

Balancing food security and environmental concerns: challenges of sustainable intensification on land and at sea

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Sustainable intensification and cleaner freshwaters: are the two compatible?

Dr Mike Dobson, Director, Freshwater Biological Association

The context for the sustainable intensification of food production

Climate change is causing and is likely to continue to cause a decrease in crop yield. At the same time, society needs to find a means to feed nine billion people (over-consumption by many in the developed world means that this is actually equivalent to around 10 billion mouths to feed) by 2050. Alongside the sustainable intensification of food production there is a need to reduce food waste and, in particular in the developing world, increase the ability of farmers to store and transport their produce to markets.

Sustainable intensification can be understood as the need to increase food production from a given area, closing the yield gap, whilst operating within environmental limits.

Methods of sustainable intensification:

- Developing and planting new crop varieties;
- Practising precision agriculture (in the application of water, pesticides and fertilisers);
- Contour farming, cover crops and reduced tillage.

In the UK we need to prevent further deterioration and reverse deterioration which has already taken place. We also need to maintain good ecological and chemical conditions in freshwaters. We know what we need to do to prevent the deterioration of land and freshwater in this country. But can we maintain good conditions whilst increasing pressure on the land?

Prior to human clearance over 85 percent of the UK was covered in trees. Now much of what remains is intensively managed.

In the east of the country in particular, arable cultivation causes clear physical disruption. In the west there is intensive livestock grazing, along with associated trampling and other processes.

The impacts of agriculture on freshwaters

Agriculture has detrimental impacts on freshwaters. Rivers are found at the bottom of slopes, so residues from agriculture and other sources inevitably run into them.

The Defra funded demonstration test catchment project has provided new insights into factors affecting water quality, for example heavy rain in March 2012 led to a huge pulse of nutrients into rivers. This led to a loss of nitrogen fertiliser from agricultural land, with consequent financial loss. The ecological consequences of nutrient inputs such as this include eutrophication, with deoxygenation and algal blooms.

Increase in system resilience is required, including reinstatement of hydrological separation. Solutions include reducing run-off through the use of buffer strips. However field drains, pipes draining water from agricultural land directly into water bodies, may bypass these measures.

Sedimentation has emerged as a significant issue in recent decades, with consequences including the smothering of habitats and deoxygenation of freshwaters. Solutions include the installation of sediment traps and adjusted ploughing regimes.

The impacts of agriculture on riparian habitats include a reduction in shading as trees and shrubs are cleared from river banks. This also has consequences for the heterogeneity of the habitat, leading to simplified structures and reduced inputs from terrestrial detritus. One solution is to restore appropriate buffer strips at the boundaries between agricultural land and waterways.

The abstraction of water also has consequences for freshwaters, with excessive abstraction leading to flow stress and an increase in the concentration of contaminants. Planting varieties of crops that can tolerate drier conditions is one means to reduce the need to abstract water for agricultural purposes.

Solutions for sustainability

Solutions include greater efficiency in agriculture: reducing nutrient inputs will save farmers money. Sediment reduction in contrast costs money initially but benefits are eventually seen in increased production.

Agricultural intensification is possible whilst reducing some immediate impacts on freshwaters. The total restoration of degraded systems is not possible but significant improvements can be achieved. Technological solutions are possible but are currently poorly used; there is a need for greater experimentation.

In solving problems in the UK however, we need to be careful that problems are not exported to other countries through an increased reliance on imports. A global view is necessary to develop sustainable agricultural systems.

Do agri-environment schemes protect and improve freshwater ecosystems?

Dr Iwan Jones, Queen Mary University of London (QMUL)

Overview of the project

The Common Agricultural Policy (CAP) accounts for over 40 percent of the budget for the European Union (EU). Agri-environment schemes financed by the CAP have been running in most EU Member States for over 10 years; these measures are voluntary for farmers to adopt. Monitoring of agri-environment schemes has taken place, but with the focus largely on terrestrial plant and animal communities. However the design of these schemes often makes it difficult to evaluate, in a robust manner, whether the schemes have been effective at reducing impacts on freshwater systems.

The Welsh Government asked a consortium comprised of ADAS, the Centre for Ecology & Hydrology and QMUL to carry out a project evaluating the success of two agri-environment schemes in Wales in improving water quality; Tir Cynnal (in which a moderate level of intervention was practised by farmers, similar to the Entry Level Stewardship scheme in England) and Tir Gofal (with a level of activity equivalent to England's Higher Level Stewardship scheme).

Over 1,000 small stream catchments were selected at random. These were then filtered until 80 catchments remained, across Wales, where catchment land-use was dominated by one of the two schemes or by agricultural land not in any agri-environment schemes, the control group. Each stream was monitored for one year, with invertebrates, macrophytes, habitat and sediment assessed. Telephone surveys were carried out with farmers across Wales, asking them questions about local conditions and farming activity.

The ADAS pollution transfer model was used to predict pollutant concentrations in each of the catchments. The model was tested against Environment Agency monitoring data. The majority of the nitrate entering rivers across Wales appeared to have originated from agriculture.

Results

The researchers expected to find that ecological condition, based on invertebrates and aquatic plants would be lowest in those streams in the 'not in scheme' control group, and highest in the streams draining catchments dominated by the Tir Gofal agri-environment scheme. Instead no difference was found, which was unexpected. Neither were levels of an invertebrate-based index of pesticide sensitivity (SPEAR) found to be significantly lower in the 'not in scheme' than in the agri-environment scheme sites. Few differences were found in ecological condition between sites based on the methodology used by the research consortium.

However, strong correlations were found between modelled diffuse pollution levels and biological indicators of organic pollution, eutrophication and the impact of pesticide runoff, which indicate that this approach is a robust way of understanding the impacts of management practices on water quality. Coupling of biological responses to modelled diffuse pollution provided a method to ground truth the models and an opportunity to use the models to predict ecosystem level effects of a range of scenarios of scheme activity. By modelling the change in farming activity on scheme entry, based on the information from the telephone survey, the project did find that the enrolment in the Tir Cynnal and Tir Gofal schemes had a large impact on the diffuse pollution running off into the rivers that were monitored.

Overall, the impact of farms of entering the schemes on water quality was found to be limited in many areas but with a very large effect in some areas. The schemes are having a profound effect on small areas where they are intercepting the run off of agri-chemicals into waterways. Elsewhere scheme activities may be directed towards other goals (e.g. enhancement of terrestrial habitat and species). Overall the team found that current agri-environment schemes in Wales do result in improved water quality, particularly with respect to pesticide load, sediment and nutrient pollution.

Impacts on source habitats of water abstraction for agriculture and aquaculture

Professor Anne Robertson, University of Roehampton

Electricity generation accounts for the most significant level of abstraction in non-tidal waters. Abstraction for the public water supply is the next most important drain on resources. Agricultural use accounts for a relatively minor proportion of abstraction, but is often greatest at driest times of year. Seventy percent of the water abstracted is returned to freshwaters but not necessarily in the same condition or in the same location.

In the UK, approximately 10 percent of freshwater is used for abstraction, excluding electricity generation. However there are large regional differences in this figure. East Anglia, London and south east England all abstract water to a greater extent than the national average. Over 20 percent

of water bodies in the UK are considered stressed. In the south east of the UK this rises to 22 percent; the only other areas of Europe that have a similar index are very dry areas. It is predicted that there will be a five per cent increase in demand for water from abstraction by 2020.

The impacts of abstraction on source habitats (with interactions between all of these impacts) include:

- Reduced velocity of water flow, with consequent effects on the respiration and behaviour of organisms;
- Reduced discharge, with impacts on habitats;
- Increased temperature of water in areas of low flow, impacting upon the metabolism of fish, for example;
- Less dilution of effluents, with impacts on water quality;
- Fine sediment deposition, clogging interstitial spaces and reducing taxonomic diversity.

Reduced flows, caused by sedimentation as a consequence of abstraction, reduce connectivity at multiple levels in the river. Connectivity may be reduced longitudinally, from source to estuary, which may influence fish migration. Connectivity may be reduced laterally, between the river and its flood plains, or vertically, within the water body itself, compromising the connection to the hyporheic zones (areas underneath the stream bed).

Hyporheic zones are very important as they are vital to the biogeochemical transformation of nutrients and heavy metals. These zones can be thought of as 'the river's liver' due to their function in detoxification. Hyporheic zones can also act as refugia for organisms during disturbances to the water's surface. An increase in sedimentation reduces this capacity.

There are significant knowledge gaps with respect to the ecology of groundwaters and how this may be affected by abstraction; monitoring focuses on the chemical quality of waters. For example, the oldest lineage of the *Niphargus* genus (crustaceans), has survived in UK groundwaters since the Miocene, thriving in cracks in aquifers. What might the impacts of abstraction be on these organisms?

Conclusion

Although the abstraction of water for agriculture and aquaculture is relatively minor, these uses exacerbate other consequences of low flows, leading to multiple interacting problems in source habitats. The impacts of abstraction on unique freshwater groundwater ecosystems is unknown and more research is needed.

Aquaculture: food and energy from the sea

Dr Kenneth Black, Scottish Association of Marine Sciences (SAMS)

Globally aquaculture will overtake wild fisheries as a source of food in approximately 2018.

Scotland has the largest aquaculture industry in the UK and is a major producer of salmon; the economic value of the Scottish aquaculture industry already exceeds that of wild fisheries. On average, farming Atlantic salmon generates 2.9 kilogrammes of carbon dioxide per kilogram of the edible parts of the fish. This is slightly higher than chicken (2.7 kg/CO_{2e}/kg) but substantially less than beef (30 kg/CO_{2e}/kg). Salmon provides a 63 percent edible yield, which compares favourably to chicken, lamb and pork.

Prior to intensive aquaculture, alternative markets were found for aquafeeds. Increased demand for these feeds from aquaculture has led to higher prices, with resulting efforts to find alternative terrestrial sources for these, rather than fish sources.

Farmed salmon are fed high-energy diets with high levels of both oil and protein. Fish oils and meals in feeds are being substituted with terrestrial oils and meals without affecting fish health and growth, but do not produce the same levels of Omega-3 fatty acids in the product. At present, some fish meals and oils are required in diets to finish salmon for market. While substituting terrestrial for marine ingredients is essential given the finite supply of forage fish, some retailers only sell salmon fed solely from fish sources.

Much research effort is being expended on developing aquaculture feeds from marine algae and yeasts, but most significantly from terrestrial plants. Using genetic modification (GM), there is the potential to produce plants bearing seeds containing omega 3 fish oils (which contain fatty acids not found in vegetable oils). It is proving difficult to engineer plants to produce DHA (Docosahexaenoic acid; one form of Omega 3 fatty acid); efforts to reproduce a second fatty acid, EPA (Eicosapentaenoic acid), are proving more successful. There remain questions regarding whether the public will wish to eat fish oils synthesised using GM technology.

At present globally humankind produces 1,500 kilotonnes of farmed salmon per annum. Feeding the amount of fish needed to produce this yield on purely vegetable sources of aquafeed would require an area of land equivalent to half of the size of Denmark. Feeding vegetable sources to farmed fish is not therefore sustainable and cannot be seen as a panacea.

One solution is to feed farmed fish alternative marine sources of food. Most mesopelagic fish are not exploited at present whilst krill could also offer an alternative feed source. However the use of krill is controversial owing to its importance in the Antarctic food web and a great deal of effort, immediately, on deck, must be put into processing it once it is caught. Copepods are another alternative but catching them is likely to be very energy-intensive, requiring a huge amount of energy to drag a net through the sea to harvest them. One species of copepod, *Calanus*, however is attracted to the surface by very fine bubbles, which could provide an alternative harvesting technique.

In the context of predicted human population growth, cultivating and subsidising terrestrial biofuels is unsustainable when this is practised on land needed to grow food. Marine biofuels could offer an alternative and through these, in particular macroalgae, aquaculture can contribute to decarbonisation of the global economy. Macroalgae can be cultivated as an energy crop at sea, where production is not in competition for land space, synthetic fertilisers and freshwater. The algae are very fast growing and can generate a huge quantity of biomass. Seaweed is already farmed in China and other Asian countries on an industrial scale; the most abundant aquaculture product in the world. Intensive work is put into strain selection and nursery practices. Anaerobic digestion of the seaweed is used to produce gas for domestic consumption – fermentation to ethanol or butanol provides useful transport fuels.

Why aquaculture can't grow: how integrating socioeconomic data can inform governance, policy and planning

Professor Selina Stead, Newcastle University

In the past, there has been a surplus of meat, largely supplied from terrestrial sources and to levels beyond demand, but this is now reaching a limit. There is therefore increasing interest in aquatic sources of protein. Aquaculture has received little attention from policy-makers because it has traditionally represented a very small proportion of total food production globally. Aquaculture is now the world's fastest growing food production sector and therefore has the potential to supply protein to meet the shortfall in predicted demand. To date most of this expansion has been in Asian countries.

Rates of food production from aquaculture have not increased greatly between 2002 and 2010, in the EU, compared to other forms of food production and to rates in other non-European countries. Europe imports approximately 63 percent of its seafood. It isn't clear why aquaculture isn't being practised to a greater extent, although constraints have been identified through the EU-funded Aquainnova Project¹. These include: the lack of a level playing field for aquaculture producers in terms of limited space and access to water resources; overly bureaucratic procedures for implementation; a complex and time-consuming licensing process; a lack of financial support for the start-up of new businesses and up-scaling of those wanting to expand. As the UK also imports a great deal of its seafood, why aren't England and Wales investing in aquaculture to address this?

There are no policies in Europe concerned specifically with aquaculture, although initiatives are underway examining strategic development. Aquaculture, from a policy and governance perspective, has tended to be considered under the umbrella of agriculture and fisheries. The current reform of the Common Fisheries Policy includes integration of aquaculture, which is encouraging given that there are overlapping interests within the fisheries sector.

A major gap and one of the biggest constraints to why the aquaculture sector can't grow in countries like England and Wales is that there are no policies that take account of the specific socioeconomic and socioecological conditions pertaining to aquaculture. Planning policy also does not deal adequately with the possibility to co-locate aquaculture with other uses of the marine environment (for example, integrating aquaculture at sites for offshore wind farms).

Aquaculture is commonly seen as a private good, as with agriculture. The public have also in the past held negative perceptions of aquaculture.

To develop aquaculture for the future, planning regulations must be amended to consider the delivery of multiple benefits, and farming of different species, at different sites and at varying spatial and temporal scales (for example integrating aquaculture with wind farms at sea or on land).

¹ 'Aquainnova' – "Supporting governance and multi-stakeholder participation in aquaculture research and innovation" - an FP7 project focusing on the creation of an international framework that will facilitate the development of vision documents and strategic research agendas on the sectoral components of European aquaculture.

Aquaculture as a business has shown extreme sensitivity to rapidly changing markets with many smaller enterprises being unable to buffer rapid falls in product prices. An area which deserves greater attention, especially in England and Wales, is the investigation of new and alternative species for aquaculture that can meet areas of growing demand. One potential and expanding area is the growing demand for Asian cuisine in the UK (local market) and overseas (export market). Newcastle University have been exploring the potential for farming sea cucumbers as a food source and as a way to clean up unwanted waste from fish farms. Sea cucumber can sell for around £45 per kilo, so could be a lucrative investment, although further work is needed to evaluate the production cycle.

Aquaculture has traditionally had a negative reputation in Africa, where it has failed previously when introduced, due to socioeconomic factors not being taken into account. Recent research has shown that countries with limited resources and issues surrounding food security and livelihood options should investigate where and how aquaculture could represent a viable alternative or supplementary livelihood. Sea cucumber aquaculture is being examined in Tanzania to see whether this livelihood can take pressure off fishing and be a source of income generation. Whether this form of aquaculture can alleviate poverty in communities socially and economically dependent on marine resources, such as depleted stocks of sea cucumbers and marine finfish, is being investigated.

Professor Stead and colleagues have found that levels of community support can be increased if the local context-specific characteristics are known such as the socioeconomic drivers to support development of aquaculture. There is evidence to suggest that aquaculture will be more likely to succeed when incentives and disincentives are known about the targeted end-users.

Conducting a Bayesian Belief Network (BBN) revealed that levels of education, time available and household income all affected the likelihood of take-up (and willingness to take-up) of aquaculture. An area of current research is exploring advanced modelling tools like BBNs to suggest where can be best to site and introduce aquaculture enterprises.

What could the UK do to support sustainable aquaculture?

There is a need to diversify aquaculture; there are a great many species that could be cultivated in this way in the UK but there is a tendency simply to focus on salmon. Thus there is a need for the UK government to explore aquaculture more widely as part of its agenda to address food security issues.

One limitation to the development of aquaculture is the lack of interdisciplinary working between researchers in the natural and social sciences; this needs to be addressed for aquaculture to grow and to realise its full potential. Professor Stead has recently completed a project funded by the Valuing Nature Network to examine how social, economic and ecological data can be integrated when introducing management interventions.

Overall, aquaculture can contribute to food security if appropriate management, planning, policies and governance structures are in place.

Questions

Should land sharing or land sparing be practised in managing the landscape?

Both; a minimum level of protection is necessary, sacrificing some areas whilst focusing protection on others. However, we now have the ability to more precisely target options to increase benefits.

Are we doing enough through agri-environment schemes in the UK to encourage sustainable agriculture?

Agri-environment schemes need to target those areas where the greatest return on investment is possible. Farmers need to be consulted on how to achieve the best outcomes for the environment from their land. Understanding human behaviour and incorporating knowledge from the social sciences to a greater extent is important when understanding how to develop successful policies for both agriculture and aquaculture: support for and engagement with policies on the part of stakeholders is important for these policies to work.

Agri-environment schemes are voluntary. Pollutant loads in watercourses depend upon take up of options and approaches by farmers, which in turn depends upon their preferences. The Department for Environment, Food and Rural Affairs (Defra) in England can offer advice but this can't be enforced: rules for compliance and enforcement could be stricter than they are.

More self-sustaining practices are needed as once payments for agri-environment schemes end it is challenging to encourage farmers to maintain sustainable farming practices in the longer term.

Why is there an imbalance in government effort with respect to incentivising and encouraging the development of fisheries and aquaculture?

The investment and focus of many governments, including Scotland, is on wild fisheries not aquaculture. There are targets to increase salmon production in Scotland, lifting the limits on the biomass that can be produced by salmon farms. This is likely to lead to a huge increase in tonnage and will bring down the cost of the product.

The lack of specific policies to deal with aquaculture, and the consideration of this industry instead under the banner of agriculture, leads to the imbalance between fisheries and aquaculture.

What are the ecological impacts of the large-scale, industrialised cultivation of macroalgae at sea?

It is difficult to ascertain as research has all been published in Cantonese and Mandarin. Industrialisation of seaweed farming on the scale seen in China would not be possible in a democratic country. China is therefore a very important place to learn lessons about the ecological impacts of large-scale aquaculture of macroalgae, but the answers are not forthcoming at present.

There are some positives. For example, some integrated farming is practised, with fisheries operating alongside seaweed production; there is therefore some recycling of nutrients. Products other than biogas can also be generated from seaweed farming, such as low-sodium salt. Seaweed farming also increases available habitat and surfaces in the sea for other organisms to take advantage of.

However, as with intensive agriculture, as soon as aquaculture is practised at an industrial scale, negative consequences emerge such as habitat change, habitat loss and fragmentation.