Definitions Of Some Ecological Terms Commonly Used In Carbon Accounting

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Introduction

The papers in these Workshop Proceedings all deal with Net Ecosystem Carbon Exchange. In the interest of clarity, this and other related terms are briefly described in the following.

AUTOTROPHIC RESPIRATION

Plants fix carbon by photosynthesis. The word "photosynthesis" is here used to denote the carbon fixed by gross photosynthesis *minus* the carbon lost by photorespiration. Some of that photosynthetically fixed carbon is lost by internal plant metabolism. This loss is termed autotrophic respiration and typically amounts to about half the carbon fixed by plants.

Figure 1: Diagrammatic representation of the main terms describing carbon fluxes in ecosystems.
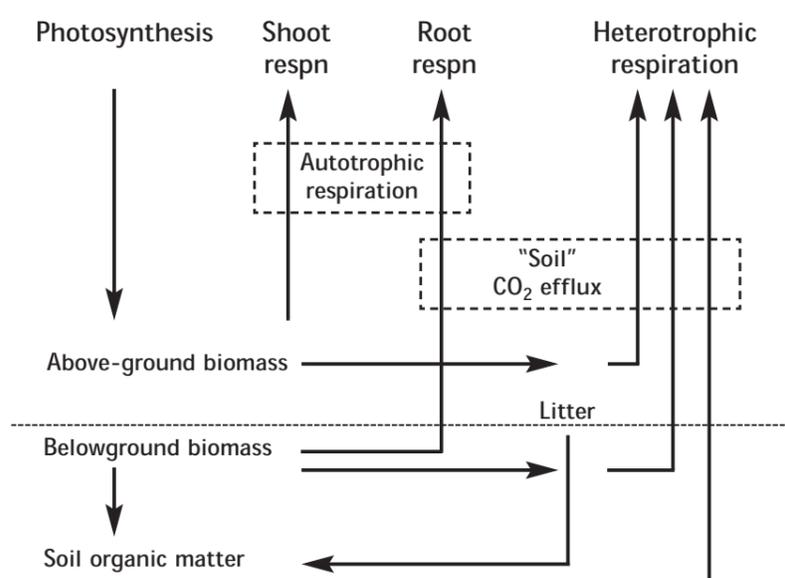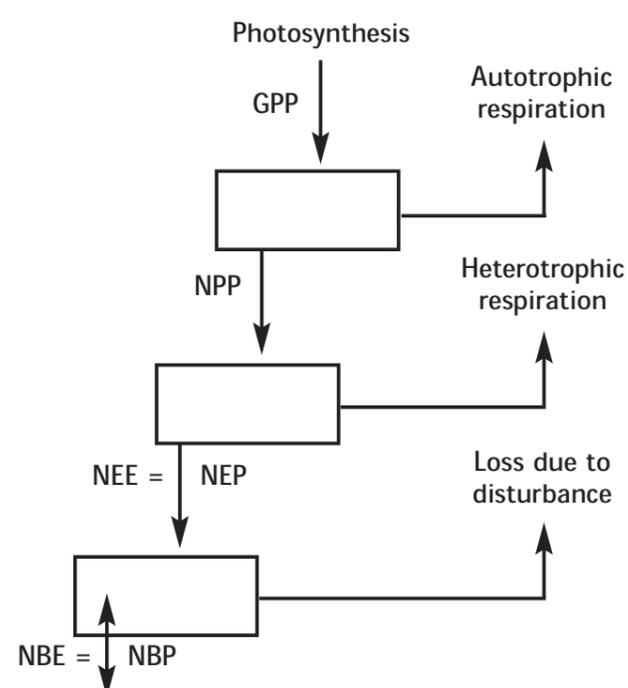

HETEROTROPHIC RESPIRATION

Heterotrophic respiration refers to the carbon lost by organisms in ecosystems other than the plants, the primary producers, themselves. It constitutes the respiration by animals that live above-ground, which tends to be a minor component and is not represented in Figure 1, but most importantly, by all those organisms (flora and fauna) that live in the soil and the litter layer and decompose organic matter that has reached the soil by litter fall, root turn-over, root exudation, dead organisms and faecal matter. It also includes the carbon release in the decomposition of standing dead trees and coarse woody debris.

Figure 2: Diagrammatic representation of the main terms describing system carbon balances. Arrows indicate that GPP and NPP are always positive (carbon gains by the system), NEE is usually, but not always, positive, and NBE can be positive or negative.

SOIL CO$_2$ EFFLUX

Soil CO$_2$ efflux is comprised of autotrophic respiration from plant roots and heterotrophic respiration from soil organisms. It may also include respiration from the litter layer on top of the mineral soil as defined in individual studies.

Total soil CO$_2$ efflux is often also referred to as soil respiration, whereas other researchers refer to soil respiration as only the CO$_2$ efflux originating from heterotrophic respiration in the soil and use it as distinct from the autotrophic respiration originating from plant roots.

GROSS PRIMARY PRODUCTION

Gross primary production (GPP) refers to the total amount of carbon fixed in the process of photosynthesis by plants in an ecosystem. A forest or grassland, for example, may fix 20 tC ha^{-1} yr^{-1} during the process of photosynthesis.

Total global GPP is estimated to be about 120 GtC yr^{-1} (Gifford 1982; Bolin *et al.* 2000), and total Australian GPP can be estimated to be 2-6 GtC yr^{-1} if one assumes that GPP is 2 times NPP and uses the estimates of NPP compiled below.

NET PRIMARY PRODUCTION

Net primary production (NPP) refers to the net production of organic carbon by plants in an ecosystem usually measured over a period of a year or more. It is GPP minus the amount of carbon respired by plants themselves in autotrophic respiration, R_a:

$$NPP = GPP - R_a \qquad (1)$$

It constitutes the total annual growth increment (both above and below ground) plus the amounts grown and shed in senescence, reproduction or death of short-lived individuals in a stand plus the amounts consumed by herbivores. Only the amount of carbon produced and lost in the year for which NPP is being calculated is counted, not what was produced in an earlier year and lost in the current year. This distinction is sometimes difficult to make in practice.

In the example of a forest or grassland, it may amount to 10 tC ha^{-1} yr^{-1} with an equivalent amount of carbon lost in autotrophic respiration. NPP in any system must be positive over periods of years. Otherwise, the system would soon lose all of its carbon and cease to exist.

Total global NPP is estimated to be about 60 GtC yr^{-1} (Steffen *et al.* 1998). Estimates of NPP for Australia have recently been compiled by M.L. Roderick (unpublished). They range from about 1 GtC yr^{-1} (D.J. Barrett, unpublished), 1.6 GtC yr^{-1} (Kirschbaum 1999), 2.0 GtC yr^{-1} (Field *et al.* 1998; DeFries *et al.* 1999); 2.7 GtC yr^{-1} (Pittock and Nix 1986 - recalculated by M.L. Roderick based on the original method), 2.8 GtC yr^{-1} (Gifford *et al.* 1992) to 3.2 GtC yr^{-1} (Roderick *et al.* 2001).

NET ECOSYSTEM EXCHANGE OR NET ECOSYSTEM PRODUCTION

Net Ecosystem Exchange (NEE) and Net Ecosystem Production (NEP) refer to net primary production minus carbon losses in heterotrophic respiration, R_h:

$$NEE = NEP = NPP - R_h \qquad (2)$$

These terms are used somewhat interchangeably, with NEE used more often to refer to these fluxes when they are addressed from a measurement of gas exchange rates using atmospheric measurements over time scales of hours, whereas NEP is more often used to refer to the same processes if measurements are based on ecosystem-carbon stock changes, typically measured over a minimal period of one year. However, these differences in usage are not firmly embedded in formal definitions.

In the example of a typical forest, of the total NPP of 10 tC ha^{-1} yr^{-1}, 5 tC ha^{-1} yr^{-1} might be lost in annual turn-over of foliage, fine roots, reproductive structures and other constituents with short longevity, and a similar amount might accumulate in growing stems. When the standing stock of carbon in the litter pool is not changing over time, the input of dead litter must be balanced by an equivalent carbon loss from decomposing litter. The forest's NEE would then be 5 tC ha^{-1} yr^{-1}.

For the example of the grassland, NEE must be closer to zero as the bulk of annually produced biomass tends to turn-over and there are not generally any accumulating biomass pools. NEE can be positive, however, if soil carbon is building up, or negative if the system is degrading and soil carbon is lost.

Total global NEE is estimated to be about 10 GtC yr^{-1} (Steffen *et al.* 1998), but there is also a wide range of uncertainty and interannual variability around this estimate. Individual ecosystems may be in balance, or positive or negative. Most systems, however, have a positive NEE, with the gradual stock increment via NEE being balanced in the longer term by relatively sudden stock losses caused by disturbance. Disturbances may be regular, such as by annual crop harvest, or occasional and irregular as by episodic fire that may recur at the same place only every 100 years, or deforestation that may remove biomass without allowing regrowth.

NET BIOME EXCHANGE OR NET BIOME PRODUCTION

Net Biome Exchange (NBE) or Net Biome Production (NBP) refers to the change in carbon stocks after episodic carbon losses due to natural or anthropogenic disturbances have been taken into account:

$$NBE = NEE - L_d \text{ or} \qquad (3a)$$
$$NBP = NEP - L_d \qquad (3b)$$

where L_d is the loss by major episodic disturbances. Some systems are not typically affected by irregular disturbances. In those systems, NBE = NEE.

Net biome exchange is the appropriate measure of system carbon balances over longer time periods. In the forest example, the forest is likely to grow for some decades or centuries and accumulate carbon in each year (NBE = NEE > 0; L_d = 0).

Eventually, the carbon may be lost in a massive disturbance, such as a fire or harvesting. In the year, when that occurs, the loss due to disturbance will be much greater than the annual increment in carbon so that NBE << 0 in that year. Summed over a longer time period, NBE will be close to zero, with the many small positive annual increments balanced by the large loss in the year of disturbance (i.e. NBE = ΣNEE - L_d). In the grassland system, NEE $\cong$ NBE is more likely, although systems subject to fires recurring every few years could have a pattern similar to that of forest systems, but with smaller and more frequent peaks and troughs.

Globally, NBE (including the effects of deforestation) is estimated to have been 0.2 GtC yr^{-1} from 1980-1989 and 1.4 GtC yr^{-1} from 1989-1998 (IPCC 2001). This suggests that the overall global accrual of ecosystem carbon is not wholly annulled by the carbon loss due to major disturbances, including deforestation. Historically (before major human influence), the quantity must have been close to 0 and can only deviate significantly from 0 while systems are out of equilibrium.

Although NBE applies to long timescales, it need not necessarily have to apply to large spatial scales despite the implication by inclusion of the term 'biome'. NBE can be monitored at the plot level over long periods, which might include disturbance events. In other words, NBE can be applied as much to the plot level as at larger spatial scales.

There is no explicit definition that distinguishes episodic loss by major disturbance (L_d) from loss by heterotrophic respiration (R_h). Broadly speaking, organic-matter oxidising processes that occur all year every year in an ecosystem contribute to R_h, while processes that oxidise organic matter in only some years would be classed as carbon losses due to disturbances.

UNITS OF MEASUREMENT

All the exchange rates described here can be expressed in units of carbon amount per unit of area per unit of time, such as tC ha^{-1} yr^{-1}. Biochemically oriented studies often use molC m^{-2} yr^{-1}. However, these fluxes are often derived from other measurements taken for different purposes and for which different measurement units may be more appropriate. These units can, in principle, be easily inter-converted, but it can also be confusing if the unit of measurement is not clearly stated in individual studies, or if the numeric values change along with any conversion in units.

Table 1: Some different units for quantifying amounts of carbon and their interconversions.

1 Mg (megagram)	=	1,000 kg	=	1 t (tonne)
1 Gg (gigagram)	=	10^6 kg	=	1 kt
1 Tg (teragram)	=	10^9 kg	=	1 Mt
1 Pg (petagram)	=	10^{12} kg	=	1 Gt
1 kg m^{-2}	=	10 t ha^{-1}		
1 molC	=	12gC		
1 tC ha^{-1}	=	8.33 molC m^{-2}		
1 molC m^{-2}	=	120 kgC ha^{-1}		
1 molCO$_2$ m^{-2}	=	440 kgCO$_2$ ha^{-1}		

For example, most data on forest growth are given in units of wood volume increments: m^3 ha^{-1} yr^{-1}. To convert from wood volume to wood mass, the density of wood needs to be known, but that can vary widely between species between values of 0.5 to over 1 tDW m^{-3}. Other biomass measurements may similarly be taken in units of dry weight. Dry weight typically contains about 45-50% carbon, and as the atmosphere ultimately gets emissions as CO$_2$, forest growth could also be expressed in units of CO$_2$. The conversion from carbon to CO$_2$ is simply based on their respective molecular weights: 12:44. So the growth of a typical forest could be expressed as:

15 m^3 ha^{-1} yr^{-1} = 10 tDW ha^{-1} yr^{-1} = 5 tC ha^{-1} yr^{-1} = 18.3 tCO$_2$ ha^{-1} yr^{-1}.

Fluxes in this paper have been expressed here as multiples of tonnes. One tonne equals 1,000 kg. Alternatively, these fluxes can also be expressed as multiples of grams or mols. Table 1 gives a list of conversions between gram-based, kg-based, tonne-based and mol-based quantities.

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