ReBALAN:CE

Recycling Biomass to Agricultural Land: Capitalising on Eutrophication

Report from a workshop held at the University of Stirling
29th – 30th August 2013

The views expressed in this document are not necessarily those of NERC. Its members or agents accept no liability for any loss or damage arising from the interpretation or use of the information, or reliance upon views contained herein.
Whilst this document is considered to represent the best available scientific information and expert opinion available at the stage of completion, it does not necessarily represent the final or policy positions of the project funders.

Dissemination status
Unrestricted

Name		Organisation
Lis	Broome	Environmental Sustainability KTN
Dave	Chadwick	Bangor University
Paul	Cross	Bangor University
Sian	Davies	EA
Fiona	Donaldson	SEPA
Claudia	Erber	SEPA
Jason	Evans	University of Georgia
Owen	Fenton	Teagasc Agriculture Research
John	Ferguson	Eco ideaM
Zoe	Frogbrook	Scottish Water
Nick	Hanley	University of Stirling
Peter	Hunter	University of Stirling
Davey	Jones	Bangor University
Fiona	Napier	SEPA
Richard	Newton	University of Stirling
David	Oliver	University of Stirling
Kenneth	Porter	University of Stirling
Richard	Quilliam	University of Stirling
Sreenivas	Ravella	Aberystwyth University
Iain	Semple	University of Stirling
Evangelos	Spyrakos	University of Stirling
Michele	Stanley	SAMS
David	Tompkins	WRAP
Mel	van Niekerk	University of Stirling
Andy	Vinten	James Hutton Institute
Ann	Wilkie	University of Florida
Nigel	Willby	University of Stirling
Geoff	Codd	University of Stirling

Overview

The overall aim of the ReBALAN:CE project is to facilitate the exchange of knowledge across the disciplinary boundaries of biology, soil and water science, microbiology, human behaviour, risk perception, waste management, economics and catchment management. In turn, we will develop a comprehensive, holistic and targeted programme of research to 'close the loop' on nutrient transfer from land to water. This will be underpinned by quantifying the risks, opportunities and multiple benefits of recycling excessive aquatic plants (AP) and algal biomass (AB) back to agricultural land.

Aims of the workshop

- To share knowledge across many different areas of expertise
- To discuss and critique the ReBALAN:CE themes
- To agree on the most pressing research needs that align with resource recovery from waste and the ReBALAN:CE vision

- To provide a networking opportunity for academics, regulators and stakeholders

Presentations and Discussions

Session 1

Jason Evans (JE) presented some case studies illustrating the unintended consequences of lake management and the way we can learn from this to manipulate the lake ecology. Water lettuce is a highly productive plant (100 t ha^{-1}) that dominated a eutrophic spring system. It was eradicated using herbicides but this had the effect of selecting for algae dominance. A similar situation was found in another spring system that began under Water hyacinth dominance and when this was eradicated using herbicides, Hydrilla (submersed) arrived. When this was eradicated, it led to the proliferation of the algae *lymbia*. In both cases management activities changed the way eutrophication was manifested. The algae was deemed less desirable than macrophytes so the movement was back to growing and cultivating aquatic weed that manatees eat. Water hyacinth is now being deliberately reintroduced to Crystal River (Florida west coast). Catchment management and source prevention is the ultimate goal but the reuse of AP&AB is not antagonistic with this. There needs to be an emphasis on managing the systems we have.

Nigel Willby put forward that AP harvesting can be carried out for different purposes: 1. For the extraction of the resource value from biomass, 2. To manage a nuisance and 3. For lake restoration. The nutrient resource potential in categories 2 and 3 is under-used and we should focus on trying to exploit this. In heavily modified water bodies (HMWB) and artificial water bodies (AWB) weed cutting and dredging is part of the management regime and permitted under WFD so we should maximise the resource value of waste from these systems. One km of canal 10 m wide or a 1 ha pond would yield about 130 – 150 kg N and 15 – 30 kg P. Emergent, submerged and floating plants need different harvesting methods and the nutrients are stored differently. The range of concentrations that offers the best opportunity for macrophyte harvesting without causing the system to flip into phytoplankton dominance is 80 – 200 µg P l^{-1}. However, phytoplankton have more N and P as a % dry weight than seagrass, microalgae and freshwater angiosperms so if they could be harvested easily we might want to focus on them as we would be able to extract relatively more nutrients. AP is harvested and used on soil in many parts of the world (eg on human and animal food crops in SE Asia) but this is not widely researched and published reports are scarce. Finally the question was raised as to how we map the ReBALAN:CE project onto Water Framework Directive (WFD) objectives.

Evangelos Spyrakos spoke about the uses of microalgae in aquaculture, agriculture, biotreatment of waste water and pharmaceuticals. To produce 100 t biomass ha^{-1} a^{-1} requires 8 – 16 t N ha^{-1} a^{-1} (1.5 % global energy consumption) and 1 t P ha^{-1} a^{-1}. Harvesting microalgae is also difficult as methods need to be species specific. The best strain of microalgae for a particular purpose is dependent on the optical density, lipid/fatty acid content, biomass composition and quantity, specific growth rate. *Chlorella sp* .was used in the example discussed to illustrate some of the challenges. Filtration did not work as the cell size of chlorella blocked the filters. Flocculation with aluminium sulphate was used instead leading to a 95 % recovery. Centrifugation was also a possibility but it is expensive, has high energy consumption and gives low levels of recovery. It would be difficult to find a method for harvesting microalgae in natural waters due to the range of species and variability in species composition.

Discussion

The wider environmental benefits were not costed in the Evans & Wilkie (2010) LCA[1], but transport was included with a distance of about 25 miles assumed in the anticipation that would be local refineries. A further refinement to the LCA would be to include using tertiary treatment of wastewater as an input value and not just the N and P value of the fertiliser as this would make the recycling of AP&AB more economically attractive.

The harvesting of sediment was discussed in relation to the high cost of transport. In the Norfolk Broads in England where sludge has been dredged, it was given to local farmers. Most of this was done 20 years ago and there is not much formal published research on the value of dredging sediment.

There was further discussion of JE's work in Florida that demonstrated firstly that water hyacinth will grow where it is cultivated and secondly that manatees will eat it; the question now is how to optimise the two things. Furthermore is it possible to cultivate plants in cages together with fish to combine nutrient cycles with food cycles and how can we optimise cultivation, species mixes etc to manage the system away from algae dominance.

Session 2

Peter Hunter (PH) started the second session by introducing the GloboLakes project. This investigates the response of lakes to environmental change, targeting 1811 lakes globally from which 1000 will then be chosen for statistical analysis. The KTAMOP project, investigating the sustainability and environmental impact of communities living in Lake Balaton's southern watershed, maps well onto ReBALAN:CE. There are large scale aquaculture systems that are being looked at in terms of their impact on water quality. This high algae and P system is flushed and drained into Lake Balaton at the moment.

Another project with the Environment Agency (EA) involves citizen science in monitoring algal blooms in lakes. Volunteers monitored 3 waterbodies in the Lake District of northern England and their data were compared with the standard monitoring procedure by the EA. Although the project was hampered by the wet summer in 2012 so (not many blooms until late October) but a bloom, identified by volunteers, was missed by monitoring from the University of Stirling, CEH and the EA who sample in the centre of the lake not the shoreline.

PH then went on to discuss cyanobacteria, cyanotoxins and human health. There is a possible route for toxins to humans through contaminated foodstuffs. Concentrations of cyanobacteria increase as P increases in waterbodies so they are likely in high biomass systems. We need to consider this risk

[1] Evans JM, Wilkie AC. Life cycle assessment of nutrient remediation and bioenergy production potential from the harvest of hydrilla (hydrilla verticillata). J Environ Manage 2010 DEC;91(12):2626-31

when harvesting and using AP&AB. Potatoes were grown and irrigated with water spiked with microcystins [MC]. MCs were found in plant tissue from the highest MC concentration irrigation spray (126µ g l^{-1}) at approximately 1 ng MC g dry wt^{-1} plant tissue. Uptake and persistence depends on toxin variant, plant species, microbe community. Studies show MCs have a phytotoxic effect on agricultural crops as well. The EU COST action project CyanoCost is looking into cyanobacteria blooms and toxins in water resources, their occurrence, impacts and management. This may be relevant to ReBALAN:CE. Work Package 3 is looking at prevention and control measures but no one is considering the reuse of this material.

Michele Stanley (MS) talked about algae in the marine environment. Seaweed aquaculture is carried out on a massive scale (170 000 tonnes per year) and seaweed is the largest single species aquatic crop in the world. Seaweed can be fermented to make bioethanol or anaerobically digested to make biogas (methane). However the ecological problems that can arise from removing beach cast seaweed mean that sites need to be selected carefully. Mixed feedstocks for example if using beachcast seaweed, are not good for biofuel production by anaerobic digestion (AD) because of rocks and partial rotting, which results in less energy from the crop. There is more interest in brown and green algae for biofuels as red algae is too valuable. The Integrated Multi-Trophic Aquaculture (IMTA) involves investigating the use of growing seaweed in aquaculture areas and near fish farms to remove N near the cages.

Finally MS mentioned a NERC project – A research needs assessment into ecosystem services looking at bioenergy and commodity chemicals production in the UK. It investigated inputs, biomass production methods and conversion processes. Key questions that emerged from the work involved the areas of:

- Site selection
- LCAs, carbon balance, sustainability information
- Role of algae in C and nutrient cycling
- How does algal cultivation affect biodiversity on the farm, water column and benthic environment?

Sreenivas Rao Ravella (SRR) talked about the Beacon Project being carried out at Aberystwyth University in partnership with Swansea and Bangor universities to develop biorefining R&D expertise in Wales. It is a Welsh European Funding Office (WEFO) funded initiative with a value of £20m. Its aim is to enable academic and industrial partners to develop and demonstrate scale-up processes for economically viable industrial applications for biorefining. He described the three facilities for biomass treatment and fermentation including machinery that extracts juice from biomass. There is also a biochar facility. Macrophyte samples from the University of Stirling comprising aquatic plant material, composted Elodea, pondweed (*Lemna sp.*) and Water Lilly are currently being processed at Bangor.

Discussion

PH confirmed that his work on MC toxins used purified MC and not wet cyanobacterial biomass in irrigation water for tomato plants so they were looking at the impact of MC toxins and not the positive effects of algal nutrients to the plants.

The in-situ processing of biomass would be very attractive and it was suggested that a group of farms could share a juicer of the type used by SRR and then only the extracted juice would need to be transported - even this could be reduced in volume.

A question was asked about kelp farms in Norway and the damage that harvesting could cause – is this industry going the way of forestry eg towards sustainably harvested kelp? MS thought that up until 2 years ago it considered sustainable. Older plants were cut and this encouraged young growth. Now however there are concerns over wider environmental impacts. In terms of transferring this type of operation to the UK it was pointed out that the marine environment in the UK is very busy and for example noise affects sea mammals. Marine spatial planning may allow countries to plan to their own needs.

Session 3

Ann Wilkie (AW) looked at making biodiesel from a variety of feedstocks with a central theme being resource recovery based on biological conversion of material to make methane. Organic materials also give biofertiliser but we need to know how to value the nutrients left over from AD.

AW discussed the benefits of using AD for food waste in Florida where it diverts waste form landfill and reduces landfill GHG emissions. Opportunities might arise with wastewater form industry eg distilleries where it might be possible to grow algae on the wastewater and sell it on to another industry. Ideas put forward for where opportunities for nutrient recovery and further research may lie include:

- Closed loop systems (Co-location synergies), merging animals with a bioethanol facility.
- Growing biomass on digester effluent from treating dairy manure.
- Bio-prospecting – identifying the best strains of algae to do the job required eg staining with Nile Red to identify lipids, which are good for biofuel production
- Use of algae to remediate landfill leachate
- Looking at the difficulties of harvesting algae. Filamentous algae could be easier to harvest. If it forms a ball or cluster it can be harvested by straining.
- Challenges of farming algae - deciding on which strains to grow, (local strains best fitted, strains indigenous to manure type), when to grow, how to harvest (size and density, mechanical/chemical, drying), is there a market for manure algae?

Owen Fenton (OF) began his talk by using the concept of the transfer continuum of nutrients from source to receptor to identify opportunities for trapping and intercepting nutrients along the pathway. He described two reviews that he had carried out. The first was to show that algae could be grown on manure waste, runoff water, drainage water from fields and in eutrophic waterbodies in a response to the fact that industry was mainly using chemical fertilisers. They found that microalgae can adapt to and grow on different organic matters. The second review looked at studies using organic manures to grow algae - digested vs undigested (slurry or dirty water). They found that the use of raw manure to grow algae is not easy and the nutrient value of dirty water is small so farmers want an alternative use for it. Digested manure is easier to work with as a nutrient supplement.

The use of flocculants with slurry before applying it to land has been trialled. This had the effect of locking the nutrients to the soil but may result in higher gaseous emissions so there is still some nutrient loss. So now they are advocating the collection of waste and using it as a substrate on which to grow nutrients on. This adopts a more holistic approach and embraces the philosophy of identifying each nutrient loss and fixing them all systematically.

Andy Vinten (AV) described his work on the Lunan catchment in eastern Scotland where he has been involved since 2006. It is a WFD failure for standing waters due to P and running waters due to hydromorphology. Soil erosion is a problem from potato farming and Rescobie loch is 3 times the annual WFD limit for P. Ten per cent of the loch is harvested annually and he is assessing the effectiveness of macrophyte harvesting to mitigate the eutrophication problems**.** Including the cost of hiring a harvester, the cost effectiveness analysis for aquatic weed harvesting at Rescobie amounted to £60/kg N and £171/kg P. This could be refined by adding in other catchment sources to mitigate septic tank inputs, and STW and land contributions

Farmers in the Lunan catchment have put in buffer strips and other measures to mitigate nutrient losses. Using data about P sources, an analysis was made for the effectiveness of buffer strips. In order to get to the 376 kg P mitigated necessary to achieve WFD standards, 20 m buffers would be needed. At this end of the mitigation scale the marginal cost effectiveness is nearly 170 £/kg P which is where it is comparable with macrophyte harvesting.

Detention bunds are used elsewhere in Scotland and are being trialled at the Lunan by adapt the method to form sediment fencing that is installed at the bottom of potato fields. These trapped 70 t of soil over 2 years. The cost effectiveness of this was also estimated and put in with the other measures and showing that target P reduction can be achieved without macrophyte harvesting if all the other measures are in place. So macrophyte harvesting is not attractive if we just think about it as a mitigation measure for P. We need to think also about other benefits for example recreation, other nutrient removal, flood mitigation.

Zoe Frogbrook based her presentation on a case study of the Loch of Lintrathen catchment. Nutrient inputs are causing Scottish Water (SW) problems with algae although not every year. The algae blocks filters, alters pH and dying algae release products affecting the taste and odour of water. Algae are also a source of organic material that can lead to THM production in the disinfection process. To control this involves more energy and more cost. Controls in place for algae include keeping Lintrathen loch as full as possible, mixing with water from elsewhere, running air blowing units to destratify water and minimising nutrient inputs to the loch. They can use powdered activated carbon (PAC) to remove taste and odour problems but need 8 t per day, and more sludge is produced. Toxins from algae can be treated by O_3 gas and PAC but this is chemical and energy intensive and very expensive. So SW is trying to look at alternatives to prevent algal blooms in the form of sustainable land management to protect and improve water quality within catchments. The sustainable land management incentive scheme involves financial help for farmers and landowners to put in measures to address eutrophication. These must be above and beyond the farming compliance obligations and are available in 6 catchments across Scotland providing management and capital items for farmers.

Discussion

NH asked about the cost benefit analysis on Rescobie loch. How transferable are the relative cost numbers to other water bodies? Relating to estimating costs of implementing different strategies for reducing N Pollution for some Scottish catchments found that while ranking instruments were stable across catchments the absolute costs varied a lot. AV replied that this was for P not N and topography and land use will have a stronger impact for P so it is quite landscape dependent. But tools are there to transfer it to other catchments and the expectation was that if done for N as well macrophyte harvesting would still be at the expensive end of the scale.

NH asked if the sustainable land management project selection process is by auction as in Devon. ZF said no, it is application based for capital items and management plans details of which are on the SW website. Farmers have to select from a list of items available and cannot make request for things outwith this. The list is designed not to include compliance items.

GC asked if the economic forecasting and CBA from Rescobie can be applied to the potential contributions to drinking water abstraction (the same species of cyanobacteria and toxins occur in Rescobie and Lintrathen). AV thought so and ZF said there was already overlap between the SW options and the measures AV discussed in the Rescobie example.

Session 4

David Tompkins (DT) introduced WRAP as an organisation working towards designing out waste and designing in recyclability to get nutrients back into the economy. WRAP focuses on quality recycled products (compost and digestate materials), which represent a standard higher than the baseline regulatory standard. They state the composition required of the products to be accredited and this gives market confidence in the standard. About 5 Mt of compost and digestate produced annually in the UK. About 70 % of the compost and more than 90 % of digestate goes to agriculture. The digestate market is rapidly increasing but it is mostly water and expensive to ship so we don't know what its long term future is. Digestate use has benefits in GHG savings, nutrient recovery and soil improvement. The challenges are transport, agronomic predictability and perceptions of quality.

Compost has a high N value but it is not available in the first year after application so products cannot be sold as N fertilisers. However it is good as a soil improver and for P and K. Green compost has a value of about £ 3.26 per tonne or £4.98 if food waste is mixed in the feedstock (adds readily available N). Digestate, in theory, could meet all crop N requirements for barley but crop efficiency is low in autumn compared to spring so in winter manure based digestate is stored. Furthermore up to 60 % of N in digestate applied can be lost as ammonium in the first 24 hours. This poses a problem in how to value the material.

Perceptions of safety in plant biomass products have to be managed. There are concerns over whether some plants or diseases survive composting. Also could HMs accumulate, persistent organic pollutants and physical contaminants form household food waste. Biowastes do have nutrient benefits but they can be difficult to realise market and specific evidence is scarce (most is in the grey literature), perceptions of safety can be difficult to manage even with regulations and standards.

Nick Hanley (NH) discussed some of the economic issues surrounding nutrient recovery from waste. In comparing management options for achieving target N levels in streams you can compare regulatory approaches to approaches based on taxes or incentives to farmers for changing management actions. There are stable rankings of policy options across catchments but absolute costs can vary a lot. Incentives are provided for farmers for how they manage the land to optimise nutrient reduction. This has traditionally been done by government by regulatory mechanisms or agri-environment schemes but there is increasing interest from the private sector paying other private sector suppliers for ecosystem services. Under what circumstances are these payments for ecosystem services most likely to emerge and what characterises a successful ecosystem service scheme?

He put forward are 2 approaches for comparing management options for N reduction:

1. Cost effectiveness of achieving water quality targets by different means not looking at the benefits just the relative costs of the options; some will be related to land use ie reducing external loading and some aimed at reducing internal load. We want to know under what circumstances is each, or a mix of both, more cost effective. What incentives would we need to offer farmers to take up the land management options and what are the behavioural incentives required for people to utilise the material?
2. What are the relative costs and benefits of a set of actions eg removing plant biomass from a lake? Need to know about size of benefits. Not just costs of actions to solve a problem such as eutrophication but benefits of macrophyte removal to people fishing, birdwatching or kayaking. The benefits would be dependent on how the waterbody was used. The benefits to birdwatchers would be different to those to kayakers. We need to try to build a benefits transfer model to predict for a waterbody what are the likely benefits for a given action. Also if the action has an outcome we can measure, such a cl-a level x years after the action, we want to relate the economic benefit to that action to that parameter and this may depend on how waterbody is used and how much it is used. But if we can parameterise the model by undertaking a number of case studies we will have a tool to predict benefit across all lakes in UK. This is what the EA does.

Iain Semple (IS) gave his view from the aquaculture industry. Fish waste contains high nutrient levels which need to be treated before being discharged to the aquatic environment. Intensification of fish farming is making it difficult to treat waste to regulatory standards, which are very stringent and new approaches to waste management are needed. Solid waste is removed by filtration and stored in tanks. These are pumped out periodically by contractors who charge for the service and can then use the waste to produce a saleable fertiliser. Fish farmers recognise the potential value of this resource which, instead of being a waste that is costly to dispose of, could become an income stream. Recently IS has spread silt to land and sowed with a wildlife mix that has proven successful. However there is urgent need for work into the treatment of the waste to convert it to a useful plant growth promoter and to reveal and standardise the composition of the waste and end products.

Discussion

RQ asked IS if there is a problem with antibiotics in fish waste? IS replied that antibiotics should not be needed on a regular basis if good fish are being reared. For trout antibiotics are not needed but for salmon there are different problems that require their use.

DO commented on the need to know the nutrient content of the end product discussed by DT. There is a parallel with overcoming resistance of farmers to take up of products from AP&AB in a market that is already well populated. DT replied that in the market development for digestate and composts there were not existing markets so they were seeking to displace conventional fertiliser use. If this is also the case for AP&AB it should not be too problematic but if selling products based on other benefits, evidence would be needed to back this up. AP&AB product are not necessarily waste derived so the perception could be that it is clean biomass compared with digestate.

NH drew a parallel with recycled water in agriculture in Crete where there was a water shortage and government wanted farmers to use recycled waste water. Farmers were resistant thinking consumers would not like it. But actually as long as it was cheap enough some farmers would use it and it. A large price discount was needed for crops such as tomatoes but less for olives. Distance form source perception.

Session 5

Fiona Donaldson (FD) presented a regulatory viewpoint from SEPA focussing on the waste management aspects of recovering nutrients form AP&AB. There are some exclusions from the Waste Framework Directive (and thus from regulation), one of which is for natural, non-hazardous agricultural or forestry material. To comply with the exclusion the material must be used in farming as a fertiliser or for energy from biomass. Also the process must not harm the environment or endanger human health. Even if something is declared a waste we can still maximise the resource under the exemptions system.

The SEPA position on biochar is that up to 30 t can be stored at any one time and up to 50 kg an hour processed under the minimum regulatory regime. Substrate must be based on untreated wood waste. If making biochar from non-waste than there are no waste controls on its manufacture.

Sian Davies (SD) explained that for the EA the WFD is the main regulatory framework that is used to reduce nutrient levels in freshwaters. The next river basin management plans (RBMPs) are due in 2015 when the ecological status for all waterbodies must be published. Programmes of measures will also be required for waterbodies not achieving GES or GEP to set out how this will be reached. Cost effectiveness is a key part to RBMP and stakeholder engagement undertaken.

Ecological status defined using normative definitions for plants, invertebrates and fish. P is a supporting element that allows biological elements to achieve Good Ecological Status. There is no inter-calibration of P standards between member states but the UK has its own P standards.

SD finished with a list of questions and concerns the EA might have surrounding nutrient recovery from AP&AB including the purpose of the harvesting, where it is to be carried out, matters of ecological damage and stakeholder engagement.:

Fiona Napier (FN) talked about maintaining La Costa SUDS pond in California where vegetation harvesting is a major annual cost to local government. An intensive monitoring programme was undertaken over 3 yrs. Established vegetation included Typha and vector concerns meant that harvesting had be done annually. FN pointed out that they had a large amount of vegetation to remove annually and this would not be the case in the UK. Summing all processes results in removal of about 44 % N and 48 % P. About 3 – 8 % of P is removed in the vegetation and 5 - 7 % of the N.

Nutrient removal can be improved by timing the harvest and they found the optimum time to harvest Typha to remove nutrients was half way through 2nd years growing cycle. This is a very site specific activity and very species specific.

FN reported on SEPA concerns over the ReBALAN:CE project. SEPA is interested and see positive applications but would like more information. Concerns have been raised were over the message being sent out that it is capitalising on eutrophication where SEPA advocate prevention and source reduction rather. What about non nutrients, sediment, FIO, pesticides? The impact of the harvesting process ecology sediment disturbance and P release needs to be demonstrated and what effect will seeding have on ecology

Discussion

It was established that plant biomass grown specifically for harvesting would not be waste if grown for that purpose but it may be controlled under other regulations to do with water quality. Sediment dredged from a water body would most likely be a waste but this would not stop it being used as a product if it had beneficial amounts of nutrients.

NW pointed out SUDS systems are not harvested in Scotland and this could be a good source of biomass. However when quantifying the amount of nutrients removed form a water body by AP&AB harvesting we must use the percentage relative to the readily available fraction in order and determine if vegetation harvesting a good way of getting at that easily available fraction.

Geoff Codd (GC) put forward three points that for consideration:

1. Removing macrophytes leads to phyto dominance but is there evidence that macrophytes in British waters can produce allelopathic substances as they can in African waters which inhibit algal growth? NW thought so but said that the evidence was not equivocal.
2. Although AB may be attractive substrates for harvesting, getting at the useful parts of the organism can be difficult. Cracking Chlorella is problematic and we cannot get at the nutrients through normal means. If the P in cyanobacteria is not available maybe we should focus on macrophytes.
3. Evidence shows that there is an epiphytic layer of toxic algae on macrophytes and this may be of concern when harvesting.

David Oliver (DO) responded to points made during earlier presentations

He confirmed that the ReBALAN:CE project was concerned both with nutrient recovery and wider environmental benefits recognising that there may be win-win opportunities but also necessary trade-offs in developing new approaches. This incorporates aims towards lake restoration and nutrient conversion.

The use of "Capitalising" has led to concerns from SEPA and Defra. DO provided reassurance that it does not reflect a desire to capitalise on eutrophication at the expense of source prevention and catchment management. He acknowledged the potential misinterpretation by using this word but the project is responding to a waste call from NERC. There is a resource that we can recover to remediate waterbodies and also supply a material to landowners. He took on board the concerns and will consider how best to name any further work.

Richard Quilliam presented slides form absent stakeholders who had been unable to attend but had sent their thoughts and comments.

National Farmers Union (NFU) said that if a product were available to the farming community that had a proven nutritional benefit there is a strong likelihood that they would use it n their land. However they warn that this is a competitive market with many proven products already available. For aquatic biomass to be successful there would have to be strong evidence of its nutritional benefits and it would need to be low cost and available in large enough quantities.

The Broads Authority (BA) is supportive of ReBALAN:CE and can offer experience in AP&AB management, an extensive data collection and established stakeholder relationships. The BA is particularly interested in project outputs relating to novel uses for biomass to achieve sustainable resource recovery.

Rescobie Loch Development Association has a particular interest in the improvement of amenity value for fishing and navigation. Their present strategy of removing macrophytes and leaving them on the shore is fraught with difficulties. They are supportive of ReBALAN:CE in researching ways of controlling nuisance AP&AB that encompass wider environmental benefits. They have local farmers who are also interested but have expressed concerns over weed seeds in the compost and plant pathogens.

Defra welcomes the project in principle as an additional approach to effective nutrient management on farms but emphasise their commitment to managing nutrient losses at source. There are concerns over the potential for environmental damage from harvesting and the benefits of this approach would need to be fully demonstrated.

USDA focuses its comments on health concerns from returning AP&AB to agricultural land. In particular they raised issues of algae serving as human and other animal pathogen reservoirs, the persistence of toxins through processing, antibiotic resistance, horizontal gene transfer and occupational safety of harvesting AP&AB.

Prof Paul Withers considers the recycling of biomass an exciting idea in offering multiple benefits and emphasised the need to consider wider benefits in economic valuations of harvesting. Macrophytes may be easier to work with and a more predictable substrate but algae offer a higher turnover rate. Sediments represent a major source of nutrients and the legacy P in sediment is holding back the recovery of aquatic ecosystems. Removing them would speed up recovery and offer a source of P. Deposition is widespread and ongoing so sediments represent a reliable substrate.

Participants separated into three breakout groups to discuss research needs under three headings and reported back on the results.

Group 1. Process based research focussing on the end products

1. Chemical composition of feedstock.

Early characterisation of feedstock is important to understand the toxicity and human health implications of working with AP&AB. Concerns over toxicity need to be addressed without causing undue alarm. We understand some of the toxicological concerns relating to AP&AB and need to apply the precautionary principle. Epiphytic communities of toxic algae may be present on surface of macrophytes that could be harmful to workers. An early warning system could be developed alongside an understanding of how to handle such materials to ensure worker protection and measure occupational exposure. We have evidence supporting the rapid biodegradation of toxins under aerobic conditions but not in relation to AD and we know that algae can absorb heavy metals/radionuclides – what about macrophytes?

We also need to characterise the nutrient potential of the biomass types to find where the nutrients are located in the plant tissue. Is this site and species specific and how does this vary seasonally? We could build libraries of information about when and how to harvest at a site and how to manage the seasonality constraints. Part of characterisation would enable luxury products to be identified and removed first to get added value before sending the biomass to AD.

2. Characterising microbial communities in eutrophic waters.

This approach could be used as a proxy for what the environmental implications are for removing a microbial community. Characterisation and determination of the dominant species in microalgae blooms could open the way for using microbial markers. Subsequently it may be possible to monitor restoration by removing AP&AB, using microbial communities as markers. Control sites will be required for harvesting trials and the presence of epiphytic communities on macrophytes in the UK also needs to be investigated. Characterising AP&AB needs to be carried out in terms of the bioavailability of nutrients in different types of biomass. P may be bioavailable in macrophytes but in harvested cyanobacteria much is trapped in polyphosphate granules and we do not know if it is bioavailable to anything. Toxins are variable but generally very stable to heat.

3. Re-suspended sediment during harvesting

More research is needed on the association of sediment with heavy metals, pesticides, and other water quality impacts.

Group 2 Systems, linkages and trade-offs

1. Which attributes of the waterbody make AP&AB harvesting worthwhile?

Feasibility studies at different sites to map lake characteristics, consider algal blooms and sediment would be the starting point. From there the investigations could move on to clusters of lakes eg eastern Scotland, Norfolk Broads and international linkages. Policy and government structures around the waterbodies would need to be understood and stakeholder buy-in and sponsors to help with specific sites should be developed.

2. Cost benefit analysis

Mechanisms and techniques for harvesting may depend on whether the focus is on macrophytes or algae or sediment. What are the wider environmental impacts (costs & benefits), and dynamic changes to a lake through time, of harvesting AP&AB? Some changes to the lake ecology will be immediate following an intervention whereas a range of catchment management approaches may bring about a long lag effect between the cause resulting in an effect on lake quality and this needs to be integrated into the Cost Benefit approach.

Using lake clusters gives a limited scope and it may be desirable to scale up and generate estimates at wider scales. Empirical data is needed to test the scalability of ideas but the benefit transfer method can be used where there is no empirical data. Other needs are to find out how to factor in the biggest gain to society where there is not a single stakeholder and how to incorporate methane emissions into wider environmental impacts.

3. Alternative to locus looking into scalability

This concerns the idea of source recovery by harvesting upstream of a waterbody for wider water quality benefits. It offers an alternative technical solution in that between the lake and catchment scales there is an upstream processing scale. Cultivating and harvesting AP&AB upstream of a lake to confer water quality benefits on a wider scale would allow source recovery and tackling of point source inputs. The use outfalls from STW to grow AP would shorten the P loop.

4. Behavioural response of farmers and landowners if they think there is a get out option.

This addresses the risk that farmers might feel less likely to engage in catchment management if they thought that biomass could be recycled to recover lost nutrients. Caution is needed in presenting the message but the effect could be tested using a stated preference exercise on nutrient management with farmers to ask what they would do under different scenarios. Other possibilities include setting up field experiments in behavioural economics (expertise at JHI, Bangor, Stirling) and testing if there is a behavioural difference depending on whether farmers think there is a get out clause. Does the more that people understand about context affect their behaviour? The proximity of effect could be explored looking at how wide ranging are the impacts or benefits - are they local or more distant?

Group 3 Policy and management

1. Regulatory responsibilities of the recovery activities

The way the EA/SEPA assesses a product depends on its end use. Reed cutting for thatch versus that for compost may be differently regulated. Regulators need a demonstration of the underpinning science behind a proposal for any new process or material. There is a lack of knowledge of nutrient levels and range of values by nutrient type in the recovered biomass and while regulators need underpinning science to base their decisions on, scientists want to know what regulation will be imposed before they start along a certain path. This paradox needs to be addressed. QA/QC of end products is needed and we have to find ways to value the products in monetary terms. Part of this could involve developing an understanding of the global economic context of the security and price trends for N and P.

2. Incentivising end users

Can we find ways to demonstrate proof of concept of a new approach/product to farmers? Labelling for N, P, K and developing a standardised product in physical form as well as nutrient composition will be important. When marketing organic fertilisers we need to make farmers aware of the availability of nutrients as well as totals. The relative merits of financial incentives and/or environment taxes should be investigated and the possibility of a producer responsibility levy on the fertiliser and detergent sectors. In this area it may be wise to look at the practicalities of how to market a product if current suppliers give their goods away as loss leaders to close out competition.

3. Scale of production

We do not yet know the size of the biomass resource and what data is available to estimate this. How to quantify this must be settled early ie total biomass versus nutrient availability and it may be possible to develop a nutrient matrix for harvesting.

4. How to optimise the interface between nutrient recovery and AD

Using AD as a component of the route to managing AP&AB could be a valuable avenue for investigation. AD units are getting smaller and this offers the possibility of proximity to the source material. Would it be possible to use biomass mapping to identify other useful sources of materials synergistic with AP&AB for co-treatment as a means of improving scale? (Thomas Kurka – Abertay University Biomass Mapping PhD).

5. Identification of SUDS systems to capture diffuse sources of soil nutrients (ties in with Owen Fenton – SUDS and living water systems)

There may be ways of growing AP&AB in SUDS to capture nutrients. The development of optimised SUDS design and integration of applied nutrient capture systems for different types of diffuse and point source nutrient losses. A user design manual that addressed the issues of what to grow for nutrient recovery would be a valuable resource.