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The unbalanced cycles of carbon, nitrogen and phosphorus: national scale forecasting

How can dynamic models of macronutrient behaviour be developed and applied to guide environmental policy?

Photo by James Hetherington 2009

Living With Environmental Change Policy and Practice Notes

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The Living With Environmental Change Partnership brings together 22 public sector organisations that fund, carry out and use environmental research and observations. They include the UK research councils, government departments with environmental responsibilities, devolved administrations and government agencies. The private sector is represented by a Business Advisory Board.

The macronutrient elements carbon, nitrogen and phosphorus are central to life processes. Their biogeochemical cycles are intertwined in air, land and water. Human activities such as industrial production, transport, agriculture, urbanisation, domestic detergent use and sewage treatment interfere with natural macronutrient cycles, unbalancing them, with unintended and largely undesirable environmental consequences. Combatting these effects requires policies that address the future impact of excess nutrients. Models can be used to help policymakers and environmental regulators to address this problem by demonstrating how multiple pollutants interact and alter in response to changes in climate, land use and atmospheric pollution.

What problems are caused by macronutrient imbalances?

Disturbance of natural biogeochemical cycles of macronutrients (carbon, nitrogen, phosphorus) by human activities is causing major environmental changes, with consequences including:

— Eutrophication and acidification of freshwaters.
— Biodiversity loss in terrestrial and aquatic ecosystems.
— Soil degradation through the loss of organic matter.
— Pollution of coastal waters.

Why do excess macronutrients in the environment pose a challenge to policymakers and regulators?

Policies that target nutrient abatement have to address multiple and complex issues. These might include:

— Diffuse or point sources of pollution.
— Pollution occurring in upland or lowland areas.
— Pollution at catchment or national scales.
— Integration of multiple nitrogen and phosphorus sources which have downstream effects in rivers (and lakes).
— Impacts on water quality of estuarine and marine areas.
— Implications for water availability and usage.

How can models help address these problems?

Mathematical models can help policymakers and regulators understand very complex and dynamic systems because they can enable us to:

— Assemble and organise our data, information and knowledge.
— Join up disparate strands of complex information.
— Incorporate new information.
— Test ideas.
— Represent dynamic processes.
— Represent temporal responses and spatial distributions.
— Forecast the response of terrestrial and aquatic systems to scenarios such as climate change, air pollution, land use change etc.
— Test the implications of change (scenario analysis).

All models have strengths and weaknesses and it is important for policymakers to base their decisions on outputs from a range of models.

What are the limitations of models for supporting policymaking?

Models can be a useful tool for policymakers and environmental regulators if they are underpinned by strong scientific understanding, and if they represent appropriate spatial/time scales.

However, policymakers should be aware of the potential limitations. For example:

— A lack of historical data to drive the model.
— Inherent uncertainty related to future simulations.
— Incomplete knowledge about processes particularly where feedbacks are overlooked eg emissions to the atmosphere resulting from increased nitrogen fertilisation.

How can we improve the effectiveness of scenario-based research?

To ensure optimal effectiveness of employing scenarios in managing and protecting the environment:

— Policymakers and regulators need to be involved in constructing scenarios so the model results are targeted, relevant and fit for purpose.
— It will be important to consider drivers for future macronutrient cycling that have been highlighted in recent research including :
  - Climate change.
  - Woodland expansion and agricultural intensification.
  - Changes in atmospheric deposition of nitrogen and sulphur.
  - Reduction in sewage effluent by assuming phosphorus stripping at wastewater treatment works.

What kind of questions can modelling studies help to answer?

Policymakers and modellers need to co-construct the questions to ensure that model outcomes meet their requirements and are achievable given the limitations of the model and available data.

Once the questions are agreed, models can help to determine:

— Whether policy measures already in place are having an effect.
— That the timescales required to meet policy targets are appropriate.
— Whether or not it is feasible to meet forthcoming policy targets. If not, through scenario analysis, alternative approaches can be proposed.
— How policies can be joined up to deliver multiple benefits (win-wins) across a number of policy areas, or conversely whether harder decisions on trade-offs between different policy objectives need to be taken.
— How best to spatially target policies and resources to achieve greatest benefit, effectiveness and value for money.
— Whether the effects of a single driver of change (climate, land use, atmospheric pollution) are more/less than the interaction between several drivers.
— Whether environmental responses to change in drivers act separately or in combination, therefore allowing stakeholders to target the most effective action.

What specific areas can be addressed with the help of modelling studies?

Policymakers can use dynamic models to measure effectiveness of national and international environmental legislation. For example, models:

— Can be used to assess the number of rivers in the UK that will comply with water quality and ecological standards in response to various scenarios. The model can help identify why some river systems fail to comply and provide an indication of the timescales to recovery (and possible compliance). Policymakers need this information to assess the efficacy of current policies, review mitigation/adaptation options and steer the development of new policies.
— Can inform multiple policy objectives. Whilst UK ecosystem carbon storage may increase in the future under a woodland expansion scenario, policymakers should consider the multiple benefits of woodland to achieve wider policy objectives (riparian woodland for diffuse pollution control, enhancing biodiversity, natural flood management etc).
— Can enable policymakers to plan strategically to meet food security and environmental targets, now we have a better understanding about the crop cultivars that are well adapted to climate change, are nutrient efficient and high yielding.
— Have shown the potential effectiveness of wastewater treatment in reducing phosphorus loads in rivers. This outcome provides a clear message to the wastewater industry, regulators of effluent and policymakers charged with reviewing current legislation.
— Imply that nitrogen deposition has affected UK ecosystems through increases in plant growth, soil carbon accumulation and plant diversity loss. Policymakers therefore need to account for the benefits and disbenefits of a single driver of change when assessing the efficacy of current and future air quality policies.

What actions do policymakers and regulators need to take to make best use of the available knowledge?

Policymakers and regulators need to:

- Get involved in planning research projects from the outset by agreeing research goals and framing questions eg
  - Straightforward questions such as "If we install tertiary treatment at a specific wastewater treatment works, what will happen to river phosphorus concentrations?"
  - Complex questions such as "How do we optimise the environmental benefits of competing policy questions?"
- Open channels of communication with the modellers to ensure that results are not misinterpreted, especially when decisions are being made about complex simultaneous interactions of carbon with nitrogen and phosphorus in the air, land and water continuum.
- Be aware that models are available in the UK that can produce outputs to inform current and new policies across a range of environmental regulation.
- Ensure that time and resource are made available at the end of research projects so they can work with scientists to put research findings into practice in order to evaluate the efficacy of environmental policies and make recommendations for future environmental regulation.
- Recognise that decisions need to be made in the face of uncertainty.
- Understand both the usefulness and limitations of the models, resolution and timescales. For example, models developed for national scale policy assessment are:
  - Relatively simple and represent a few key processes.
  - Ideal for evaluating policies at national or large river basin scales.
  - Suited to long term assessments of policies over decadal timescales.
  - Most suitable for assessing the efficacy of current or future policies/practice at national/regional scales or for larger catchments (ie > ~250 km^2).
  - Most relevant for temporal resolutions of seasons/years.
  - Only able to simulate the effects of processes which are explicitly included in the model.

Further information

This note was written by Rachel Helliwell (The James Hutton Institute), Edward Tipping (Centre for Ecology and Hydrology), the wider Long Term Large Scale (LTLS) project team and stakeholders and draws on the NERC and Scottish Government funded "Analysis and simulation of the Long-Term / Large-Scale interactions of C, N and P in UK land, freshwater and atmosphere", which is part of the Macronutrient Cycles Programme.

Useful resources:

LTLS project website https://wiki.ceh.ac.uk/display/ltls/Home

Macronutrient Cycles Programme website http://macronutrient-cycles.ouce.ox.ac.uk/

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