# Equation setup

* : time. At the moment I’m just using and in a before-and-after setup, but I think you should be able to extend this to time *series*.
* , : Total energy at ,
* , : Total number of individuals at ,
* : Average energy at , ;
* : Change in total energy as the ratio
* : Change in total individuals as
* : Change in average energy as . Tells us how the size spectrum is shifting.

# Hypotheses/concepts this addresses

* Is *N* a proxy for *E*?
  + Only robust if niche structure can be assumed fixed.
* Do we detect a general increasing or decreasing trend in *E* for N. American bird communities? Contrast with findings based on only *N*; Dornelas/Gotelli lit
* What qualitative dynamics *do* we detect
  + Size-biased declines accompanied by overall declines in function/productivity: There’s a perception that we’re losing the larger-bodied species and, I think, an accompanying intuition that this means overall function/productivity must be declining. But! We haven’t really evaluated:
    - if small species can or are increasing to compensate. They might if the losses are a) driven by a shift but not overall reduction in resource availability or b) not necessarily tied to resource availability, but free up resources the small species can access. They might not, if a) declines come from the *loss* of the resources the large species are using or b) the resources remain, but the small species can’t use them (as in the case of, say, hunting out the megafauna or trapping out the krats).
    - The magnitude of abundance/E declines due to loss of large individuals relative to the total community. It’s possible that we lose a few very noticeable individuals, but because they started out rare, this doesn’t make a big impact on either total abundance or total E. This isn’t to say that those losses aren’t important, just that their importance shows up on different axes.
  + Community-level regulation of state variables.
    - Species might all be stable
    - Or, fluctuations in population-level abundances cancel each other out
      * Just abundances: If the cancelling-out happens without regard to size, we might see static N but changing E. If, for example, a small species loses a bunch of individuals but a large species happens to gain them, E will increase.
      * Size-structured regulation: Cancelling-out happens *within size classes*. This is the only way you get fluctuations in **species** but no accompanying shifts in either N or E. That is, if DM loses individuals, DO - *and not PP or DS* – gains those individuals.
  + *E* and *N* trade off; zero-sum
    - There are random or directed shifts in species/size composition, but *E* remains fixed and *N* therefore varies predictably/constrained-ly
  + Levees/locks
    - The size structure is stable despite changes in the overall community size. Like systems of locks raising and lowering boats without changing their arrangement.
  + Niche shifts coupled with overall expansions + declines
    - The least regulated scenario, of which the size-biased declines is a specific manifestation. The community is just very dynamic
    - If I had to guess, I would say that population-level unbounded random walks would get you here most often. Even if they tend to cancel out for *N*, they seem unlikely to also cancel out for *E.* In which case the size structure is likely to change resulting in a change in total *E*. I’m not 100% on this intuition, though.

# Some very general interpretations

* E and N coupled: trade-offs (shifting niche structure) 🡪 compensation
* E and N coupled: levees (stable niche structure) or a reflecting pool (which can be zero change, or size-structured regulation of population change)
* E and N decoupled: expansion or contraction coinciding with shifting niche structure

Note that none of these interpretations can be uniquely identified with the *N* trajectory alone!!!

# Some notes

* We can interpret changes in *E* as either a change in resource availability (or even more broadly, niche space – think of predator escape, etc etc) or as a kind of emergent outcome of how well the available species are exploiting the available niche space. I tend to default to talking about it in terms of resource availability, but that’s imprecise and might be seeding some unfounded intuition.
* In all cases, “stable” really means *either* no change or change cancelling out to the same mean. In the case of *e*, I think it *extremely difficult* to get no change in the mean but have change in the size structure (because metabolism does not scale linearly with size)
* I am *very interested* in which of these patterns seem more likely to emerge from random walks
* Need also to be nuanced around the difference between *affirmatively detecting “stability”* and *not detecting change*

# Approach

1. Establish null models/baselines from simulated communities
   1. It’s not immediately obvious which of these outcomes would be most likely to emerge from different flavors of random fluctuations combined with issues of small n and the breadth of the size spectrum.
      1. Random fluctuations – most versions of random walk must be some form of constrained.
         1. All species random walk in *n* without regard to size or *e*. Intuition: On average no change in *N* but drift in *E* and *e*. Counterpoint: A realistic SAD means dominant signal will be from few, very abundant, species. In which case, apparent shifts tracking whatever happens to dominant species?
         2. Size structured random walks: Similarly-sized species fluctuate in abundance relative to each other, but relative abundance across *size classes* remains fixed. Would lead to static *E* and *N*, but I suspect very hard to achieve.
         3. Trends: All species have the same trend regardless of size. Guess: locks + amplification/decline?
      2. Small n: Intuition based on what we expect to happen based on infinity time series doesn’t apply. Even for a community with many species, only a few of them are likely to be highly abundant and thus dominate the signal.
      3. Width of size spectrum: A narrow size spectrum, or a lot of similarly-sized species, will make it tough (or impossible) for some patterns to emerge.
   2. Run simulations with realistic/relevant toy communities under different sets of random walks and constraints
      1. Define a **few** sets of initial conditions broadly matching the parameters (S, N, size pool, size/abundance relationships if applicable) found in BBS
      2. Randomization scenarios:
         1. True random walks
         2. Size-agnostic trends
         3. Size-biased trends
         4. Very little change
         5. Highly-contrived regulation
      3. Sort simulations into outcomes
         1. Which scenarios lead to which outcomes?
         2. To what extent can we distinguish between scenarios?
         3. How is this modulated by community characteristics (*S*, *N*, *E*, width of size spectrum)?
2. Generate timeseries size data based on BBS following Thibault et al 2011
3. Evaluate BBS outcomes relative to null models
   1. Rerun simulations tailored to initial conditions for each BBS community
   2. Sort BBS outcomes and compare to simulations
4. Based on the outcomes, follow-up analyses can collect additional lines of evidence for explanation in biological terms
   1. Amplification/declines: NDVI
   2. Niche shifts: land-use change, …
   3. Locks: distinguish stability all-the-way-down from size-structured fluctuations

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| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| *dE* | *de* | *dN* <1 | | *dN* = 1 | | *dN* >1 | | Dominant signal | | Interpretation |
| *dE* <1 | *de* <1 | Large species **must** decline  **If** small species decline, they must decline proportionately less than large species. They may increase or remain the same | | Large species **must** decline Small species **must** increase, but not to complete energetic compensation. | | Large species **must** decline  Small species **must** increase, but not to complete energetic compensation. | | Overall community declines, the weight of which falls on large species.  Possible loss of niche space used by large species, but not (fully) accessible to small species. | | Shift + decline  *Size-biased downgrading* |
| *de* = 1 | *SS overlap: high* | Community declines without changing structurally. |  | |  | | Overall community declines uniform across sizes | | Locks + decline |
| *SS overlap: low* | Size spectrum shifts balanced above/below mean *e* | Overall community declines and SS redistributes with change offset above/below mean *e* | | **Balanced** shift + decline. A special case of trade-offs? |
| *de* >1 | Small species **must** decline  **If** large species decline, they must decline proportionately less than small species. They may increase or remain the same | |  | |  | | Overall community declines, the weight of which falls on small species. | | Shift + decline |
| *dE* = 1 | *de* <1 |  | |  | | Large species decline and small species increase to complete compensation. | | Capacity/activity remains the same *amount* but changes *form* such that it is more accessible to small species. | | Shift + fixed; trade-offs  *Portal* |
| *de* = 1 |  | | *SS overlap: high* | Entire community is stable. |  | | *SS overlap: high* | Change in capacity or species orthogonal to size. | Locks + fixed. Any population fluctuations are regulated *within* the size structure. |
| *SS overlap: low* | Balanced shift | *SS overlap: low* | SS rearranges within tight constraints | Balanced shift. A special case of trade-offs? |
| *de* >1 | Small species decline and large species increase to complete compensation. | |  | |  | | Capacity/activity remains the same *amount* but changes *form* such that it is more accessible to large species. | | Shift + fixed; trade-offs |
| *dE* >1 | *de* <1 |  | |  | | Small species **must** increase  **If** large species increase, must increase proportionally less than small species. They may decline or remain the same. | | Community gain, favoring small species.  Possible increase in resources available only to small species. | | Shift + expansion |
| *de* = 1 |  | |  | | *SS overlap: high* | Community amplifies without changing structurally. | Overall community increase, no size bias. | | Locks + expansion |
| *SS overlap: low* | Balanced shift | Overall community increases and SS redistributes with change offset above/below mean *e* | | **Balanced** shift + increase. A special case of trade-offs? |
| *de* >1 | Small species **must** decline  Large species **must** increase. The size difference must be large enough for the large species to **over**compensate in *E* without compensating in *N*. | | Small species **must** decline  Large species **must** increase. The size difference must be large enough for the large species to **over**compensate in *E* and only match, not increase, *N*. | | Large species **must** increase  **If** small species increase, must increase proportionally less than large species. They may decrease or remain the same. | | Community gain, favoring large species. | | Shift + expansion |
| *E* advantage shift | To small |  | | In all of these cases, *N* Is on average not changing. But, we see very different energy dynamics & consistent processes! | |  | |  | |  |
| No shift |  | |  |
| To large |  | |  |