Use of Size Spectra as a Holistic Indicator of Change for Fisheries and Ecosystem Management

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Abstract

Organism body size is a fundamental trait associated with multiple processes that govern ecological attributes such as metabolism, development, movement, and feeding. As such, the size distribution of organisms within an ecosystem can provide a wealth of information on ecological structure and function from population to ecosystem scales. In particular, the general decline in abundance (N) with body size (M)—large organisms are rarer than smaller ones—gives key insights into the transfer of energy in food webs. For a community, this measure is often referred to as the community size spectrum (CSS) and can be described mathematically with the power law, $N \sim M^{\lambda}$, where λ represents the rate of decline in abundance with M. Here, we present examples from ongoing monitoring programs, e.g., the National Ecological Observatory Network (NEON) and invasive species management of silver carp in the Mississippi River basin, that showcase the response of CSS to drivers of ecological change (e.g., temperature, resource availability, species invasion). With these examples, we show CSS has a number of positive attributes for potential as a holistic, theory-based indicator for ecosystem management. Specifically, it: 1) is quantitative, 2) is flexible to taxonomic and taxonomy-agnostic approaches, and 3) encapsulates a wealth of information on ecological processes, such as individual metabolism, predator–prey interactions, and trophic energy transfer efficiency. Given that the collection and analysis of body size is a common measurement in many management and monitoring programs, there is a potential opportunity to integrate CSS into current management practices. We discuss possible hurdles to broader use of CSS, opportunities to overcome these hurdles, and invite discussions to further the development of holistic indicators for use in fisheries and ecosystem management.

Size spectra & related @ AFS 2025

- Xu, Y. "*Interannual variation of fisheries communities based on size spectrum analysis*" Mon. Aug. 11 @ 4:30. Rivercenter Conf Rm. 11
- Mruzek, J. et al. "*Why invasive carp seem to violate the energy-equivalence rule*" Wed. Aug. 13 @ 8:00. Rivercenter Conf Rm. 14
- McDunn, C. et al. "*Examining Fish Community Size Spectra as an Indicator of Invasive Carp Removal*" Wed. Aug. 13 @ 10:15. Rivercenter Conf Rm. 14

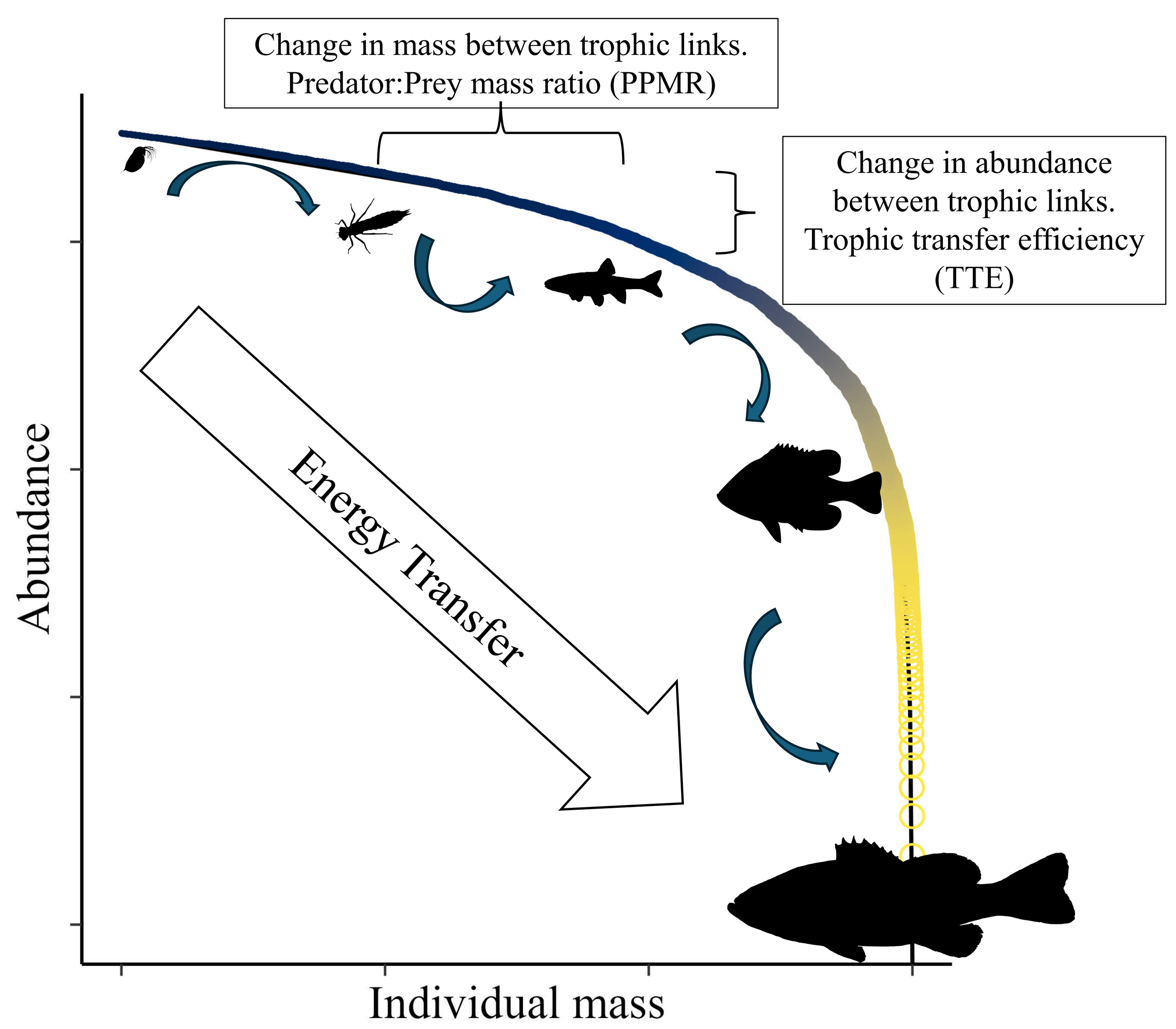
Supporting Theory

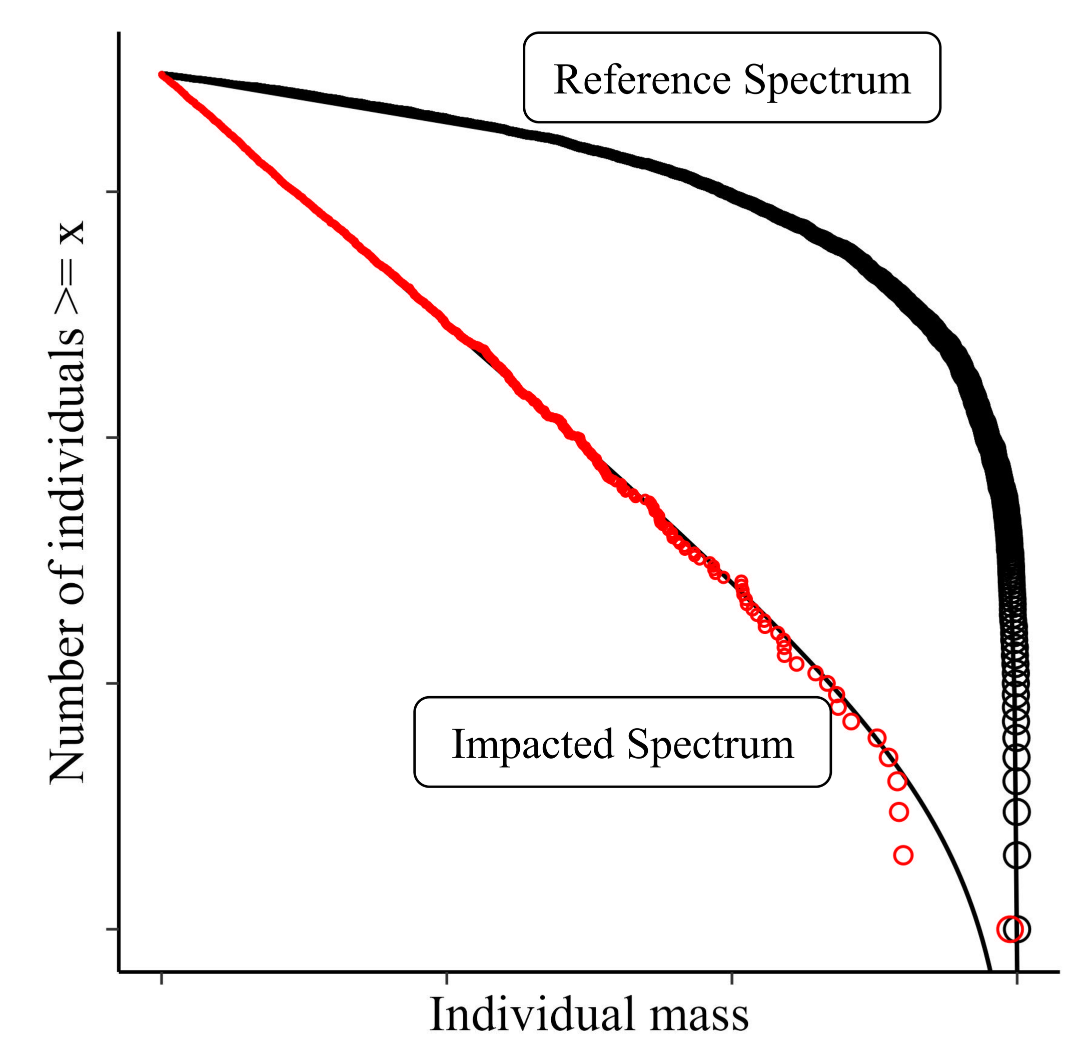
General Summary:
- The decline of abundance (N) with mass (M) is one of the most consistent patterns in ecology
- Described by a power law as: $N \sim M^{\lambda}$
- The scaling exponent, λ, describes the relative rarity of small to large individuals
- "Small" changes in λ represent large differences
  - Probability of sampling 10g individual is 0.5% when λ = -1.6
  - This decreases to 0.01% when λ = -2.1, a 50-fold difference
- λ represents a measure of ecosystem trophic transfer efficiency (TTE)
  - Smaller λ represents 'Steeper' ISDs and reduced ecosystem TTE

Quantitative theory:
- λ is predicted to be a function of 1) metabolic scaling (M^{α}), trophic transfer efficiency (TTE), and Predator:Prey mass ratio ($PPMR$) as:

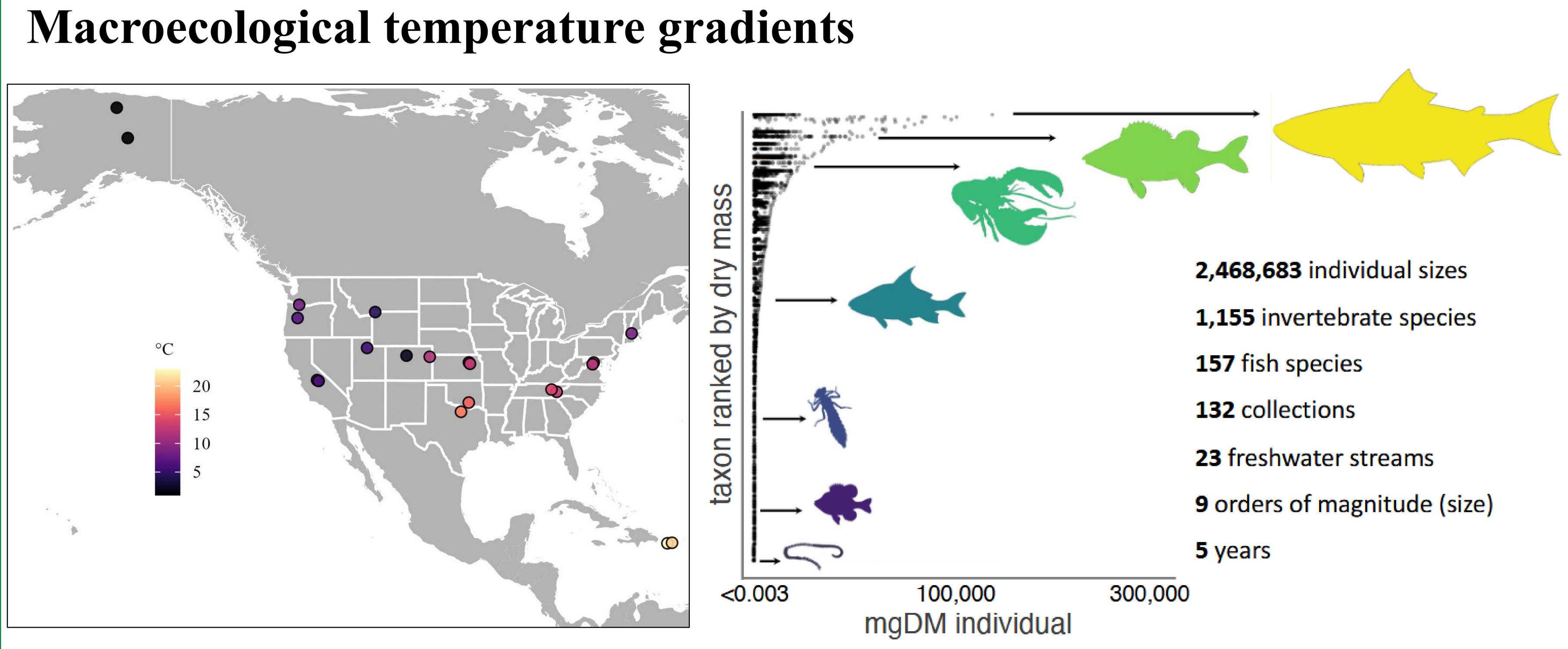
$$\lambda = \frac{\log(TTE)}{\log(PPMR)} - \alpha + \varepsilon$$

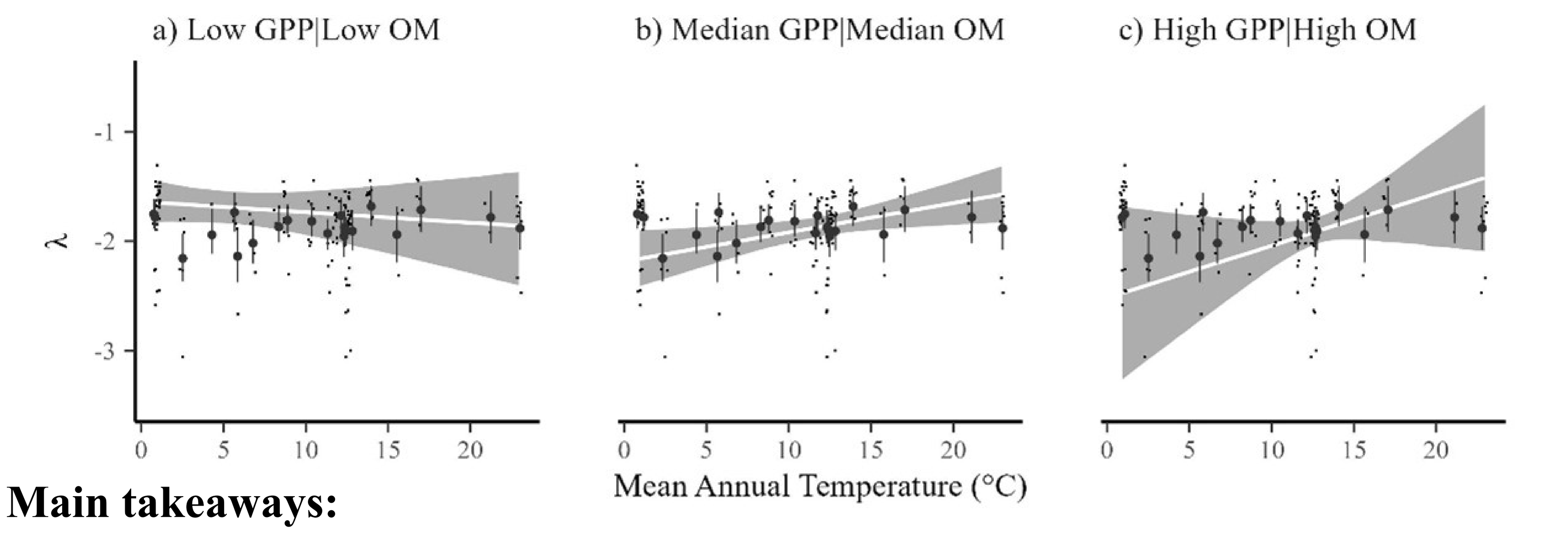
- Additional 'error', ε, can be a function of external subsidies
- Under common values of α, TTE, and PPMR, λ ≈ -2
- This provides a quantitative reference state to compare ecosystem change to perturbations:
  - Fishing regulations
  - Invasive species
  - Eutrophication





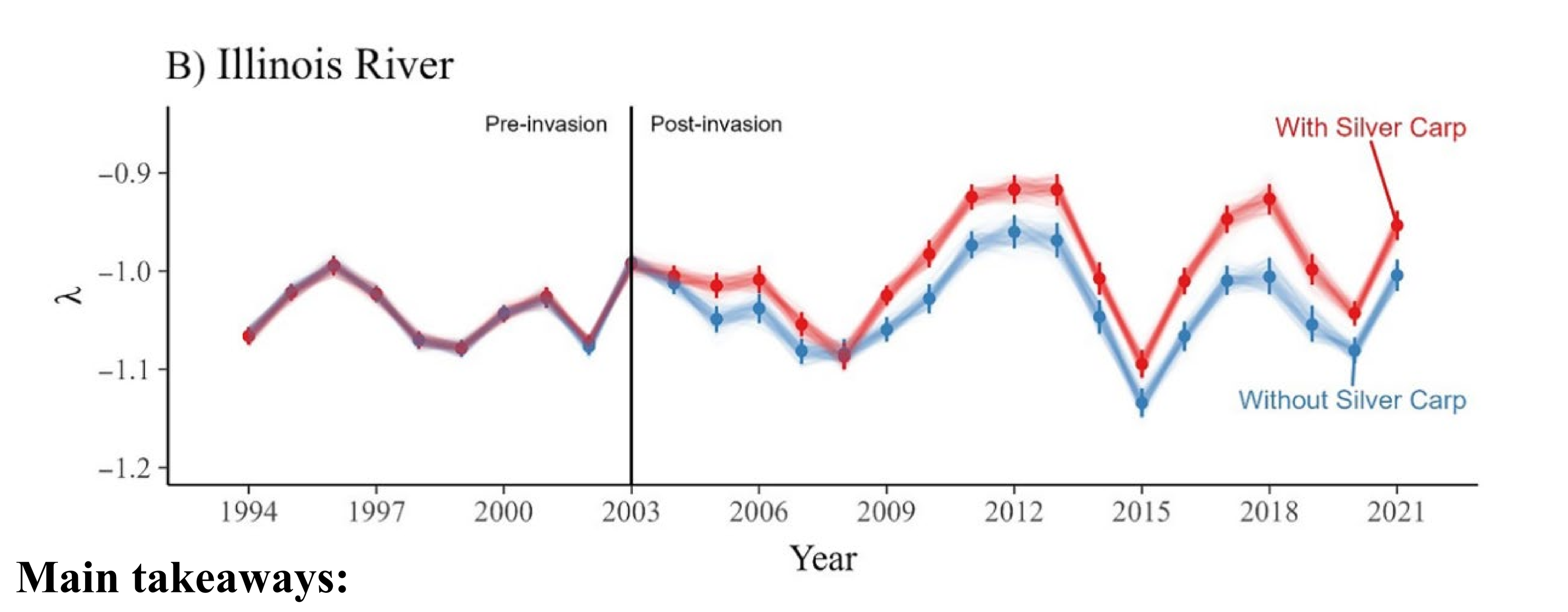
Macroecological temperature gradients



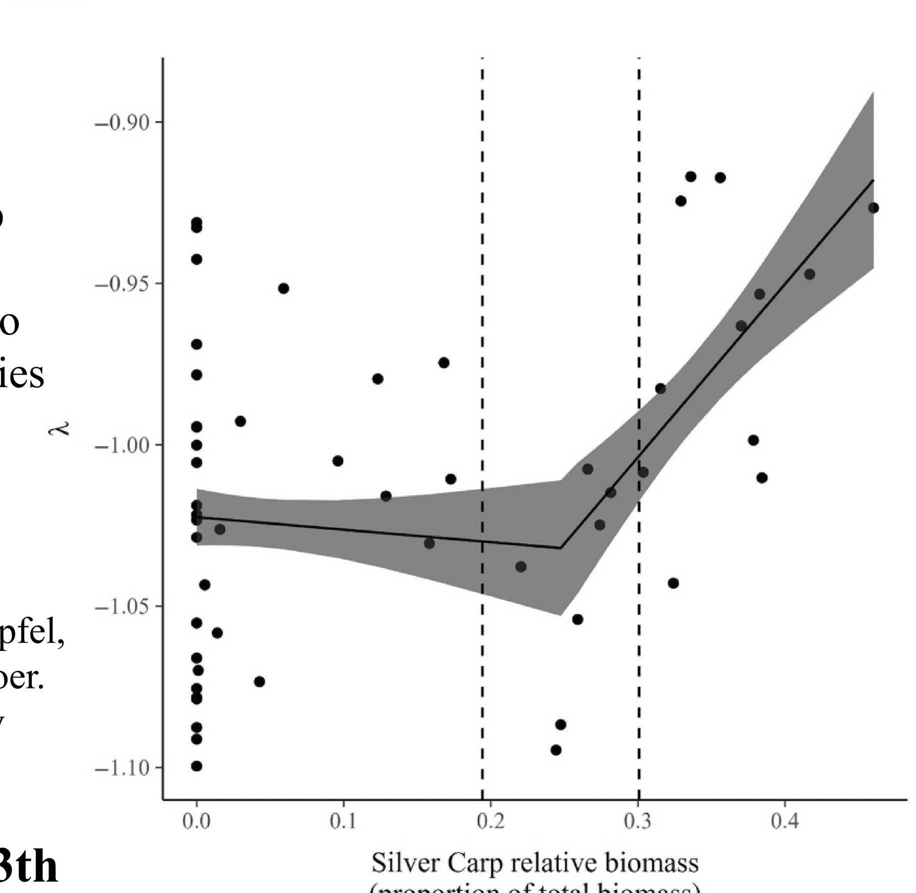


Main takeaways:
- Size spectra vary across streams from Puerto Rico to Alaska: stream medians range -2.1 to -1.6
- ISDs highlight interactions between temperature and basal resources availability across macroecological gradients
- Temperature has neutral to negative effects at low resource availability, but its effects become positive at higher resource availability
- Warming is predicted to have divergent effects dependent on resource availability

Invasive species monitoring



Main takeaways:
- Size spectra respond to Carp invasion
- Large body, low trophic position Carp cause 'shallowing' of ISDs
- ISDs show threshold response to Silver Carp relative biomass
- Potential indicator to guide removal targets to minimize ecosystem effects of invasive species



Read the full paper:

Novak, B., B. A. Murry, J. S. Wesner, V. Gjoni, C. C. Arantes, E. Shepta, J. P. F. Pomeranz, J. R. Junker, K. Zipfel, A. Stump, L. E. Solomon, K. A. Maxson, and J. A. DeBoer. 2024. Threshold responses of freshwater fish community size spectra to invasive species. Ecosphere 15:e70090.

And see related talks on Wed. August 13th

Interested in the patterns and drivers of size spectra in streams?

We are recruiting for postdoctoral scholar and PhD student positions on an NSF-funded project to understand the physiological and food web mechanisms of size spectra change across macroecological gradients at the University of South Dakota and the University of North Texas.

Postdoc: contact jeff.wesner@usd.edu
PhD: contact james.junker@unt.edu

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Size spectra offer potential as an integrative, holistic metric of ecosystem status and change

Advantages:
- Taxonomically agnostic (w/ complimentary species-level approaches)
- Integrates many difficult to measure ecological processes
- Quantitative with strong theoretical backing
- Requires single, easily measured variable—body size
- More realistic representation of feeding relations
  - Individuals interact, not species *per se*

Limitations:
- Integrating across different sampling gears requires care
- More integration with species-based approaches needed
- Power law exponents can be difficult to estimate
  - Recent advances in open-source tools
    - Bayesian, multilevel inference: *isdbayes* (https://github.com/jswesner/isdbayes)
    - Multi-method toolkit: *sizeSpectra* (https://github.com/andrew-edwards/sizeSpectra)

More information and resources