Grazing, trees and trout 24th June 2017

Feed the land . . .

Peter Cunningham
Skye & Wester Ross Fisheries Trust
info@wrft.org.uk
Feed the land . . .

1. What is fertility?
2. Fertile places in Wester Ross
3. Ecosystems and nutrient flow
4. Deforestation, fire and loss of fertility
5. Animals and phosphorus export
6. How to conserve and replenish phosphorus?
In Wester Ross, soils are thin and generally infertile:

Land of glaciated mountains, lochs and short, swiftly flowing salmon rivers . . .
underlain by Torridonian sandstone and Lewisian Gneiss.

hard, resistant to weathering, un-yielding rock.
Barren mountains . . .
Sparsely vegetated slopes

Beinn Damh forest: where are the trees?
Trees cling to inaccessible ledges

Abhainn Dearg
Unstable rivers

Strath na Sealga, upper Gruinard: note alder woodland along floodplain
Uninhabited ‘wilderness’ . . .
with ‘near pristine’ oligotrophic lochs . . .
unproductive grazing areas . . .
... a naturally infertile, nutrient deficient, unproductive landscape?

Sundew

Bog asphodel

*Narthecium ossifragum*

"bone breaker"
1. What is fertility?

**Soil fertility**: refers to the ability of a soil to support plant growth.
A fertile soil has the following properties:

• It is rich in nutrients necessary for basic plant nutrition, including nitrogen, **phosphorus** and potassium;

• It contains sufficient trace elements for plant nutrition, including boron, chlorine, cobalt, copper, iron, manganese, magnesium, molybdenum, sulphur, and zinc;

• It contains soil organic matter that improves soil structure and soil moisture retention;

• It contains a range of microorganisms that support plant growth.

Phosphorus

Phosphorus is essential to all life forms.
Humans are approximately 1% Phosphorus

Too much phosphorus causes eutrophication

One of our greatest government-led achievements for the environment, to date, has been the cleaning-up of 'eutrophied' waters.
However, there are many parts of the world where levels of fertility have fallen as a result of human impacts.
It was during the work on the nutrient aspects, that I realised that phosphorus was the key limiting nutrient in many ecosystems, eg forests, heather moorlands and upland grasslands here in the northern UK.

https://www.youtube.com/watch?v=RNUSgY2NbFM
Biological productivity in Wester Ross is primarily limited by the availability of phosphorus, P

(refs: e.g. McVean’s fertilisation trials at Beinn Eighe NNR)
How does phosphorus availability vary across Wester Ross? Is the distribution and availability of phosphorus in the landscape entirely natural?
2. Some fertile places in Wester Ross

The Island of Longa (Loch Gairloch) is enriched with nutrients from nesting sea birds, and provides good winter grazing for sheep.
Islands around Loch Ewe have also been fertilised by sea birds.
Eilean Furadh mor
Isle of Ewe: breeding area for Greylag geese and herring gulls

Seagull pellet
Upland areas in Wester Ross are not uniformly infertile . . .
Rocks and knolls in prominent positions in upland areas have been enriched with nutrients delivered by birds and mammals.
Eagle pellet (containing fur) and grouse dropping from a green knoll in the Tollie Hills
Why is this rock green?

Otter spraint with fish bones.
The Little Gruinard River

(Special Area of Conservation for Atlantic Salmon)
Most Atlantic salmon return to freshwater only once to spawn . . .
Salmon jaw and primroses, as found, May 2010
In the past, many more salmon returned to Scottish rivers from the sea each year.

How much marine nutrient was transferred to terrestrial ecosystems in Scotland in the past?
“…what if I told you that the trees are here, in part, because of salmon? That the trees that shelter and feed the fish, that help build the fish, are themselves built by the fish?”

-- Carl Safina, essayist for *Salmon in the Trees*
Juvenile salmon survey

Plenty of salmon fry and parr in the main river . . .

. . . but many of them are very small . . .
Gairloch Primary 6 and 7 pupils on a Life in Lochans fieldtrip.

Near redds lots of small fry

At loch outlet fewer big fry
Small fry . . . . . . . . . and small parr

Lower Flats of Little Gruinard
Below Fionn Loch outlet

Big, faster growing, one year old parr
Where juvenile salmon densities are high, growth tends to be slower. Where juvenile salmon densities are low, growth tends to be faster. Juvenile salmon production is determined by habitat area, food availability and stream fertility.
Food for trout and juvenile salmon
Fionn Loch islands, Little Gruinard catchment.

Trees!
(no grazing)

Fionn Loch Trout (caught by Ala MacKenzie)
Boulders with berries *in* the Little Gruinard River
Boulders with berries in the Little Gruinard River
A forest on a boulder?

May, 2010

September, 2016
Succession: a forest on a boulder

Q. Where does the phosphorus come from?

- Lichen, moss; meadow pipit.
- Bird droppings.

- Lichen, moss, grass, heather, rowan tree; spider’s web, meadow pipit
- Bird droppings, spider droppings, trapped midges . . .

- Lichen, moss, grass, heather, blaeberry, rowan tree; spider’s web, crow perch
- Bird droppings: crow, thrushes, pipits, wren; spider droppings; dead insects . .

- Lichen, moss, grass, heather, blaeberry, rowan, birch, juniper, crowberry, bearberry, juniper, willow; spiders web; wren, stonechat, bird’s nest . . .

- Bird droppings; Pine marten droppings; spider droppings, dead insects . . .
Isolated oak tree, North Erradale (where crows and a buzzard often perch)
Leopard with antelope in acacia tree
Fertile places can be found around houses.

Glen Torridon September 2010
(big) Gruinard River headwaters

Sheneval bothy at the foot of An Teallach is popular with hill walkers (and salmon poachers!) . . .

Nearby soils are richer in earthworms and support a (?healthy) population of moles . . .
Sheneval bothy at the foot of An Teallach is popular with hill walkers (and salmon poachers!) . . .

Nearby soils are richer in earthworms and support a (?healthy) population of moles . . .

The stream is green and mossy . . .
... and supports fat, healthy salmon parr ...
These are oak trees!!
Break – any questions?

Succession . . . sustained by P imports?
3. Ecosystems and nutrient flow

Why is there a greener patch in the bog . . . ?

Bog near Redpoint (2002)
There is a lot of bog in Wester Ross!
Temperate rainforest
Temperate rainforest . . .

[. . . or rainwood (Fenton, 2016) . . .]

. . . can be found around Loch Gairloch . . . supporting a high diversity of epiphytes.
Fallen Douglas fir in Flowerdale

This decomposing tree now supports a diverse assemblage of lichens, mosses, ferns, grass, blaeberry, cotoneaster, a small rowan tree, and a birch tree.

Look: no soil! (except the birch)

Nutrients are being obtained almost entirely from the decomposing tree.
Soil fertility: the ability of a soil to supply plant nutrient

**Ecosystem fertility**: the ability of an ecosystem to circulate life-sustaining nutrients to its component parts (?

*(from ‘Refertilising Scotland’ presentation at ‘Reforesting Scotland’ meeting in Torridon Community Centre, September 2010)*

?Fertile & productive ecosystems need not be dependent upon fertile soils if nutrients can be recycled and circulated within the biota
Ecosystem Fertility: A new paradigm for nutrient availability to plants in the humid tropics

Tadakatsu YONEYAMA¹, Toshiaki OHKURA² and Naruo MATSUMOTO³

¹Department of Applied Biological Chemistry, the University of Tokyo, Yayoi 1-1-2, Bunkyo-ku, Tokyo 113-8657, Japan, ²National Institute for Agro-Environmental Sciences, Tsukuba, Ibaraki 305-8604, Japan and ³Japan International Research Center for Agricultural Sciences, Tsukuba, Ibaraki 305-8686, Japan

Abstract

Soil fertility has been an important factor in sustainable plant production in native and agricultural fields in temperate climates such as that in Japan. Soil fertility is assessed based on the availability of nutrients, in particular inorganic nitrogen (N) and phosphorus (P), from soil-accumulated organic matter (SOM) via microbial immobilization and mineralization. However, the pool sizes of SOM in humid tropics such as those in Thailand are small and they are turned over rapidly; under such circumstances, the tropical soil fertility would soon be depleted. To meet the urgent requirement of plant nutrients for high plant productivity, we define a direct supply of plant nutrients (i.e., residue fertility) from raw plant and microbial residues. The residue fertility may be driven by the activities of soil fauna (e.g., earthworms, collembolans, termites) and micro-organisms (e.g., saprophytic fungi, protozoa, bacteria), and the released nutrients may be collected and absorbed directly by plant roots including root hairs, and via arbuscular mycorrhizal hyphae. Here, we propose the Ecosystem Fertility paradigm: the Ecosystem Fertility may consist of various ecological nutrient availabilities including both residue fertility and soil fertility. The structure and function of Ecosystem Fertility driven by the above-mentioned biodiversity in different ecosystems may supply not only inorganic N and P but also various forms of nutrients. However, the underlying mechanisms of the Ecosystem Fertility remain to be determined. For the quantification of the various activities and routes involved, the use of molecular and ecosystem approaches may be highly valuable.

Key words: biodiversity, decomposers, ecosystem fertility, nutrient release, organic matter, soil fertility.
Phosphorus availability is dependent upon ecosystem processes.
Simplified Phosphorus budget model!

Ecosystem
(can be whatever scale you choose)

Soil / Sediment
(P ‘bank’)

Biota P

P cycling

P imports

P exports
Phosphorus budget

**P imports**
- Anthropogenic (food, fertiliser, detergents, etc.)
- Physical and chemical (atmospheric deposition, rock erosion)
- Biological (wild plant and animal materials)

**P exports**
- Anthropogenic (livestock, crops, timber, effluents, etc.)
- Physical and chemical (erosion and leaching)
- Biological (wild plant and animal materials)

**P cycling**
- Soil (P ‘bank’)
- Biota P

**Ecosystem**
Rainforests are forests characterized by high rainfall, with between 2500mm and 4500mm of rain per year.
Tropical Rainforest

**P imports**
- Anthropogenic
  - Physical and chemical (atmospheric deposition, rock erosion)
  - Biological (wild plant and animal materials)

**P exports**
- Anthropogenic
  - Physical and chemical (erosion and leaching)
  - Biological (wild plant and animal materials)

**P cycling**
- Soil (P ‘bank’)
- Biota (P in biomass)

Ecosystem: highly evolved & biodiverse
Deforested hills in Madagascar . . .
Cleared tropical Rainforest
Cleared tropical rainforest (e.g. for oil palm)

P imports
- Anthropogenic (food, fertiliser, detergents, etc.)
  - Physical and chemical (atmospheric deposition, rock erosion)
  - Biological (wild plant and animal materials)

P exports
- Anthropogenic (carcasses, crops, timber, effluents, etc.)
  - Physical and chemical (erosion and leaching)
  - Biological (wild plant and animal materials)

Biota P
- Soil (P ‘bank’)

P cycling much reduced

Ecosystem: biodiversity collapses
Intensive agricultural area
Intensive agricultural area

P imports
- Fertiliser
- Physical and chemical
- Biological (e.g. geese!)

P cycling
- Soil (P ‘bank’)
- Biota P

P exports
- Crops
- Physical and chemical (soil erosion and leaching)
- Biological (e.g. geese)

Ecosystem?
Traditional agriculture
Crofting townships around the coast

Melvaig and Alltgrishan in 2004
Traditional agricultural area

Agricultural Ecosystem: people are a part of the system

P imports

Anthropogenic

Physical and chemical

Biological

P cycling

Soil (P ‘bank’)

Biota P

P exports

Anthropogenic

Physical and chemical (erosion and leaching)

Biological
Ecosystem nutrition: forest strategies for limited phosphorus resources

https://www.bodenkunde.uni-freiburg.de/forschung/SPP1685
Break – any questions (or answers)?
4. Loss of vegetation, fire & phosphorus export

http://www.ross-shirejournal.co.uk/News/Fresh-spate-of-Ross-wildfires-spark-muirburn-warning-01042013.htm
Hillsides are burnt to promote fresh growth.
Little Gruinard River, May 2010 (inside fenced enclosure)

Wildfire in 2007
Vegetation on this boulder survived the fire.
25% of the P in vegetation and leaf litter was lost on burning and not recovered within 10 years, representing a loss of over 2kg of P per ha.

(2kg P is the equivalent to that in about 4 sheep)
Beinn Eighe National Nature Reserve

*(now core nature conservation area in Wester Ross Biosphere)*
How ‘natural’?
Refertilising Wester Ross, Beinn Eighe NNR, 7th April 2016

Link to meeting reports: http://www.wrft.org.uk/downloads/files.cfm?id=39
Beinn Eighe NNR field excursion 7th April 2016

Setting off through the pine wood . . .
Beinn Eighe NNR field excursion 7th April 2016

*Heading up the Pony Path*
Rob Dewar examining a juniper bush on one of the knolls. We were discussing how pine marten and other animals visit these places and leave their droppings, providing additional nutrient for plant growth.
Close up of grouse droppings by bearberries on the knoll in the previous picture. Ro Scott was the first to spot the bearberries! Wouldn’t it be a fine thing to have more bearberry bushes in Wester Ross.
At the opposite end of the fertility spectrum to the ‘green knolls’ are areas of ground which support very little vegetation. A typical example is shown below. Soils have been trampled and washed away, and the plants that are present (note bog asphodel flower stalks in picture below) are indicative of very low nutrient status.
Stunted pine trees:

The tree in the picture has only its last year’s stunted pine needles. Ken Knot explained how the trees adapt to nutrient stress: where there are inadequate nutrient, the trees shed their older needles after reabsorbing some of the nutrients which they can use to grow new needles. This tree is just surviving in no more. Nearby was a similar sized tree that had died.
‘Naturalness

Below about 400 m the vegetation has evidently been modified by a combination of woodland clearance, grazing by sheep and deer, and moor-burning.

The vegetation of much of the higher ground, above the natural upper limit of woodland, appears to be unburnt and so lightly grazed that it may well be in a near-natural state.’
Fertilisation trials were carried out on Beinn Eighe NNR in the 1960s by Donald McVean to find out how to enhance soil fertility and establish tree seedlings. Details are sketchy, but 50 yrs on, results could still be clearly seen. Looks like the trial was successful??
Inside area fertilised

- 100% soil cover
- Thicker vegetation including all plants seen outside area except club moss.
- Scabious and tormentil also present.
- Spiders seen.
- Grouse droppings.

Outside area fertilised

- ~50% soil cover
- Patchy vegetation
- Club moss
In June 1961 D.N. McVean applied phosphate fertiliser at 3 oz to the square yard to two small rectangular plots within M15c(ii) Trichophorum-Erica wet heath on quartzite at NH 003 621.

‘The treated vegetation is now more continuous than the surrounding sparse M15c(ii) heath.

It has a noticeably greater cover of the moss Racomitrium lanuginosum (50-75%) and the lichens Cladonia portentosa, C.arbuscula and C.uncialis (30-50%) than does the surrounding heath.

The heather is better-grown and supports a richer epiphytic flora, chiefly of the lichens Hypogymnia physodes, Platismatia glauca and Peltigera sp. and the liverwort Frullania tamarisci.

The lichen Cetraria islandica is noticeably well-grown. ‘

‘One cannot say for sure whether the vegetation in the plots which were examined in this survey has become more natural or less natural in the last 36 years.’ (?)
Beinn Eighe NNR hillside

P imports
- Anthropogenic
  - Physical and chemical (unyielding quartzite)
  - Biological

P cycling
- Soil (P 'bank')

P exports
- Anthropogenic
  - Physical and chemical
  - Biological

Ecosystem impoversihed
Inside fertilised area
(50+ years following fertiliser application)

P imports

- Anthropogenic (2008)
- Physical and chemical
- Biological (e.g. grouse droppings)

P cycling

- Biota
- Soil (P ‘bank’)

P exports

- Anthropogenic
- Physical and chemical
- Biological (e.g. insects)

Ecosystem enriched:
higher productivity and higher biodiversity . . .
... c. green knoll

(... more or less natural than the surrounding area?)
Small stunted pine tree near the Pony Path. Note the sparse and patchy vegetation surrounding the wee tree.
‘The intensity of grazing at Beinn Eighe before the arrival of humans is not known; it might have been no less intensive than at present, and it may well have varied over the 7500 years since the establishment of the vegetation in the Boreal period. It is possible that the current grazing intensity (outside the exclosures) is at a more or less "natural" level. Even if this is the case it is evident that the low-altitude heathlands will not readily develop back into woodland.

The previous woodland clearance means that there are now far fewer sources of seeds and the impoverished soils are deficient in the nutrients needed for trees to establish strongly.’
‘... Any saplings which do survive soon become conspicuous in a bare landscape and are preferentially grazed.

**Grazing might need to be reduced to an unnaturally low level for long enough to allow trees to regenerate and soils to recover. This process might take several tens or even hundreds of years.’
5. Animal export

• The removal of deer, sheep or cattle from upland catchment areas represents an unnatural loss of phosphorus from the ecosystem.

• How many cattle sheep and deer have been removed from headwater catchment areas over the past 100++ years?

• How much phosphorus does this represent?

• How much phosphorus has been returned to the areas where the animals grazed?
Human populations were higher in the past in some areas
Have fertility levels changed as a result of land use and wildlife management practices?
How have fertility levels and patterns changed as a result of land use and wildlife management practices?
This map shows all land parcels which have a predominant land use code for Common Grazing.

IACS field register snapshot from 16th January 2010 obtained by permission from Scottish Government Rural Payments and Inspections Directorate (RPID).

Database tables courtesy of Scottish Government Rural and Environment Research and Analysis Directorate (RERAD).


Reproduced from Ordnance Survey map data by permission of Ordnance Survey © Crown copyright MLURI 100019294 2010. All rights reserved.
Fires, peat cutting, grazing and trampling by cattle, sheep and deer have denuded large parts of Wester Ross with loss of vegetation, soil and loss of ecosystem fertility.

Inverasdale grazings area.
In some areas there is very little soil, peat, or organic material left.
Peat cut and removed?

Over 50% of the soil has been eroded and washed away.

What does this represent in terms of lost fertility?
How much less fertile are grazing areas in Wester Ross now than they were in the past?
Vision for crofting . . .

Our Vision for Crofting

19. Crofting is an integral part of life in the Highlands & Islands and can deliver a wealth of benefits to crofters and the crofting community in the Highlands and Islands and other designated parts of Scotland.

20. A well-regulated crofting system will encourage these wider benefits:

- Population retention through occupation of crofts, with associated economic and cultural benefits, including the use of the Gaelic language in Gaelic-speaking communities
- Affordable housing solutions - an incoming crofter of a bareland croft will normally be eligible to apply for support through the Croft House Grant Scheme and apply for reasonable decrofting of land
- Various environmental benefits through the sustainable use and management of crofts and common grazing
- Increased production of livestock and food from crofts
- The strengthening of shared management practices and development of common grazing schemes
- Fairness to individual crofters and owner-occupier crofters.

‘. . . Increased production of livestock and food from crofts . . .’

REGULATION ON COMMON GRAZING – COMMUNITY COHESION THROUGH SHARED ASSETS

28. Crofting provides a unique opportunity through common grazing land to take advantage of the benefits derived from shared management of the common grazing. Reciprocal help between crofters with crofting tasks was also once commonplace and continues today in some places.

29. Through effective regulation of common grazing and support for common grazing committees, the Commission will help:

- Increase self-regulation by grazing committees – grazing committees often carry unrivalled knowledge about crofting in their township
- Increase, where appropriate, stocking levels, crofting activity on common grazing and related activity on crofts
- Strengthen crofting townships and connections between crofters, and encourage best practice on common grazings
- Where appropriate, improve biodiversity by effective management of the natural resources on common grazing land
- Increase the opportunities of management schemes on common grazing
- Increase the opportunities of renewable energy and forestry schemes on common grazing, with associated carbon reductions and associated economic benefits to crofters and crofting communities
- Encourage management of communal assets
- To protect better quality inbye land by encouraging use of common grazing land for affordable housing or community facilities in liaison with planning authorities, as appropriate
- Increase the opportunities for crofting communities to consider community land purchase.

‘... Increase, where appropriate, stocking levels, crofting activity and related activity on crofts...’
SUSTAINABILITY

118. The Crofting Commission will take a long-term view of crofting and the crofting community when discharging its regulatory and executive functions. The Crofting Commission recognises that it has limited powers to deliver sustainable development, even within crofting communities, but will work with other stakeholders and partners in order to assist with Scottish Government sustainable development objectives.

119. A long-term view is a key concept in the sustainability of crofting and sustainable development of the crofting community. In discharging its functions, the Commission will consider the impact of changes on future generations. The Crofting Commission will exercise its discretion to balance the interests of individuals (and enterprises which will support and sustain them) and the interests of the crofting community. The Crofting Commission will use this discretion in the discharge of its regulatory functions to assist crofters and crofting communities, where appropriate, in diversification activities.

120. The Commission will also work, insofar as it falls within its statutory remit, with partners and stakeholders to develop land use strategies and encourage biodiversity on croft land that is protected and/or subject to nature conservation designations.

Is there an objective for restoring and maintaining the fertility of croft land (?).
Break – any questions (or answers)?

How is soil fertility managed in crofting townships elsewhere?
Animal export (continued) . . .

Why is there a greener patch in the bog . . .?
Where nutrients are recycled . . .

. . . from vegetation to sheep, and back to vegetation . . .

• growth of plants - and insects - can be prolific

• more insects: more food for trout, salmon, birds . . .
If deer carcasses are taken off the hill and phosphorus is not replaced. .

http://www.thefield.co.uk/stalking-2/where-to-go-stalking-in-scotland-in-2016-29934
Fertility studies of grazing areas in the SNP

Shultz et al (2006) demonstrated that within the Swiss National Park [SNP] red deer move phosphorus by defecating in different areas from where they graze.

They recognised a long term nutrient depletion from grazed areas within the SNP.
Figure 3. Spatial patterns of A phosphorus (P) removal by red deer grazing offtake, and B P input by red deer dung deposition on the subalpine grassland of Alp Stabelchod. C Relationship between P removal/P input and soil-P pool. D Relation between P removal/P input and short-grass cover. P removal, ○—dashed line; P input, ●—solid line.
In this study, the soil P pool over much of the study area was typically between 200 and 300 kg P/ha.

Across much of Wester Ross (e.g. Inverasdale grazings area; Beinn Eighe NNR) it is probably usually much less than that . . .
Subsequently, Flueck (2009) produced much larger estimate of 0.32 kg/ha/yr of P transfer from out of the Swiss National Park on the basis that most deer die or are killed by hunters outside the park during autumn and winter months.

Is this the sort of analyses that could be repeated for individual estates, Beinn Eighe NNR & Deer Management Group areas to understand long term changes in P availability, and the size of the P deficit?
Phosphorus loss of ~0.1 kg /Ha/yr of P . . . = 10kg /km²/yr of P

http://www.thefield.co.uk/stalking-2/where-to-go-stalking-in-scotland-in-2016-29934
Hypothetical annual P budget example for 1km$^2$ of uninhabited unfertilised Wester Ross deer forest (i.e. open hill) burned every 40 years and stocked at 8 deer per km$^2$ where 1 deer is culled and carcass removed each year

**P imports 4kg**
- Anthropogenic 1kg
  - (Feed block 0.2kg; other humans & dogs... 0.8kg)
- Physical and chemical 2kg
  - (Rain 1kg P; Rock 1kg P)
- Biological (wild) 1kg
  - (Fish, otter and birds 1kg or more if sea birds come inland)

**P exports 13kg**
- Anthropogenic 6kg
  - (Exported deer carcasses 1kg; smoke and ash if burned every 40 years, 5kg [based on loss of 200kg P with each fire])
- Physical and chemical 4kg
  - (soil erosion and leaching 4kg, possibly very much more where soil poached)
- Biological (wild) 3kg
  - (deer faeces in run-off 2kg when soils and vegetation thin; blown grass, leaves, etc. 1kg)

**P cycling**

**Soil (P ‘bank’)**

**Biota**

**Ecosystem: possible net loss of >9kg P per km$^2$ per year?**
Deer Management Groups in Scotland have been preparing a series of management plans . . .

Partly, this has been in response to concerns expressed about the impact of the deer population in Scotland.
The Impact and Management of Deer in Scotland

This document was written as a submission to the Scottish Parliament’s Rural Affairs, Climate Change and Environment Committee.

Introduction

It is now widely understood that Scotland was once a heavily wooded country and that bringing back a good amount of forest cover would have important social, economic and ecological benefits, as well as contributing significantly to Scotland’s climate change targets. The largest single barrier to achieving this is overgrazing, primarily by red and roe deer. Creating new forests on overgrazed land is harder, slower and much more expensive than is on properly grazed land and generally has poorer results.

The current mechanisms for reducing the number of deer to levels that are not damaging have failed, despite having had decades to prove that they can work. It is time to consider the example of other northern European countries with similar climates and ecologies that manage to maintain healthy deer populations and strong hunting traditions alongside high levels of forest cover that provide jobs, recreation and a host of ecological advantages.

The effects of deforestation

Deforestation does not simply remove the trees from the landscape: it causes a cascade of knock-on effects that lead to an ecosystem that is altogether poorer, less productive and less stable. The change in upland land management to large scale sport shooting and sheep grazing that started in 1750 exacerbates these effects considerably.

The loss of shelter from trees means that the remaining plants and animals suffer far more exposure. Stock and wild animals alike have to dedicate much more of their metabolism to simply keeping warm: it has been estimated that two extra degrees of wind chill in cattle leads to a requirement for five pounds worth of extra feed per animal per day. Where the ground vegetation is grazed by animals which crop it short — i.e. sheep or deer — it is generally kept so low that most plants are unable to flower and set seed, removing a valuable food source for invertebrates, small mammals and birds such as capercaillie and eventually leading to the loss of those plants.

In this way, deforestation and overgrazing result in a massive loss of biodiversity. This is shown by the enormous spotting bags of a wide range of species that were reported by the Highland estates during their first years of operation. The numbers recorded then simply do not exist now.

When woodland is removed in a country like Scotland with heavy rainfall, nutrients are leached out of the soil leading to soil acidification and podzolisation. Podzolisation occurs when iron is leached out of the upper soil horizons and is deposited lower down as iron oxide. The iron oxide can then form a hard iron ‘pan’ that plant roots cannot break through. The acidic soils, and shallow rooting depths, are suitable for heathy plant species, such as heather, that produce litter that decomposes very slowly due to the high tannin content. This further acidifies the soil and, in very wet areas, leads to a build up of peat and yet further soil acidification.

On steep slopes, soil degradation, regular burning and continuous grazing lead to soil erosion. This, in turn, leads to faster silting up of lochs and reservoirs. Removal of woodland cover also means that water runs off more quickly, thus increasing the likelihood of floods at lower levels and increasing the drying out of soils during dry spells. Salmon spawning streams become too warm for young fish to survive due to the lack of shade. A lack of deciduous trees along the streambed also means a lack of leaves falling in and providing nutrients for invertebrates and, ultimately, fish.

Continuous high levels of grazing by sheep and deer have also resulted in a spread of less nutritious grass species such as white bent (Bentha arvensis) and purple moor grass (Molinia caerulea). Sheep and deer are selective grazers as they avoid these species, leading to their spread. Cattle, by contrast, are less selective and can keep these species in check. They also trample bracken and so can reduce its cover.

The impacts of herbivores and the consequent decline in the condition and extent of woodland, together with changes in land use and land management, has resulted in:

- nutrient losses from soils
- acidification of soils
- pest formation
- soil erosion and landslides
- silting up of lochs and reservoirs
- flooding
- drying out of soils
- lack of natural tree and shrub regeneration
- spread of rough grasses and bracken
- loss of salmon spawning grounds
- loss of shelter for deer and domestic stock
- loss of species richness and associated biodiversity

Benefits of a forested landscape

To understand what a difference could be made by restoring Scotland’s forests, we need to look at similar countries which have not lost their forests. Norway is a good example as it shares Scotland’s northern, Atlantic climate and mountains terrain but has a different political and land-use history: Switzerland, Austria, Germany and many Eastern European countries also hold useful lessons.

The Deer Management plans follow guidance from SNH.

http://wsutherlanddmg.deer-management.co.uk/
The plans present detailed information about the number of deer within respective areas and set targets for deer numbers and harvest levels for future years.
... detailed targets for deer populations and stocking densities and culls are presented.

http://nwsutherlanddmg.deer-management.co.uk/wp-content/uploads/2015/12/NWS-DMP-Background-Information.pdf

6. Long Term Vision
Members generally support the long term vision for deer populations and their management as laid out in Scotland's Wild Deer – A National Approach. Members also fully support the Code of Practice on Deer Management, and all work is carried out in accordance with Best Practice Guides, which continue to evolve.

- Deer populations will be managed sustainably so that their management is fully integrated with all local land uses and land use objectives.
- Such management will ensure high standards of deer welfare and public safety, and play a constructive role in the long term stewardship of local habitats.
- Local deer management will continue to deliver and further develop its positive contributions to the rural economy. Deer management and wildlife management more generally within the Group will be seen as an attractive and worthwhile occupation associated with high standards of skills and employment practice.

7. Strategic Objectives
The main objectives for the Group’s deer management during the period of this Plan, are as follows, in all cases adhering to Best Practice Guidelines:

(i) To safeguard and promote deer welfare within the NWSDMG area.
(ii) To achieve an appropriate balance between deer and their habitat, and between deer and other land uses, to minimize unacceptable damage to agricultural, forestry or sporting interests, and to maintain and improve the condition of the natural heritage.
(iii) Within the constraint of (ii) and the necessary management culls associated with this, to fulfill the annual sporting and venison production objectives of individual Members. During this plan this will amount to some 457 stags and approx 1130 animals overall annually.
(iv) To maintain a confined but viable population of sika deer in the woodlands in the south of the Group.
(v) To market such activity and produce to best advantage.
(vi) Without prejudice to (ii), to roughly maintain the overall size of the herd over the period of this plan, 2015-20, to bring local numbers in to line with actual sporting and other aspirations in that area, and to facilitate an overall grazing regime that will gradually improve the overall condition of designated sites. It is anticipated that the target summer population will then be some 3148 stags, 3716 hinds and 1337 calves, by 2019, and 3550 stags, 3550 hinds and 1345 calves by 2025, and numbers will be maintained at this level, subject to ongoing reviews of group objectives and regular habitat condition monitoring. The difference in the two population totals is to try and achieve a 1:1 ratio of stags: hinds by the end of the ten year period, allowing numbers to gradually converge over the ten years.
(vii) To ensure such resources, training and monitoring capacity that is required are made available to achieve the above objectives.
However, I can’t find any targets for maintaining the P fertility of deer pasture areas, to sustain levels of deer production?

Has this been investigated?
If deer carcasses are taken off the hill and phosphorus is not replaced.

"These ostensibly mild-mannered herbivores have acquired a murderous interest in the chicks belonging to the large population of Manx shearwaters (Puffinus puffinus) that nest on the ground around this island. Quite simply, the deer frequently bite off the heads of these unfortunate young birds in order to chew their bones. A detailed study, conducted by Glasgow University zoologist Dr. Robert Furness, confirmed the behavior and his findings were reported in 1988.

"The reason for this bizarre activity appears to be that Rhum, which is only a small island, is deficient in certain minerals - in particular calcium and phosphorus - that the deer require to sustain their dietary balance and metabolism. Elsewhere, deer circumvent this problem by chewing their own shed antlers, or even the bones of dead deer. On Rhum, however, which is amply supplied with defenseless shearwater chicks that make easy prey, the red deer have become carnivorous. They kill the birds to supply themselves with bony material to chew on and are therefore able to obtain the minerals they require." (Shuiker 2001:118)
Break – any questions (or answers)?

Do any estates manage the fertility and productivity of the areas where deer may graze?
A salmon carcass represents about 15g of phosphorus, enough fertiliser to produce 5kg to 7.5kg of dried plant material.

Phosphorus budgets: what else can we quantify?

Keith Williams
Phosphorus budgets

200 salmon carcasses contain roughly the same amount of phosphorus as three red deer or about 1,000kg – 1,500kg of dried plant material

\[ \times 200 \quad \text{or} \quad \times 1,000kg \quad \text{or} \quad \times 3 \]

= \sim 3\text{kg of Phosphorus}
balanced ‘biological’ P budget model, e.g.

**P imports**
- Biological 400 salmon / year (6kg P)

**P cycling**
- Soil (P ‘bank’)
- Biota

**catchment area**

**P exports**
- Biological 6 deer removed from catchment area (many others can be cycled within it)
What would happen to deer populations if they were not culled?

Trees for Life: Dundreggan

July, 2010
Locations of deer carcasses after winter 2010
No traces of highest carcasses
(search error or completely scavenged?)
Only tufts of skin from middle carcasses
Picked skeleton of lower carcasse – knawed bones strewn around
Maggot infested remains of carcasses nearest path
How would wolves and bears affect carcass location and recycling of nutrients in a more natural situation?
Where predators are present, nutrients from carcasses are recycled back into the ecosystem.

In the low resource environment of the Arctic tundra, the impact of a muskox (Ovibos moschatus) carcass on surrounding vegetation was still dramatic after 10 years (Danell et al. 2002), which emphasizes that carcass effects may last longer in some systems.

http://www.indefenseofplants.com/blog/2015/12/11/arctic-bone-nurseries
Break – any questions (or answers)?

Green knoll: phosphorus & biodiversity hot spot?
6. How to conserve and replenish phosphorus . . .

http://www.sunfrost.com/images/compost_toilet_full_size.jpg
Some human factors which affect the fertility of ecosystems

• extirpation of top predators (wolves, bear)
• destruction of forests
• burning vegetation
• continuous grazing pressure (cattle, sheep, deer)
• export of phosphorus in animal carcasses

= cultural oligotrophication?
Soils, ecosystem fertility & salmon smolt production in Wester Ross

1. Much of Wester Ross is underlain by hard, insoluble Lewisian gneiss, Torridonian sandstone or Moine granulite, yielding very little nutrients.

2. Soil fertility is therefore dependent upon the retention and cycling of nutrients, particularly phosphate, through the ecosystem.

3. Unlike many rivers in the east of Scotland, there is little human habitation within the catchments of local rivers so little added nutrient from human sources.

4. In the past there were more people living in river catchment areas. Without modern sanitation, they contributed to nutrient recycling and fertility.

5. Historically there were bears and wolves. Wolves eat deer, ingesting bone and recycling phosphates.

6. Peat has formed where sphagnum moss smothers the ground, acidifying the soil and preventing aerobic decomposition.

7. Look for wee green knobs in the peatlands where birds and mammals have enriched the soil: note the increased plant growth and biodiversity.

8. Similar green patches are found along river banks where otters defecate. In the autumn, these otter "spraint sites" may contain salmon bones.

9. Adult salmon deliver nutrients of marine origin to headwater streams especially if their carcasses are scavenged by other animals.

10. Given sufficient phosphate (e.g. bone meal in mammal faeces), elder trees grow in symbiosis with symbiotic nitrogen-fixing bacteria, further enriching riparian soil fertility.

11. Most plants develop mycorrhiza networks with symbiotic fungi which deliver phosphate to plant roots in exchange for carbohydrate.

12. Earthworms help to recycle and retain organic matter and increase the porosity of riparian soils.

13. Heather burning is carried out to convert woody matter to ash, thereby releasing nutrients to promote the growth of grasses and other leafy matter for grazing deer or livestock.

14. Increasingly heavy rain leaches nutrients from soils and washes away ash from fires. Spates erode away the richest riparian soils notably where elder trees have died back.

15. Growth of periphyton is faster where the streambed is stable and stream fertility is naturally high.

16. Flat-headed 'Heptagenid' mayfly larvae scrape periphyton from the streambed. Other mayfly and caddisfly larave gather or filter organic detritus including leaf and periphyton fragments.

17. Salmon parr growth rates are highest where the food supply is richest. Over-winter survival and smolt production may depend upon the supply of mayfly and caddisfly larvae.

18. Well-nourished smolts are better prepared for life at sea than emaciated smolts.
Solution: apply P fertiliser?

Ground Rock Phosphate fertiliser applied initially at 125g / tree

Gairloch Estate: Balle Mor native woodland restoration

Note grass growth
Many estates have developed enclosed woodlands to stabilise streams and enhance food availability.
Gairloch Estate: Balle Mor
native woodland restoration
A deer carcass contains ~1 kg of phosphorus, mainly in bones.

Sand Woodland Grant Scheme (last Sunday – 18th June 2017)
Many trees have died after about 10 years . . . due to exposure, desiccation & starvation ?
Fertiliser was applied initially at only ~10g Multicote fertiliser / tree.

Most trees are still small.

However, this tree was planted on a whole bag of fertiliser (1.5kg) to see what would happen . . .

Trees were planted in ~2006

It is now over 3x the height of all the other rowan trees that were planted nearby at the same time!

Gairloch Estate: Balle Mor native woodland restoration – photos taken October 2016

Thank you to Colin Simpson.
However; note that application rates should be carefully considered . . !!
We may run short of phosphorus in future years.
Phosphorus is a chemical element that is essential to life because of its role in numerous key molecules, including DNA and RNA; indeed, organisms require large amounts of P to grow rapidly. However, the supply of P from the environment is often limiting to production, including to crops. Thus, large amounts of P are mined annually to produce fertilizer that is applied in support of the ‘Green Revolution.’ However, much of this fertilizer eventually ends up in rivers, lakes and oceans where it causes costly eutrophication. Furthermore, given increasing human population, expanding meat consumption, and proliferating bioenergy pressures, concerns have recently been raised about the long-term geological, economic, and geopolitical viability of mined P for fertilizer production. Together, these issues highlight the non-sustainable nature of current human P use. To achieve P sustainability, farms need to become more efficient in how they use P while society as a whole must develop technologies and practices to recycle P from the food chain. Such large-scale changes will probably require a radical restructuring of the entire food system, highlighting the need for prompt but sustained action.
The Human Nutrient Cycle is an endless natural cycle. In order to keep the cycle intact, food for humans must be grown on soil that is enriched by the continuous addition of organic materials recycled by humans, such as humanure, food scraps and agricultural residues. By respecting this cycle of nature, humans can maintain the fertility of their agricultural soils indefinitely, instead of depleting them of nutrients, as is common today.

Food-producing soils must be left more fertile after each harvest due to the ever-increasing human population and the need to produce more food with each passing year. Instead, we deplete our soils of nutrients by discarding organic materials as waste, rather than returning them back to the soil.
Sustainability Challenges of Phosphorus and Food: Solutions from Closing the Human Phosphorus Cycle

Daniel L. Childers, Jessica Corman, Mark Edwards and James J. Elser

Abstract

The Green Revolution has led to a threefold growth in food production in the last 50 to 75 years, but increases in crop production have required a concurrent increase in the use of inorganic phosphorus as fertilizer. A sustainable phosphorus supply is not assured, though, and food production depends on mineral phosphorus supplies that are nonrenewable and are being depleted. Phosphorus is effectively a nonsubstitutable necessity for all life. Because mineral phosphorus deposits are not distributed evenly, future phosphorus scarcity may have national security implications. Some projections show economically viable mineral reserves becoming depleted within a few decades. Phosphorus-induced food shortages are therefore a possibility, particularly in developing countries where farmers are more vulnerable to volatile fertilizer prices. Sustainable solutions to such future challenges exist, and involve closing the loop on the human phosphorus cycle. We review the current state of knowledge about human phosphorus use and dependence and present examples of these sustainable solutions.

Keywords: phosphorus, food security, sustainability, human phosphorus cycle

© 2011 by American Institute of Biological Sciences

http://bioscience.oxfordjournals.org/content/61/2/117.short
Transition towards Circular Economy in the Food System

Alexandra Jurgilevich 1,* Traci Birge 2, Johanna Kentala-Lehtonen 3, Jaisa Korhonen-Kurki 3, Janna Pietikainen 4, Laura Saikku 5, and Hanna Schösser 2,4

1 Department of Environmental Sciences/Helsinki University Centre for Environment, University of Helsinki, Viikinkaari 2A, P.O. Box 65, Helsinki 00114, Finland
2 Department of Agricultural Sciences, University of Helsinki, P.O. Box 27, Latokartanonkaari 5, Helsinki 00114, Finland
3 Forum for Environmental Information/Helsinki University Centre for Environment, University of Helsinki, Viikinkaari 2A, 2209, P.O. Box 65, Helsinki 00114, Finland
4 Finnish Environment Institute (SYKE), Mekhelininkatu 34a, P.O. Box 140, Helsinki 00260, Finland
5 Research Division of Food and Health Sciences, University of Bayreuth, Universitätsstraße 30, Bayreuth 95440, Germany

* Correspondence: Tel.: +358-451-87-6070
+ These authors contributed equally to this work.

Received: 9 October 2015 / Accepted: 7 January 2016 / Published online: 16 January 2016

Abstract: Growing population and increased demand for food are putting pressure on food production and increasing environmental impacts, such as eutrophication and pollution. Food waste is also a major problem. In this article we argue that the food system is not sustainable. Furthermore, we explore the transition towards circular economy using the transition theory towards sustainability. We discuss the transition towards circular economy (focusing on nutrient flow), the consumption stage (using surplus and waste management) and prevention.

Keywords: circular economy; sustainability; food system; food waste; surplus

1. Introduction

Our current food production and consumption has huge negative environmental impacts, such as eutrophication and pollution. Approximately 30%–50% of food intended for human consumption ends up being wasted. Current inefficiency in the food system means we lose about 1.3 billion tons of food every year, or about 1/3 of what is produced. More than $700 billion dollars a year, or even two trillion dollars when social and economic costs are included, is lost to enhance and optimize for sustainability within the Western world. Circular economy uses theory and principles from industrial ecology to enhance industrial metabolism in industrial ecology, which is defined as the study of industrial systems and approaches to making them more ecologically efficient and effective. Industrial ecology is about increasing the efficiency of materials and substances, and reduce both resource consumption and discharges into the environment. Industrial metabolism in industrial ecology refers particularly to the idea of industrial systems working as natural ecosystems. Circular economy is an industrial ecology that is restorative by design and mirrors nature in actively enhancing and optimizing the ecosystems. It applies several principles from nature: production output of waste, resilience through diversity, the use of renewable energy sources, systems thinking, and cascading flows of materials and energy.
Conclusions 1

• There is considerable variation in the fertility of ecosystems across Wester Ross in space and time.

• Human impacts have greatly affected ecosystem fertility and phosphorus availability; both directly (e.g. via harvesting of trees, sheep and cattle) and indirectly (e.g. extinction of top carnivores, settlement patterns, moorburn, . . .).

(agree / disagree?)
Conclusions 2

• Some parts of Wester Ross were more fertile, more biodiverse, and more productive in the past than they are at present.

• Phosphorus deficits may be as much as 100kg P/ha in some areas, especially where vegetation has been lost and soils have been eroded away.

• We should focus more on restoring fertility and conserving phosphorus to sustain production of livestock, deer and other wildlife, and rebuild &/or strengthen our rural economy.
Proposal

If fertility levels have fallen . . .

. . . a case can be made for ‘ecological fertilisation’: the gradual restoration of nutrients to areas from where nutrients have been lost, to restore fertility, enhance biodiversity and biological productivity.

Ecological fertilisation could mimic the natural patterns and rates of nutrient transfer that would have existed within the Wester Ross landscape in the past.

or other P rich fertiliser . . .?
A little fertiliser, fairly often (not a lot of fertiliser all at once) . . ?

A bit like feeding the birds . . ?

Larachantivore woodland (upper Gruinard) . .
Ecosystem nutrition in Wester Ross: conserving & replenishing phosphorus

- Composted food wastes from schools, hotels & restaurants can be used as soil enhancer.
- Ash from incinerated farm salmon carcasses is rich in phosphorus.
- Byres or polytunnels for overwintering livestock provide P-rich manure for use as fertiliser in the spring.
- Septic tank soak away run off.
- Managed wetland nutrient trap.
- Sheep which eat seaweed can be overwintered along the shore as they help to transfer nutrients to coastal grazilands.
- Other spraint site.
- Sea trout & salmon deliver marine nutrients to headwater streams.
- Compost food wastes from schools, hotels & restaurants can be used as soil enhancer.
- Ash from incinerated farm salmon carcasses is rich in phosphorus.
- Byres or polytunnels for overwintering livestock provide P-rich manure for use as fertiliser in the spring.
- Septic tank soak away run off.
- Managed wetland nutrient trap.
- Sheep which eat seaweed can be overwintered along the shore as they help to transfer nutrients to coastal grazilands.
- Other spraint site.
- Sea trout & salmon deliver marine nutrients to headwater streams.

- Compost food wastes from schools, hotels & restaurants can be used as soil enhancer.
- Ash from incinerated farm salmon carcasses is rich in phosphorus.
- Byres or polytunnels for overwintering livestock provide P-rich manure for use as fertiliser in the spring.
- Septic tank soak away run off.
- Managed wetland nutrient trap.
- Sheep which eat seaweed can be overwintered along the shore as they help to transfer nutrients to coastal grazilands.
- Other spraint site.
- Sea trout & salmon deliver marine nutrients to headwater streams.

- Compost food wastes from schools, hotels & restaurants can be used as soil enhancer.
- Ash from incinerated farm salmon carcasses is rich in phosphorus.
- Byres or polytunnels for overwintering livestock provide P-rich manure for use as fertiliser in the spring.
- Septic tank soak away run off.
- Managed wetland nutrient trap.
- Sheep which eat seaweed can be overwintered along the shore as they help to transfer nutrients to coastal grazilands.
- Other spraint site.
- Sea trout & salmon deliver marine nutrients to headwater streams.

- Compost food wastes from schools, hotels & restaurants can be used as soil enhancer.
- Ash from incinerated farm salmon carcasses is rich in phosphorus.
- Byres or polytunnels for overwintering livestock provide P-rich manure for use as fertiliser in the spring.
- Septic tank soak away run off.
- Managed wetland nutrient trap.
- Sheep which eat seaweed can be overwintered along the shore as they help to transfer nutrients to coastal grazilands.
- Other spraint site.
- Sea trout & salmon deliver marine nutrients to headwater streams.

- Compost food wastes from schools, hotels & restaurants can be used as soil enhancer.
- Ash from incinerated farm salmon carcasses is rich in phosphorus.
- Byres or polytunnels for overwintering livestock provide P-rich manure for use as fertiliser in the spring.
- Septic tank soak away run off.
- Managed wetland nutrient trap.
- Sheep which eat seaweed can be overwintered along the shore as they help to transfer nutrients to coastal grazilands.
- Other spraint site.
- Sea trout & salmon deliver marine nutrients to headwater streams.
Refertilisation can help to support and revive fragile communities.

http://www.ross-shirejournal.co.uk/imagelibrary/Client_Images/Client00007/02001000/02001802.jpg

Picture from Gairloch Heritage Museum Calendar, 2015
Opportunities for new Wester Ross Biosphere?

• Develop a clearer understanding of ecosystem nutrition;

• Ecosystem fertility restoration and management studies;

• Demonstration projects to learn and extend information about managing fertility.

• ‘Think globally . . . (productive landscapes), . . . act locally’.

Beinn Eighe NNR
Thank you
Managing wild trout production from oligotrophic lochs: options for a 5-10 ha fishery

**Catchment areas**

Small shallow lochs with large catchment areas have rapid flushing rates and water quality may fluctuate widely. Larger lochs with small catchments have more stable pH and fertility and can lead to reduced catchment fertility.

**Inflowing streams**

Feeder burns can be managed to enhance or minimise spawning habitat for trout food production according to requirements.

**Large herbivores**

Light grazing promises nutrient recycling and may increase the production of edible insects, but however, heavy grazing alters plant diversity & species composition and can lead to reduced catchment fertility.

**Terrestrial insects**

Insect production relates to soil fertility and plant growth. Insects include leaf hoppers, ants, crickets, free ranging trout, and dung beetles.

**Automatic supplementary feeder**

Grow your own alternative to stocking where fishing pressure is heavy (e.g., 100 kg feed ≈ 50 kg trout/year).

**Wave-washed shallows**

Mayfly & stonefly larvae graze algae & moss from stones and hide beneath. Create sheltered areas for 'broadstocks' of frogs, newts, corixy, water beetles, dragonflies...

**Deep water**

Productivity is inversely proportional to depth. Little sunlight reaches the Loch bed at depths >4m, especially where water is peaty.

**Trout production (2-10+ kg/ha year)**

Growth relates to population density and food availability. Trout can grow quickly even in mildly acidic waters (pH 5.5-6).

**Sheltered shallows**

These areas provide the best feeding. The hatching of insects from weedy areas may be 3x that from areas where weeds are absent.

**Nutrient availability**

Phosphates limit productivity of land & water. Annual losses via soil erosion, run-off and 'export' of deer & livestock can be offset via gentle application of fertiliser, e.g., bone meal or rock phosphate (2.5 kg/ha catchment area/year).

**Bird densities**

Breeding success of divers, ducks, waders may relate to Loch fertility (pH) & angler disturbance (-ve). Informed anglers are respectful of nesting birds.

**Floating island**

Secluded bird nesting site. Also source of nutrients via bird droppings.

**Outlet**

Changes in Loch level relate to outlet profile wide.

Peter D. Cunningham 2/2002