Including ecosystem properties and services into your web site: Comments and recommendations by Bill Shipley, 2nd version

The first thing to remember is that the quantitative prediction of almost all ecosystem properties, and many ecosystem services, will require site level information on both traits and environmental conditions. Trait information alone is not sufficient. For example, net primary productivity (the amount of new plant biomass that is produced per unit area and per unit time) at a given site is clearly affected by which plant species that you plant but, at the global scale and based on the natural vegetation of sites, NPP is quite well predicted by a purely abiotic variable: potential evapotranspiration (which is an interactive function of temperature and precipitation). I doubt if the addition of traits would improve the r2 at this global level, but it should improve site-level accuracy.

If you want to provide quantitative predictions

Such prediction equations will be of the form Y~f(traits)+f(climate) + … (depending on the ecosystem property/service)

If you want to provide quantitative predictions of such ecosystem properties, including some measure of precision, then you will need information that includes, for each site, (1) a measurement of the ecosystem variable, (2) its geolocation (to get information on climate), (3) the relative abundance of each species and (4) the traits of these species. You already have #4 (TRY). There also exist public data bases giving abundances of each species (#3) for many sites. Here are the main ones.

sPlot/sPlotOpen:

A global repository of vegetation-plot data (lists of species in plots with abundance / cover)

VegBank: www.vegbank.org

Vegetation plot archive (especially U.S., but accepts global data). Contains plot records, species abundances, cover, etc.

LOTVS: www.lotvs.csis.es

Long-term vegetation time series, many plots, with species abundance data

Global Index of Vegetation-Plot Databases (GIVD) is not a dataset of species abundances per se but a meta-database giving information about many vegetation-plot data sources worldwide (so you can discover more databases: www.givd.info/

EVA (European Vegetation Archive) (as part of ReSurveyEurope / broader European vegetation data) is also a key data resource for European relevés

I do not have any experience in using these public data bases. I assume that the plots in these data bases are georeferenced, but I do not know for sure. After you combine these vegetation data bases with TRY, you can obtain the community-weighted means of the traits. Given the georeferences, you will be able to get some basic climatic information. I cannot say how difficult or easy it will be to combine these data sets together.

The main difficulty is in getting information on ecosystem properties or services #1. For instance, asking ChatGPT to "give me the names, and web addresses, of publicly available data bases that give the net primary productivity of local sites. Net primary productivity will be measured as physical scales of a few square meters to a few hectares" does produce a list of 6 data sets that cover many parts of the world. However, to be useful, the sites in these 6 data sets must also exist in the vegetation data bases (i.e. #3) and at approximately the same time of collection (since species composition and abundance can change over time at the same site). I doubt that this is the case, but I don't know. If true, then you can't produce quantitative predictions of NPP.

Unfortunately, net primary productivity is probably the best measured ecosystem property. Data sets for other ecosystem properties and services are much rarer and much smaller.

In my opinion, it would be a major task, and maybe impossible, to produce quantitative prediction equations linking net primary productivity to plant traits + climate. This opinion is even stronger for other ecosystem processes and services.

If you want to provide qualitative predictions

The use of CSR scores (which you already have) can produce scientifically supported qualitative predictions of several ecosystem properties. The next section of this document gives the justification for the listed ecosystem properties and my personal evaluation of my confidence in the generality of these qualitative predictions.

Net primary production of plant biomass (NPP)

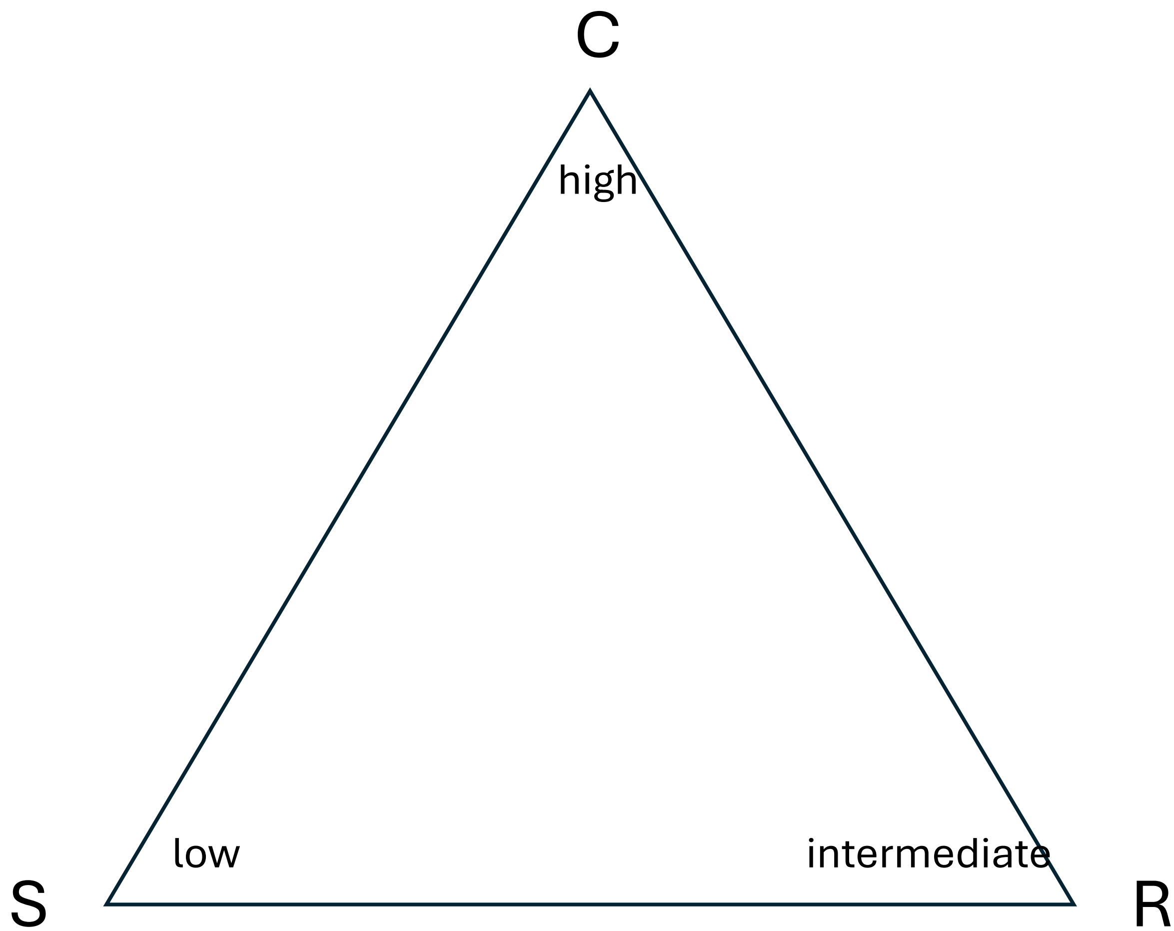
NPP is a measure of the amount of new living plant biomass per unit of space produced per unit of time. Often, this is measured per square metre of ground area with units of $g/m^2/t$ (or hectares for forests). Total NPP is very difficult to measure because it includes the production of roots, and most researchers only measure aboveground ANPP, with the reasonable assumption that there is an allometric link between aboveground and belowground plant growth. In practice, ANPP is usually measured as the difference between the amount of aboveground living biomass at the start of the growing season and the amount of aboveground living biomass at the maximum before any senescence begins. NPP (or ANPP) is then expressed as the product of the amount of living biomass at the beginning of the growing season and the growth efficiency of this biomass, which is the ecosystem equivalent of the relative growth rate of a single plant (g/g/t), which is exactly equivalent to a compound interest rate. See (Garnier and Navas 2013) Chapter 6. The English version of this book is (Garnier et al. 2016). Equation 6.2 of (Garnier and Navas 2013) presents the mathematical link between specific net primary productivity (i.e. NPP standardised to the amount of living biomass at the start of measurement and community-weighted relative growth rate (RGR).

We know that potential RGR (i.e. RGR of a plant growing alone in optimal conditions) is strongly correlated with a suite of traits in the Worldwide Leaf Economic spectrum. For instance, high RGR is positively correlated with high SLA, low LDMC, high leaf nitrogen content, low wood density (in trees), thin leaves, leaves with less lignin etc. Chapter 6 reviews these points and presents the empirical evidence linking these traits to ecosystem productivity. (Vile et al. 2006) provides strong empirical evidence linking NPP in grasslands and community-weighted maximum RGR.

The CSR axis going from stress tolerators (S) at one extreme to competitors (C) and ruderals (R) at the other extreme is defined almost entirely by the traits linked to NPP. The community-weighted versions of these traits, and the link to the position of vegetation along this axis, are therefore, in my scientific opinion, very well supported. As an historical aside, the first CSR ordination of Grime actually used maximum relative growth rate of a species as the variable used to quantity the S to (C,R) axis of the CSR triangle. It was the strong correlation between RGR_{max} and the more easily measured traits that allowed researchers to replace RGR_{max} with these traits, resulting eventually in the simplest CSR method of Piece et al. (Pierce et al. 2017).

The difference between the C and R end of the CSR triangle, in terms of NPP, is that communities at the C end do not experience large amounts of density-independent death of plants (i.e. disturbances like fire, flood or human activities that remove plants). They therefore have both large amounts of living biomass at the start of the growing season and high specific net primary productivity, and this further increases NPP. Communities at the R extreme, while having high specific net primary productivity, are constantly loosing biomass from disturbances, and so their NPP is lower.

Here is how NPP varies along the CSR triangle.

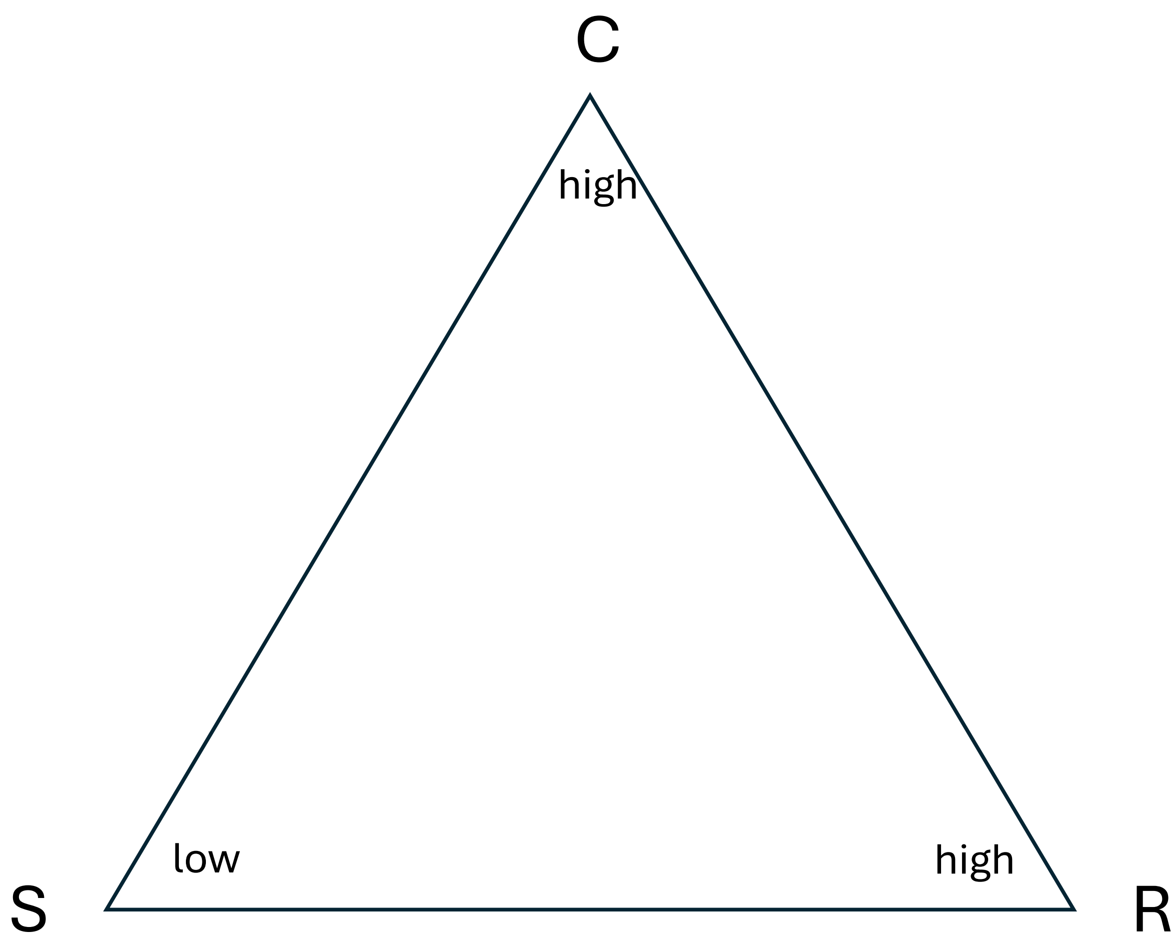


Net primary productivity

Decomposition rate of dead plant biomass

The production of living plant biomass (NPP) results in atmospheric CO_2 being removed from the air and in soil nutrients being removed from the soil. Living plant biomass represents a pool of stored carbon and nutrients. Eventually, plant tissues die; this dead plant material is usually called "litter" in the ecological literature. This litter decomposes at different rates. As decomposition progresses, the stored CO_2 is returned to the atmosphere via respiration of decomposing organisms and the stored nutrients return to the soil and decomposer organisms. At large geographic scales, climate (temperature and precipitation) are important, but at local scales decomposition rates depend mostly on the physical and chemical properties of the dead plant material as well as some physical soil properties (soil pH, local soil moisture content and soil aeration).

There is a large literature of leaf and wood properties that affect the decomposition rate of litter. Leaves with a low leaf dry matter content (LDMC), high SLA, a high concentration of remaining nitrogen, and with lower concentrations of lignin have higher decomposition rates. Many empirical studies have documented this trend and chapter 6 of (Garnier and Navas 2013) reviews and documents these trends. Notice that these traits are the same ones related to NPP, but in the opposite direction: traits that increase NPP also increase litter decomposition rate and thus the rate at which carbon and nutrients are cycled from the environment, into the living plants, and out again into the environment. In my scientific opinion, the following qualitative predictions are sound.



Litter decomposition rate

Carbon storage away from the atmosphere

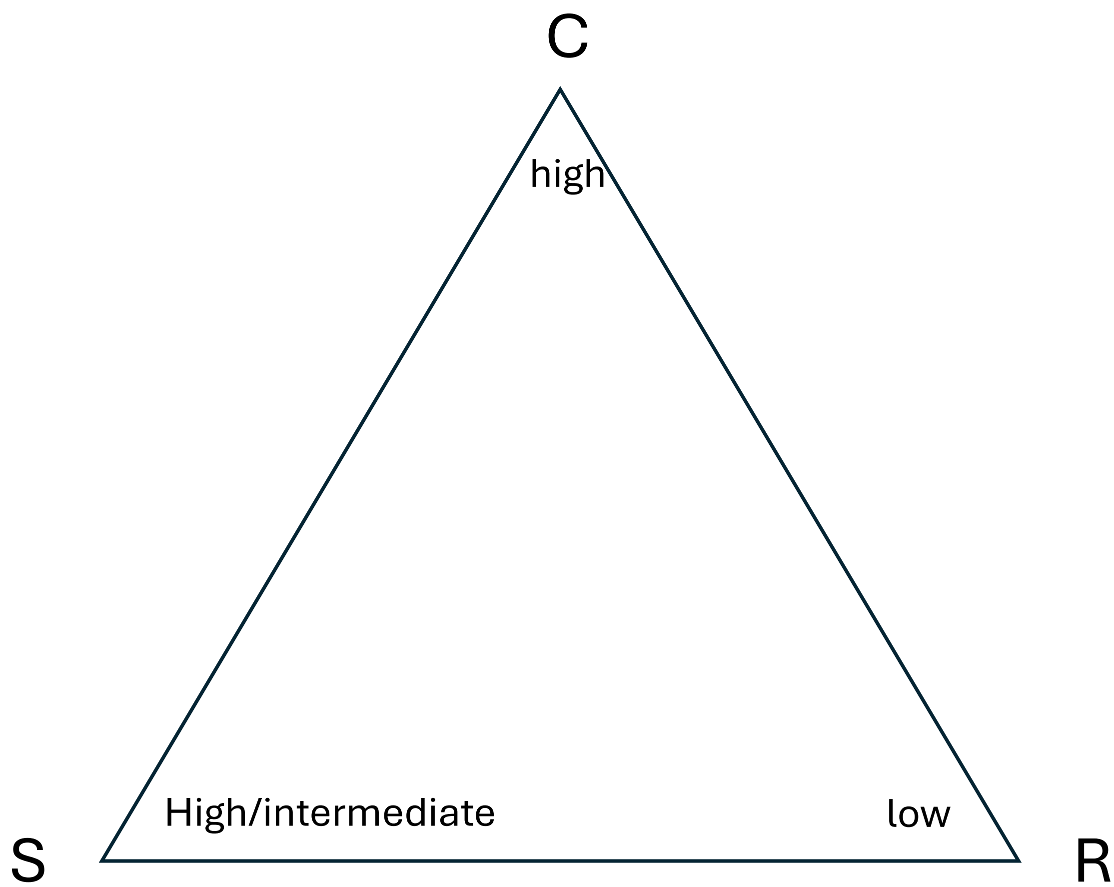
The amount of carbon stored in either living plant material or in decomposing plant litter is simply the difference between the capture of atmospheric CO_2 vis NPP and its release via litter decomposition. Recalcitrant soil carbon (i.e. organic carbon that is stable and does not decompose for long periods of time) is somewhat more complicated because it is affected by physical soil properties (pH, soil aggregation and structure), and it is also determined by chemical litter properties like lignin and tannin content (which are correlated with LDMC).

Combining the triangles for NPP (removal of CO_2 from the atmosphere) and for decomposition (return of CO_2 to the atmosphere), we can make the following qualitative prediction. My confidence in this prediction is only slightly lower than for the first two, simply because the question of long-term sequestration via recalcitrant carbon is less-well understood, and the relationship of plant traits and such recalcitrant carbon is less-well studied.

The S end: CO_2 is only slowly captured via NPP, but the plant tissues are long-lived, the eventual slow production of litter decomposes slowly. The actual amount of carbon stored in the living and dead plant material be high.

The C-end: CO_2 is rapidly captured via NPP (both due to high growth efficiency and a large standing biomass), the plant tissues are relatively short lived (except of tree trunks) but living biomass is not rapidly destroyed by density-independent events (i.e. low disturbance rates). The large amount of litter produced decomposes rapidly. The actual amount of carbon stored in the living and dead plant material be high.

The R-end: CO_2 is rapidly captured (due to high growth efficiency) but less than at the C-end because there is only a small standing biomass due to frequent and intense density-independent death due to disturbances. The plant tissues are relatively short lived (little or no wood production) The litter produced decomposes rapidly. The actual amount of carbon stored in the living and dead plant material be low.

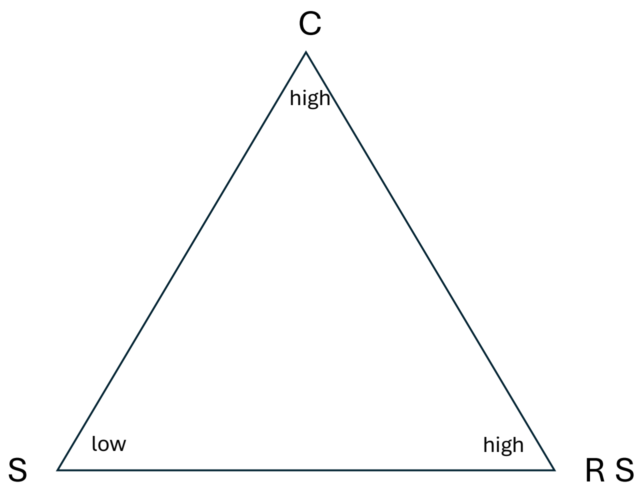


Atmospheric CO_2 removal and storage

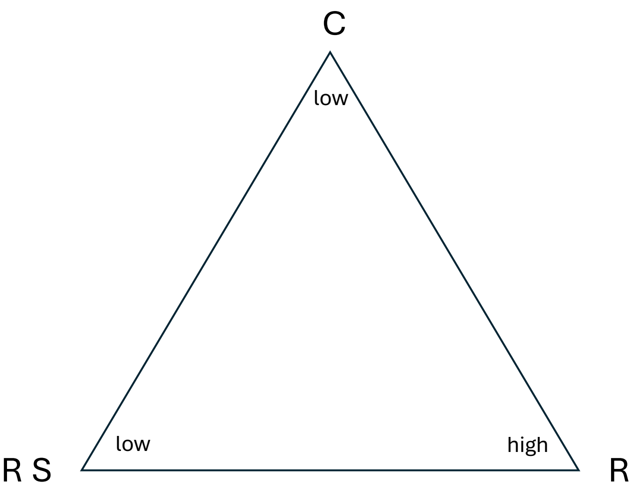
Nutrient cycling and nutrient loss

Nutrient cycling refers to the amount of nutrients that pass from one pool to another per unit time and space. The main pools (for the vegetation component) are : soils (including the soil decomposer community), living plant tissues and dead plant tissues. Nitrogen is especially important because the only inputs of new nitrogen into an ecosystem are via nitrate-fixation by Rhizobium bacteria (in symbiosis with legumes), nitrate fixation via Frankia (in symbiosis with some Alders etc.) as well as some nitrate deposition from nitrate oxide deposition (fossil fuels) and nitrate and ammonium additions in agriculture. Other soil nutrients can also be added via weathering of bedrock. Nutrient loss in a local geographical location occurs when the nutrients in any of these pools is lost to another geographical location, due to leaching or removal of biomass.

The more rapidly new plant biomass is produced, the more rapidly soil nutrients are removed from the soil and stored in the living biomass. The longer the living tissues persist, the longer these nutrients remain in this biomass pool. The more rapidly the living tissues die and become litter, and the more rapidly this litter is decomposed, the more rapidly the nutrients re-enter the soil pool. Therefore, combining what we know about NPP and decomposition, we can predict how nutrient cycling and loss will vary in the CSR triangle. My scientific confidence in these qualitative predictions is as strong as for NPP and decomposition. Note that the C end has high rates of nutrient cycling but low levels of nutrient loss. This is because the large standing biomass rapidly captures the released nutrients from decomposition. The R end has large rates of nutrient cycling but also large amounts of nutrient loss because the high levels of density-independent death (high disturbance rates) means that the rapidly released nutrients via decomposition cannot often be captured before the nutrients are leached away.



Nutrient cycling



Nutrient loss

Soil erosion

I consider that our understanding of how plant traits relate to prevention of soil erosion, and especially how this maps onto the CSR triangle, is ***lower*** that for the previous ecosystem properties. Obviously, prevention of soil erosion is dependent of a large standing biomass of plants, and on dense and deep roots. C-dominated plant communities will have the largest standing biomass, and so C-dominated communities should be best to reduce soil erosion. Clearly, erosion is strongly dependent on soil properties (especially soil texture (sand/silt/clay content) and on precipitation rates. My best guess (with only a moderate level of confidence) is that soil erosion will be low in C-dominated communities (because there is a large amount of plant biomass and densely growing plants), will be intermediate/low in S-dominated communities and will be low in R-dominated communities.

I could find very few research papers that specifically deal with this topic. I also asked ChatGPT to "*Please review what is known about the relationship between rates of soil erosion and the CSR strategy theory of Grime. Provide the most important references*" and very little of use was returned.

Garnier, E., and M. L. Navas. 2013. Diversité fonctionnelle des plantes. Traits des organismes, structure des communautés, propriétés des écosystèmes. de boeck.

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Vile, D., B. Shipley, and E. Garnier. 2006. Ecosystem productivity can be predicted from potential relative growth rate and species abundance. Ecology Letters **9**:1061-1067.