ANNOUNCEMENT

Discussion meeting on Terrestrial NPP

December 17-18 2013

CEH Lancaster

Net Primary Production, the annual net fixation of carbon (gC m^{-2} a^{-1}), is a key ecosystem variable, as a driver for carbon cycling, a response to climate and nutrient availability, and a determinant of biodiversity. A major aim of agriculture is to maximise harvestable produce which often but not necessarily means maximising NPP, i.e. crop yield. However, the site-specific measurement of NPP is not straightforward, and is by no means routine in research projects on natural or semi-natural ecosystems. At larger scales, NPP is estimated by flux tower measurements and remote sensing, but these involve interpretation based on limited ground-truthing. Global-scale assessments of NPP are mainly based on its dependence upon temperature and water availability and neglect nutrient dependence, perhaps producing a misleading picture of global distributions.

In current UK-based research projects within the NERC BESS and Macronutrient Cycles (MNC) programmes there are strong needs to know NPP, especially (a) to explain, model and predict ecosystem nutrient cycling, and (b) to investigate how ecosystem productivity and biodiversity affect one another. NPP is also a key concept in the NERC Greenhouse Gas Emissions and Feedbacks (GHG) programme. An appreciation of NPP is relevant to ecology, earth system science and environmental policy development.

This meeting will provide a forum for discussion and interchange of ideas from different perspectives. Given the immediate demands of the BESS and MNC programmes, there will be a UK focus, but other places and larger scales are not excluded.

NPP Meeting 17th-18th December 2013

Attendees

Boyle	John	University of Liverpool
Cosby	Jack	CEH Bangor
Davies	Jessica	Lancaster University / CEH Lancaster
Ineson	Philip	University of York
Jarvis	Susan	Aberdeen University, CEH Lancaster
Marshall	Miles	CEH Bangor
Mills	Robert	WSL Switzerland
Monteith	Don	CEH Lancaster
Morrison	Ross	CEH Wallingford
Rowe	Ed	CEH Bangor
Rowland	Clare	CEH Lancaster
Smart	Simon	CEH Lancaster
Street	Lorna	Heriot-Watt University
Tipping	Ed	CEH Lancaster
Toberman	Hannah	University of Liverpool / CEH Lancaster
Ullah	Sami	University of Keele
Ward	Helen	CEH Wallingford
Weightman	Andy	Cardiff University
Whitmore	Andrew	Rothamsted Research
Wu	Lianhai	Rothamsted Research

Introduction – Ed Tipping

- ET gave the background to the meeting. There are strong needs to know NPP in the NERC BESS and Macronutrient Cycles (MNC) programmes. Especially to explain, model and predict ecosystem nutrient cycling, and to investigate how ecosystem productivity and biodiversity affect one another. NPP is also a key concept in the NERC Greenhouse Gas Emissions and Feedbacks (GHG) programme. *This meeting will provide a forum for discussion and interchange of ideas from different perspectives.*
- Definitions of NPP were made. The question was raised whether there should be a distinction between production and productivity. Phil Ineson says difference between productivity and production is important. Productivity includes material that is quickly turned over in rhizosphere and herbivory etc.
- Definitions of terms surround NPP such as GPP NEE NEP followed. Typical values for GPP 100-3000. NPP is generally ½ GPP, with respiration being the other half.
- It is typical to assume that half of NPP is above ground – but what is the justification for this?
- Factors influencing NPP were outlined: temperature; moisture; photosynthetically active radiation, CO2, nutrients, pollutants leaf are index.

Central questions for meeting:

- Do different measurements or estimates of NPP agree?
- What spatial and temporal scales can we work at?
- Are above-ground and below-ground NPP related?
- What determines NPP?
- How well can models perform?
- What is needed to relate productivity to diversity?

Discussion and questions

- With regards to distinguishing between 'productivity' and 'production' - need turnover rates for productivity, whereas production = total over time.
- For productivity need to consider that different nutrient turnover processes occurring within an ecosystem may occur at different time scales e.g. rate of plant biomass turnover vs. rate of soil microbial biomass turnover.
- The terms 'production' and 'productivity' in ecology have been borrowed from economics where 'production' = how much is made over time, and 'productivity' = a measure of efficiency i.e. a ratio of how much made vs. materials put in. Whereas in ecology 'productivity' is not a measure of efficiency. Measures of efficiency in ecology include C, nutrient and light use efficiency and leaf economics spectrum.
- When constructing ecosystem C budgets for a given time period, need to be careful that C fluxes are constrained to that time period – e.g. DOC released from a soil horizon may be from plant C fixation that occurred in the given time period concerned and/or from plant C fixed in a previous time period.
- C loss via heterotrophic respiration by pathogens living on plant surfaces is generally not considered in NPP calculations – therefore is a need to look into this.

- Disparity between global relationship between NPP and soil C stocks and that found for the UK using Countryside Survey data: i.e. positive relationship globally (stronger without tundra site), whereas negative for the CS UK data (with peats sitting at the low productivity-high soil C extreme).

Simon Smart – TNPP measurement – plant based sampling

- The aim of work discussed is to improve JULES as JULES lacks N&P cycling needed to catch variability in NPP across Britain. JULES doesn't reproduce soil C storage well and is energy water balance based.
- The approach to making measurements to achieve this was discussed. The UK is very heterogeneous and grassy. Samples were made across water, biodiversity and productivity gradients. Sub-catchments in the Conwy were sampled - 52 plots, 12 habitats 2013-2014. Plant species were identified in quadrants.
- Characterised as dominant abundant frequent and occasional plant types.
- As many different ways to measure NPP as to define. Here peak biomass is cut, and an autumn cut made. There are issues with compensatory growth – should stock be excluded
- Methods were adapted to different PFTs
    - Cranked wires for sphagnum
    - Calluna sampling planned from areas with different burn histories.
    - Woodland ANPP = leaf litter + ground flora + woody increment. Litter measured in autumn, ground flora summer and spring, tree coring to give woody increment. Moss meshes.
- This time next year measurements will draw to a close.
- Summary:
    - Resources for sampling are limited
    - Low level of replication
    - ANPP is a function of 2013 weather

Discussion and questions:

- That the JULES model struggles with predicting C stocks in low productivity habitats was discussed.
- Parameters used for determining ANPP in JULES discussed; and it was highlighted that JULES is more physics based than biological parameterised, and that contains little consideration of nutrient dynamics.
- Importance of distinguishing between soil concentrations of C and actual stocks was highlighted (i.e. taking account of differing bulk densities).
- (and the point was raised that whilst Countryside Survey reports soil C as %'s, as high % C soils tend to be of deeper depths, the continuation of high C %'s to depth may cancel out the low bulk densities of C rich soils vs. mineral soils??).
- Importance of plant traits vs. environmental drivers in determining plant litter decomposition was discussed. It was highlighted that litter from peat forming plants such as Sphagnum will still decompose fairly quickly if transferred to an oxygenated environment

suggesting environment more important than plant litter traits; but likelihood = that both plant traits and environmental drivers both important in determining litter decomposition rates.

- Grazing effects on below-ground plant production discussed; and it was agreed that there is a lack of data on this.
- It was highlighted that regular inputs of C may be very important for soil faunal and microbial biodiversity.
- That we are lacking data on plant trait vs. NPP relationship for bryophytes was raised.
- Need for caution raised that leaf-area index is not necessarily always a good indicator of photosynthetic capacity – i.e. there is a need to focus more on actual leaf functioning.

Helen Ward & Ross Morrison– Measurement Flux Towers

- Discussed eddy covariance methods
    - Give continuous, long term measurements over 50 to a few hundred metres.
    - Sampled at 10-20Hz
    - Covariance of measurements over 30 minutes gives flux.
    - The greater the height of measurement the larger the area of measurement.
    - Outlined the stages of processing and corrections needed to go from raw data to flux measurements – which are not inconsiderable.
- What is measured?
    - Eddy covariance gives the vertical CO2 flux = NEE
    - Anthropogenic influence discussed. This can be taken account with use of statistics.
    - Important to have an understanding of the other factors to aid interpretation:
        - Landcover
        - Surface conditions
        - Meteorology
        - Models needed to give footprint. Heterogeneous sites can suffer sampling bias due to prevailing weather conditions
- Ross Morrison detailed example results for the Fens.

Discussion and questions:

- It was clarified that gas flux chamber measurements are required to distinguish autotrophic and heterotrophic respiration in flux tower derived ecosystem productivity calculations.
- The suite of data adjustments used to interpret flux tower data are now fairly standard amongst research groups and are still being developed.
- The question was raised as to how we can validate the C fluxes made by Flux-towers? And it was suggested that we can't at present with the technology available, but that the best approach we have is to add up fluxes from specific pathways measured by focused procedures such as chamber measurements and isotope work. There are energy balance problems – a missing 20%. Scintillometry measures higher energy flux. Caution against using gap filled measurements.

- Techniques can be verified in less heterogeneous, more stable areas. However, there are issues if corrections are based on nice/ideal conditions only.
- The finding that the lowland peat site Ross is working has been losing C during the dry periods of the three years measured so far was discussed. And it was suggested that peat stratigraphy could be used to look at C stock development of the peat profile over time to investigate past patterns of peat C gain and loss.

Phil Ineson – NPP Chamber Approaches

- Where can C go?
- NPP is difficult/impossible to measure
    - Mass balance approaches - a small change in a large number
    - Fluxes – assumptions and errors in measurement
- 13CO2 labelling
- NPP problems
    - Stem CO2 efflux – respiration or soil CO2? 13CO2 pulse experiments have shown that CO2 exiting via the stem is from respiration not channel soil CO2.
    - Is mycorrhizal C flux part of NPP or detrivore system?
        - Is the flux significant?
            - 60% soil
            - 25% mychorrhiza
            - 15% roots
        - Interesting temperature sensitivity effect - Soil respiration more sensitive to temperature than the mycorrhrizal respiration.
- Issues with chamber measurements
    - Some debate over the influence of pressure humidity and temperature.
    - Is dynamic mixing of air in chamber needed?
    - Debate about which regressions to use for flux calculations
- These issues were tested with mesocosm experiment – mass balance checked against chamber estimations. Results of which:
    - PAR correction needed
    - Measure night fluxes at night only.
    - There was no detectable nitrogen effect
    - Flux Vs Mass Balance matched.
    - No other corrections significant

Discussion and questions

- The question was raised as to whether ecosystem respiration rates differ between night and day? It was discussed that a number of studies show that they do (and that eddy co-variance derived ecosystem C budgets don't at present use actual measurements for daytime respiration – instead use the night-time rate with a temperature based correction factor).
- Following from the experimental work presented in Phil's talk regarding upward transport of carbon from below ground to above ground in trees, it was discussed as to whether

aerenchymatous plants might facilitate upward $C0_2$ flow from below ground via their aerenchyma?

- Where to put mycorrhizal C pathways in primary productivity budgeting was discussed (i.e. particularly problematic if their C acquisition switches between symbiotic and saprophytic).

Lorna Street – Chamber NEE measurements 13C isotope labelling in the Arctic

- Leaf area index and total leaf N predict Arctic NEE
- Relating to Ineson's talk – needed to add a temperature sensitive term in order to model GPP.
- A clear linear relationship between LAI to Canopy N was presented measured for most vegetation types in Alaska
- One theory for this is that the plants optimise carbon gain – as if along a pareto curve.
- There is more variance at higher LAIs – this may be the influence of canopy closure.
- N distribution in canopy is not related to latitude – related to light diffusion.
- The role of isotopes discussed. They allow us to partition C respired and that stored in plant tissue.

Discussion and questions

- The question was raised as to whether a similar relationship between light, canopy N allocation and primary productivity occur outside of the Arctic? With the answer being that at present we don't know, and it was then discussed that perhaps N wouldn't necessarily be as efficiently allocated in ecosystems that are less N-limited than is generally the case in the Arctic.

Clare Rowland – NPP from Earth Observations

- Main methods:
    - Optical – rate potential rate of photosynthesis
    - Structural – based on growth rate
- Scale:
    - Canopy
    - Landscape
    - Global
- Optical methods
    - Use reflectance of red and green - NDVI
    - Processing steps – Earth observation data is transformed into NDVI, which is then used to estimate NPP via a physical model such as MODIS or an empirical model
    - NPP from MODIS is very dependent on temperature data
- Why are we interested in NPP?
    - use of NPP/NPP proxies to quantify ecosystem functioning
    - use of NPP/NPP proxies as an early indicator of vegetation stress/degradation
    - explore links between NPP & biodiversity

- Validation of this method is difficult due to the scale, and the shared assumptions in deriving NPP.
- Structural methods
    - Use Lidar or radar
- **Discussion and questions**
    - That the validation of remotely sensed NPP assessments is difficult was discussed.
    - MODIS data is easy to access. There are issues with getting UK data due to cloud problems. Lidar avoids this issue.

Andy Whitmore – NPP and Agriculture

- The first NPP experiment – Jean Baptiste Van Helmont 1580-1644. Weighed willow and soil, added water and weighed again after 5 years.
- Justus von Leibig 1803-1973 – plants obtain C and N from the atmosphere.
- John Bennet Lawes 1814-1900 , disputed atmospheric source of N, and set up Broadbalk experiment and others at Rothamsted to prove that plants get N from the soil.
- Many long term experiments at Rothamsted concerned with measuring yield – a proxy of NPP:
    - Broadbalk Wheat
    - Park Grass
    - Hoosfield Spring Barley
- Discussed results from Broadbalk. Mean yields have increased with introduction of liming, herbicides and new cultivars. Plateau around the 1980s – could this be the influence of fungicides on soil N mineralisation?
- Discussed the RothC model and estimation of NPP using the model in inverse mode.
    - Issues with parameterising model for nearby sites
    - No allowance for herbivory.
- Maximum NPP lost to herbivory for grass systems is 25% (Phil Ineson) and probably more like 5%
- AW is interested in 'Useful Primary Production'
- kJ in wheat straw is high – same magnitude as the grain – however on returning this to the soil, the soil C does not increase to the expected extent (RothC predicts much higher C incorporation) – How can we make the microbes work for us?

Discussion and questions

- The question was raised as to why the unmanured wheat is still doing pretty well in the Goulding et al 2008 study, and Andy suggest this may be due to nutrient inputs from atmospheric deposition and/or soil mining.
- It is highlighted that herbivory hasn't been taken account in the NPP estimates Andy presents from agricultural studies, and Andy suggests that this may not make a marked difference as herbivory is akin to fast litter decomposition as C goes into and out of herbivores very rapidly.

- That wheat straw added back to the soil post-harvest is broken down so rapidly that it doesn't contribute C to build up soil c stocks is highlighted, and Andy raises the discussion point as to whether we could/should manipulate soil microbial communities/litter characteristics to promote retention of straw derived C in the soil.
- That trade-offs amongst the provision of different ecosystem services exist but are often overlooked is highlighted.
- The question was raised as to whether now that we supply agricultural ecosystems with sufficient nutrients that C fixation is not limited by nutrient availability, is crop yield therefore only determined prevailing weather conditions and does JULES (i.e. which doesn't take nutrient availability into account) therefore do a good job of predicting agricultural productivity? And it was highlighted that the genetic potential of varieties is a major driver to consider which affects crop yields.
- That break crops have also been shown to increase crop yields in following years was also highlighted.
- It was highlighted that proportionally less N is lost to leaching from agricultural ecosystems now than in the past, but that the amount of N lost to leaching may still be considerable as more is added now than in the past.
- It was highlighted that we don't have enough data on how above-ground yield changes affect below-ground C allocation and the structure and dynamics of rooting systems.
- The question was raised as to how soil depth may affect NPP via root nutrient acquisition and uptake potential and rooting space? And Andy suggested that a major effect of soil depth may be that shallow free draining soils limit crop yields due to restricted water storage capacity.

Ed Rowe – Relationships between NPP and Ellenburg N

- NPP
    - = carbon or energy flux into the ecosystem
    - = a rate
    - = unmeasurable
    - = a platonic concept
- NPP consists of: harvested material; stover; material senesced before harvest; material eaten before harvest; growth after harvest; volatised above ground material; that respired by diseases; roots; roots senesced before measurement; roots eaten before measurement; root growth after measurement; exudates; diseases respiration below ground; and symbionts;
- What data do we have and what do we need?
    - We can take partial measurements, and then using ratios of NPP constituents from literature we can derive C flux into soil.
- Can NPP be derived from plant traits? Ellenburg N is an indicator for central European plant species pertaining to nutrient availability.
- Ellenburg N correlates with yield – example from the Park grass experiment.
- NPP is a fundamental and distinctive property of ecosystems

- **Proxies for NPP:**
  - Mean Ellenberg N score
  - Mean typical Specific Leaf Area (e.g. m^2 leaf g^{-1} C)
  - NDVI
  - Biomass and flux measurements

Discussion and questions

- It was suggested that it would be good see Ellenberg N plotted against NPP for a large data set.

Don Monteith – Links between DOC export and terrestrial NPP

- Discussion of research resulting from observations made by the acid water monitoring network.
- UK upland DOC concentrations increasing over past three decades, attributable to acid deposition. 14C data suggests that this is young carbon being lost.
- What can DOC tell us about NPP in upland systems?
  - Harrison et al GCB 2008 – DOC production linked to productivity. NPP estimate based on light use efficiency and temperature.
  - DOC fluxes examined for large network of lakes in Norway. NDVI found to be strongest predictor of Norwegian DOC concentrations and fluxes (Larsen et al 2011 GCB).
  - Same exercise performed for Sweden, with fewer lakes. Days when temperature exceeds 0deg was found to be a good predictor of total organic carbon.
  - In the UK we have ~20 sites in acid monitoring network. For measurements at these sites altitude, % peat and rainfall are the most significant explanatory variables.
- Summary: DOC is predictable for uplands. There is evidence to suggest that DOC export is linked to NPP. The energetic approach to modelling NPP makes mechanistic sense. Role of water and nutrients can then be described with respect to light use efficiency.

Discussion and questions

- The up to date picture of where our understanding of drivers of contemporary trends in freshwater DOC concentrations is at was discussed and Don re-iterated that catchment altitude effects on terrestrial NPP (driven by altitudinal trends in solar irradiation) is a key driver.

Ed Rowe –Effects of pollution on NPP

- Presentation was to be given by Gina Mills, but unfortunately she couldn't attend.
- Work being carried out is examining the influence of ozone pollution on wheat yields. A data mining exercise was carried out. It found that there are large relative losses in biomass with ozone pollution

Discussion and questions

- That plant species don't all show the same response to ground-level ozone was discussed; e.g. Sphagnum biomass shows a positive relationship.
- The question was raised as to whether ground-level ozone and atmospheric N deposition may have had an interactive effect on NPP over recent times?

Final Discussion

A major point that seems to have emerged over the course of the talks is that cross verification of techniques is needed:

- Simon Smart suggested that perhaps using the form of camera work that Clare Rowlands discussed with biomass NPP measurements.
- Rob Mills highlighted that NDVI cameras are now available and are cheap and deployable (http://www.decagon.com/products/canopy-atmosphere/light/srs-spectral-reflectance-sensor-ndvi-pri/)

Another interesting point that emerged is that a fraction of respiration was found to be temperature insensitive by both Phil Ineson and Lorna Street.

A problem that was identified throughout the course of the talks was how to address the below ground biomass:

- How can temporal changes be considered?
- Is the use of borescopes/rhizotron cameras sufficient?
- The amount of below ground material vs. above ground is of importance to models like N14C as the above-below ground split influences the plant stoichiometry. This split is not necessarily constant however – plants transition from root investment to shoot investment under nutrient enrichment.
- Could 13C pulse labelling be used to better determine the amount of carbon being allocated below ground?