SCHOOL FOR ADVANCED STUDIES LUCCA

Species Vulnerability and Ecosystem Fragility: A Dual Perspective in Food Webs

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Emanuele Calò, PhD Student in Complex Systems and Networks

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The Topic: Background

- Conservation ecology faces the urgent task of preserving ecosystems, with a focus on understanding the consequences of species loss.
- Species loss can trigger cascading effects, leading to secondary extinctions that amplify initial damage.
- Assessing species "importance" is crucial for mitigating extinction cascades, especially in the face of increasing anthropogenic threats.

The Topic: Our Contribution

- Network approaches, e.g., food webs, have emerged as effective tools for understanding complex ecosystem interactions.

- Our research introduces a novel methodology that measures a species' dual nature in food webs: as prey (Importance index) and as predators (Robustness index).

Data: 6 food webs

- **Florida Bay**: Trophic flows through the ecosystem of Florida Bay, including various species such as seagrass and algae producers, microfauna, fishes, mammals, and avifauna.
- ***Cypress Dry Season***: Cypress wetlands in South Florida during the dry season.
- **Mangrove Wet Season**: Mangrove ecosystem in South Florida during the wet season.
- **St. Marks**: Winter's Halodule wrightii (shoal grass) community in Goose Creek Bay, St. Marks National Wildlife Refuge, Florida.
- **Coachella**: Sand community in the Coachella Valley desert. The biota includes species of vascular plants, vertebrates, arachnids, microorganisms, and insects.
- **Benguela**: Benguela Marine Ecosystem, including marine mammals and fisheries.

Building the Networks

- Food webs are directed networks where the direction follows the energy flow. An edge from node i to node j means that species i preys upon species j.

- Self-loops are allowed (cannibalism can occur).

- We add a root to represent the intrinsic loss of matter of every species:
  - Primary producers originate all matter in the food web receiving it from the external environment: we add links from the primary producers to the root.
  - We add a link from the root to every node.

Network Properties

	# nodes + 1	# links	density (%)
St. Marks	49	275	11.5
Benguela	30	234	26.0
Coachella	30	294	32.7
Florida	126	2078	13.1
Cypress	69	634	13.3
Mangrove	95	1439	15.9

The Algorithm: Fitness Centrality

- Fitness centrality is a powerful tool for assessing network vulnerability.
- It can identify nodes that, when removed, lead to the isolation of many other nodes.

$$V_i^{(n)} = \delta + \sum_{j=1} A_{ij}/V_j^{(n-1)} \quad \text{with} \quad V_i^{(0)} = 1.$$

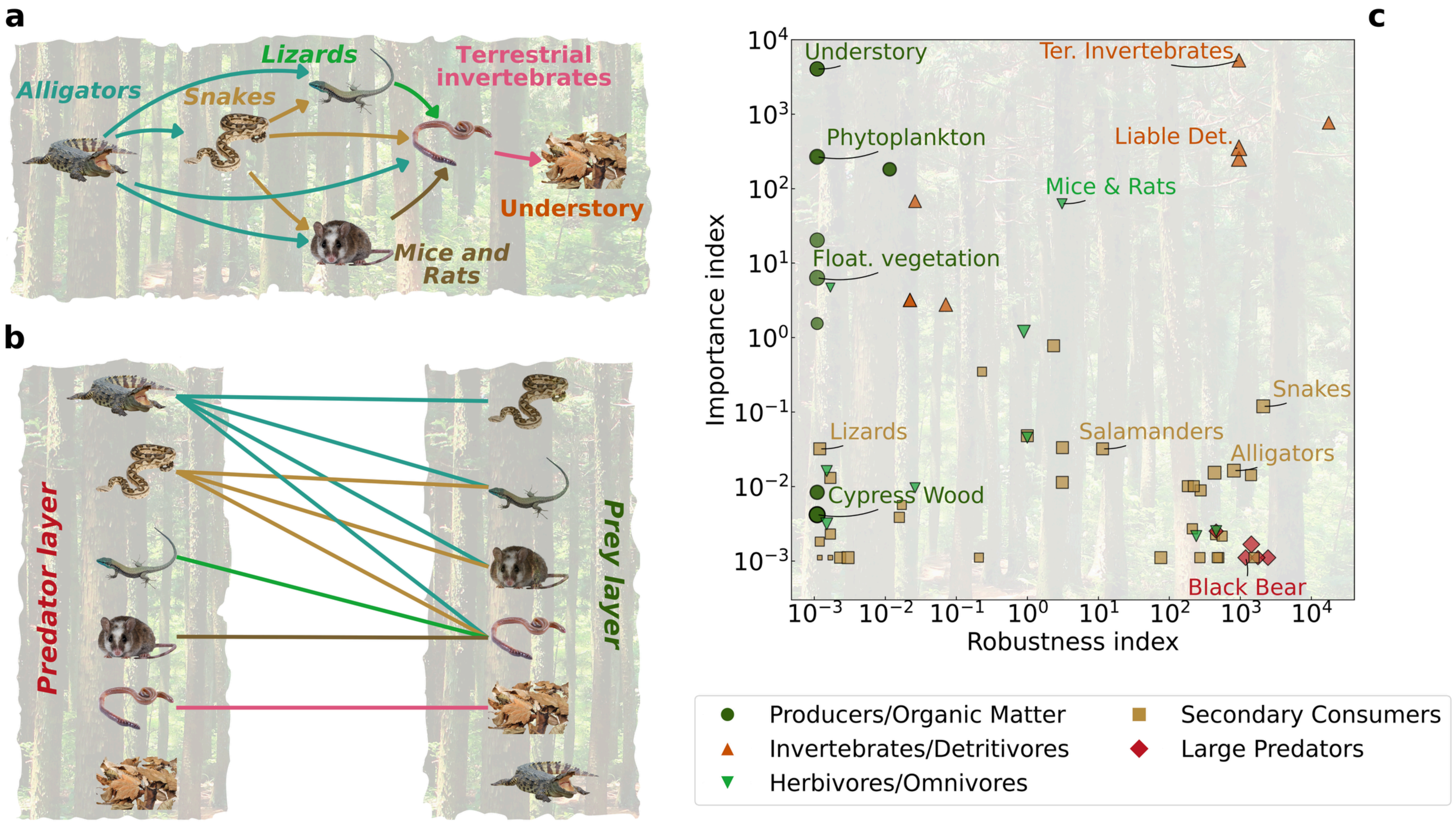
Vito D P Servedio et al 2025 J. Phys. Complex. 6 015002

The Algorithm: Fitness Centrality

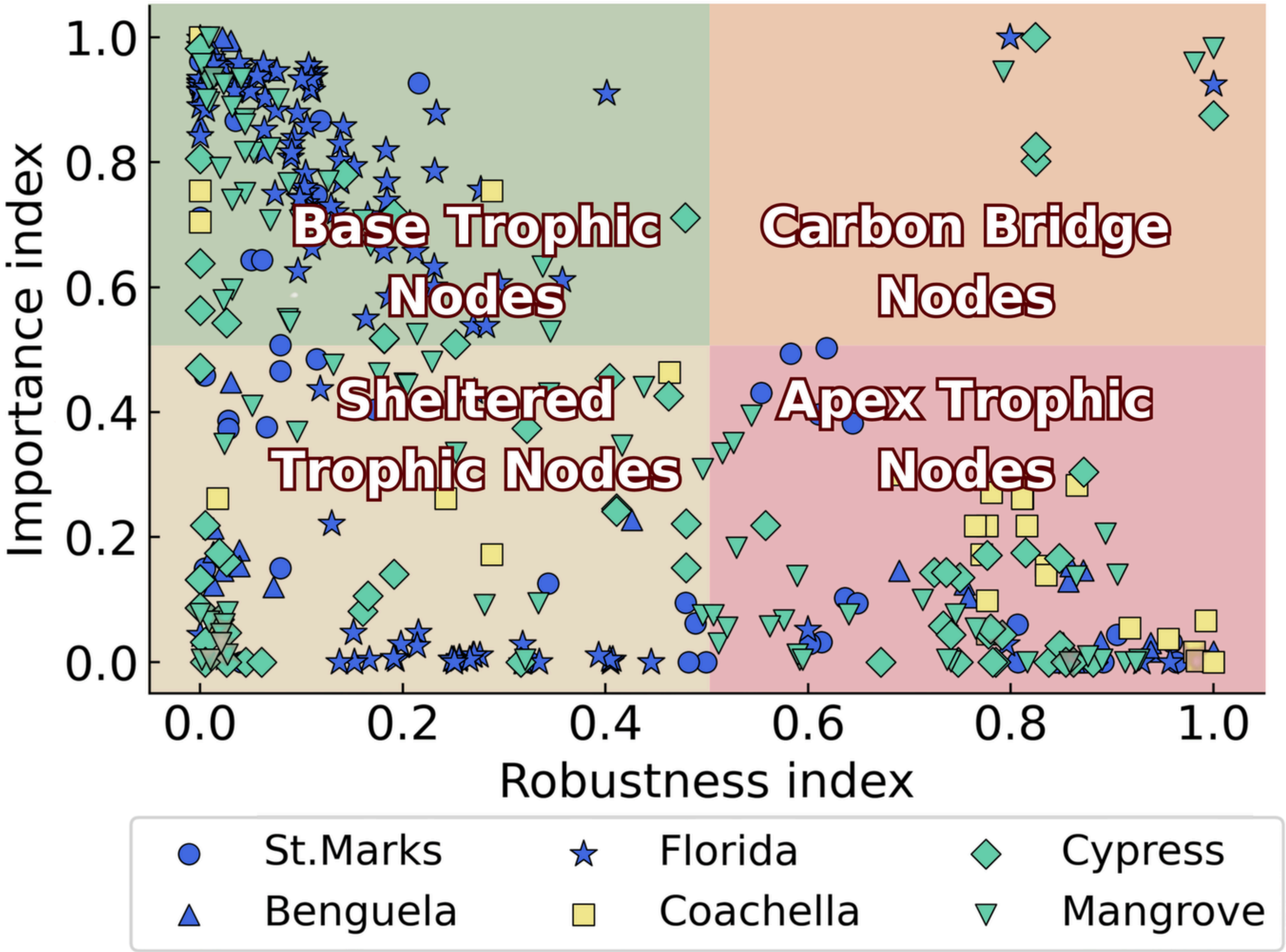
- In directed networks, Fitness Centrality disentangles the direction of links, producing two quantities for each species:
  - *Robustness index*, related to the outgoing links (capturing its predatory ability and resilience to extinction).
  - *Importance index*, related to the incoming links (measuring its centrality as a carbon source and its relevance within the food web).
- We define the Robustness index and Importance index of species *i* as:

$$\begin{cases} R_i^{(n+1)} & = & \delta + \sum_j M_{ji} \,/\, I_j^{(n)} \\ I_i^{(n+1)} & = & \delta + \sum_j M_{ij} \,/\, R_j^{(n)} \end{cases} \quad R_i^{(0)} = I_i^{(0)} = 1 \;\forall i.$$

Ready for our Algorithm

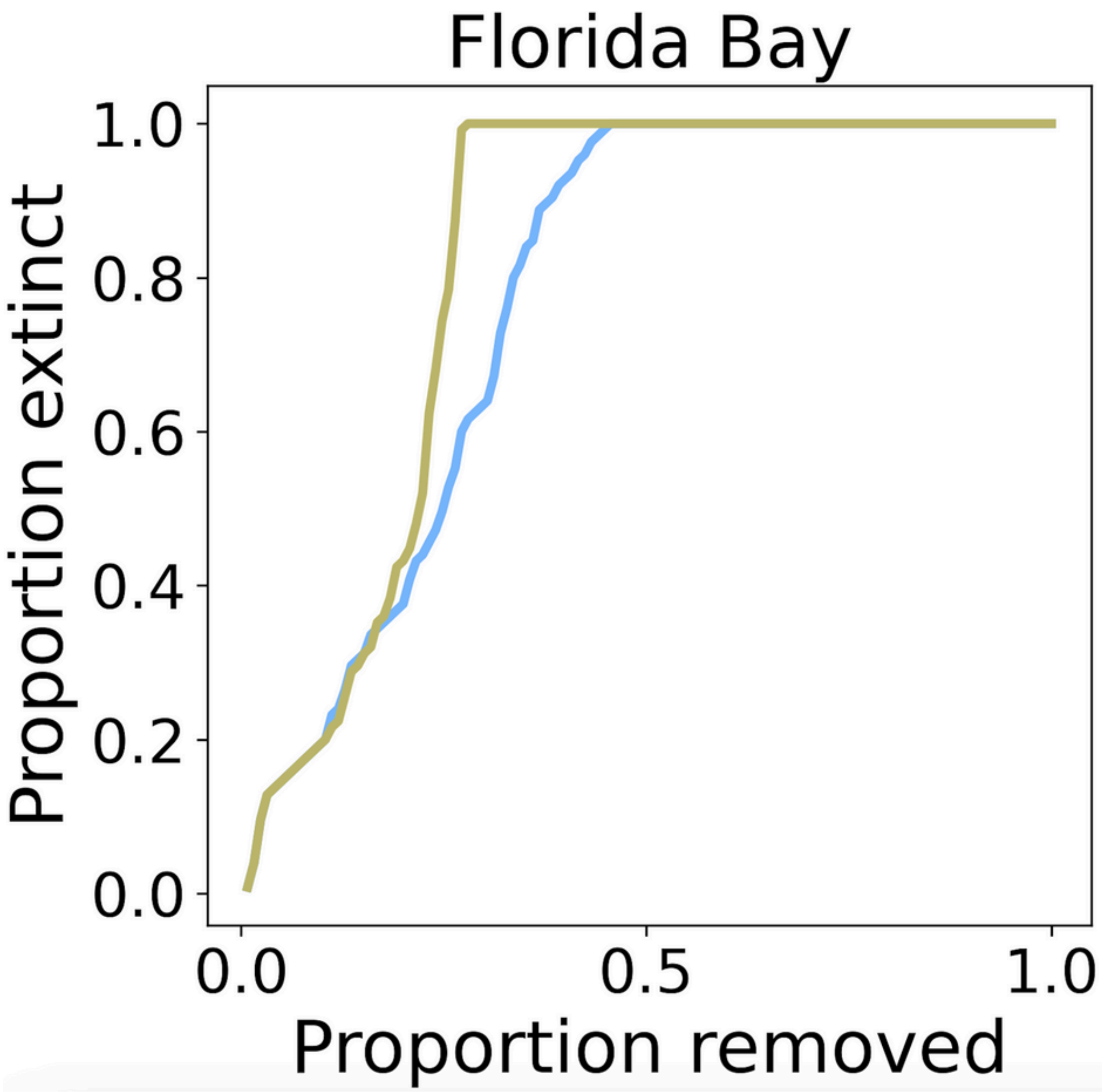


Robustness index–Importance index Plane



Evaluating Species Importance: Extinction Areas

- Species are removed progressively based on rankings computed at the beginning.
- A species is extinct when it has no outgoing links or only one self-loop (cannibal species).
- The process continues until all species are extinct.
- The total fraction of extinct species is plotted against the number of removed species (extinction curve).



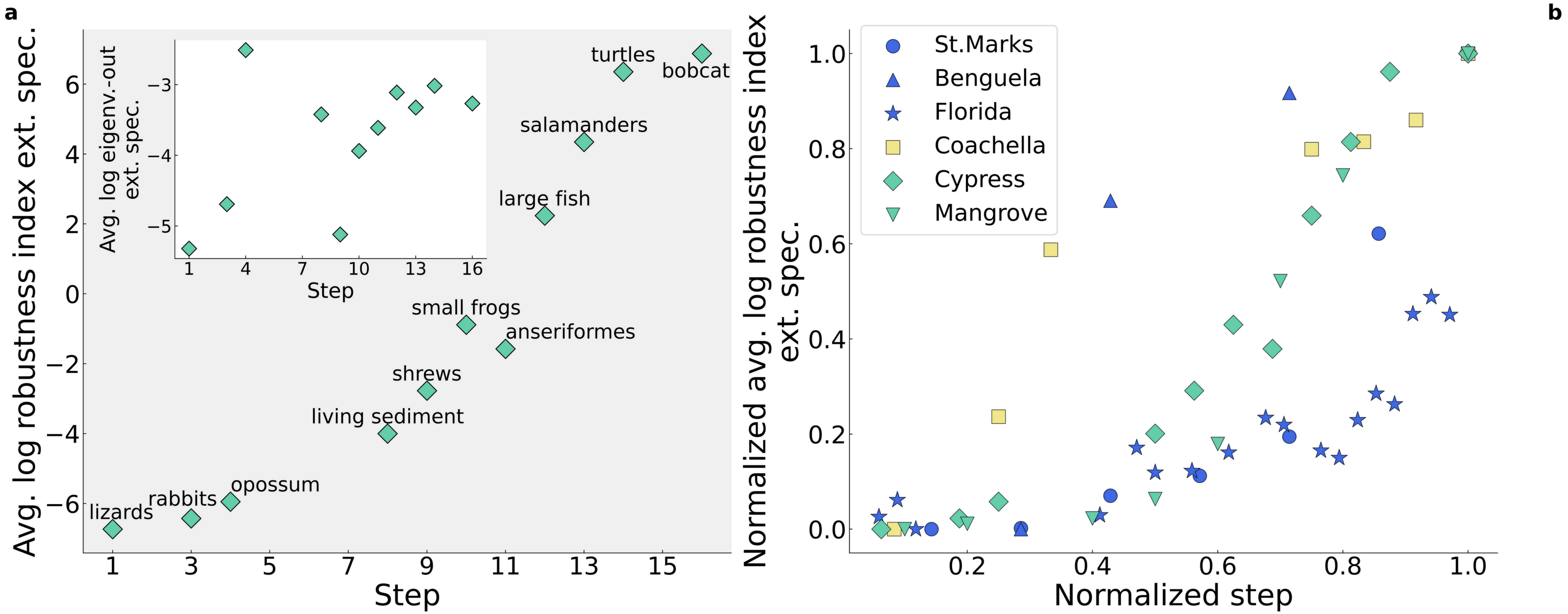
Evaluating Species Importance: Extinction Areas

- The extinction area is calculated as the integral of the extinction curve, ranging from 1 (all extinct after first removal) to 1/2 (no secondary extinctions).
- Higher extinction areas indicate that important species were removed early.
- Rankings based on Importance index, Eigenvector-in, and in-degree are compared.

Evaluating Species Importance: Extinction Areas

	in-Degree (%)	**Eigenvector-in (%)**	**Importance index (%)**
St. Marks	85	**92**	91
Benguela	77	**95**	91
Coachella	71	76	**79**
Florida	65	**82**	**82**
Cypress	79	82	**87**
Mangrove	73	**95**	94

Evaluating Species Resilience: the Robustness index



Conclusions

- Diverse ecosystems reveal a universal structure when analyzed on the Robustness index-Importance index Plane.
- The Importance index is among the most effective measures for identifying species that trigger cascading extinctions.
- The Robustness index indicates which species demonstrate greater resilience to extinction events.

Limitations

- The framework simplifies the representation of basal species by linking them to a common root node, overlooking their resource dependencies.
- The importance of some species might be underestimated due to aggregation biases in network construction.
- Food webs are treated as static and binary, simplifying real-world dynamics and not accounting for adaptive behaviors.

Vito D. P. Servedio
Complexity Science Hub

Giordano de Marzo
Enrico Fermi Research Center
Konstanz University

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Thank You!

Do you have questions?

Calò, E., De Marzo, G., & Servedio, V. D. (2025).
Species vulnerability and ecosystem fragility: A dual perspective in food webs.
Chaos, Solitons & Fractals, 199, 116741.

Emanuele Calò