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Connectivity: A Critical Component of Hydrological and Ecological Flux Assessments

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U.S. Department of the Interior
U.S. Geological Survey

Theme: Hydroecological Connectivity

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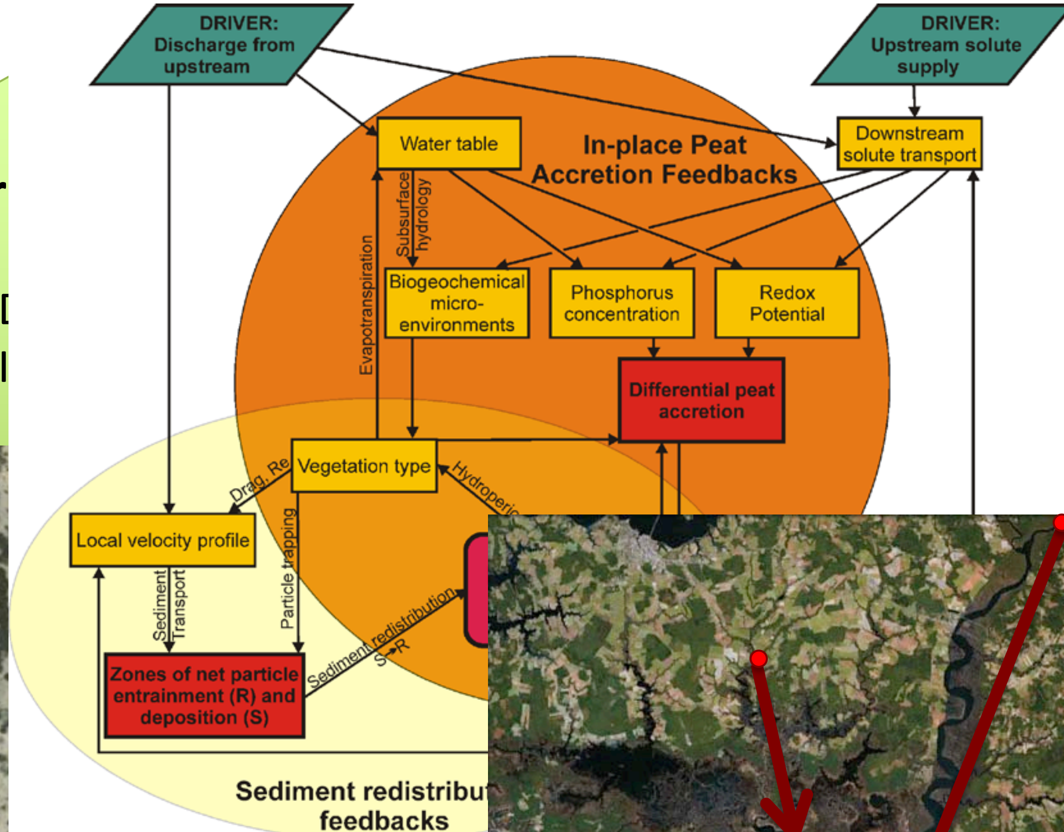

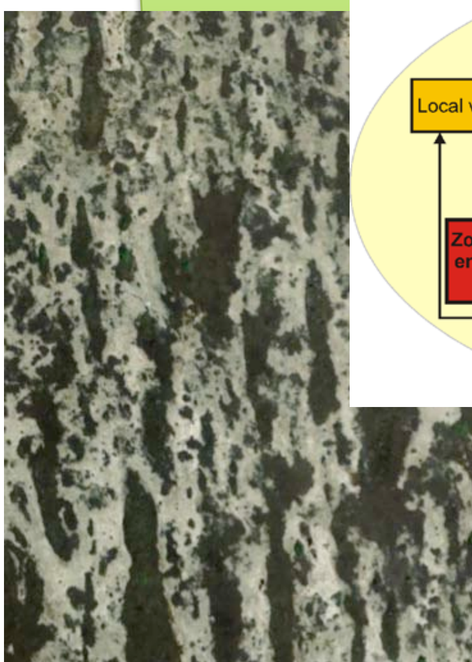

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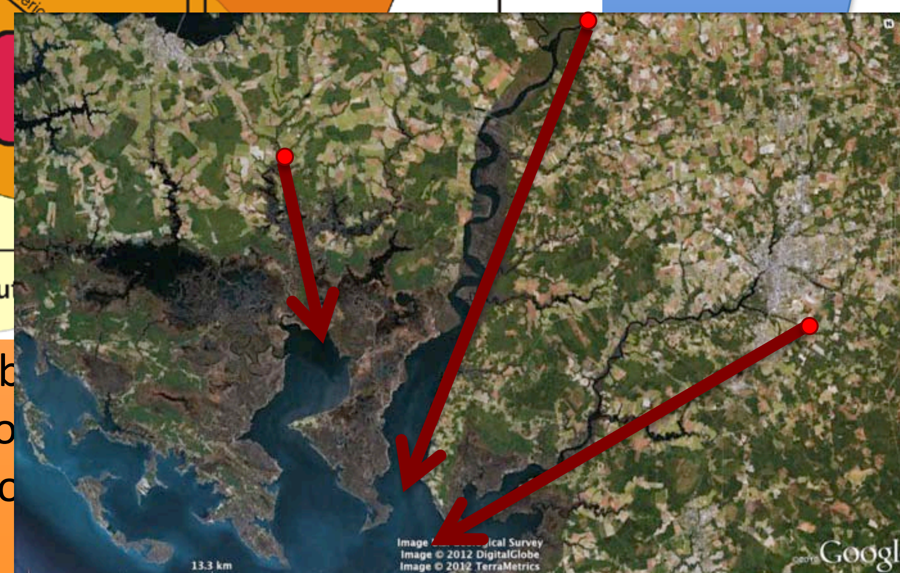

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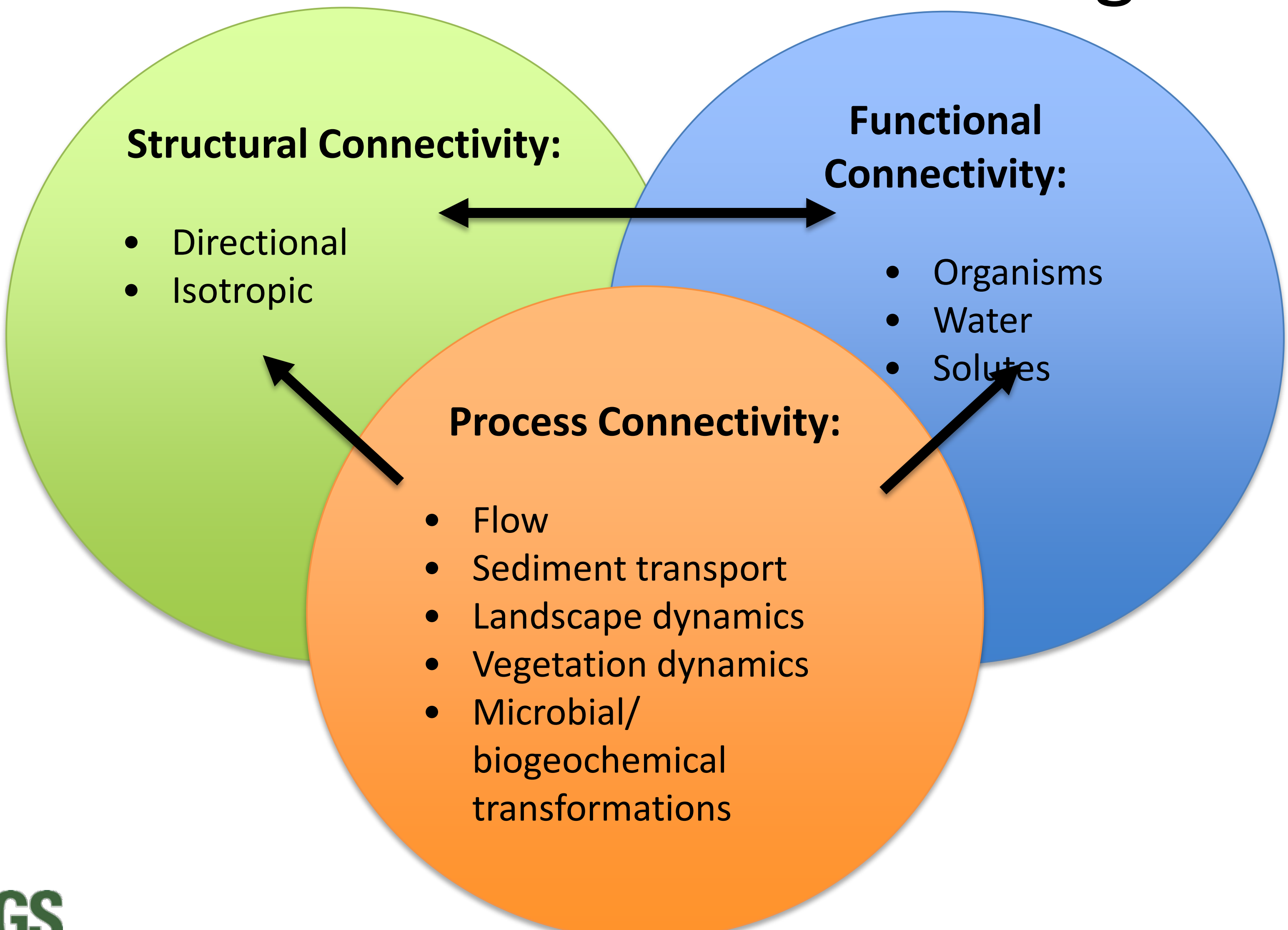
Structural and **Functional** Connectivity of Interest for Watershed Management



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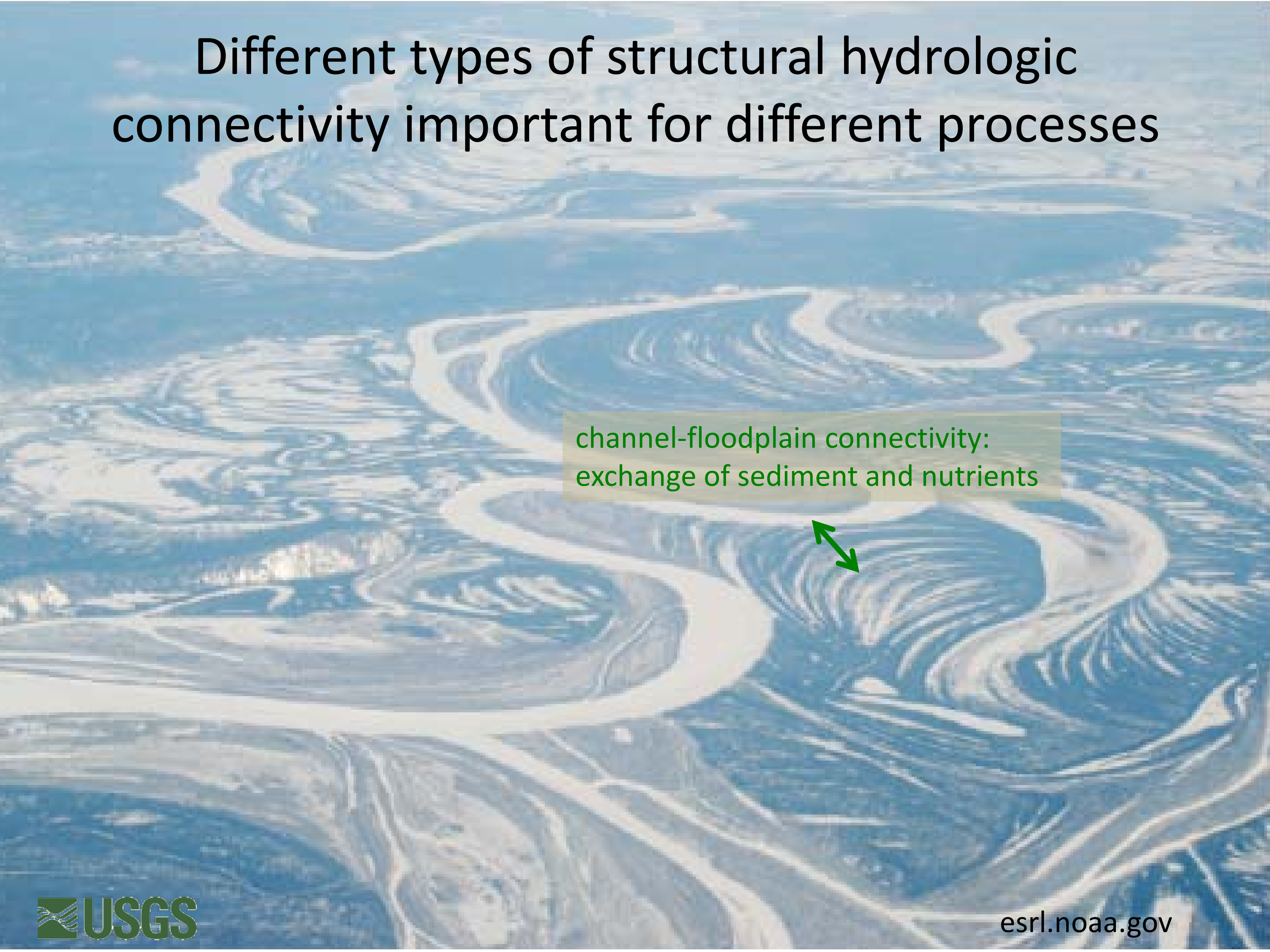
Different types of structural hydrologic connectivity important for different processes



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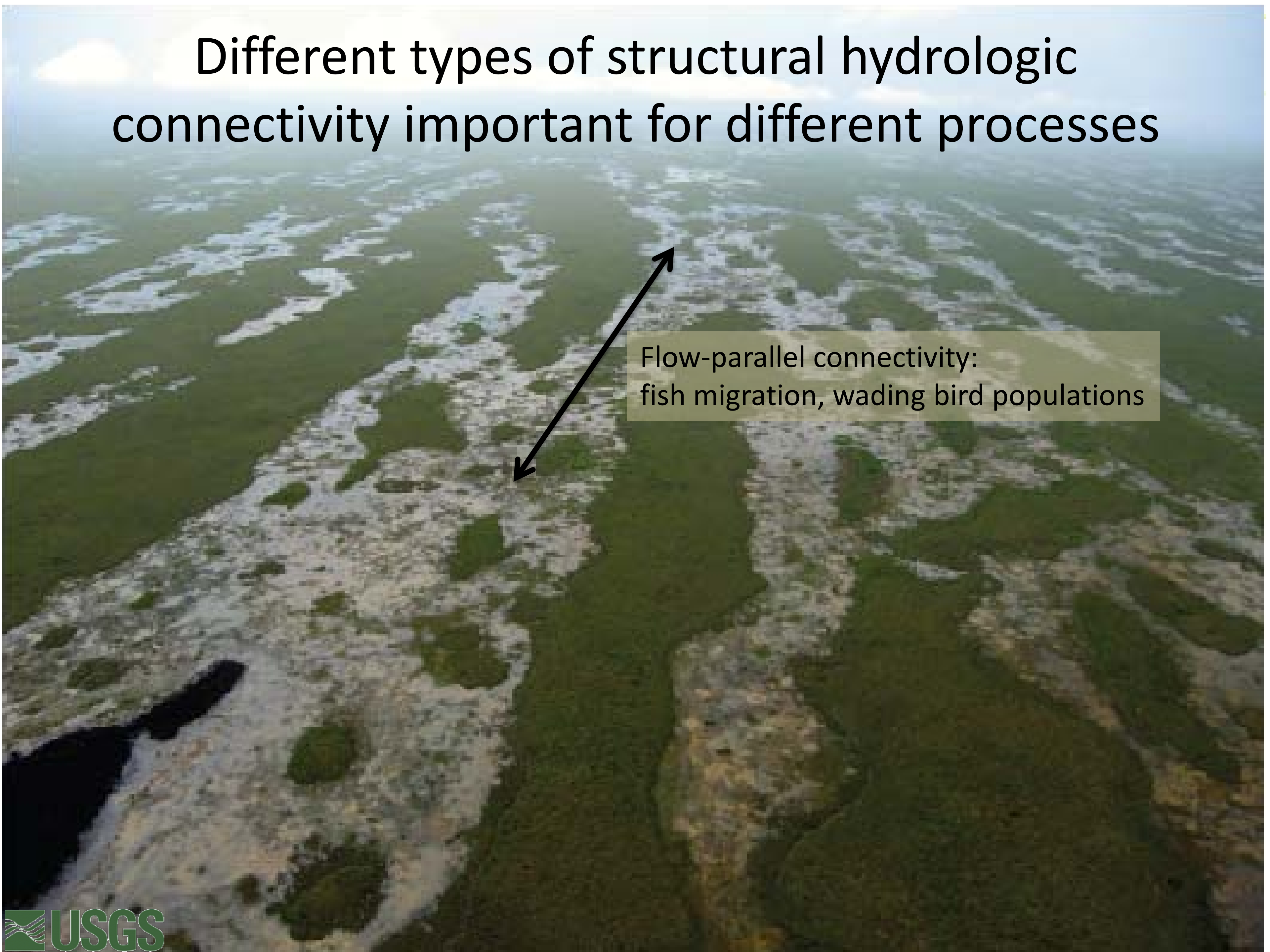
Different types of structural hydrologic connectivity important for different processes



Different types of structural hydrologic connectivity important for different processes

Dendritic connectivity

Image: Stijn Temmerman

Connectivity perpendicular to flow

Image: Jiri Rezac

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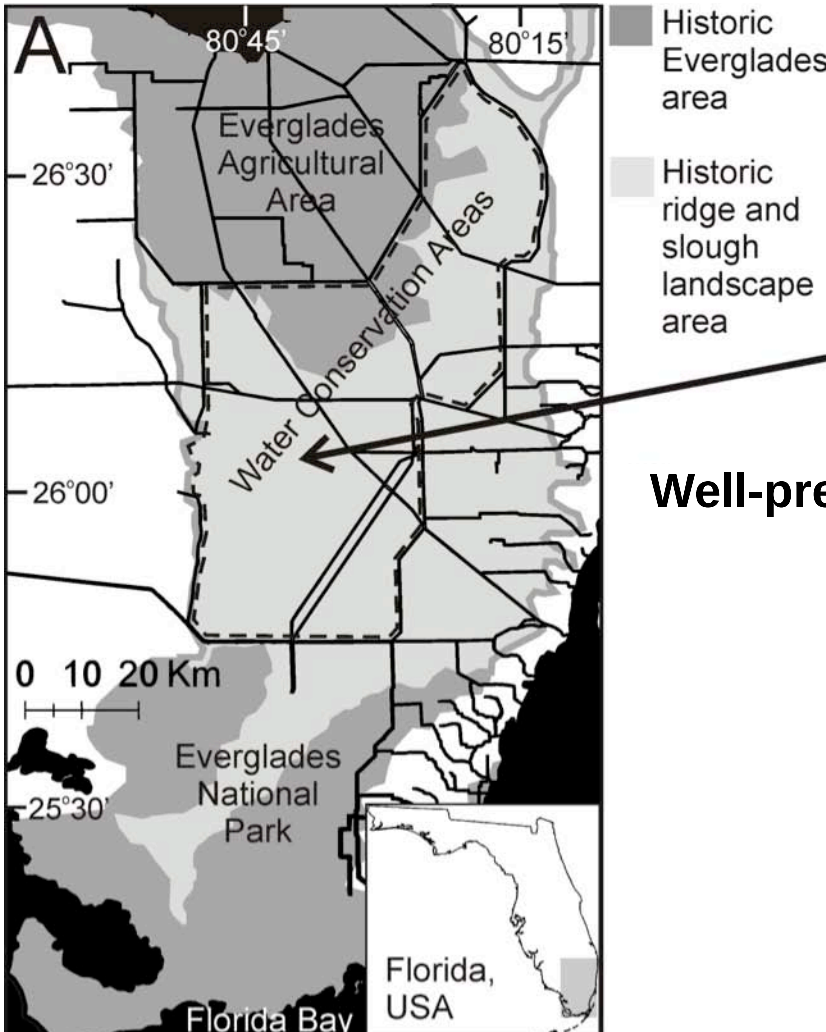
High connectivity of sloughs a goal of Everglades restoration



Well-preserved ridge and slough landscape

Degraded ridge and slough landscape

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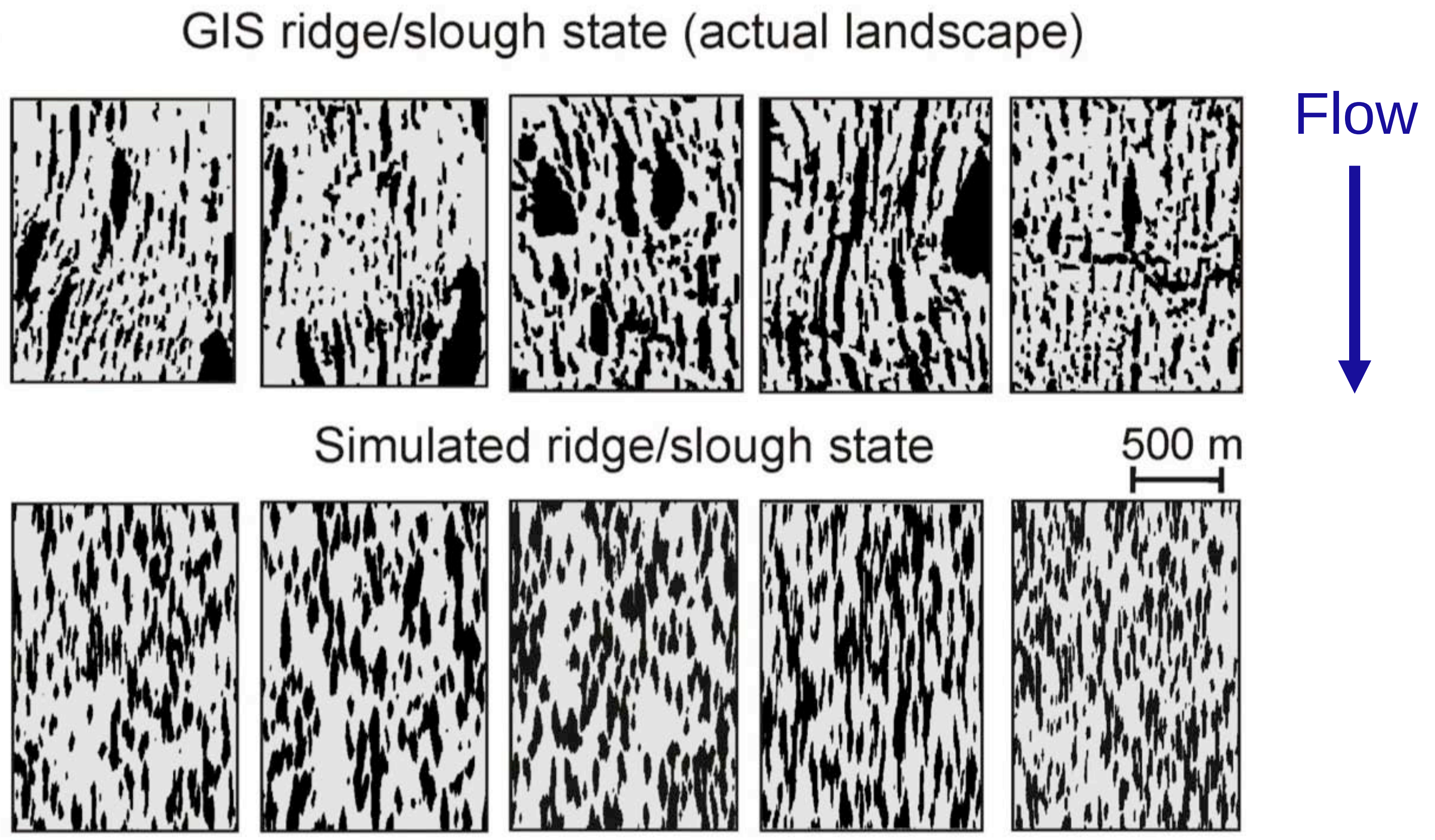
Larsen and Harvey, American Naturalist, 2010

RASCAL (Ridge and Slough Cellular Automata Landscape) model can reproduce Everglades landscape structure and connectivity changes over time



Wu et al., *Ecol. Complex.*, 2006

Larsen and Harvey, *The American Naturalist*, 2010

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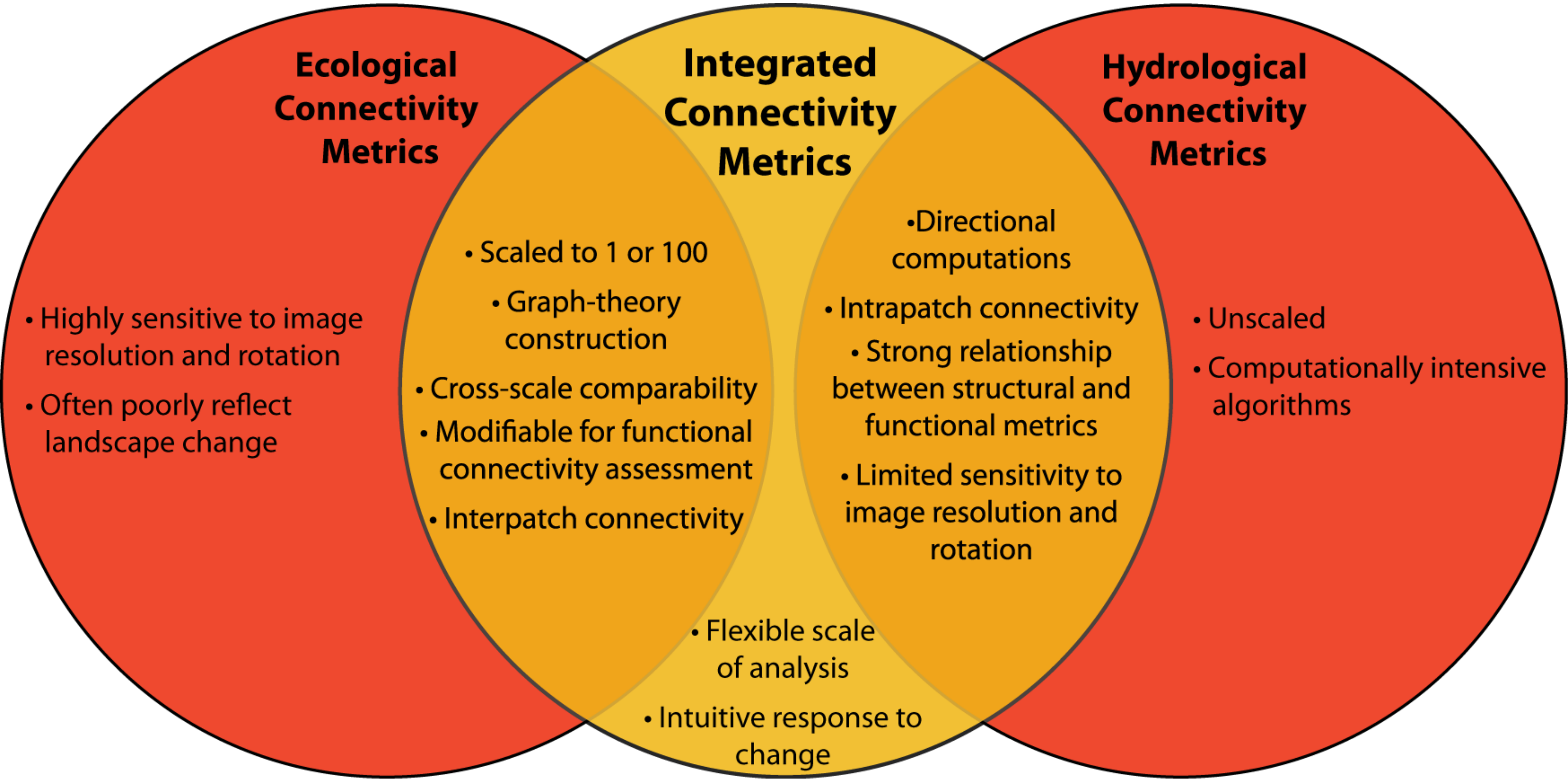
Methods to quantify connectivity abound in hydrology and ecology, with little unification between fields



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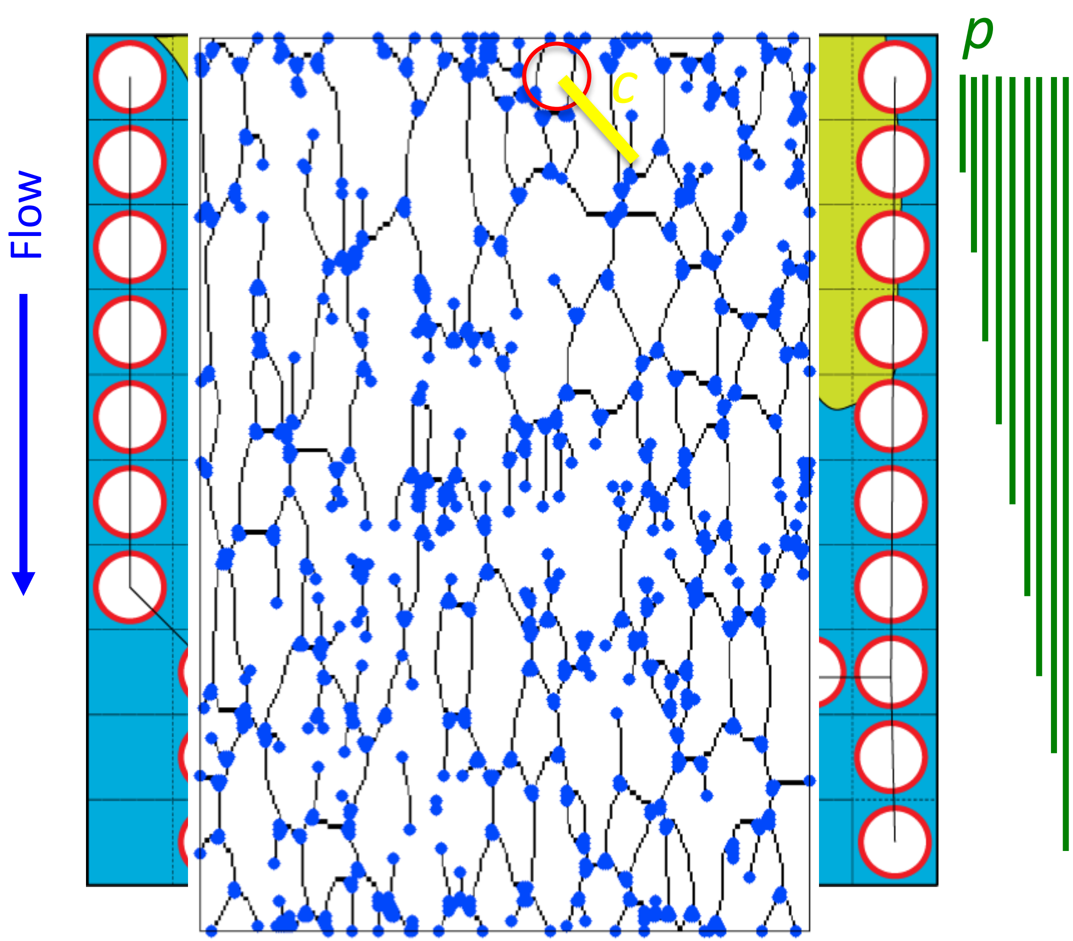
Directional Connectivity Index (DCI): A graph theory-based, multiscale sinuosity index



1. Represent binary landscape image as a skeleton network.
2. For each node, determine shortest connected distance (*c*) to a node at a particular projected distance downstream (*p*).
3. Calculate the *p*/*c* ratio.
4. Average *p*/*c* over all nodes and all downstream projected distances.

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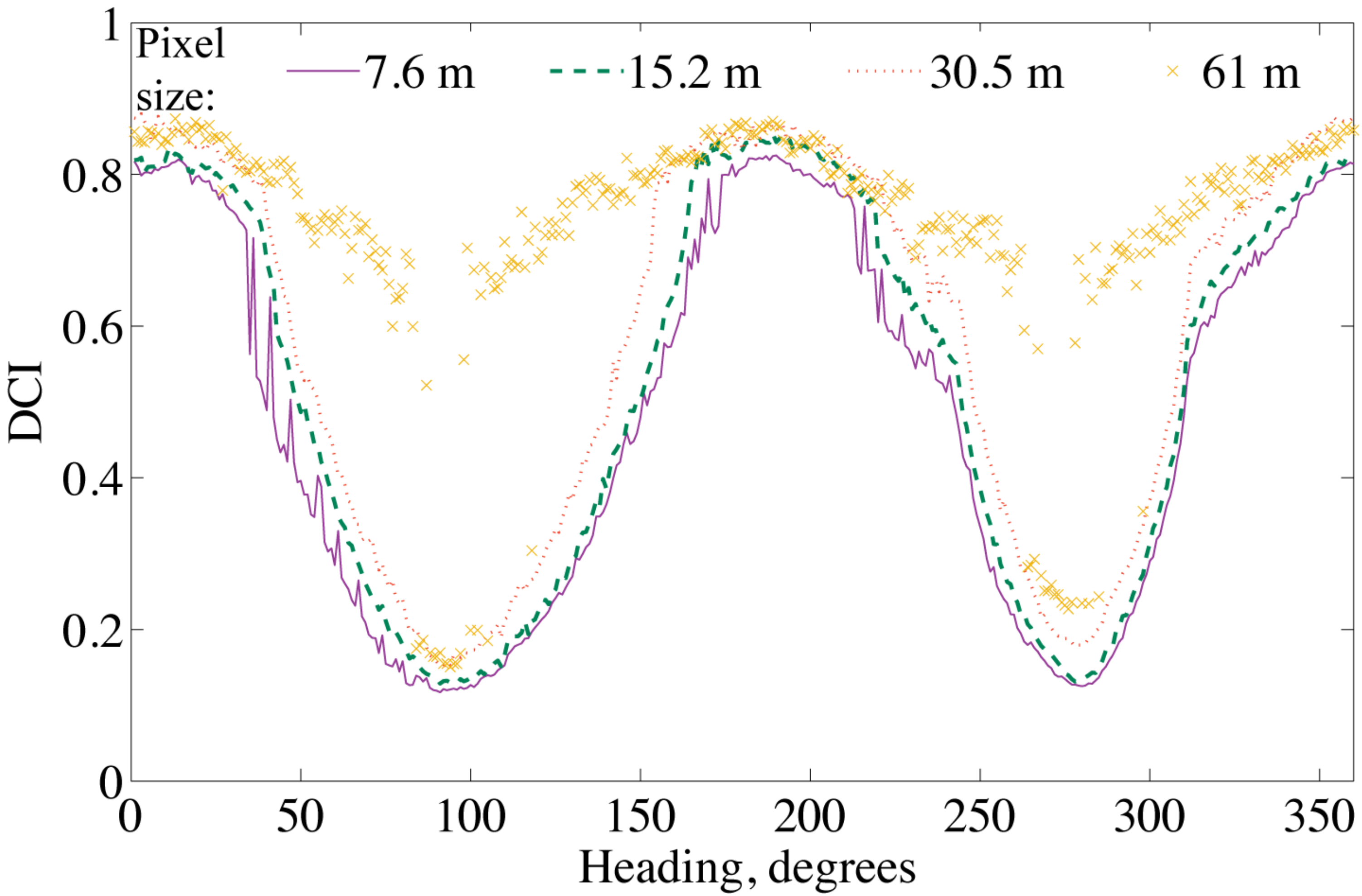
Within a range of resolutions, DCI minimally sensitive to image resolution



Everglades GIS image

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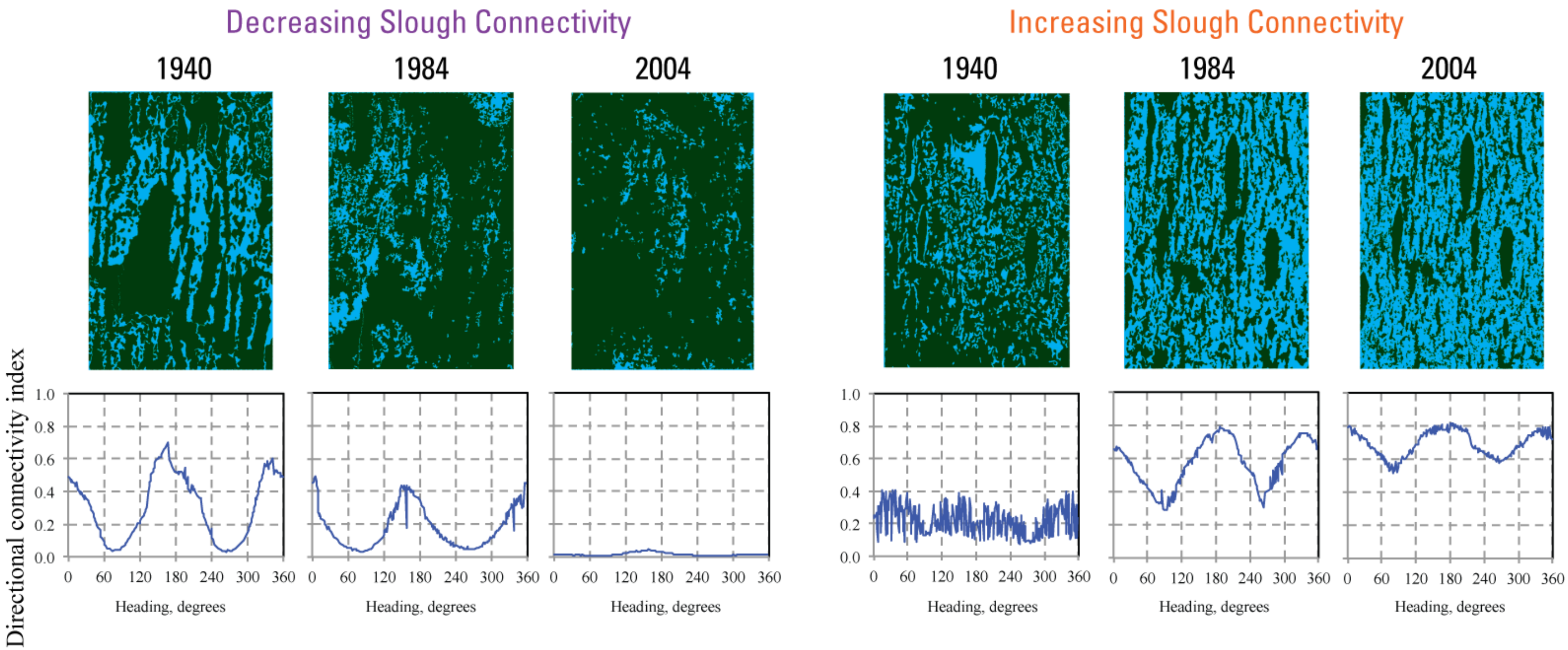
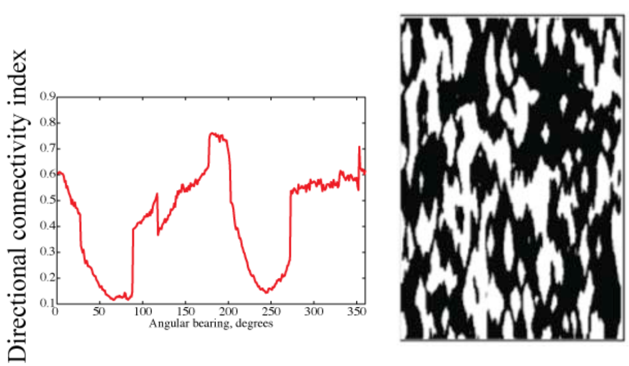
DCI intuitively reflects connectivity differences and provides information-rich means of comparing landscapes

Everglades landscapes experiencing different types of change through time





RASCAL simulation outcome

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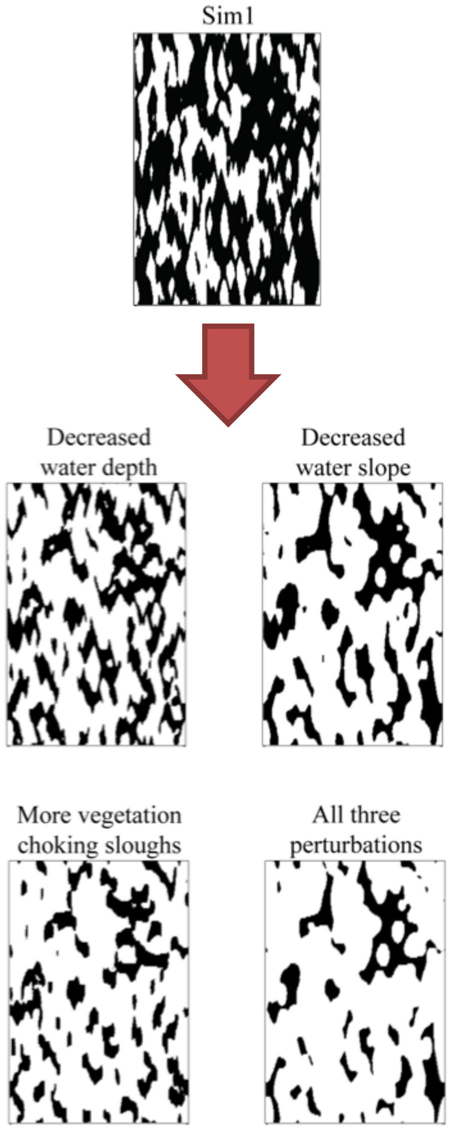
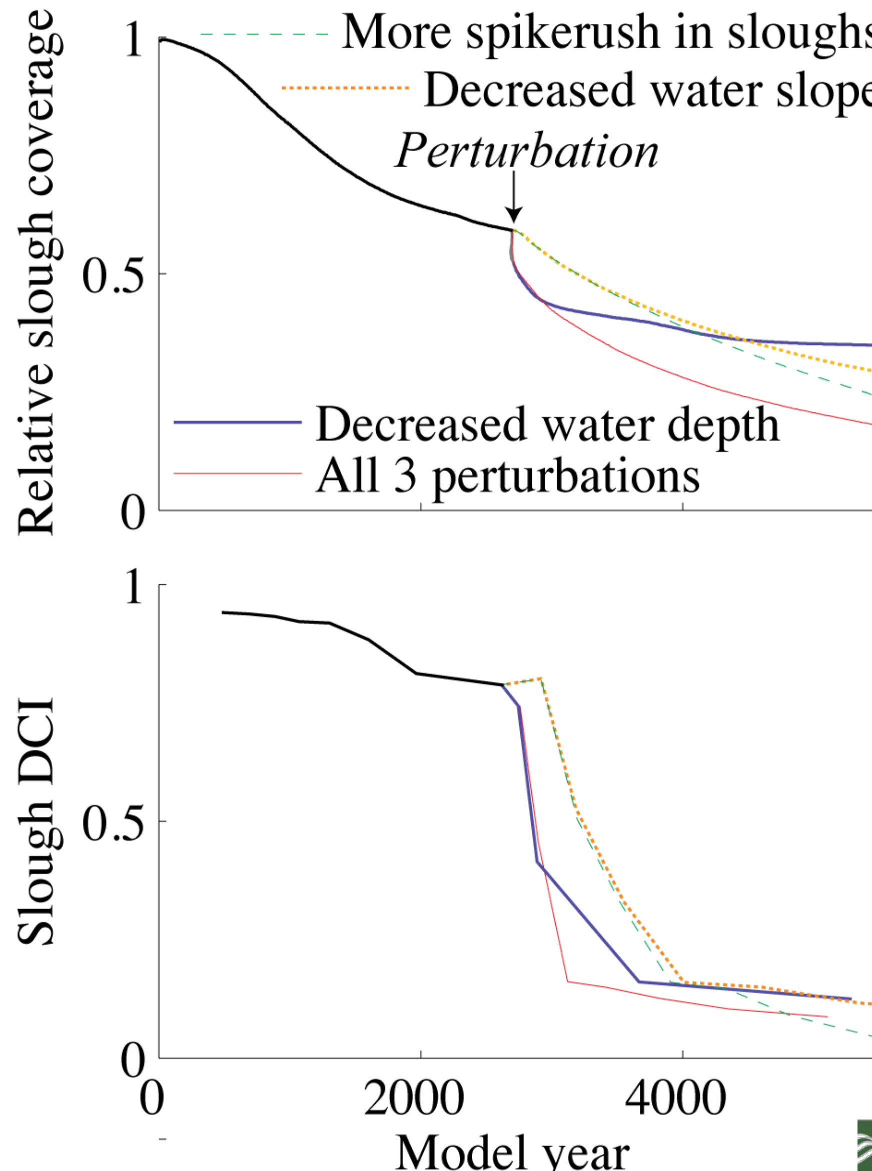
Slough connectivity lost more rapidly than slough area after hydrologic perturbation





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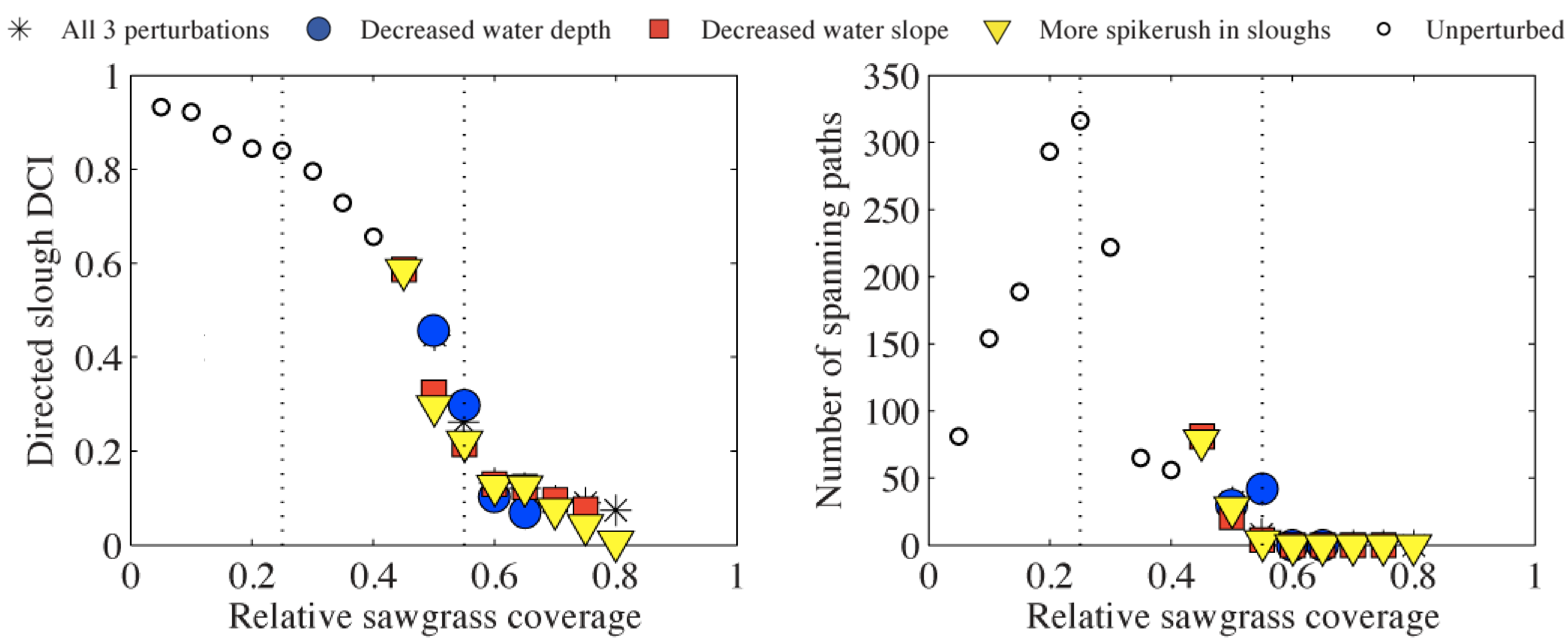
Rapid changes in DCI indicate approach of the percolation threshold



I. Ridge formation: ridges grow within a highly connected slough matrix

II. Ridge expansion: ridge growth begins to cut off spanning paths through sloughs

III. Below percolation threshold: scale of remnant sloughs becomes smaller as ridges grow

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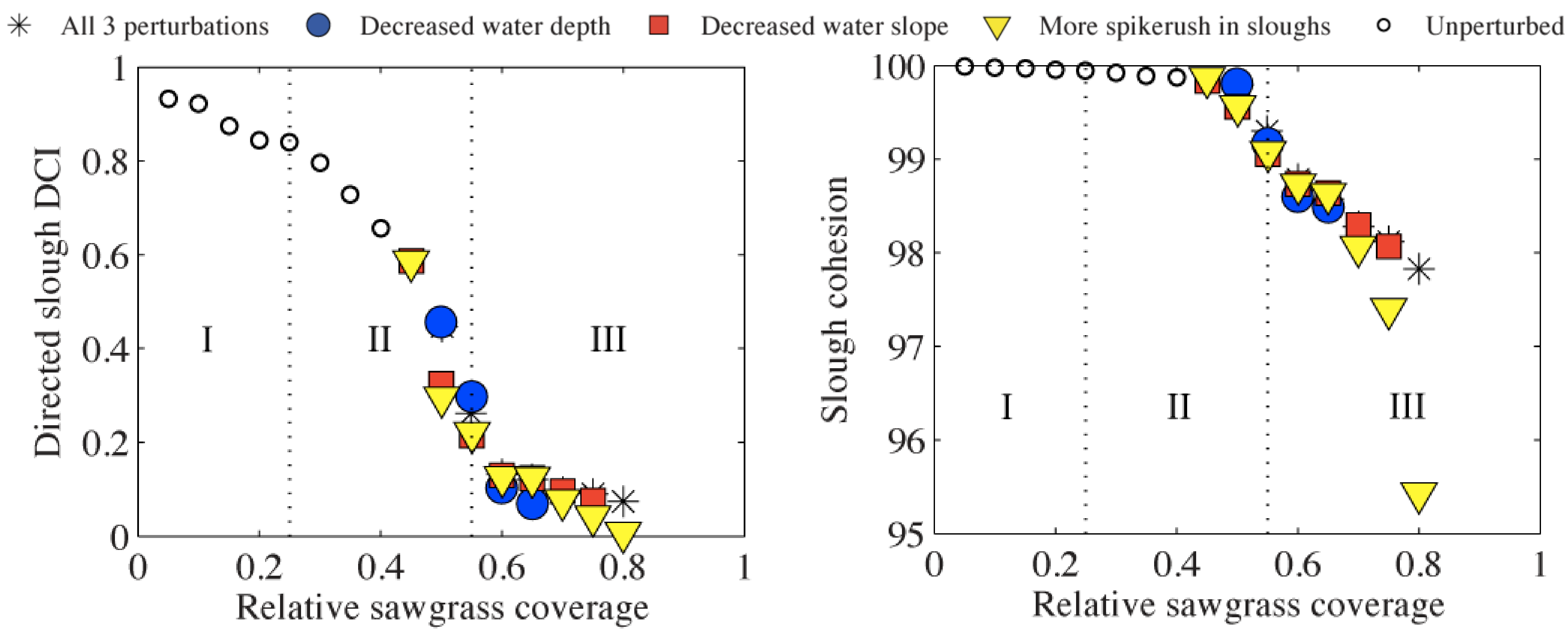
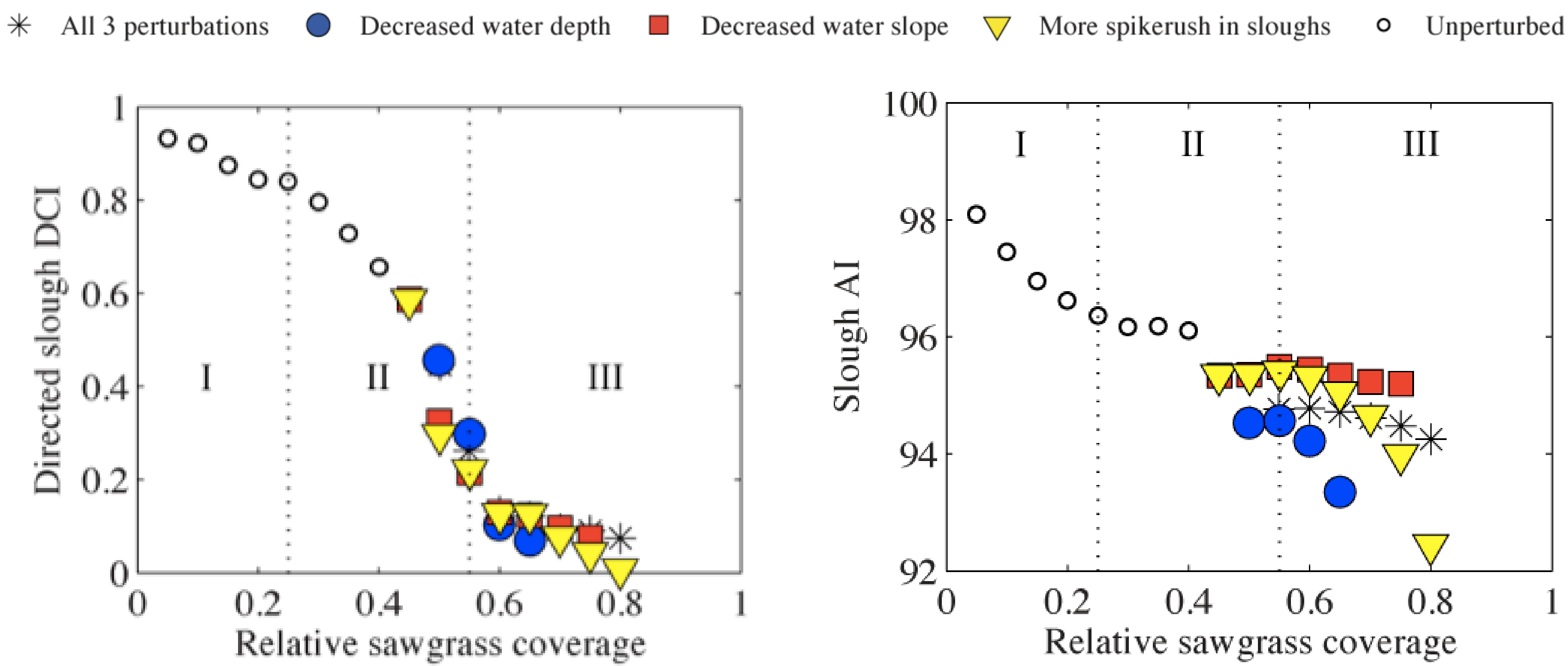
DCI more sensitive than cohesion to approach of percolation threshold



Changes in DCI more intuitive than other ecological connectivity metrics



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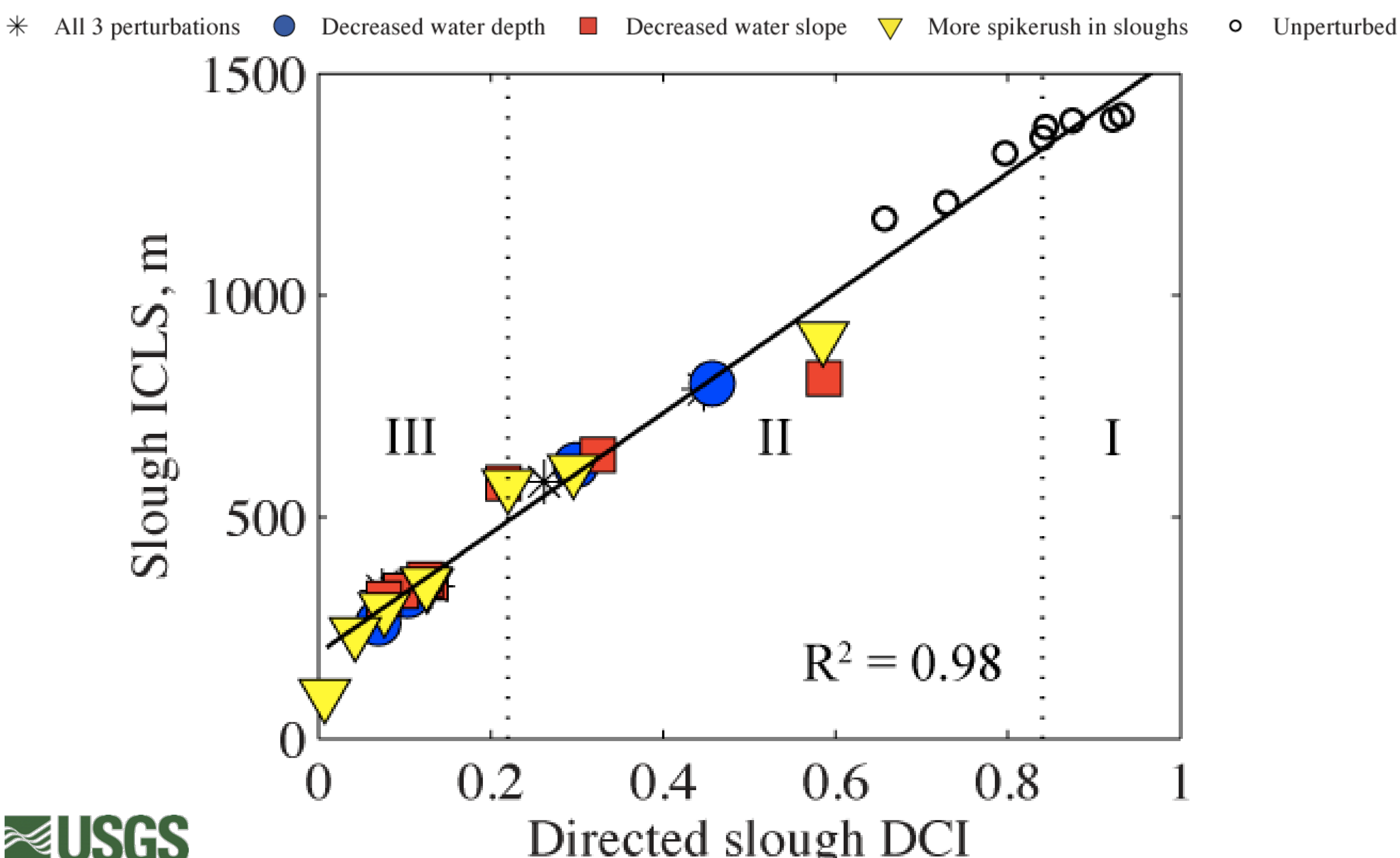
DCI closely related to computationally intensive integral connectivity length scale in hydrology



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Groundwater hydrology forges path for linking connectivity to upscaled permeability

$$k_{eff} = \boxed{\left(\frac{1}{A} \int_A k^{\omega} \, dA \right)^{1/\omega}} \propto v_{mean}$$

from image analysis and vegetative flow resistance parameters

- -1 < ω < 1
- ω depends on channel connectivity and area (e.g., Ronayne and Gorelick, Phys. Rev. E., 2006)
- In groundwater, connectivity quantified using mean spanning path tortuosity (scale-dependent)
- Tortuosity ~ 1/sinuosity
- Empirically relate mean spanning path tortuosity to DCI
- What is the relationship between v_{mean} and k_{eff} in surface water?

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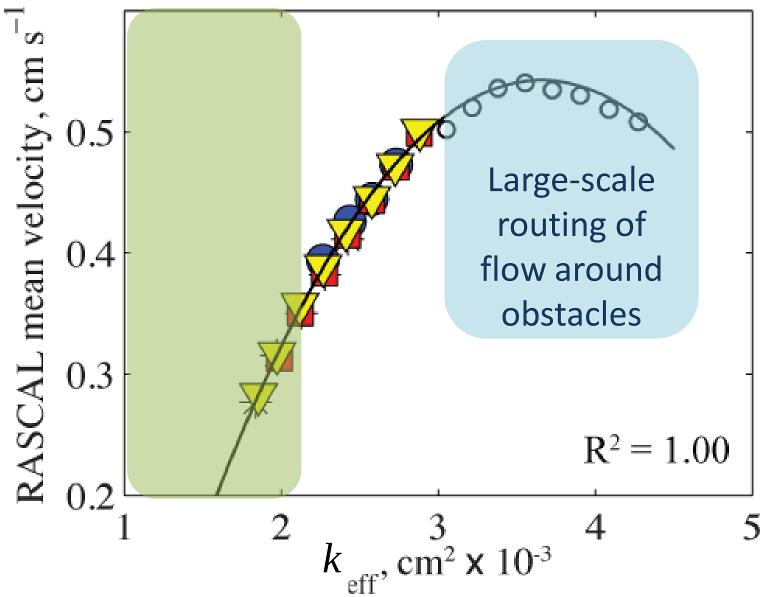
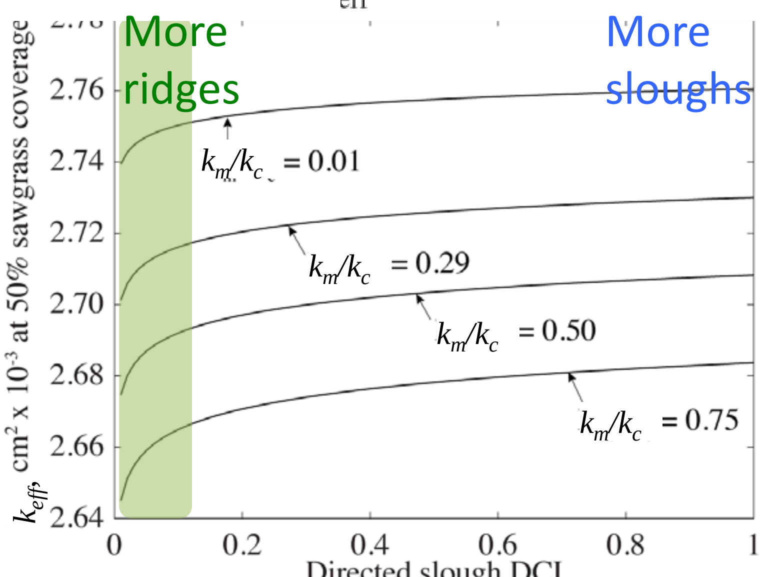
Potential for large-scale prediction of hydrologic fluxes from image analysis





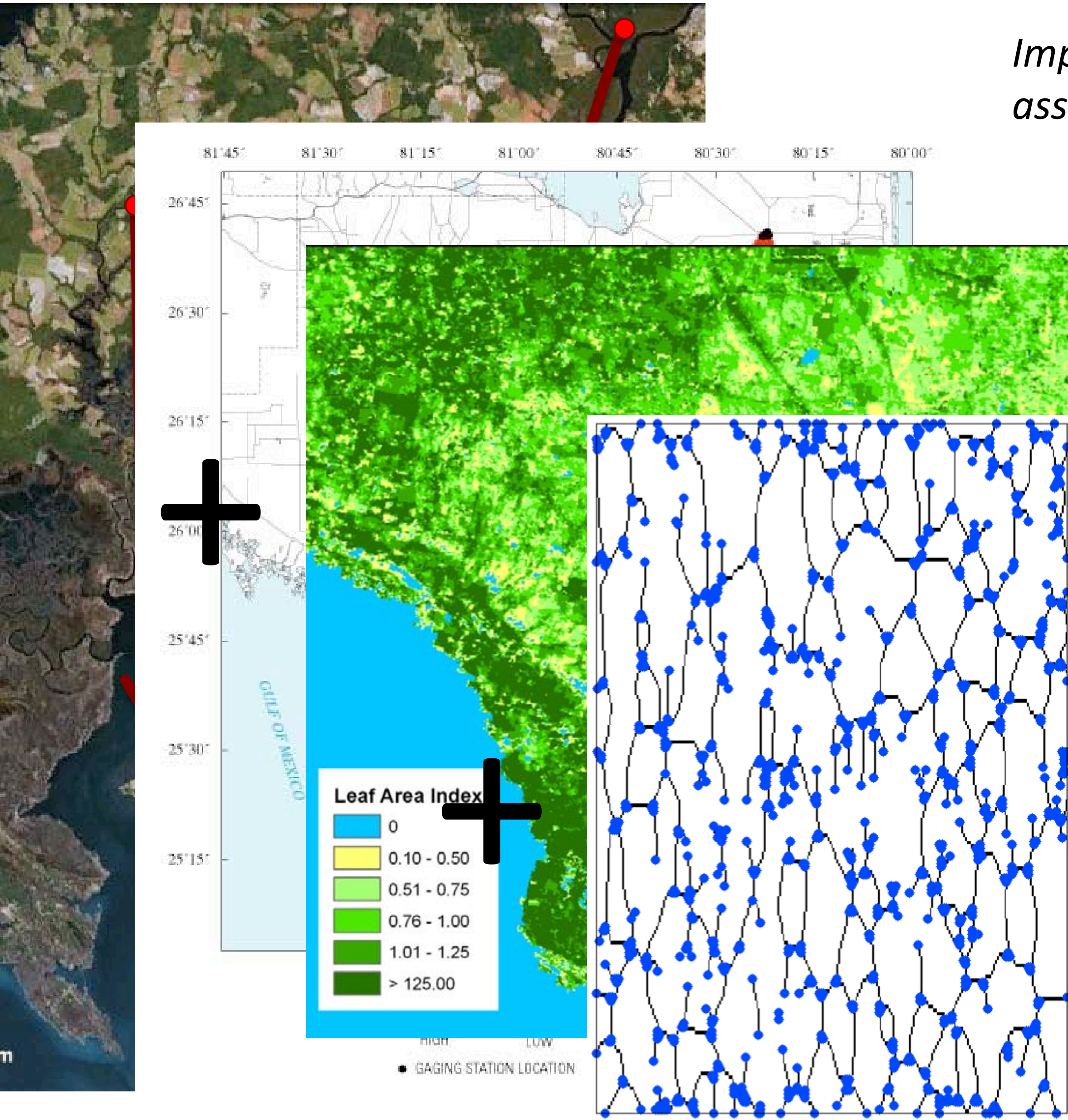
Large-scale mean velocities predictable from effective permeability…

… but we need to explain the shape of the relationship with theory.

Low sensitivity of k_{eff} to DCI at high DCI might be an artifact of extrapolation.

Most groundwater systems

Promising functional connectivity applications in restoration science



Improved contaminant flux assessments

Large-scale prediction of fluxes of water and solutes (P) resulting from different management activities

Image credits:
Google Earth
USGS Fact Sheet 2006-3087
Skalak, Jones, Larsen, and Harvey, in prep.
L. Larsen

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Acknowledgements

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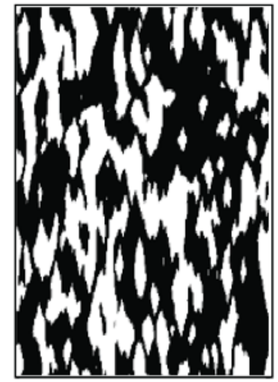
DCI varies in expected manner for test landscapes and offers advantages over other indices

Connectivity Index Values for Different Landscapes

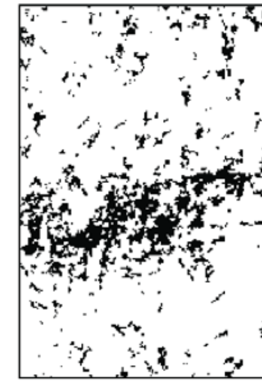
Conserved1

Conserved2

Sim1



Degraded1



Percent ridge area	38	55	41	86
DCI	**0.72**	**0.35**	**0.57**	**0.02**
Cohesion	99.9	99.4	99.9	96.3
Aggregation	96.5	91.5	95.4	77.0
γ-index	0.0005	0.0003	0.0006	0.0005
K_{eff}, cm^{-2} x 10^{-3}	3.10	2.54	2.99	1.68
ICLS, m	1325	864	901	137
Semivariogram range, m	302	151	119	461