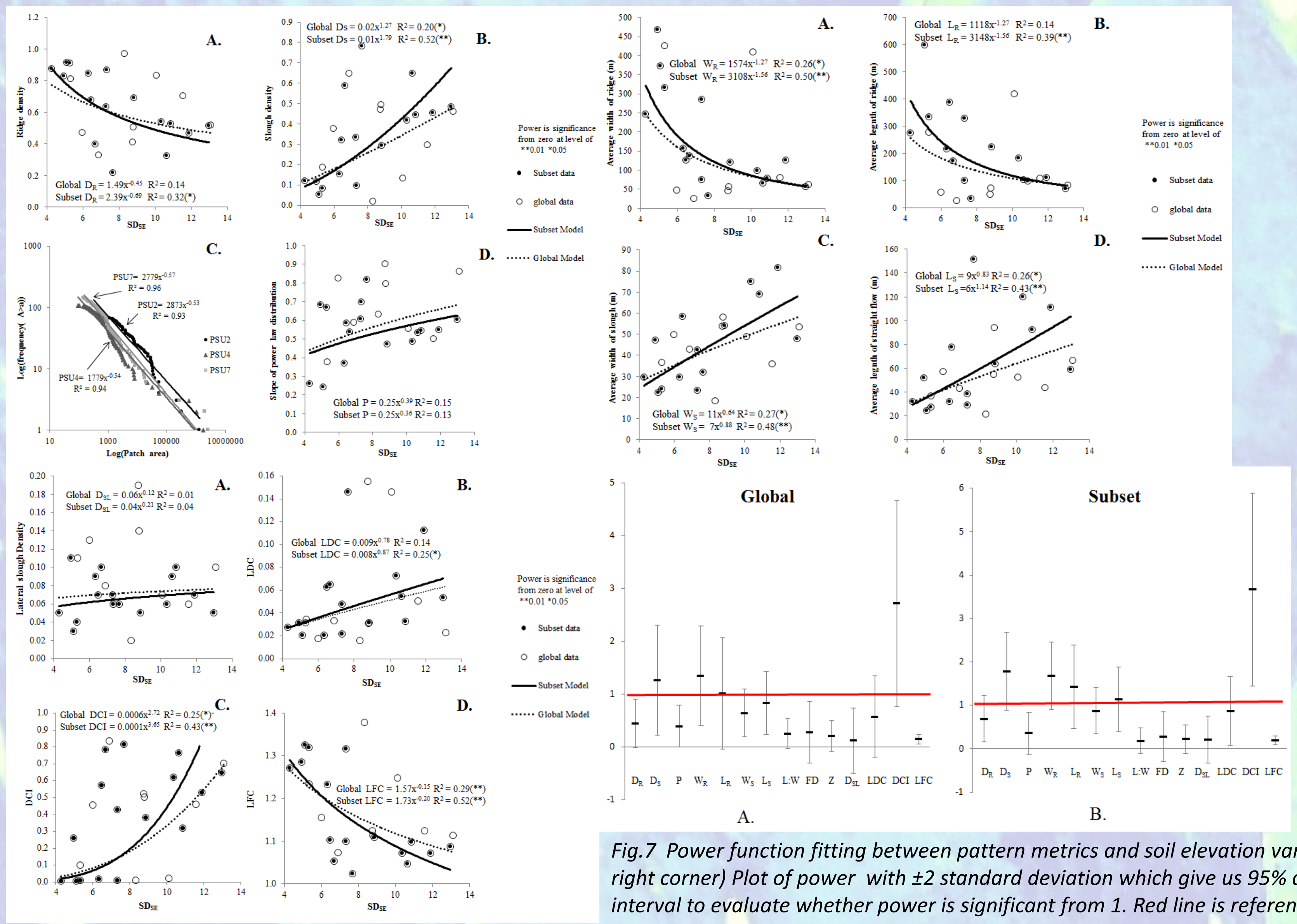


*Fig.7 Power function fitting between pattern metrics and soil elevation varicnce. (Lower right corner) Plot of power with ±2 standard deviation which give us 95% confidence interval to evaluate whether power is significant from 1. Red line is referencing where power = 1.A is global dataset. B is subset data.*

- **Pattern Metrics vs. Soil Elevation Distribution Standard Deviation ($SD_{SE}$)**
  - Subset data (n = 13 from WCA3) were better fit than the global data (n = 25 across the Greater Everglades)
  - Composition metrics (Ridge density $D_r$ and Slough density $D_S$) were strong predictors
  - Geometry metrics (e.g., lacunarity - LAC, fractal dimension – FD) has limited utility for assessing landscape condition
  - Metrics that consider connectivity (LDC, DCI, LFC) exhibited the strongest predictions of soil elevation variance
  - DCI (Directional Connectivity Index) was the only leading indicator of soil elevation variance

## Discussion

- **Are the metrics specific?** The pattern metrics to diagnose landscape condition are relatively effective only if the metrics measure the specific ecosytem driver dynamic.
- **Are the metrics sensitive?** while patch composition and geometry changes are relatively easy to visualize and intuitive, they are not as sensitive as the connectivity metrics indicating the foundational importance of hydrological connectivity to landscape and its assessment.
- **Leading or lagging?** Only DCI (Directional Connectivity Index) showed promise as a leading indicator.
- Action items to water management and restoration assessment in the Everglades ridge-slough landscape:
  1) Soil elevation monitoring is irreplaceable. Continuing large area soil surveillance is vitally important.
  2) Pattern metrics almost universally **lag behind soil elevation changes**.

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