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Carbon-use efficiency across scales: are there general patterns from individual organisms to communities and ecosystems?

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Carbon (C) cycling is driven by biological activity, which controls both C fixation (autotrophs) and mineralization (heterotrophs). While each biological component 'uses' C in different ways, all organisms convert C into new biomass and release C via respiration and other C loss pathways. Organic C retained into biomass (e.g., microbial biomass) has a chance of being stored in the ecosystem if it is not consumed by other organisms, possibly feeding slow-cycling pools that sequester C in the long-term. C-use efficiencies (CUE) can be used as indices to assess how much C is retained as biomass (at the scale of individual organisms or communities) or stored (at the ecosystem scale) vs. released as mineralized products or in organic form. CUE is typically defined at the organism scale as the ratio of C used for growth over C taken up. This organism-level definition can be applied to both heterotrophs and autotrophs, and can be extended to microbial, animal, and plant communities. Analogous definitions of CUE have also been developed for whole ecosystems (=net ecosystem exchange over gross primary productivity), and for soil and sediment systems to quantify C storage capacity (=net C accumulation rate over C input rate). Here we synthesize current definitions and conceptual understanding of CUE across this wide range of scales. As a first step, confounding factors that are likely to generate 'apparent' patterns in CUE (e.g., cell turnover) are assessed with specific examples. As a second step, trends in CUE are evaluated as the scale is increased from organisms to ecosystems, considering autotrophs and heterotrophs, and comparing aquatic and terrestrial systems. In general, CUE decreases as the spatial and temporal scale of interest is increased, because of higher contributions of heterotrophic activity and C recycling. Based on these results, CUE emerges as a highly flexible quantity that should be interpreted with caution as it does not elucidate specific C cycling mechanisms. However, CUE can be used as a useful index to compare how C is partitioned between storage (in biomass or in long-term pools) and release among systems at the same scale.