

Ecosystem fertility and (wild)life production in Wester Ross

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for

Assynt Field Club, Lochinver

17th November 2016



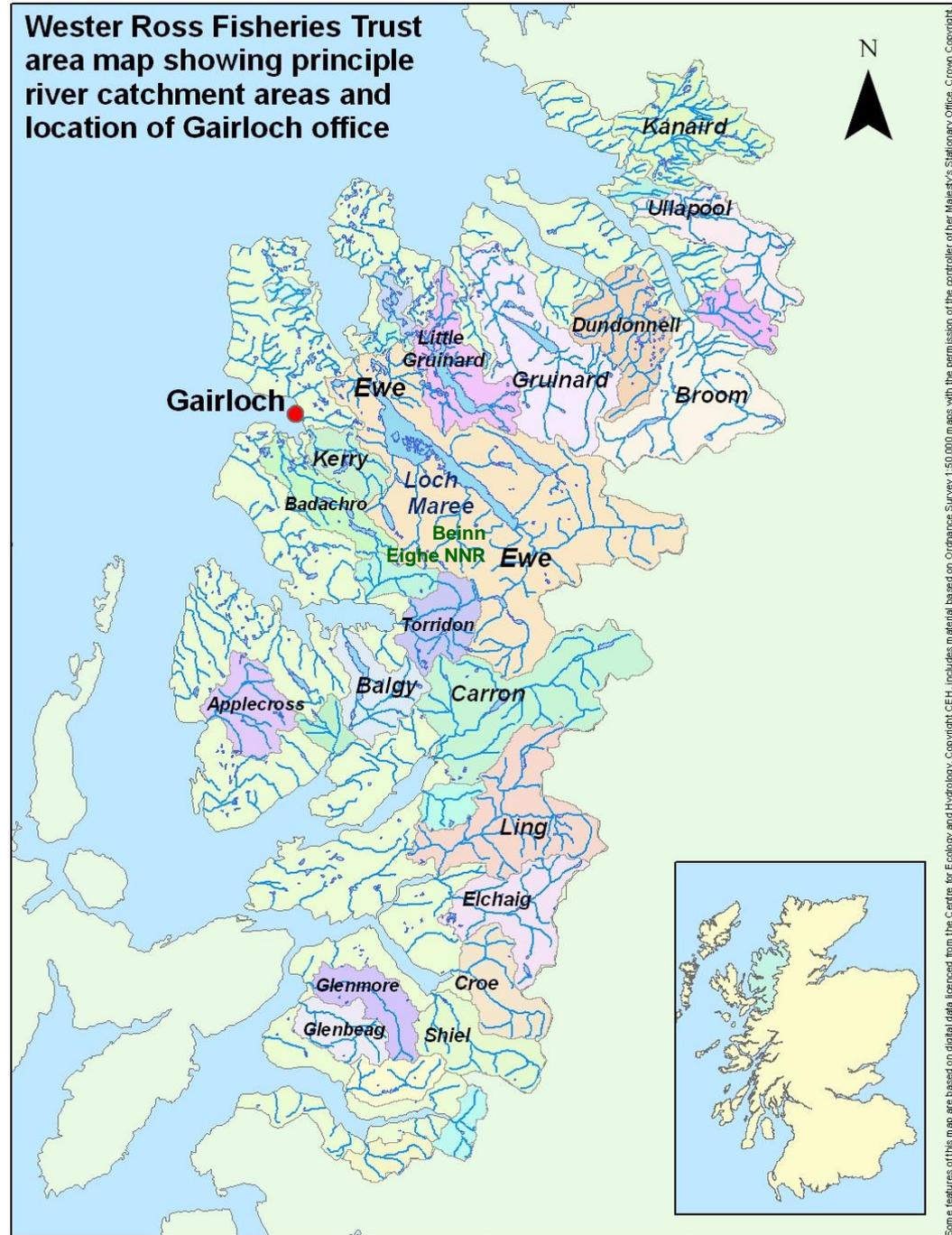
Raptor perch in Beinn Eighe NNR



The overall Purpose of the Wester Ross Fisheries Trust is:

To maximise and sustain the natural productivity of wild salmonid fisheries in the rivers and lochs of Wester Ross.

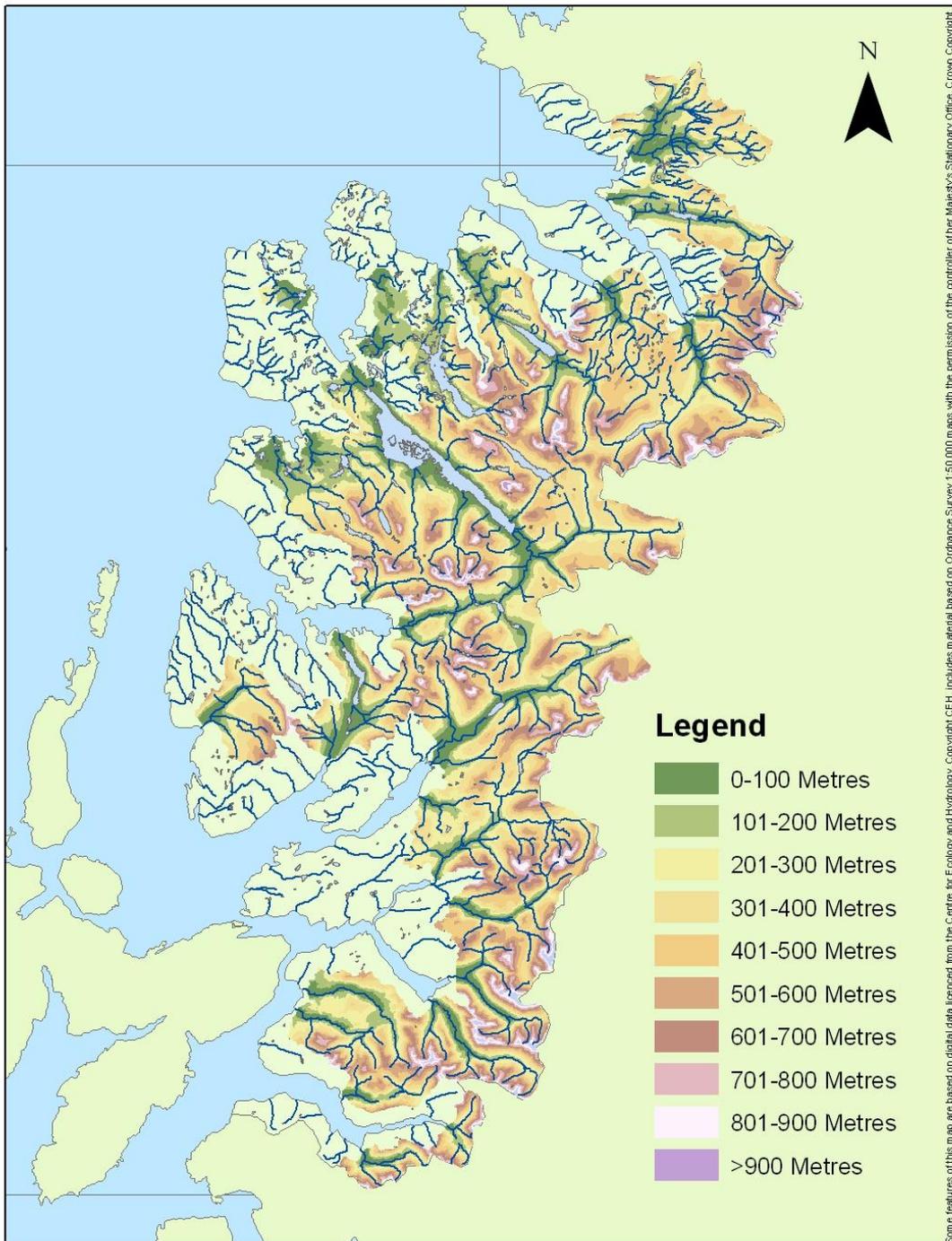
Wester Ross Fisheries Trust area map showing principle river catchment areas and location of Gairloch office



Outline of talk

1. What is fertility? Phosphorus as a limiting nutrient
2. Fertile places in Wester Ross
3. Ecosystems and nutrient flow
4. Deforestation, fire and phosphorus export
5. Animals and phosphorus export
6. How to conserve and replenish phosphorus?



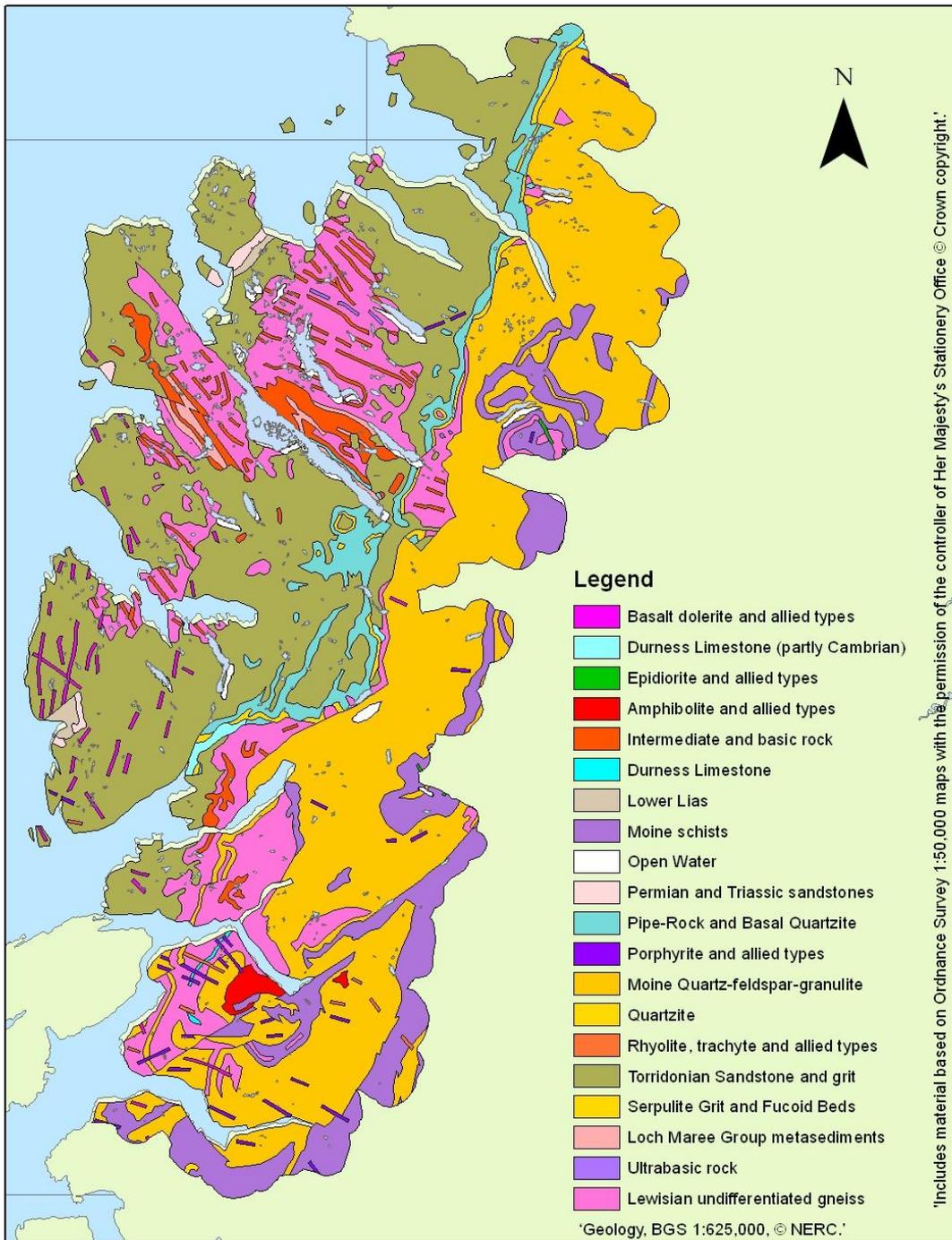


In Wester Ross,
soils are thin and
generally infertile:

Land of glaciated
mountains, lochs and
short, swiftly flowing
salmon rivers . . .



Torridon and Liathach by Lulu Strader, Sept 2010

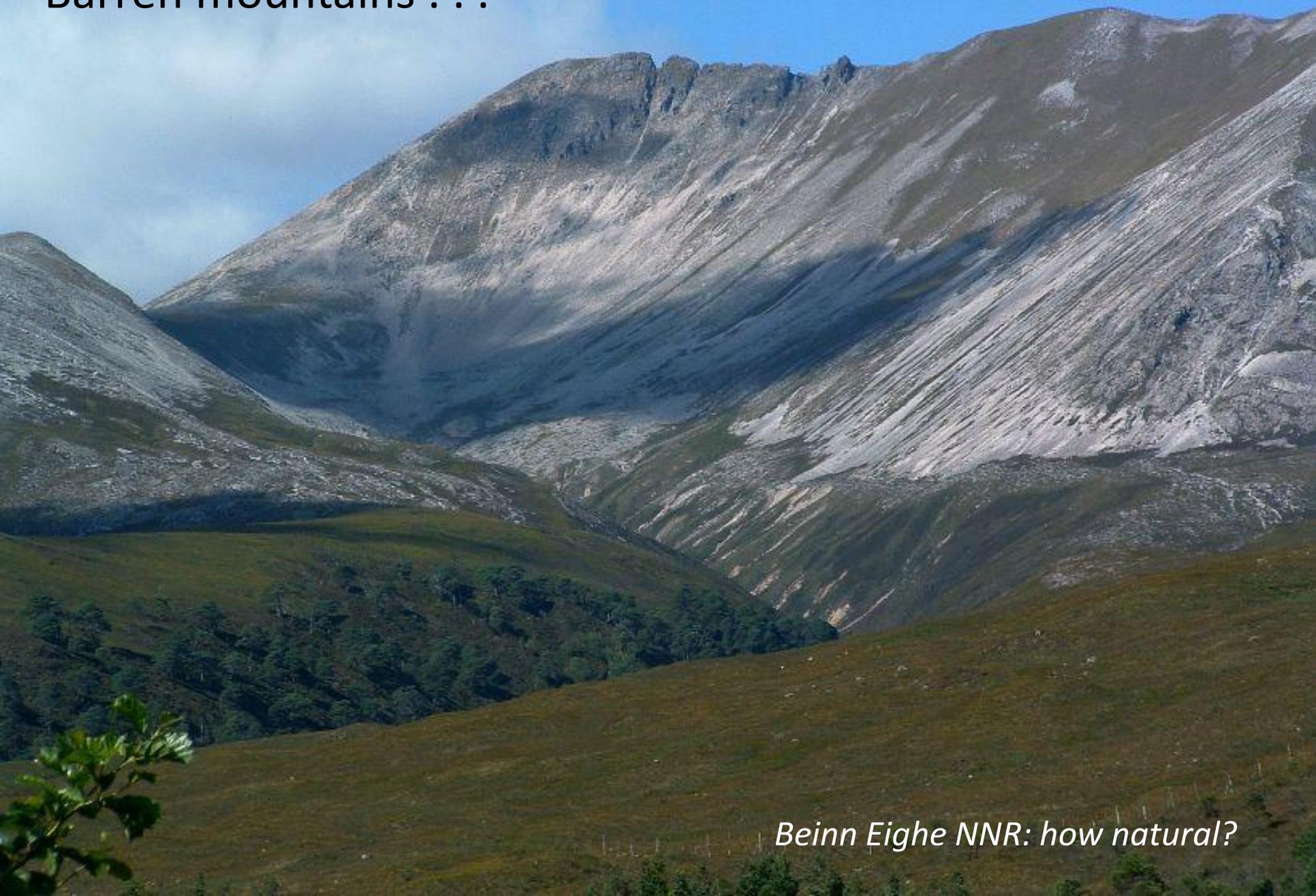


... underlain by
Torridonian sandstone
and Lewisian Gneiss.



hard, resistant to
weathering,
un-yielding rock.

Barren mountains . . .



Beinn Eighe NNR: how natural?



Sparsely vegetated slopes

Beinn Damh forest: where are the trees?

A landscape photograph showing a mountain range under a blue sky with scattered white clouds. In the foreground, a rocky stream flows over a waterfall, surrounded by lush green trees and vegetation. The middle ground features a steep, grassy slope leading up to a large, flat-topped mountain peak. The overall scene is a natural, rugged environment.

Trees cling to
inaccessible ledges

Abhainn Dearg

Unstable rivers



Strath na Sealga, upper Gruinard: note alder woodland along floodplain

Uninhabited 'wilderness' . . .



*Fionn loch and Dubh loch
from Beinn Airigh charr*

with 'near pristine' oligotrophic lochs . . . :



Loch Maree . . .

... 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.

https://en.wikipedia.org/wiki/Soil_fertility

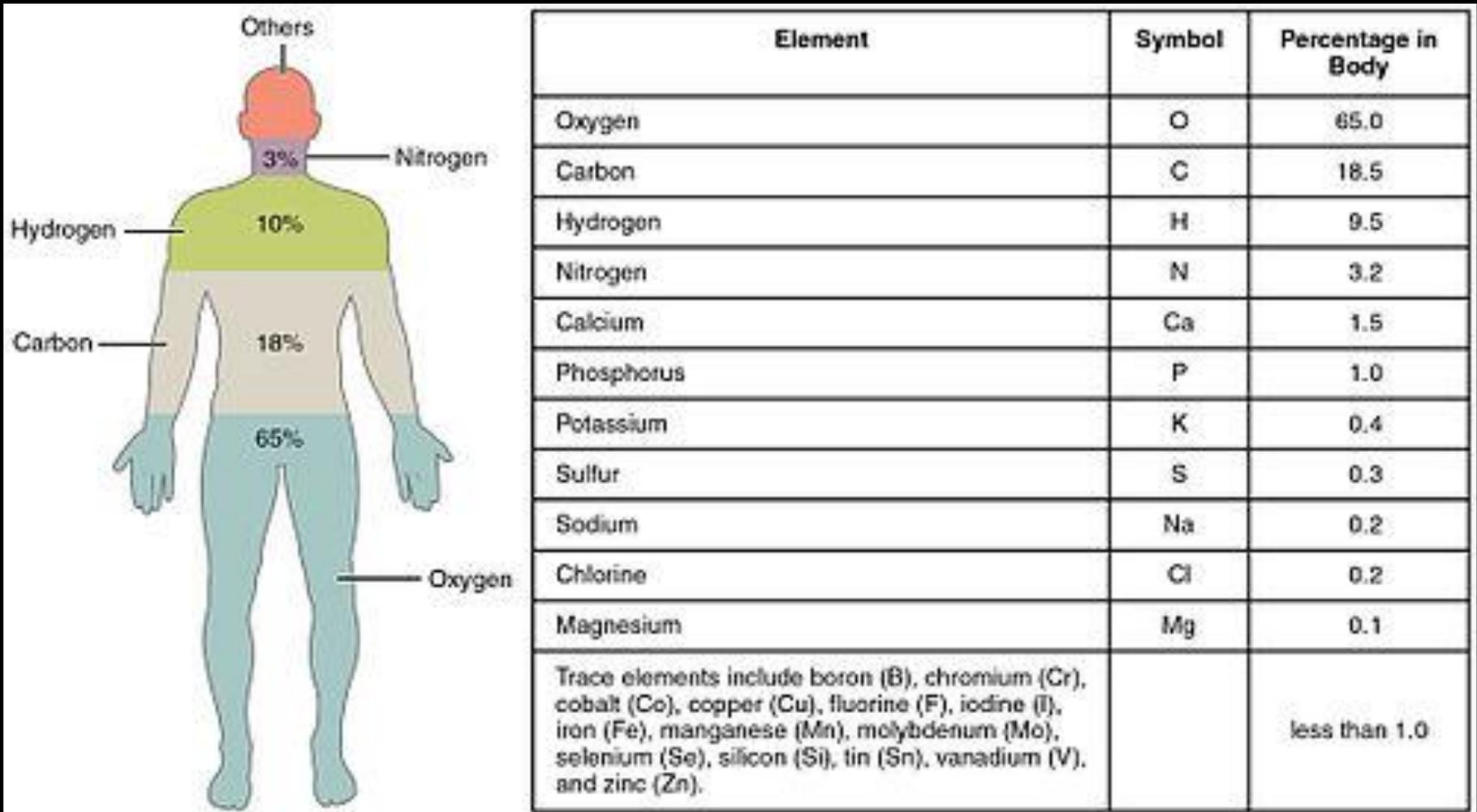
Phosphorus

Phosphorus is essential to all life forms.

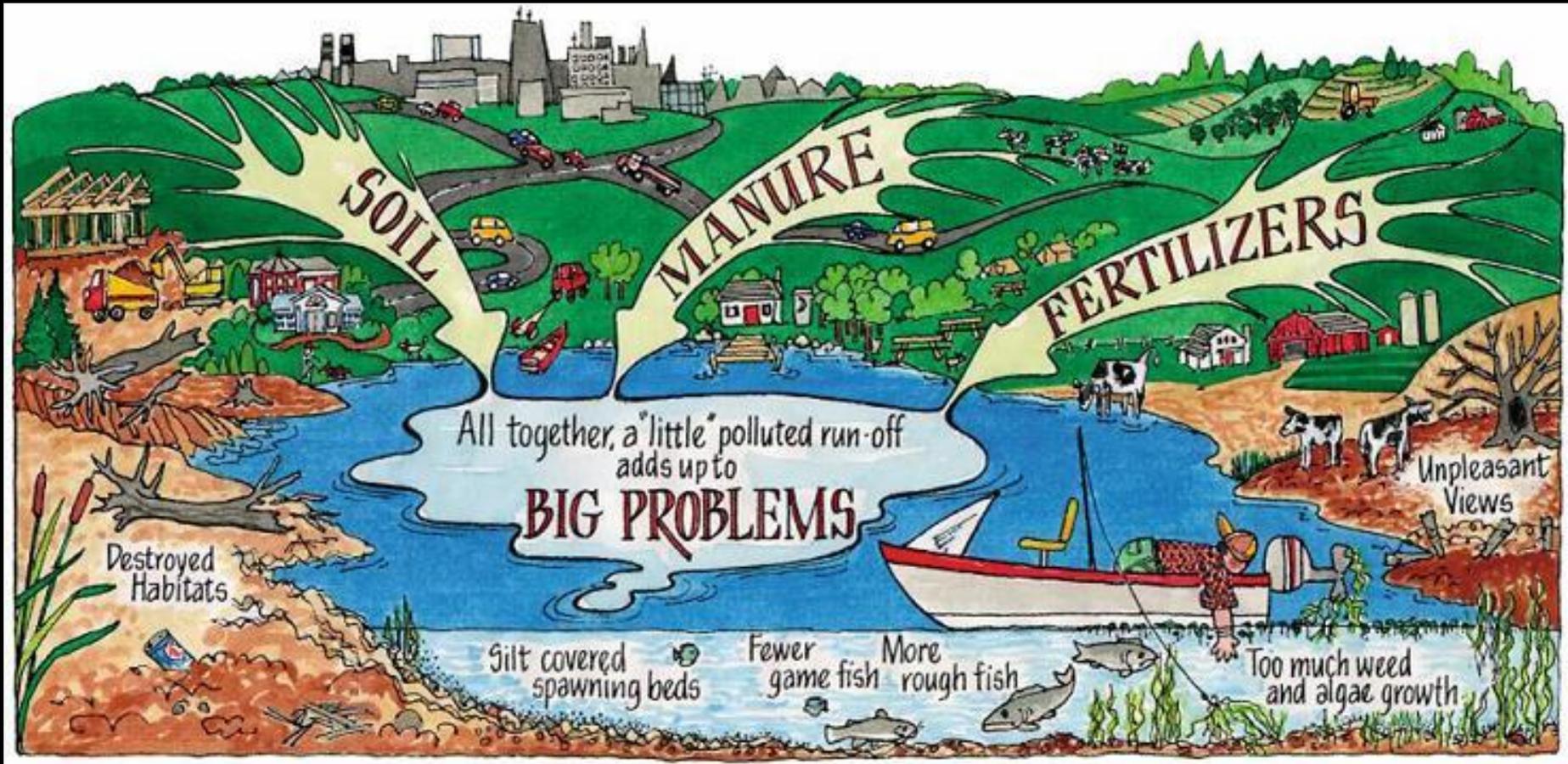


Assorted bones, Aultgrishan shore 3rd April 2016

Humans are approximately 1% Phosphorus



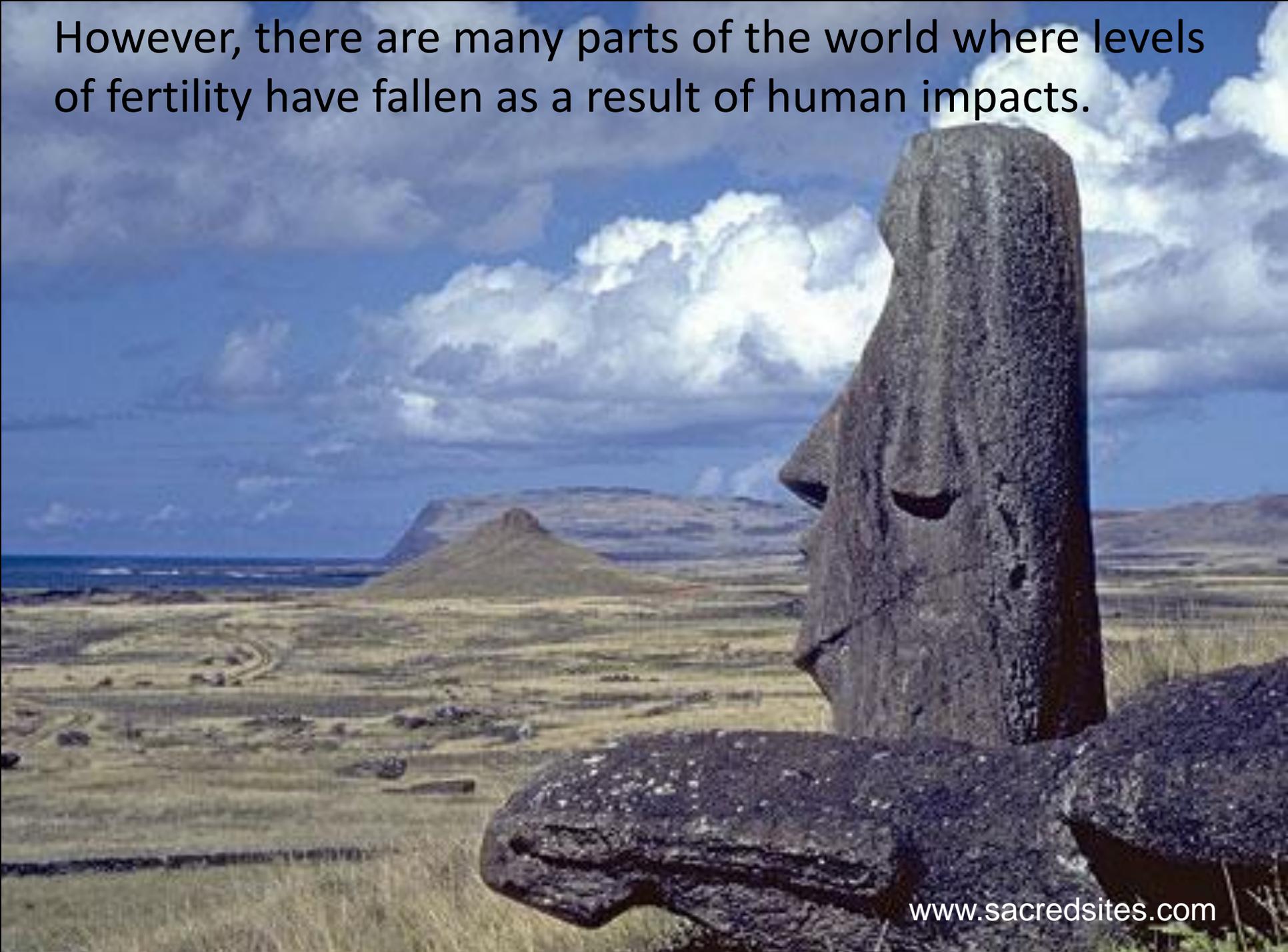
Too much phosphorus causes *eutrophication*



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.



An international Organic Phosphorus Workshop took place in October 2016

OP2016 - Guest of Honour Anthony F Harrison - Speech replay

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.



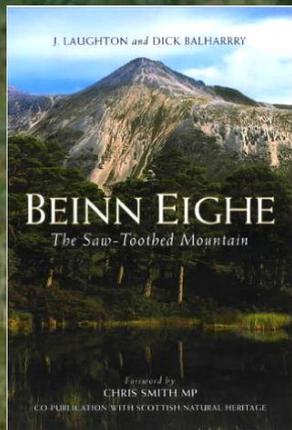
Organic Phosphorus
Workshop 2016



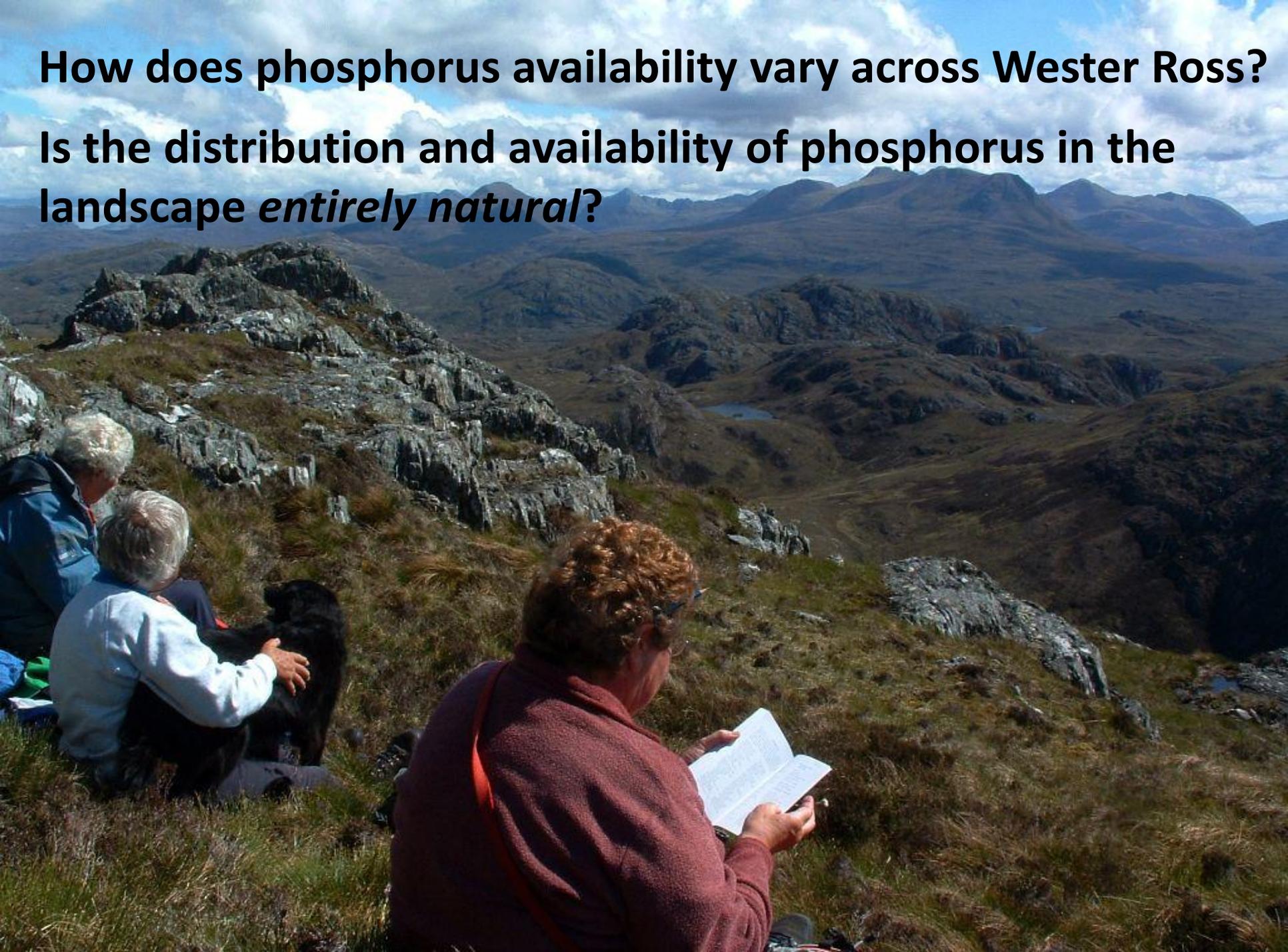
<https://www.youtube.com/watch?v=RNUSgY2NbFM>

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)

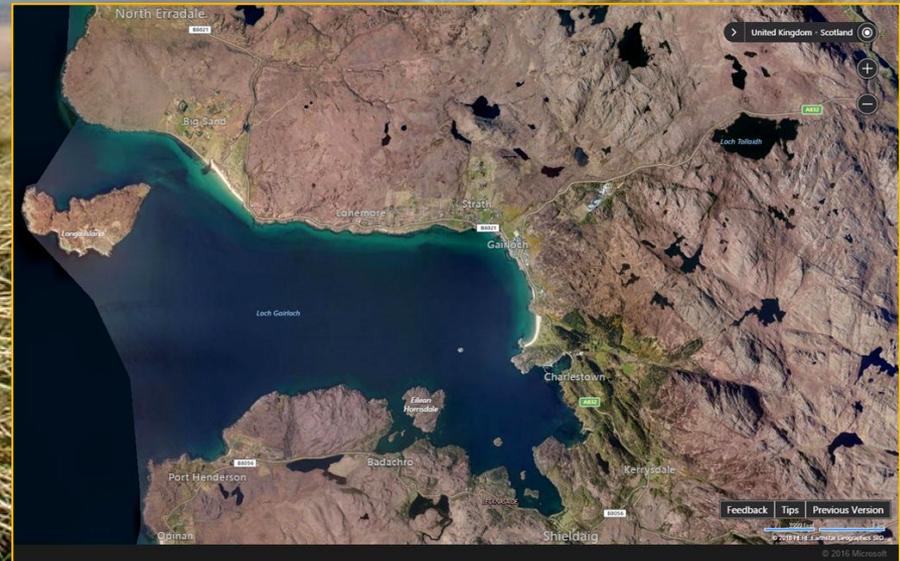


How does phosphorus availability vary across Wester Ross?
Is the distribution and availability of phosphorus in the landscape *entirely natural*?



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



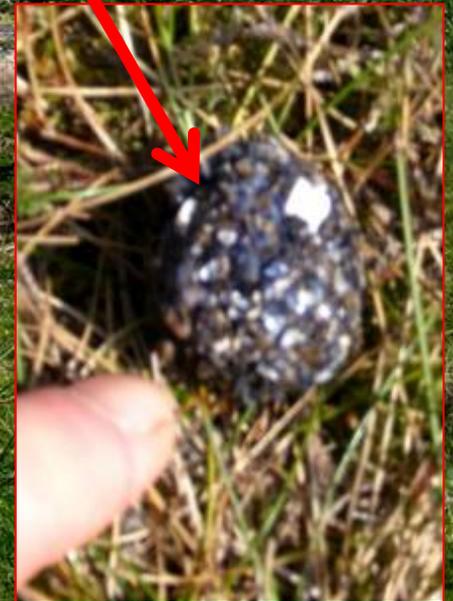


Eilean
Furadh mor



Isle of Ewe: breeding area for Greylag geese and herring gulls

Seagull pellet



Upland areas in Wester Ross are not uniformly infertile either . . .



Watching an eagle above Beinn Eòrna NNR

Rocks and knolls in prominent positions in upland areas have been enriched with nutrients delivered by birds and mammals.



Raptor perch in Beinn Eighe NNR

I found mouse burrows in this green knoll.



September 2010



Eagle pellet (containing fur) and grouse dropping from a green knoll in the Tollie Hills

This green hummock near
Gairloch may be used by foxes . .
.note the sheep bones!



Why is this rock green?



Otter spraint with fish bones.



Most Atlantic salmon return to freshwater only once to spawn . . .



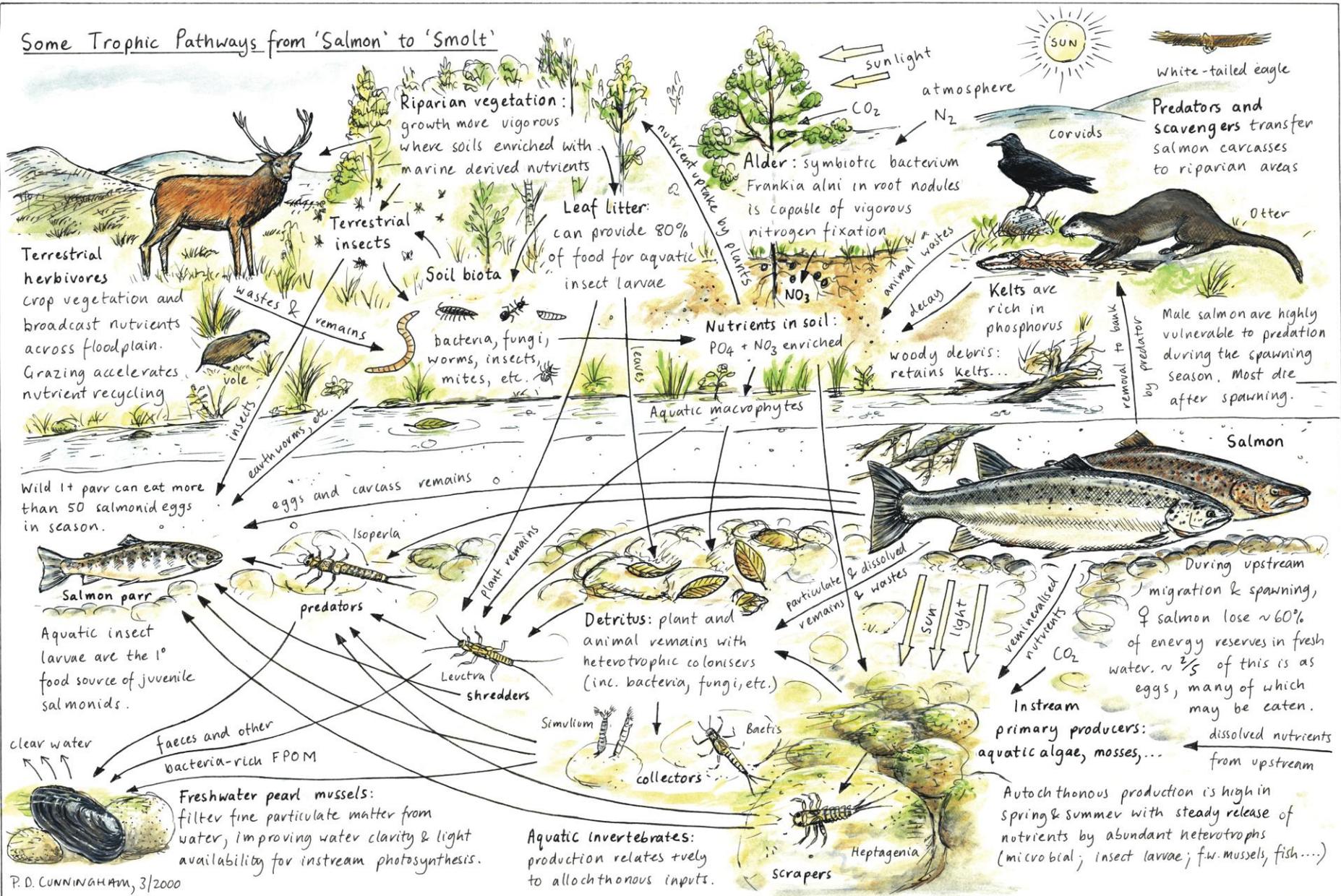
Little Gruinard River

*Salmon jaw and primroses,
as found, May 2010*



Adult salmon provide food for juvenile salmon

Some Trophic Pathways from 'Salmon' to 'Smolt'



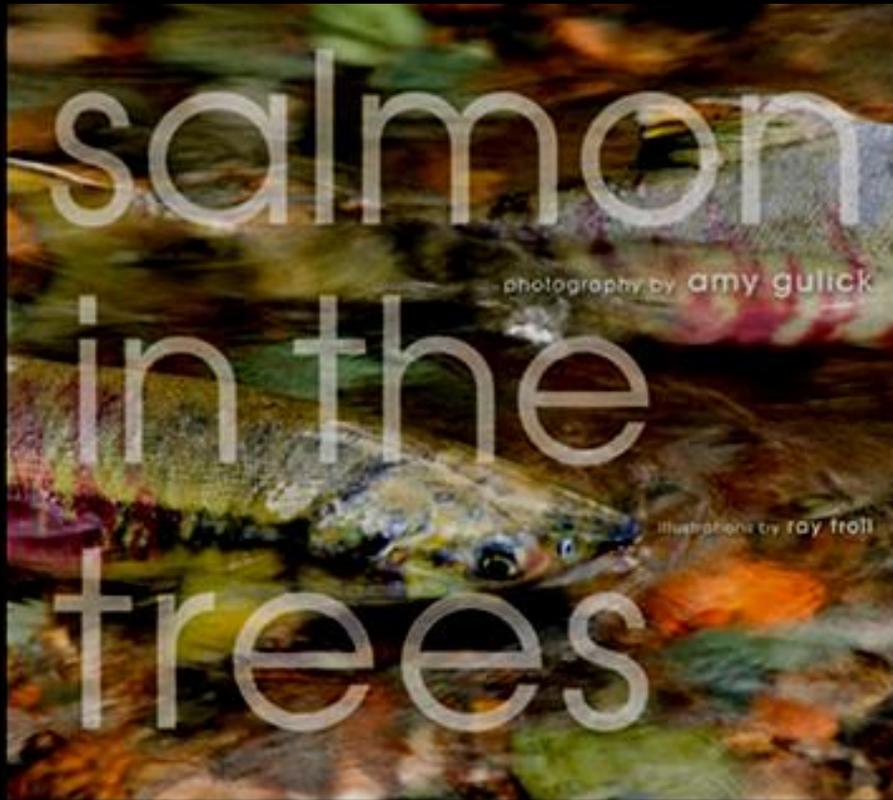


In the past, many more salmon returned to Scottish rivers from the sea each year.

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***

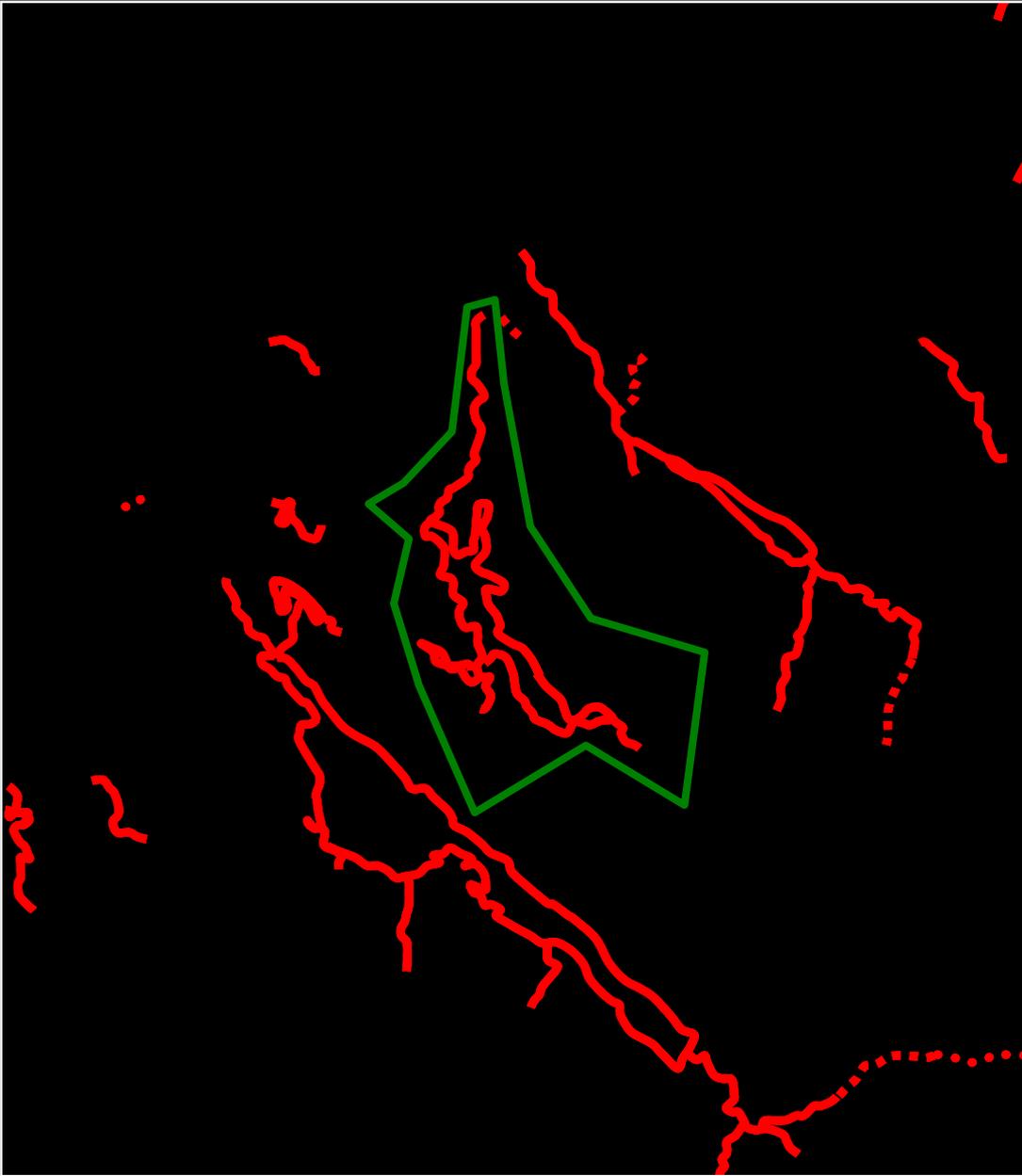


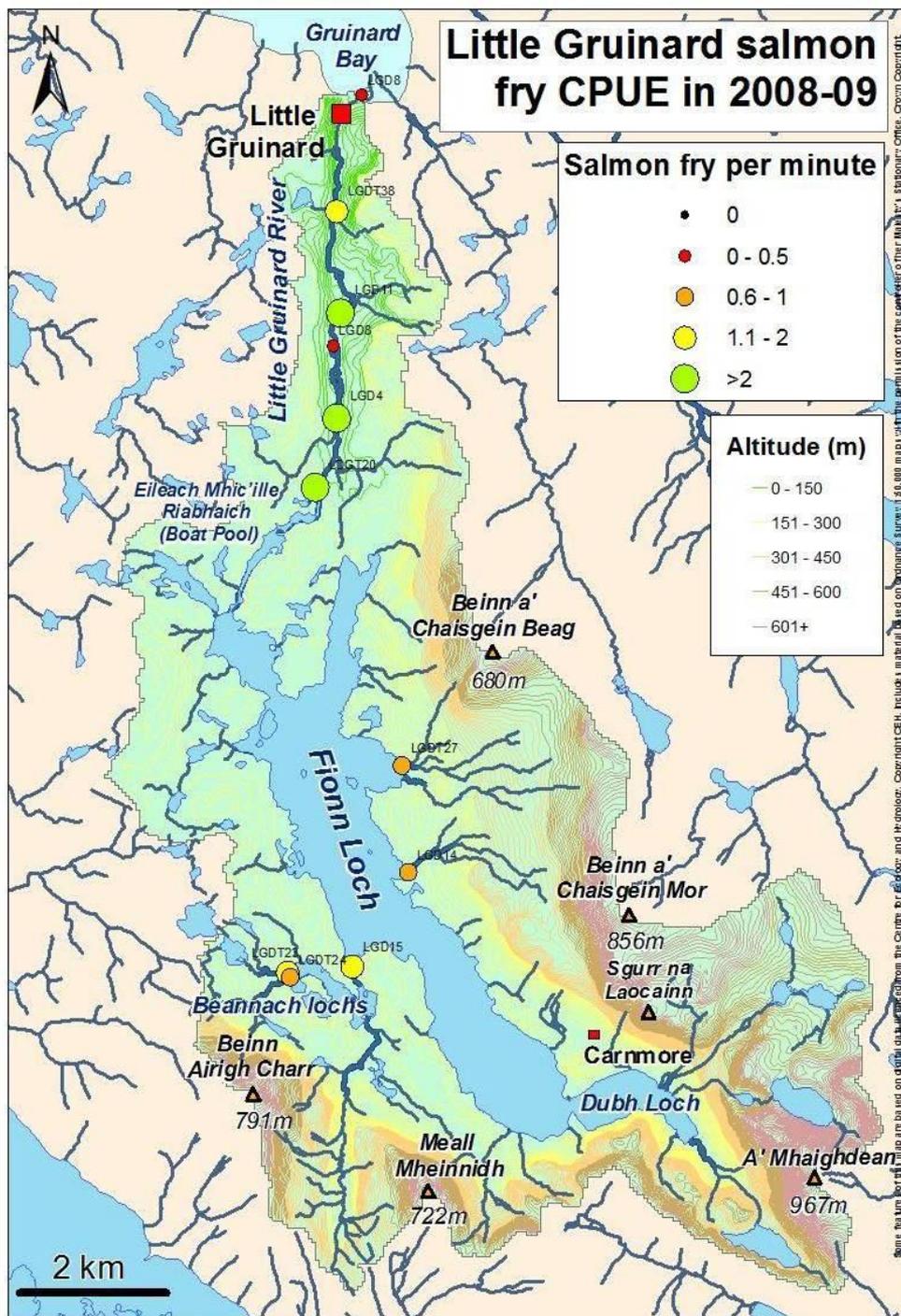
photos by Amy Gulick



The Little Gruinard River

*(Special Area of
Conservation for
Atlantic Salmon)*

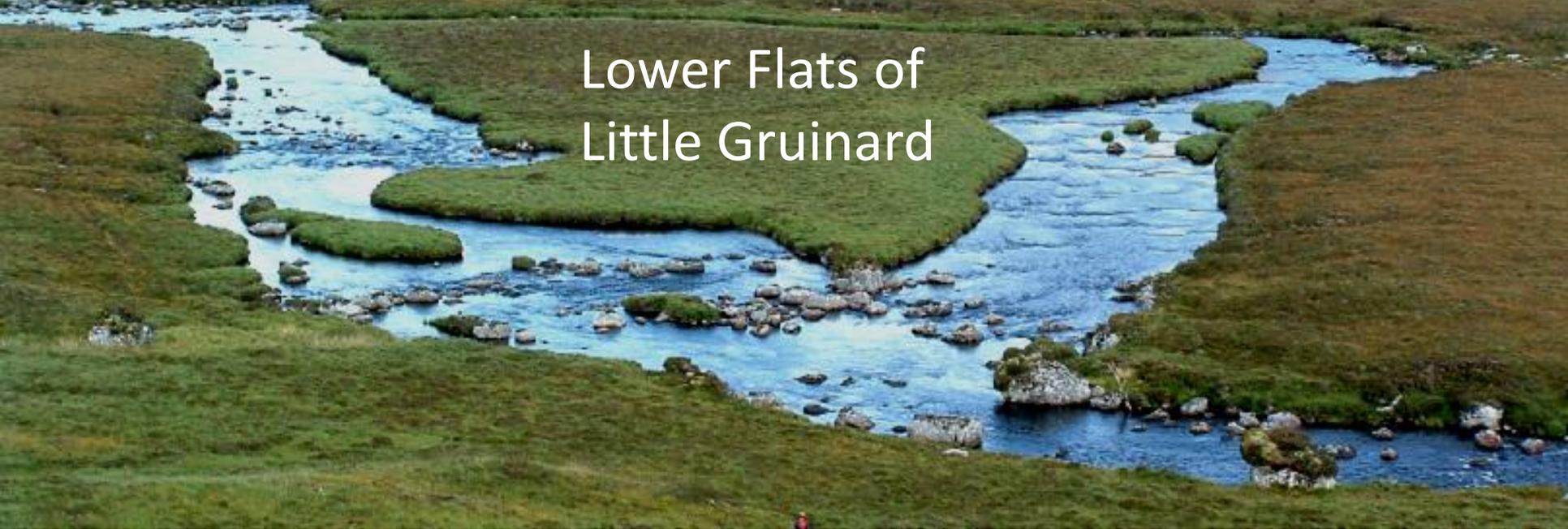




Densities of juvenile salmon are consistently high in the main river . . .

. . . but many of them are very small . . .

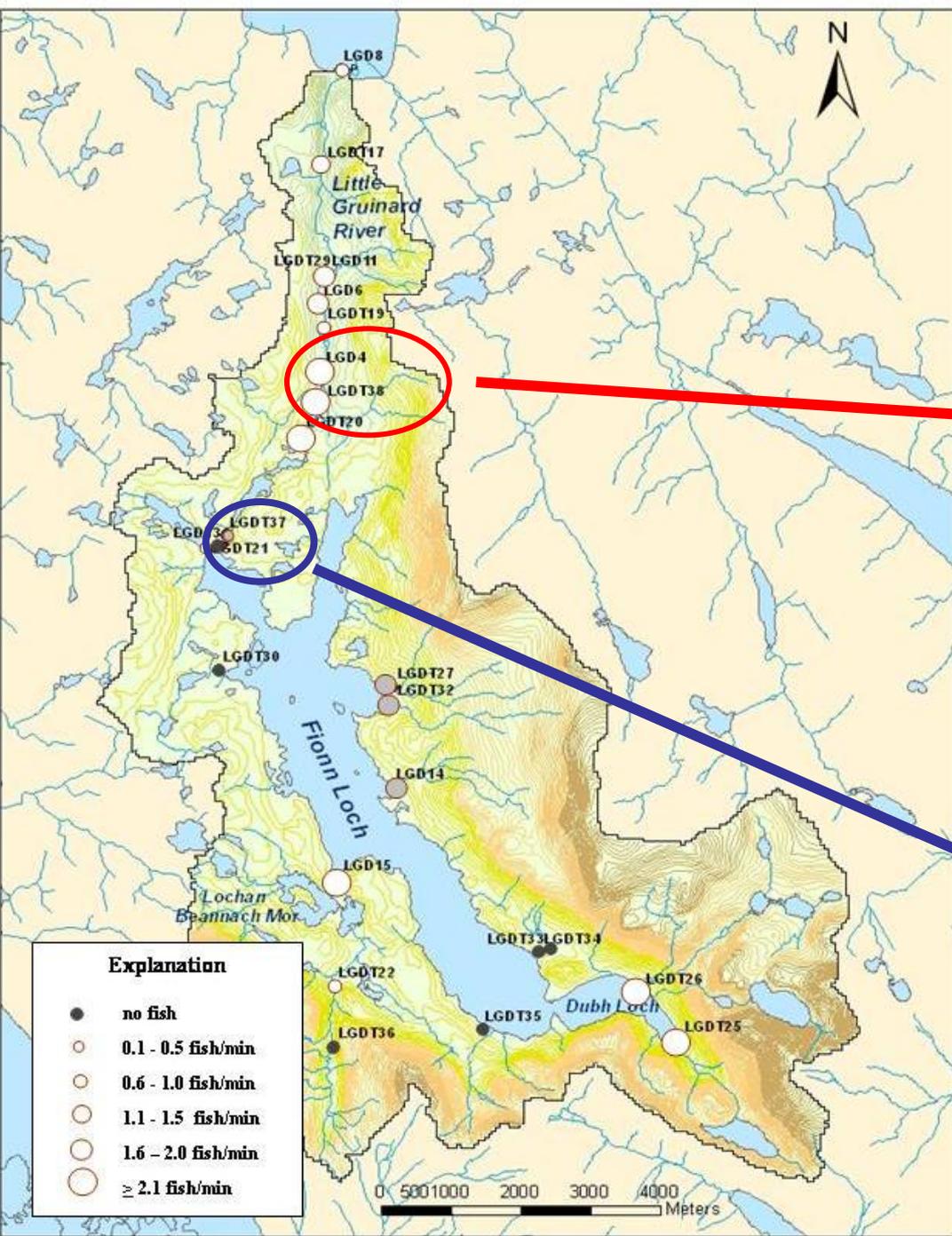
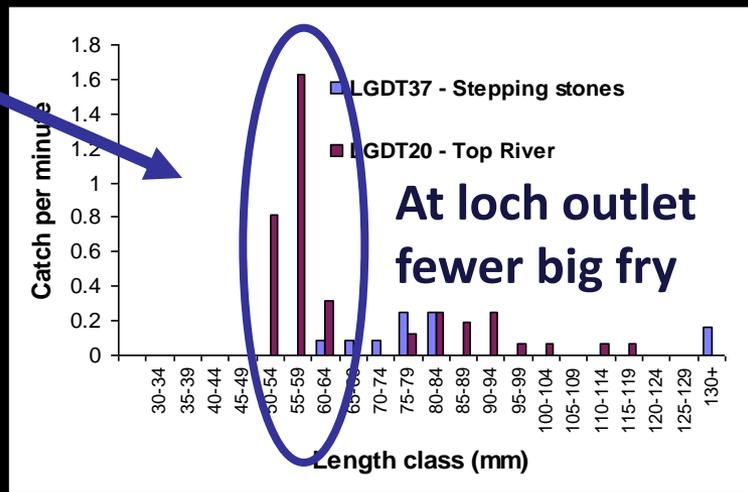
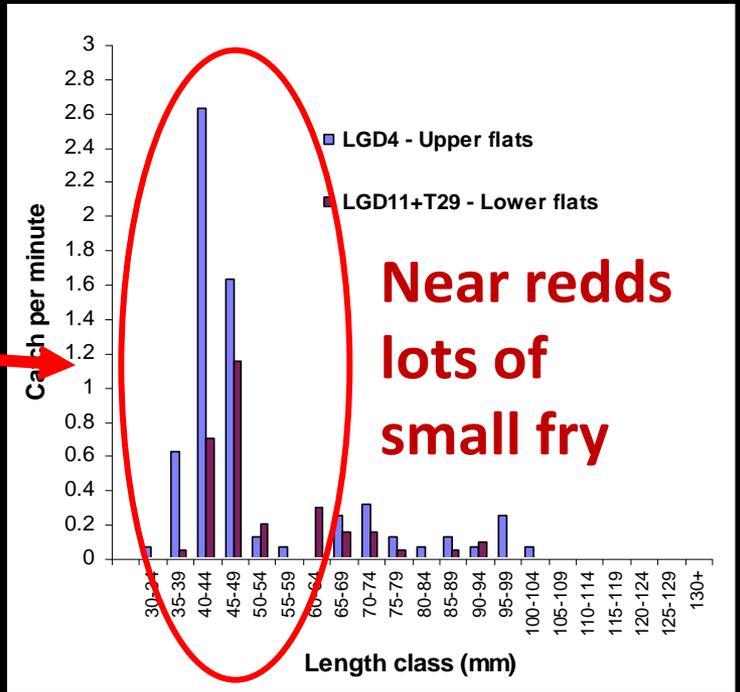
Lower Flats of
Little Gruinard



Small fry and small parr



Juvenile salmon 2006



Below Fionn Loch outlet



Big, faster growing, one year old parr



- Juvenile salmon production is determined by habitat area, food availability and stream fertility



Fionn Loch

Beannach lochs

from Beinn Airigh charr

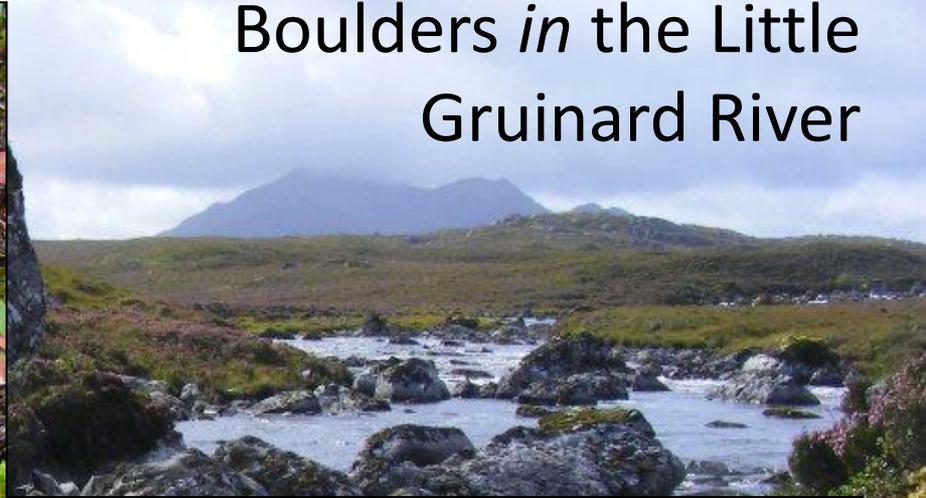
Fionn Loch islands, Little Gruinard catchment.



Boulders *in* the Little
Gruinard River



Boulders *in* the Little Gruinard River



Boulders by the Little Gruinard River, September 2016



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, blueberry,
rowan tree;
spider's web, crow perch*

***Bird droppings: crow,
thrushes, pipits, wren;
spider droppings; dead
insects . .***



*Lichen, moss, grass,
heather, blueberry, rowan,
birch, juniper, crowberry,
bearberry, juniper, willow;
spiders web; wren,
stonechat, bird's nest . . .*

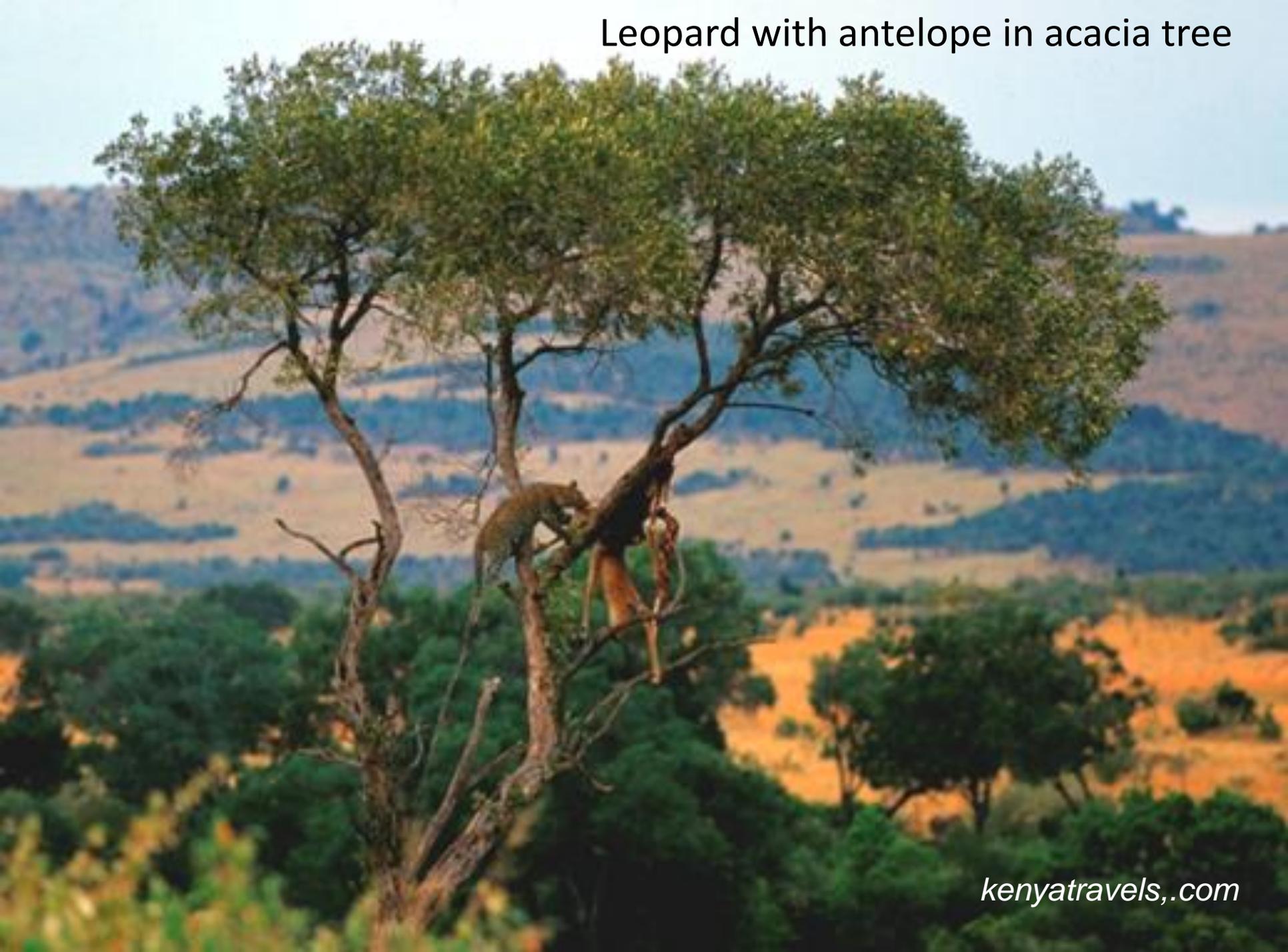
***Bird droppings; Pine
marten droppings; spider
droppings, dead insects . . .***



**Isolated oak tree, North Erradale
(where crows often perch)**



Leopard with antelope in acacia tree



Fertile places can be found
around houses



Glen Torridon September 2010

nettles



ARKive

© www.osfimages.com



*(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!!



Sheneval
bothy

Break – any questions?



Succession . . . sustained by P imports?

3. Ecosystems and nutrient flow

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

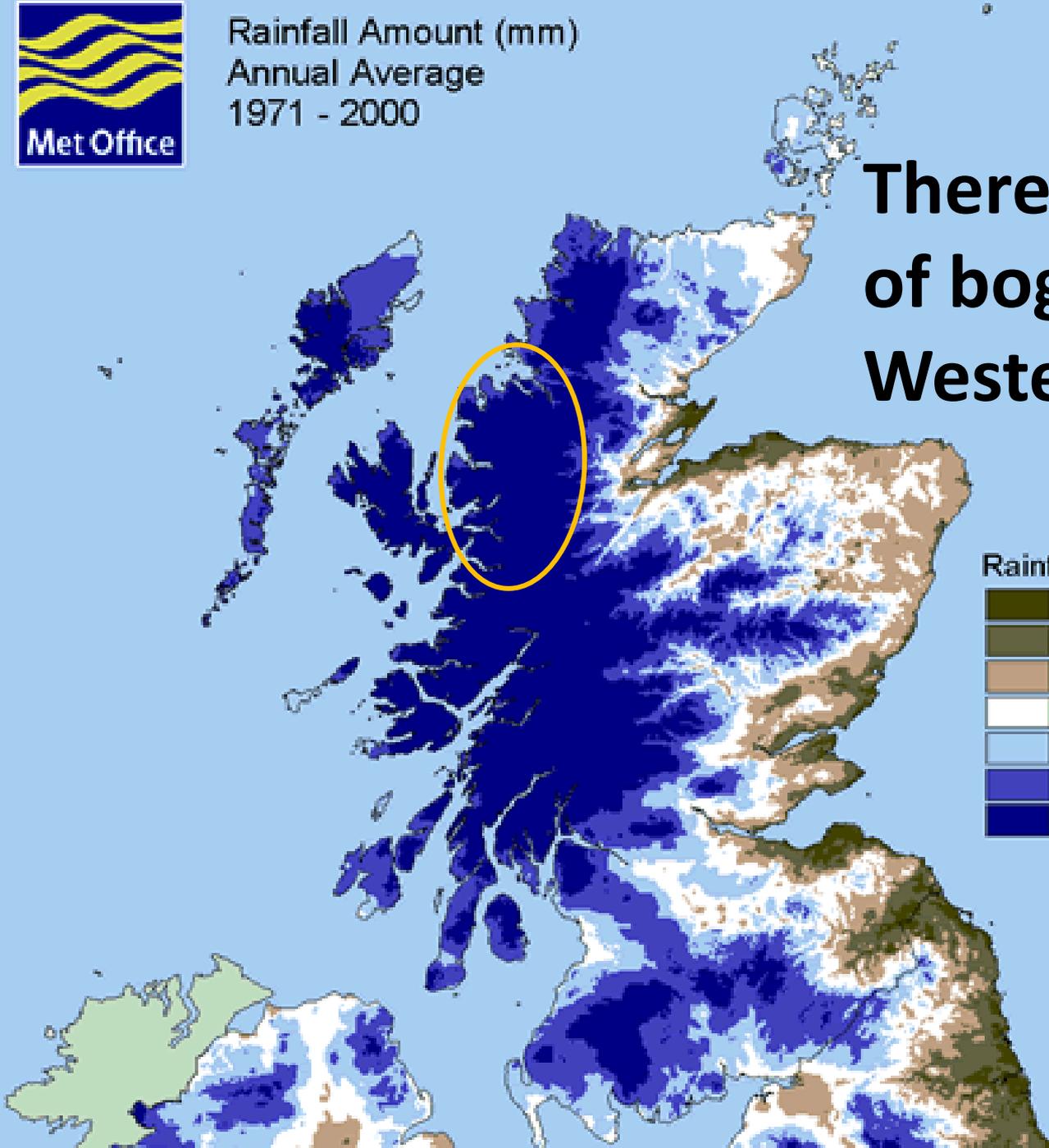
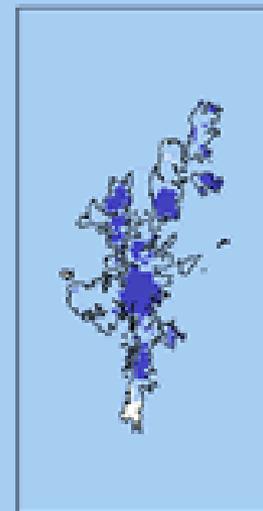


Bog near Redpoint (2002)

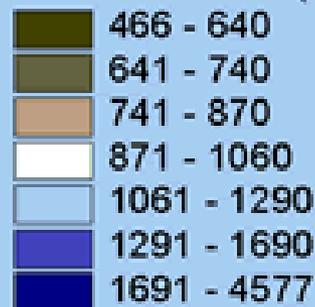


Rainfall Amount (mm)
Annual Average
1971 - 2000

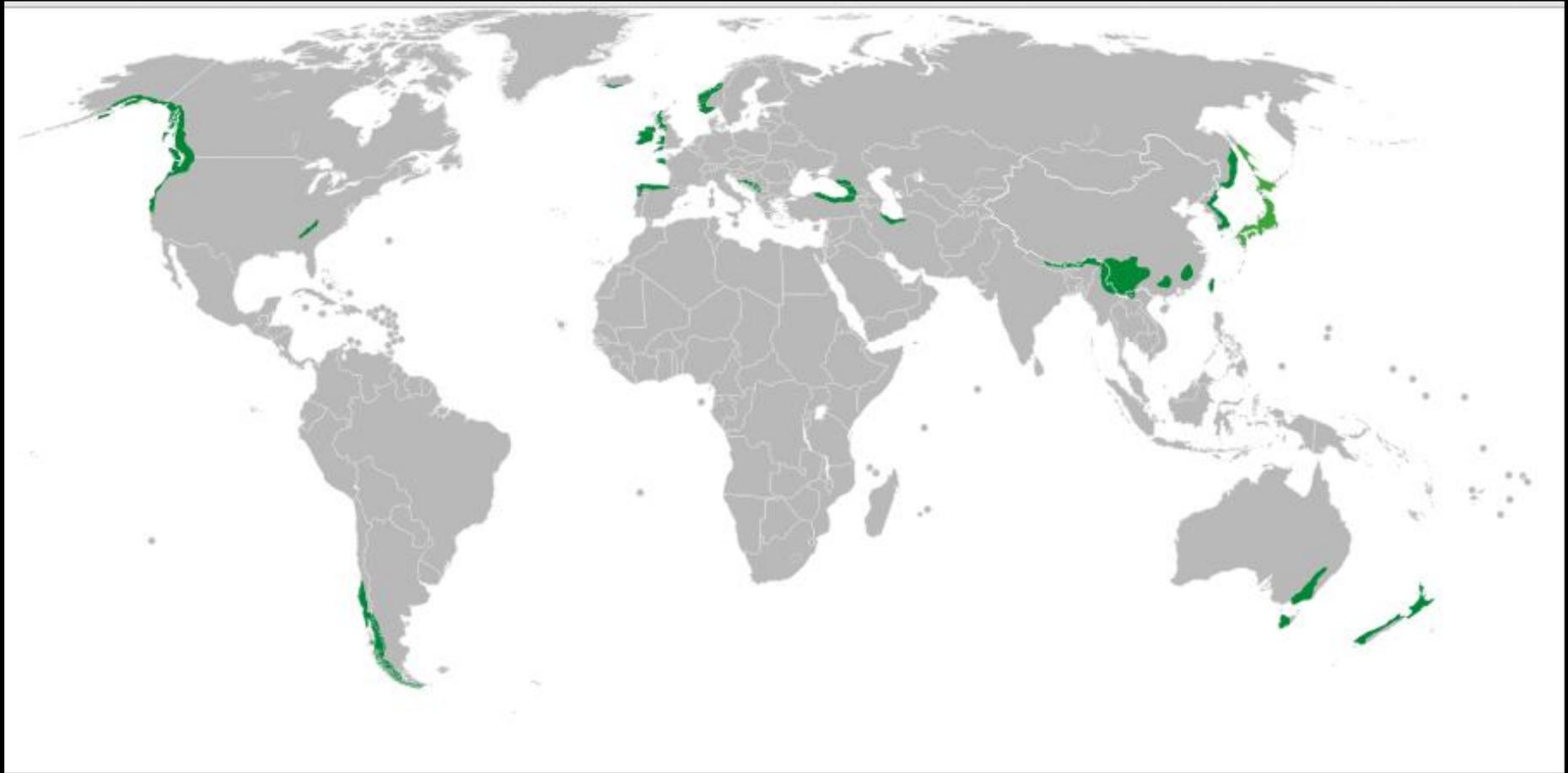
**There is a lot
of bog in
Wester Ross!**



Rainfall Amount (mm)



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 from the decomposing tree and other biota.

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)*

Reforesting
Scotland

*Fertile & productive ecosystems need not be
dependent upon fertile soils if nutrients can be
recycled and circulated within the biota*

REVIEW ARTICLE

Ecosystem Fertility: A new paradigm for nutrient availability to plants in the humid tropics

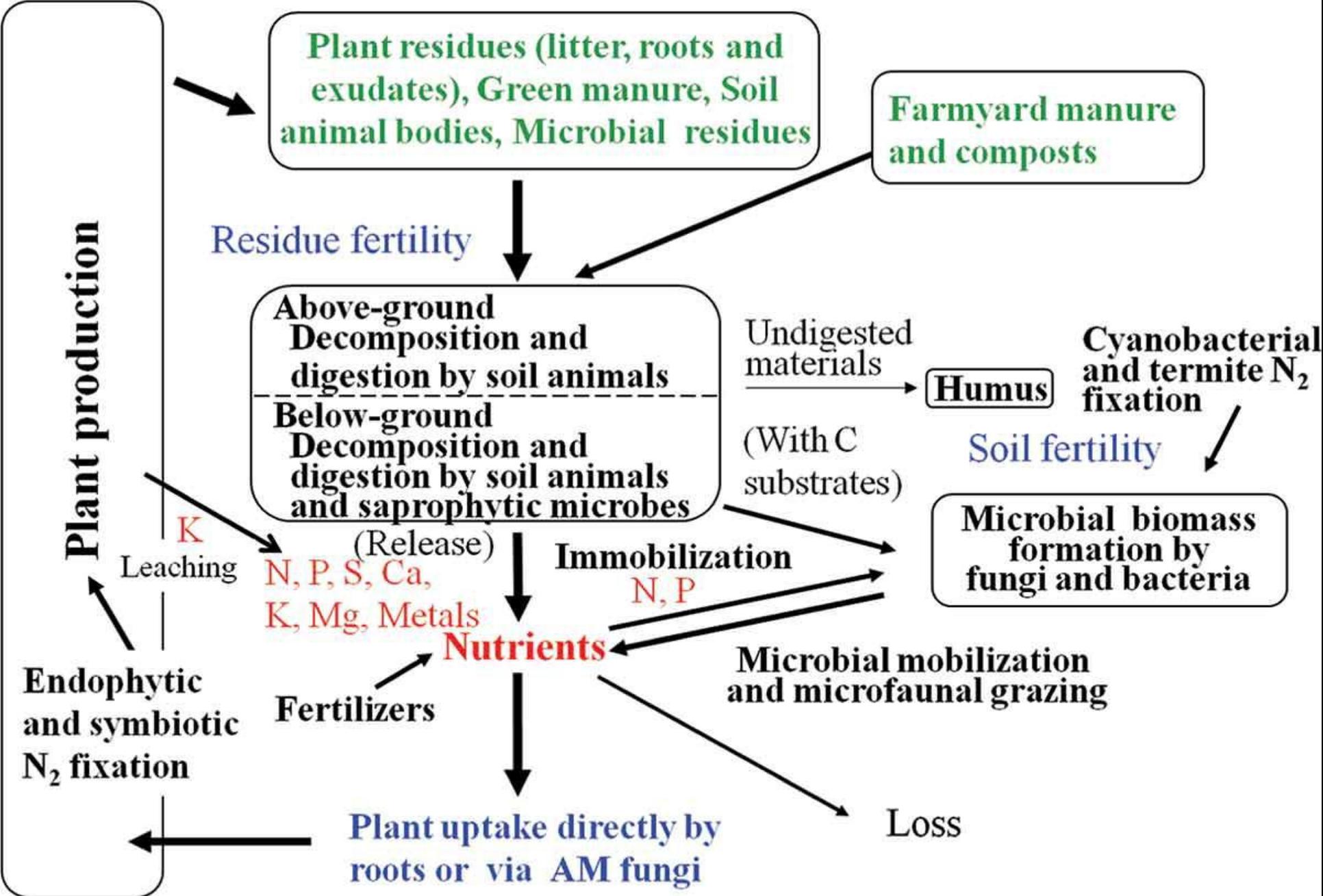
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Abstract

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 phyphae. 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.

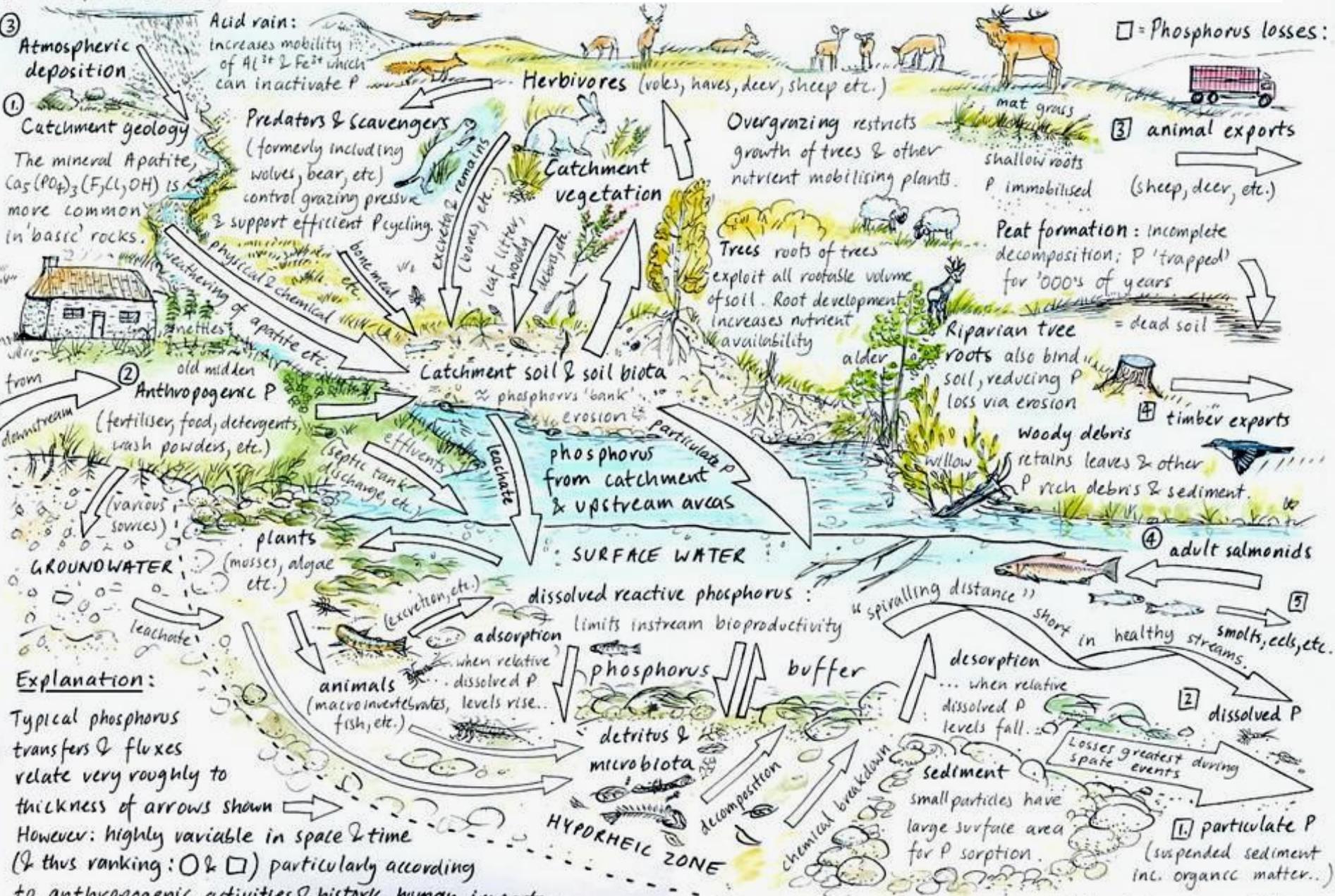
Key words: biodiversity, decomposers, ecosystem fertility, nutrient release, organic matter, soil fertility.



Phosphorus availability is dependent upon ecosystem processes

○ = Phosphorus sources:

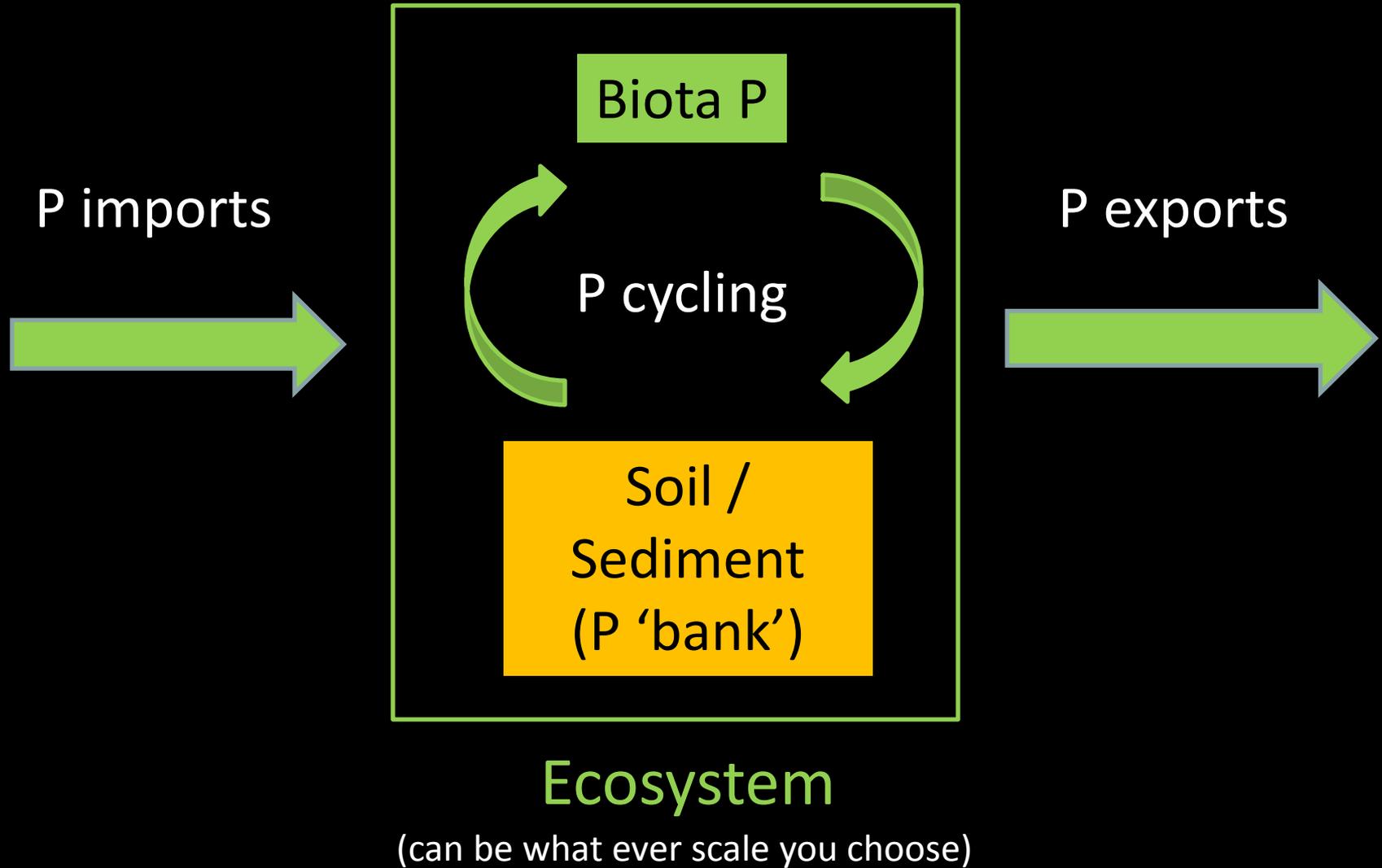
□ = Phosphorus losses:



Explanation:

Typical phosphorus transfers & fluxes relate very roughly to thickness of arrows shown. However: highly variable in space & time (& thus ranking: ○ & □) particularly according to anthropogenic activities & historic human impacts.

Simplified Phosphorus budget model!



Phosphorus budget

P imports



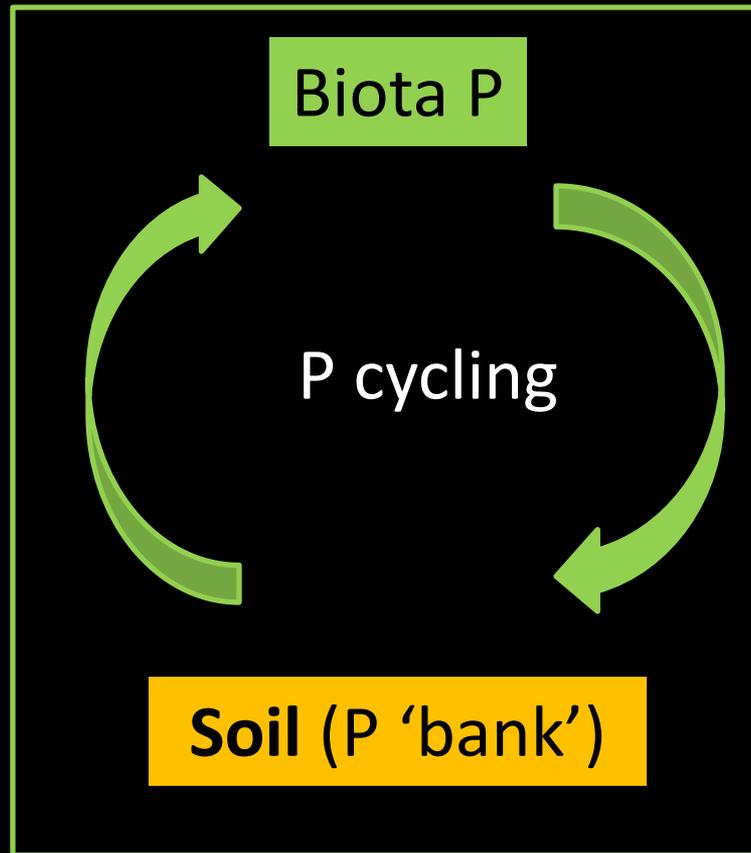
Anthropogenic
(food, fertiliser,
detergents, etc.)



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)

Ecosystem

Tropical rainforest

A photograph of a tropical rainforest. In the foreground, several tall, slender trees with dense green foliage stand prominently. The background shows a valley filled with more trees, partially obscured by a thick layer of white mist or low clouds. The sky is overcast and grey.

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

Tropical Rainforest

P imports

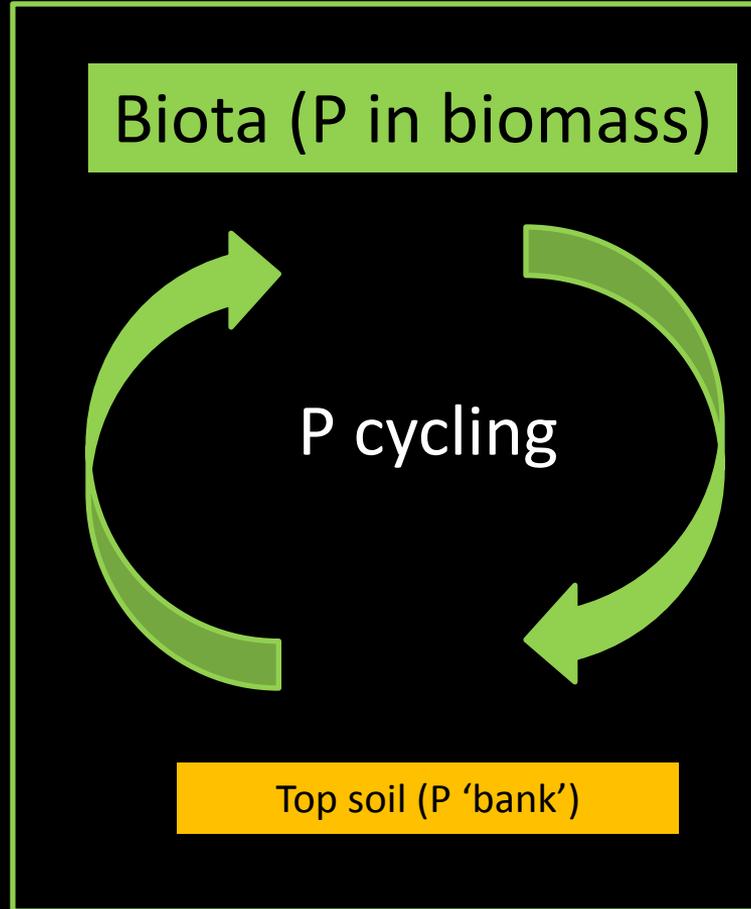
Anthropogenic



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)

Ecosystem: highly
evolved & biodiverse

Deforested hills in Madagascar . . .



Cleared tropical Rainforest



Jungle clearance Sarawak

Cleared tropical rainforest (e.g. for oil palm)

P imports



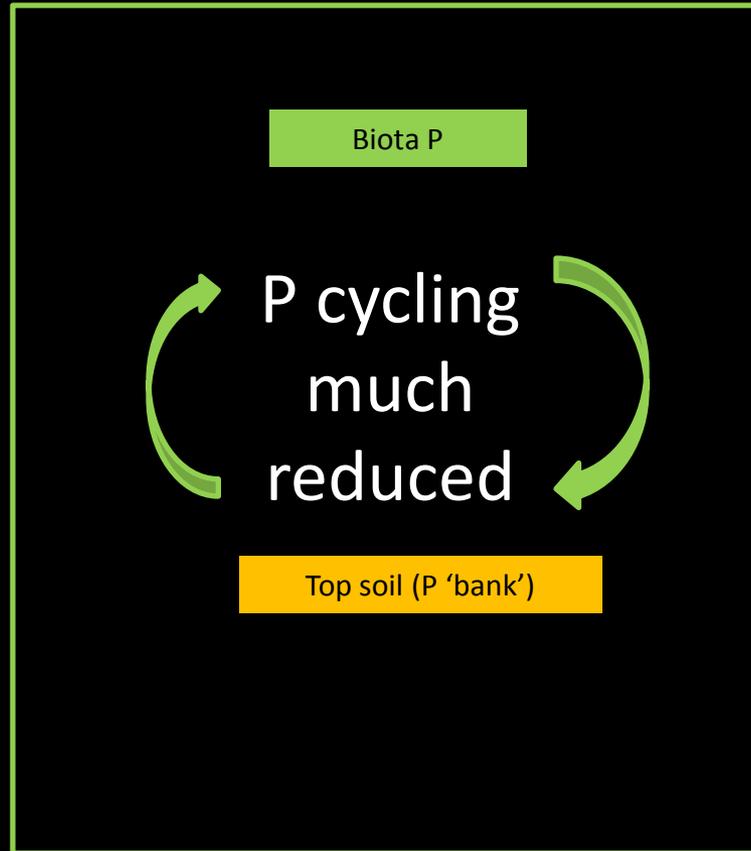
Anthropogenic
(food, fertiliser,
detergents, etc.)



Physical and chemical
(atmospheric deposition,
rock erosion)



Biological
(wild plant and animal
materials)



Ecosystem:

biodiversity collapses

P exports



Anthropogenic
(carcasses, crops,
timber, effluents, etc.)



Physical and chemical
(erosion and leaching)

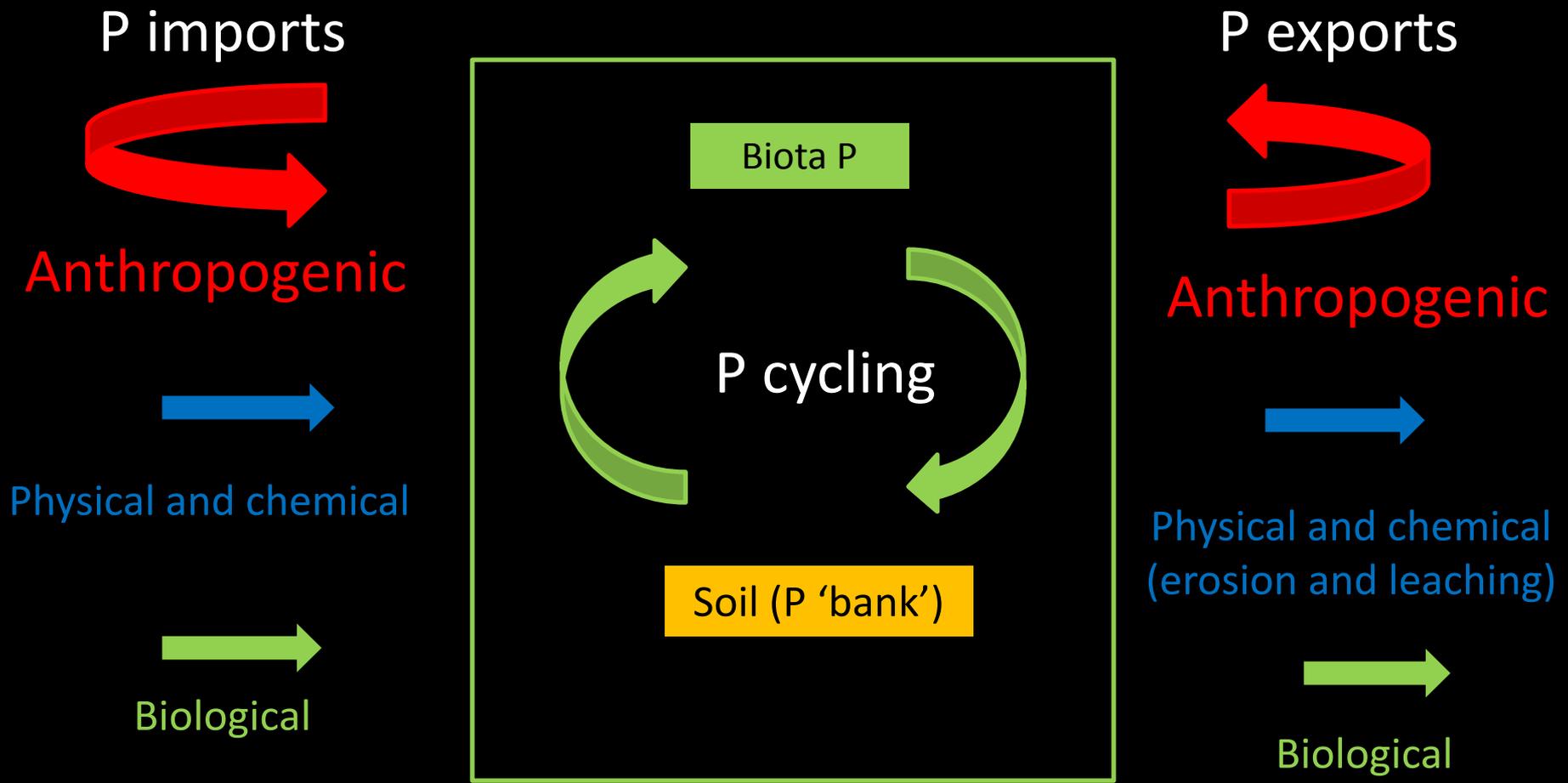


Biological
(wild plant and animal
materials)

Traditional agriculture



Traditional agricultural area



Agricultural Ecosystem: people are a part of the system

Crofting townships around the coast



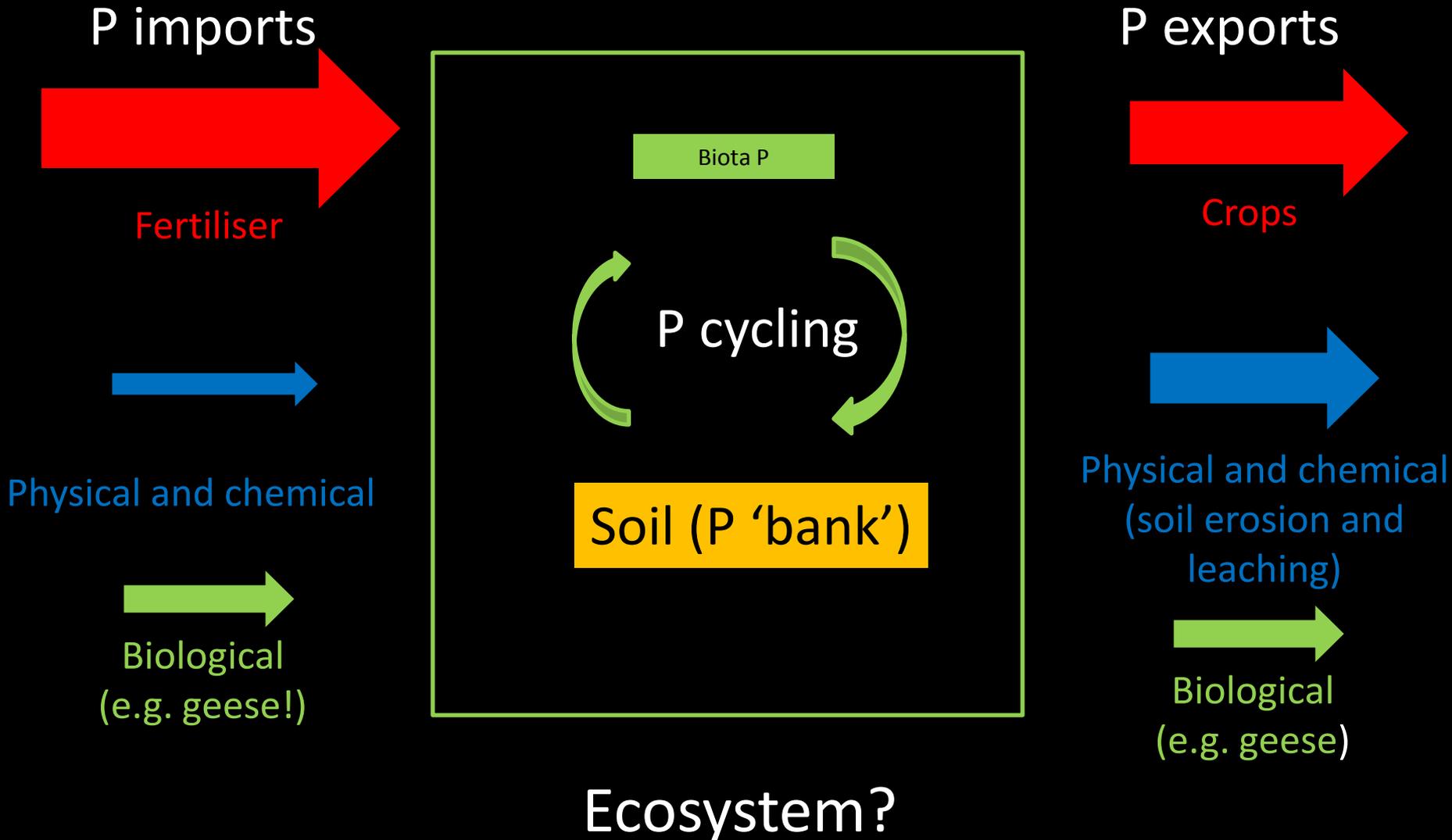
Melvaig and Alltgrishan in 2004

Intensive agricultural area



Andy Hay (rspb-images.com)

Intensive agricultural area



Break – any questions (or answers)?

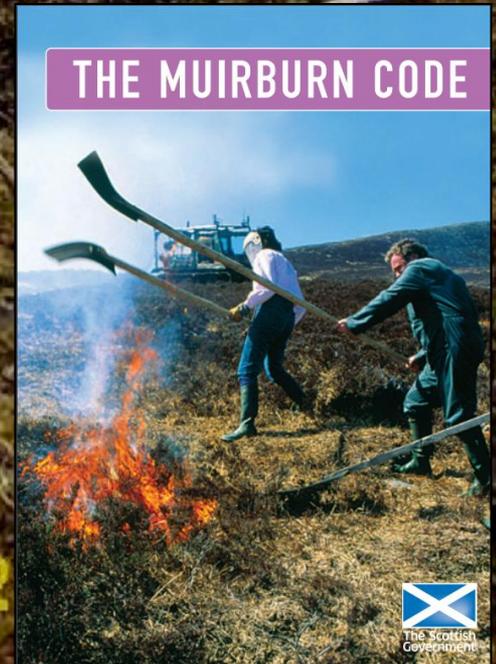


‘Ecosystem fertility . . .look: no soil!’

4. Loss of vegetation, fire & phosphorus export



Hillsides are burnt to promote fresh growth.



Little Gruinard River, May 2010 (inside fenced enclosure)

Wildfire in 2007

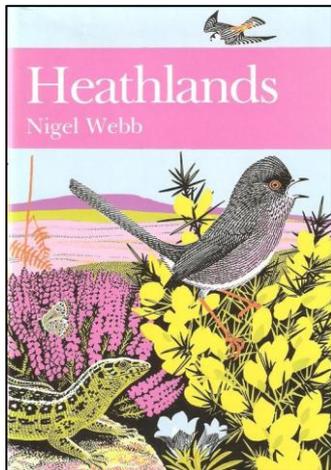


Vegetation on this boulder survived the fire.



How much phosphorus is lost in a moor burn?

Nutrient Balance Sheet for an Area of Lowland Heath (expressed as kg per ha)						
<i>from Webb, 1986</i>						
	Sodium (Na)	Potassium (K)	Calcium (Ca)	Magnesium (Mg)	Phosphorus (P)	Nitrogen (N)
Vegetation (heather heathland)	4.7	34.3	33	13.4	4.1	107.7
Leaf litter	0.7	5	15.2	3.8	4.2	74.5
Total	5.4	39.3	48.2	17.2	8.3	182.2
Soil (0-20cm)	84	288	229	236	37	2210
% [of P] in veg. and leaf litter lost on burning	28%	21%	26%	23%	26%	95%
amount remaining after burning	3.9	31	35.7	13.2	6.1	9.1
amount lost	1.5	8.3	12.5	4	2.2	173.1
Nutrient content of 1 years rainfall	25.4	1.2	4.7	5.6	0.01	5.2
Nutrient content of 12 years rainfall	305	14	56	67	0.12	62
Nutrient balance after 12 years	+303	+5.7	+43.5	+63	-2.08	-111
<i>Figures are in kg per ha</i>						



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**.

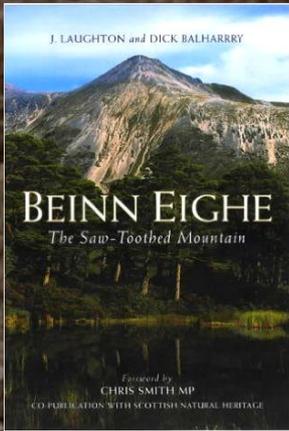
(2kg P is the equivalent to that in about 4 sheep)

Beinn Eighe National Nature Reserve

(core 'nature conservation' zone within the 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>



Forestry Commission Scotland
Coimisean na Coilltearachd Alba

Cromarty Fisheries



giving nature a home



SRUC



the National Trust for Scotland
a place for everyone



Game & Wildlife CONSERVATION TRUST



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



Beinn Eighe NNR field excursion 7th April 2016

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.



Beinn Eighe NNR field excursion 7th April 2016

Close up of grouse droppings by bearberries on the knoll in the previous picture. Ro Scott was the first to spot the berries! 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.



Beinn Eighe NNR

'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.



Fertilised area

Unfertilised area

**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



Beinn Eighe NNR

VEGETATION SURVEY OF
BEINN EIGHE, WESTER ROSS, 1997

A.B.G. Averis and A.M. Averis

January 1998

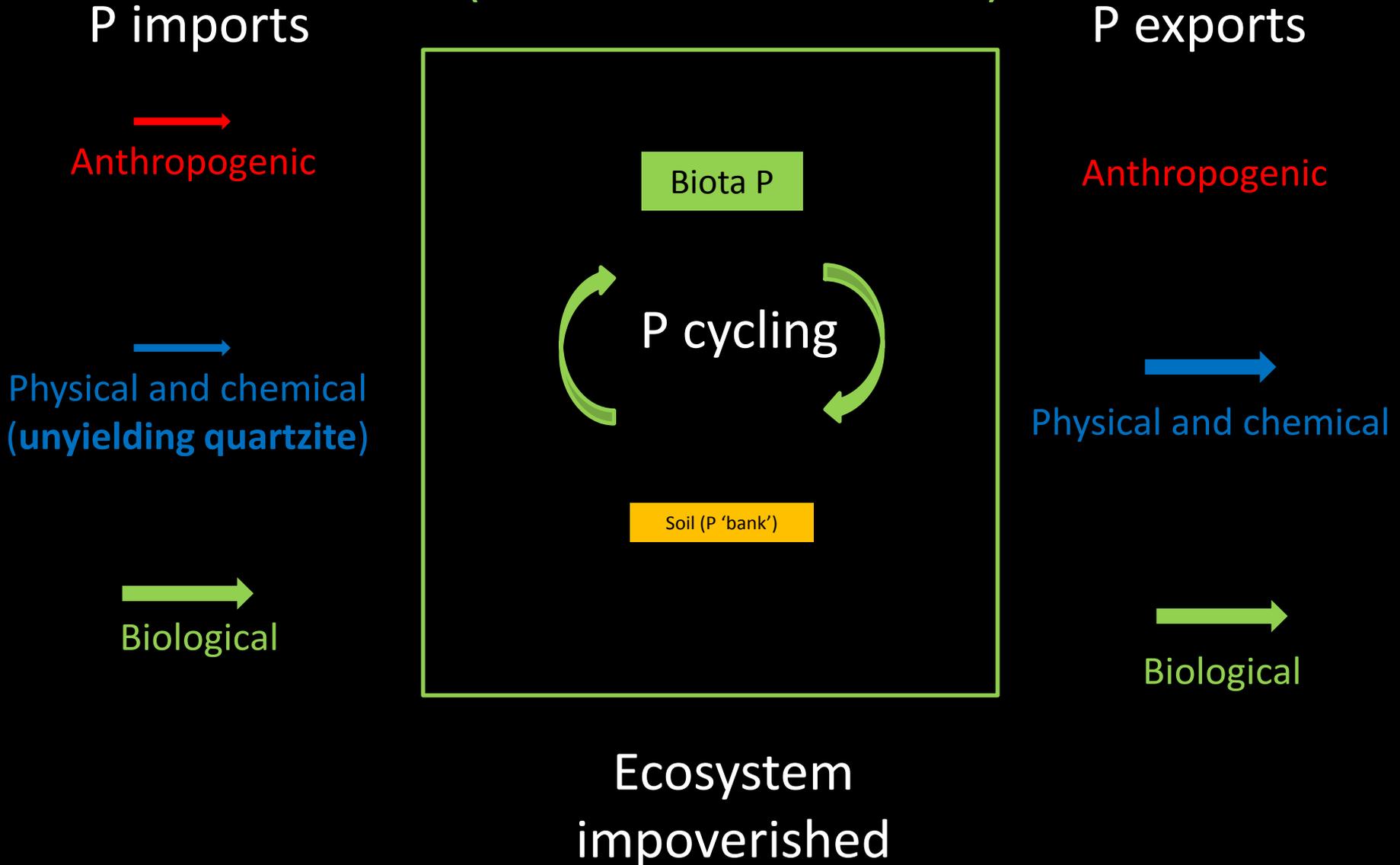
Scottish Natural Heritage contract HT/97/98/13

‘In June 1961 D.N. McVean applied phosphate fertiliser at 3 oz to the square yard [**~120kgP/ha**] to two small rectangular plots within M15c(ii) *Trichophorum-Erica* wet heath on quartzite at NH 003 621.’

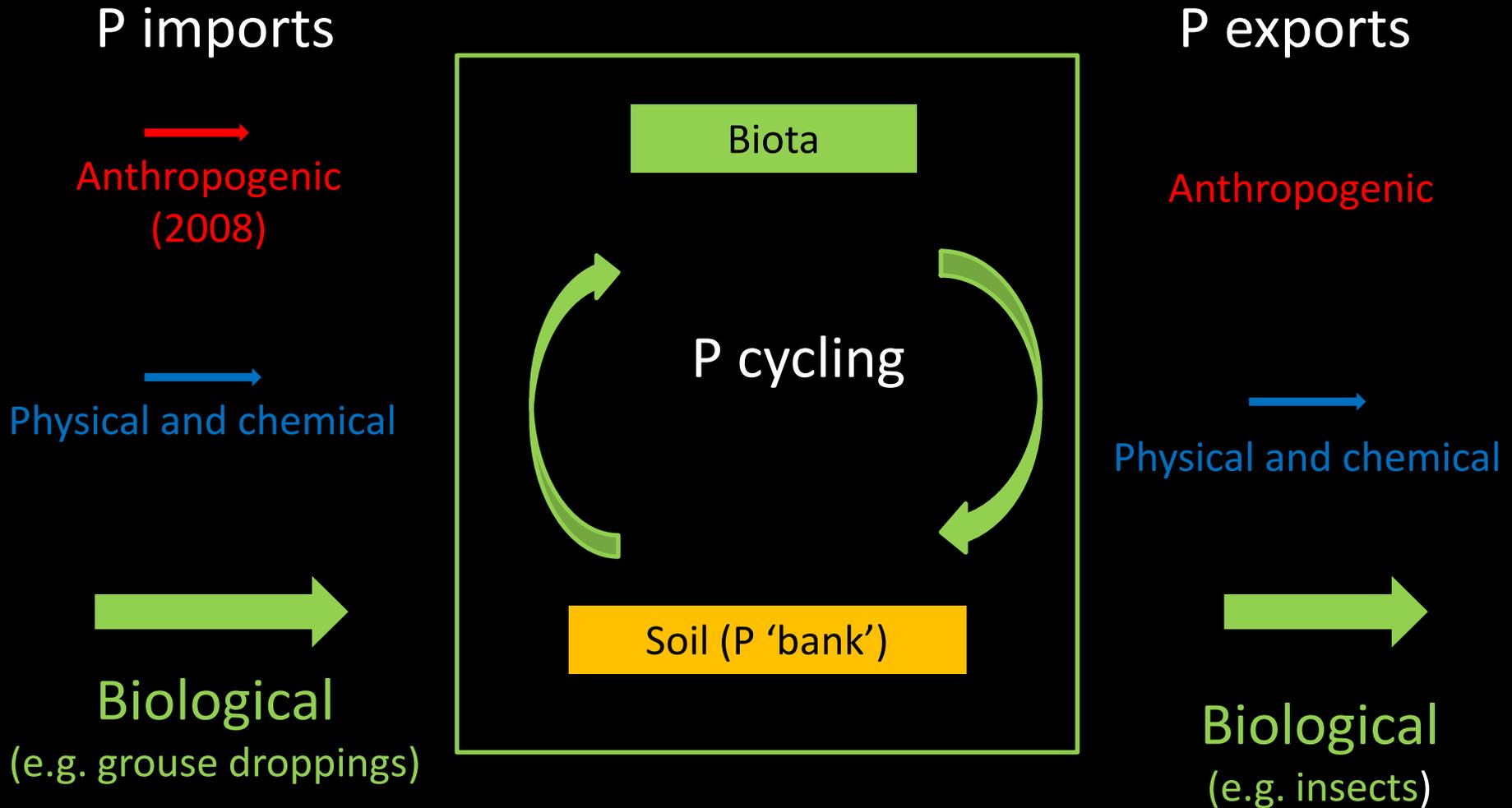
- ‘The treated vegetation is now more continuous than the surrounding sparse M15c(ii) heath.
- It has a noticeably greater cover of the moss *Racomitrium lanuginosum* (50-75%) and the lichens *Cladonia portentosa*, *C.arbuscula* and *C.uncialis* (30-50%) than does the surrounding heath.
- The heather 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 (outside fertilised area)



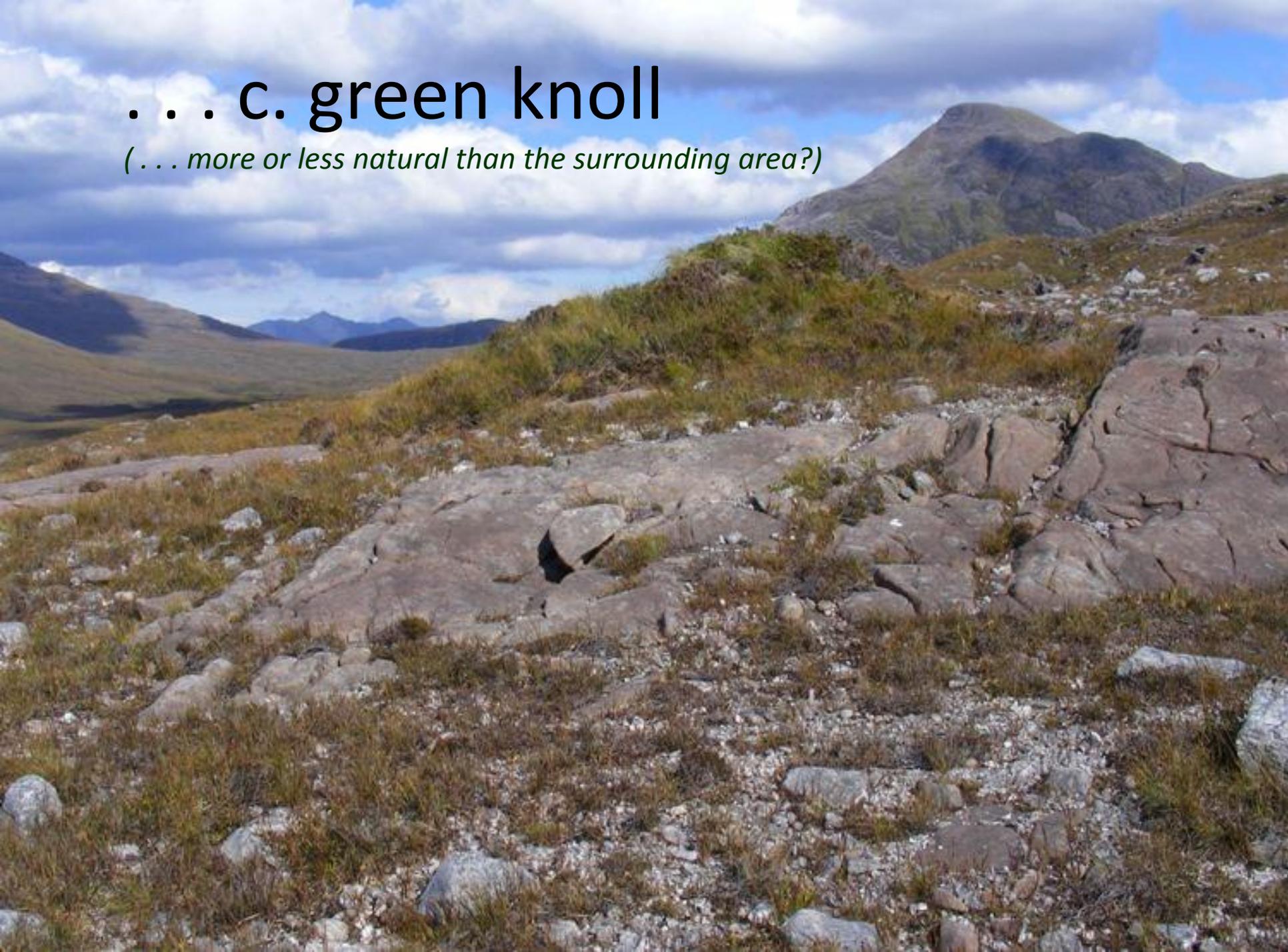
Inside fertilised area (50+ years following fertiliser application)



Ecosystem enriched:
higher productivity and higher biodiversity . . .

. . . c. green knoll

(. . . more or less natural than the surrounding area?)



Beinn Eighe NNR field excursion 7th April 2016

Small stunted pine tree near the Pony Path. Note the sparse and patchy vegetation surrounding the wee tree.



Beinn Eighe NNR

VEGETATION SURVEY OF
BEINN EIGHE, WESTER ROSS, 1997

A.B.G. Averis and A.M. Averis

January 1998

Scottish Natural Heritage contract HT/97/98/13

‘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.***

Beinn Eighe NNR

VEGETATION SURVEY OF
BEINN EIGHE, WESTER ROSS, 1997

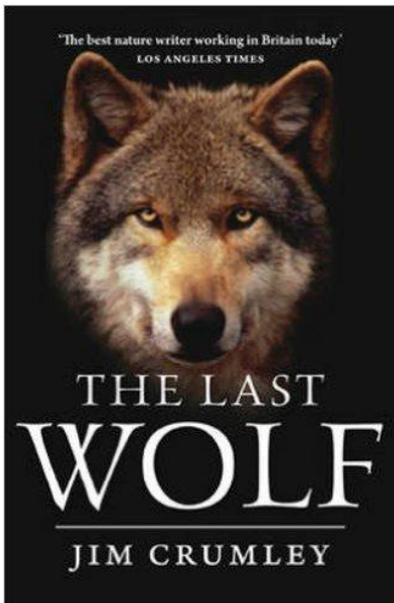
A.B.G. Averis and A.M. Averis

January 1998

Scottish Natural Heritage contract HT/97/98/13

‘... Any saplings which do survive soon become conspicuous in a bare landscape and are preferentially grazed.

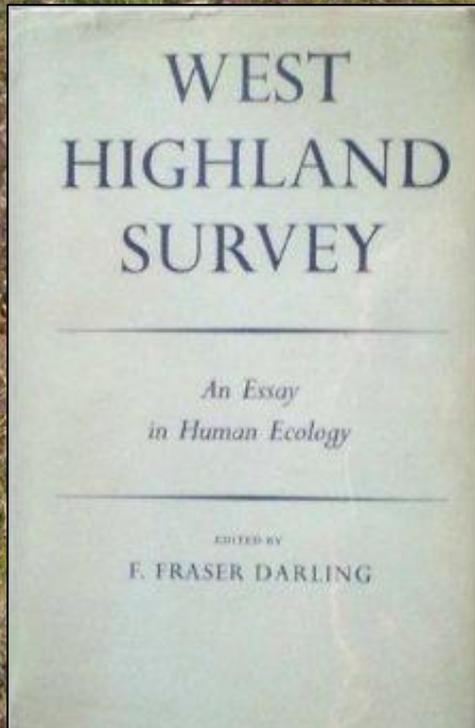
Grazing might need to be reduced to an unnaturally low level for long enough to allow trees to regenerate and soils to recover. This process might take several tens or even hundreds of years.’



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?



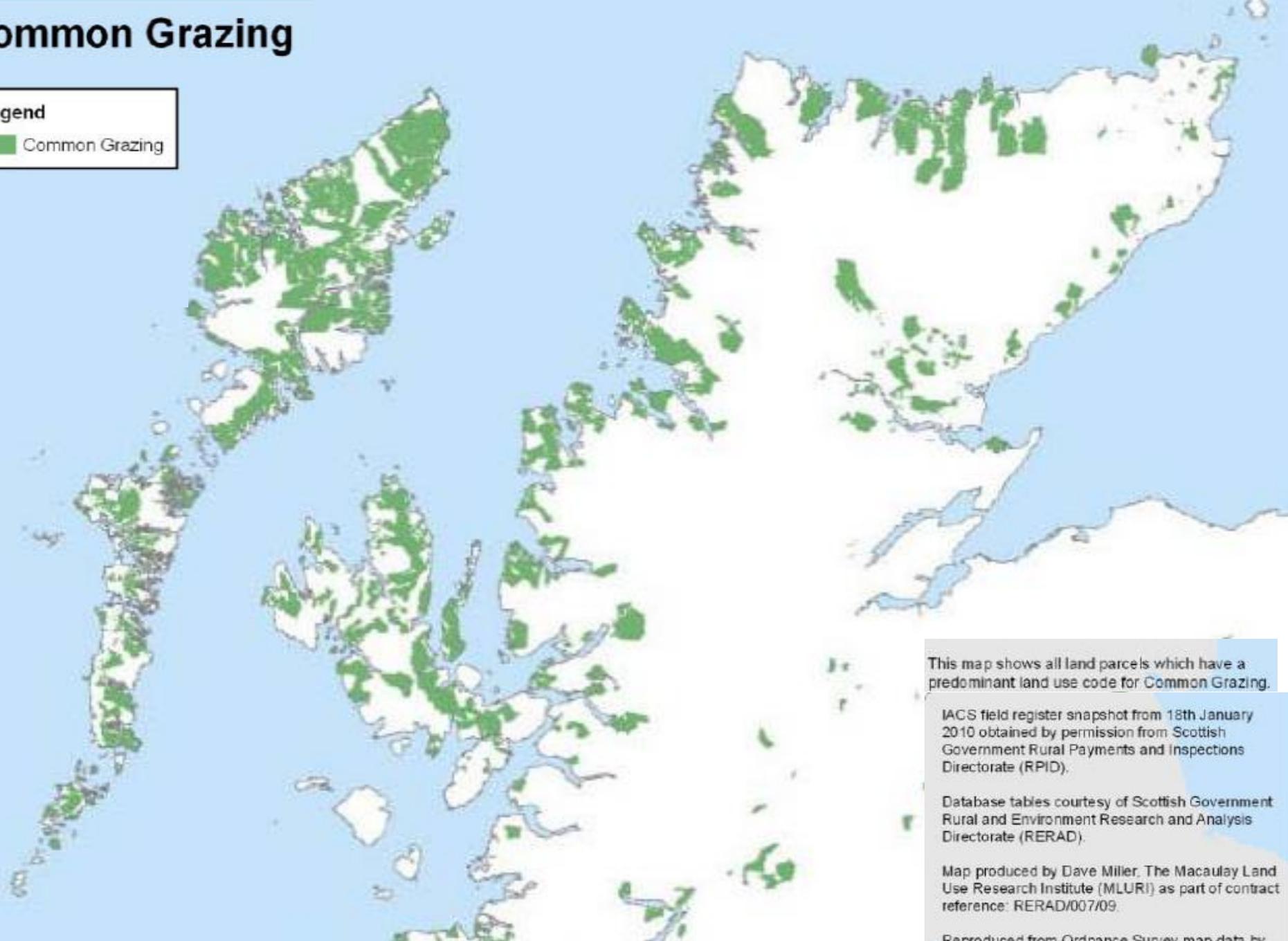
How have fertility levels and patterns changed as a result of land use and wildlife management practices?



Common Grazing

Legend

Common Grazing



This map shows all land parcels which have a predominant land use code for Common Grazing.

IACS field register snapshot from 18th 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).

Map produced by Dave Miller, The Macaulay Land Use Research Institute (MLURI) as part of contract reference: RERAD/007/09.

Reproduced from Ordnance Survey map data by permission of Ordnance Survey © Crown copyright MLURI 100019294 2010. All rights reserved.

Fires, 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 or organic material left.

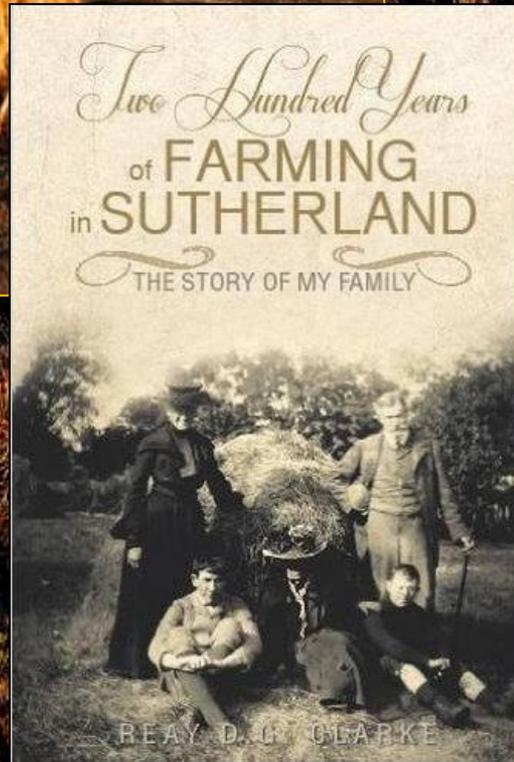


Over 50% of the soil has been eroded and washed away.

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?





CROFTING COMMISSION
COIMISEAN NA CROITEARACHD

CROFTING COMMISSION

POLICY PLAN

November 2015

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 . . .'



CROFTING COMMISSION
COIMISEAN NA CROITEARACHD

CROFTING COMMISSION
POLICY PLAN

November 2015

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. . . ’



CROFTING COMMISSION
COIMISEAN NA CROITEARACHD

CROFTING COMMISSION

POLICY PLAN

November 2015

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 . . . ?



Bog near Redpoint (2002)



Where nutrients are recycled . . .

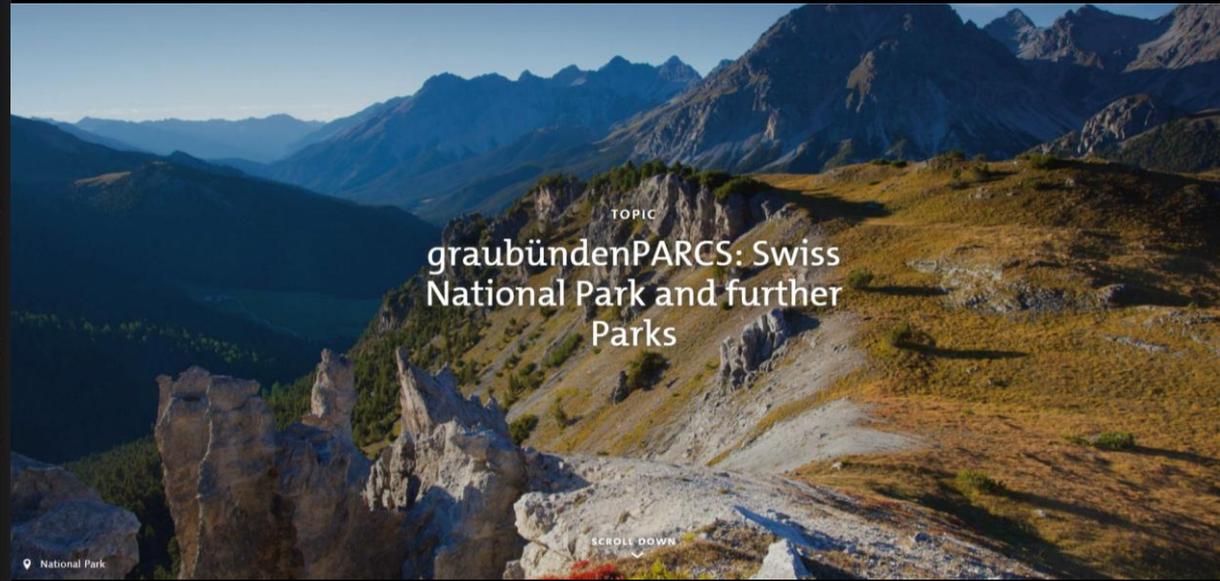
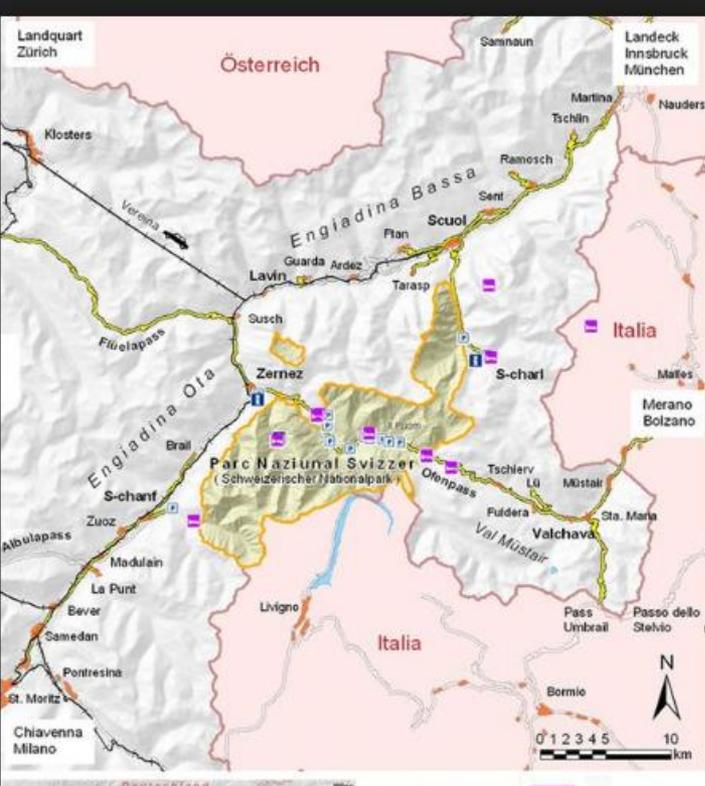
. . .from vegetation to sheep, and back to vegetation . . .

- *growth of plants - and insects - can be prolific*
- *more insects: more food for trout , salmon, birds . . .*

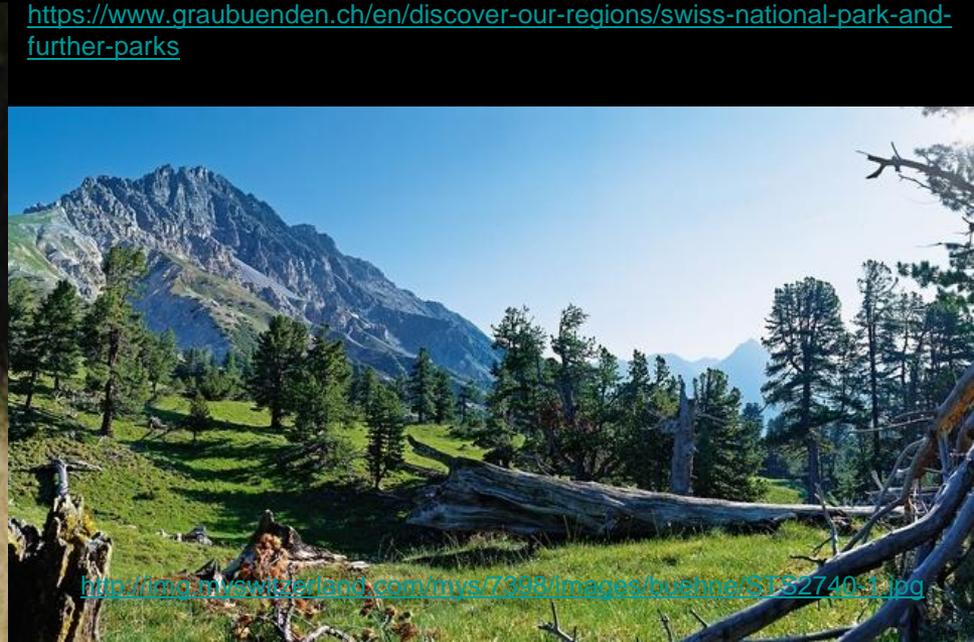
If deer carcasses are taken off the hill and phosphorus is not replaced. .



Fertility studies of grazing areas in the SNP



<https://www.graubuenden.ch/en/discover-our-regions/swiss-national-park-and-further-parks>



https://www.graubuenden.ch/sites/default/files/styles/grf_global_s/public/story_image/natur-essvm-rothirsch-nationalpark.jpg?itok=vc9uv8l9

<http://img.myswitzerland.com/img/7399/images/bushna/ST-52740-1.jpg>

Phosphorus Translocation by Red Deer on a Subalpine Grassland in the Central European Alps

Martin Schütz,^{1*} Anita C. Risch,^{1,2} Gérald Achermann,¹
Conny Thiel-Egenter,^{1,3} Deborah S. Page-Dumroese,⁴ Martin F. Jurgensen,⁵
and Peter J. Edwards⁶

¹Swiss Federal Institute for Forest, Snow and Landscape Research, CH-8903 Birmensdorf, Switzerland; ²Department of Biology, Biological Research Laboratories, Syracuse University, Syracuse, New York 13244, USA; ³Institute of Systematic Botany, University of Zurich, CH-8008, Zurich, Switzerland; ⁴Rocky Mountain Research Station, USDA Forest Service, Moscow, Idaho 83843, USA; ⁵School of Forest Resources and Environmental Science, Michigan Technological University, Houghton, Michigan 49931, USA; ⁶Geobotanical Institute, Swiss Federal Institute of Technology, CH-8044 Zurich, Switzerland

ABSTRACT

We examined the role of red deer (*Cervus elaphus* L.) in translocating phosphorus (P) from their preferred grazing sites (short-grass vegetation on subalpine grasslands) to their wider home range in a subalpine grassland ecosystem in the Central European Alps. Phosphorus was used because it is the limiting nutrient in these grasslands. When we compared P removal of aboveground biomass due to grazing with P input due to the deposit of feces on a grid of 268 cells (20 m × 20 m) covering the entire grassland, we detected distinct spatial patterns: the proportion of heavily grazed short-grass vegetation increased with increasing soil-P pool, suggesting that red deer preferably grazed on grid cells with a higher soil-P pool. Biomass consumption related to increased proportion of short-grass vegetation, and therefore P removal, increased with increasing soil-P pool. However, within the two vegetation types (short-grass and tall-grass), consumption was independent from soil-P pool. In addition, P input rates from defecation increased with increasing soil-P pool, resulting in a constant mean net P loss of 0.083 kg

ha⁻¹ y⁻¹ (0.03%–0.07% of soil-P pool) independent of both soil-P pool and vegetation type. Thus, there was no P translocation between grid cells with different soil-P pools or between short-grass and tall-grass vegetation. Based on these results, it is likely that the net rate of P loss is too small to explain the observed changes in vegetation composition from tall-herb/meadow communities to short-grass and from tall-grass to short-grass on the grassland since 1917. Instead, we suggest that the grazing patterns of red deer directly induced succession from tall-herb/meadow communities to short-grass vegetation. Yet, it is also possible that long-term net soil-P losses indirectly drive plant succession from short-grass to tall-grass vegetation, because nutrient depletion could reduce grazing pressure in short-grass vegetation and enable the characteristic tall-grass species *Carex sempervirens* Vill. to establish.

Key words: *Cervus elaphus*; elimination pattern; grazing pattern; phosphorus removal/input; succession; Swiss National Park.

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.

http://www.fs.fed.us/rm/pubs_other/rmrs_2006_schutz_m001.pdf

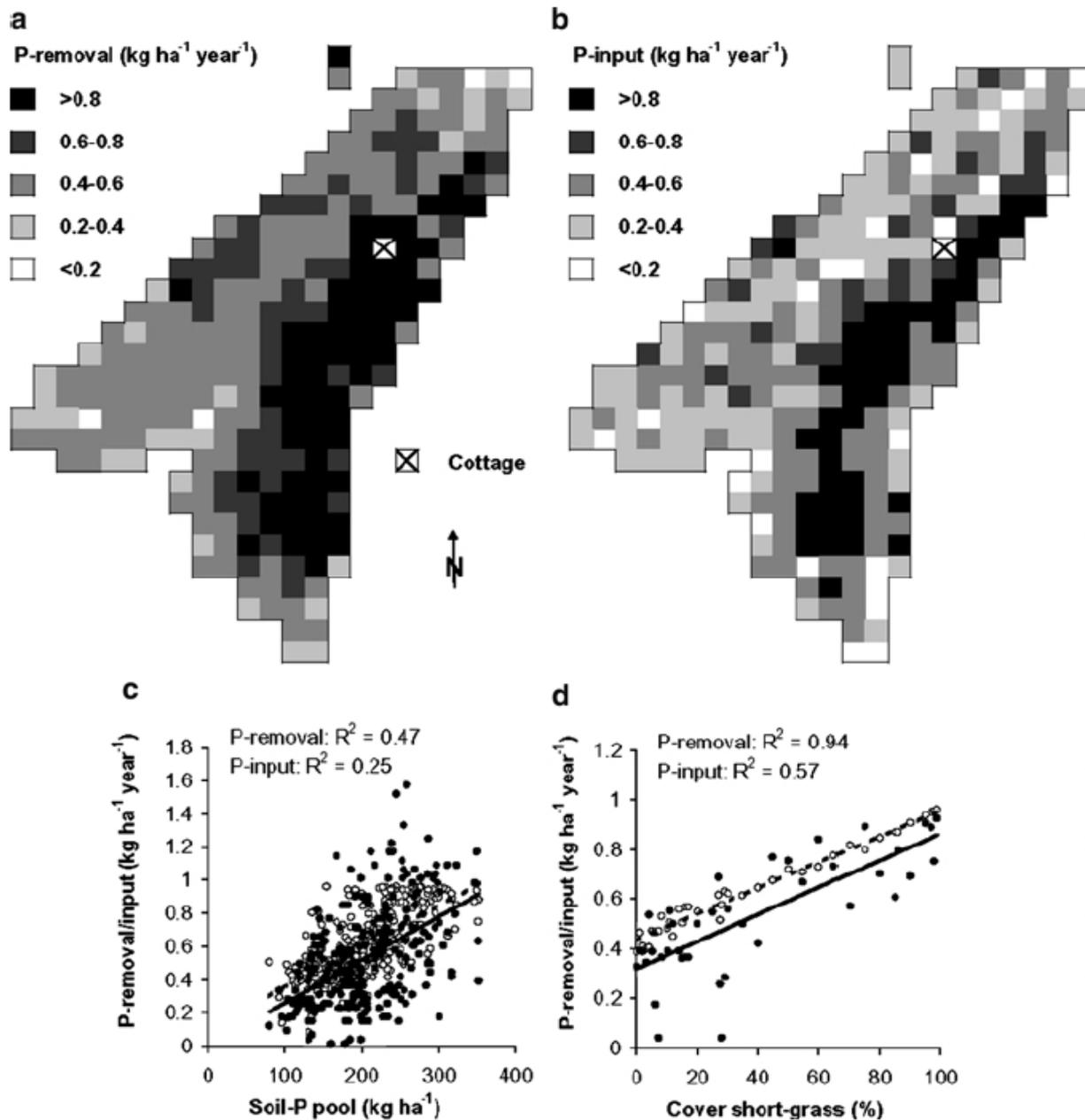


Figure 3. Spatial patterns of **A** phosphorus (P) removal by red deer grazing offtake, and **B** P input by red deer dung deposition on the subalpine grassland of Alp Stabelchod **C** Relationship between P removal/P input and soil-P pool. **D** Relation between P removal/P input and short-grass cover. P removal, ○—dashed line; P input, ●—solid line.

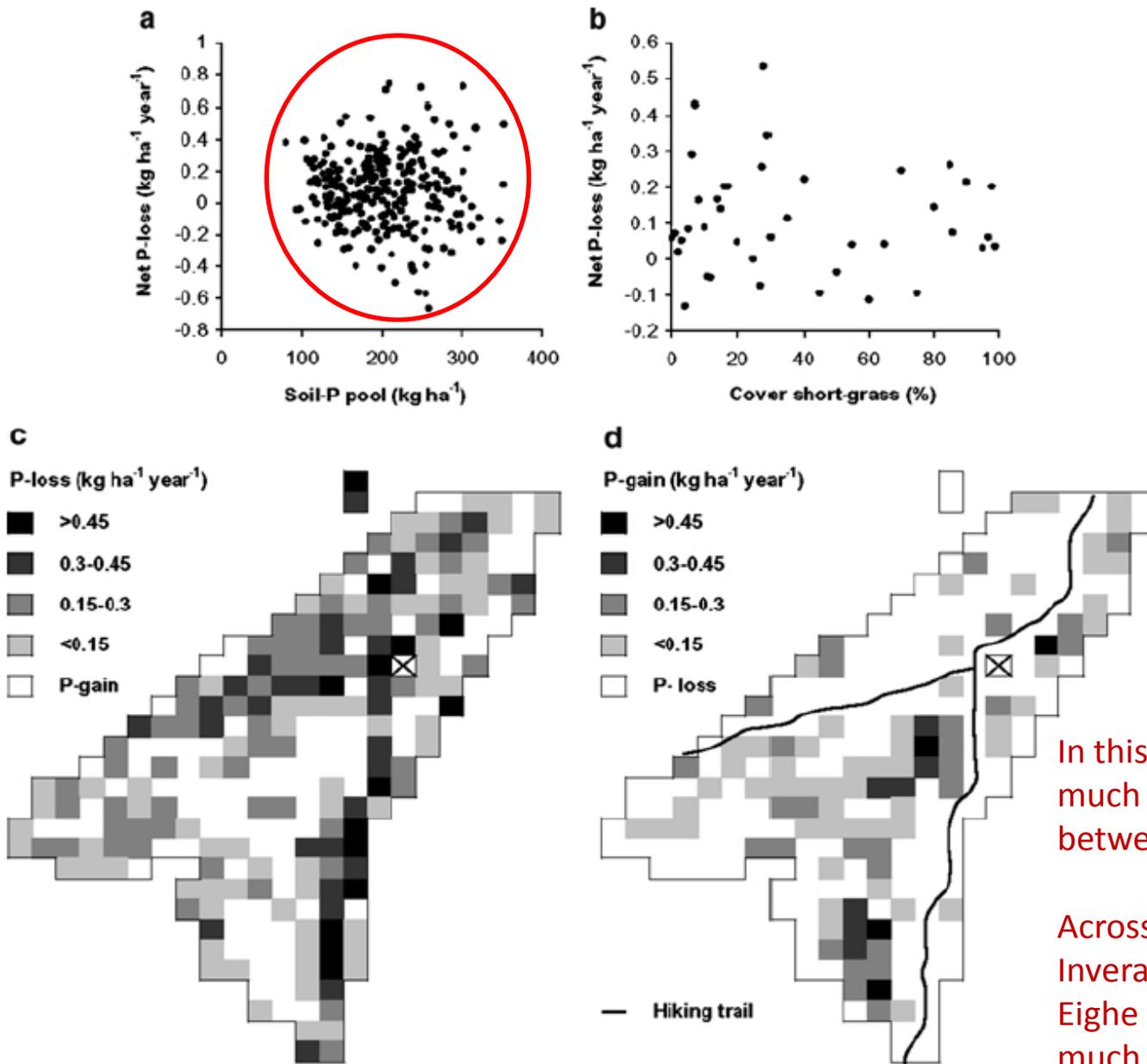


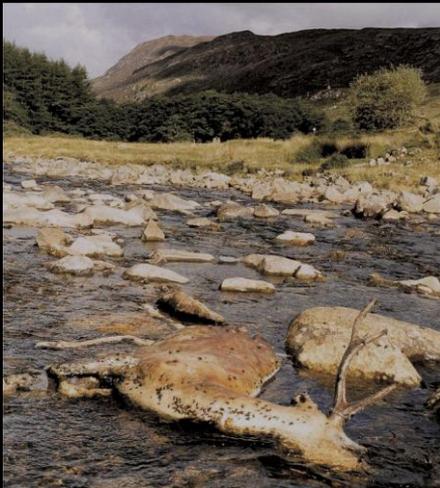
Figure 4. Relationship between **a** net phosphorus (P) loss and soil-P pool, **b** net P loss and cover of short-grass vegetation. Spatial patterns of **c** net P loss (removal > input) and **d** net P gain (input > removal) on the subalpine grassland of Alp Stabelchod.

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 Eithe 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?



Article

Biotic Translocation of Phosphorus: The Role of Deer in Protected Areas

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² Instituto de Análisis de Recursos Naturales, Universidad Atlántida, 7600 Mar del Plata, Argentina

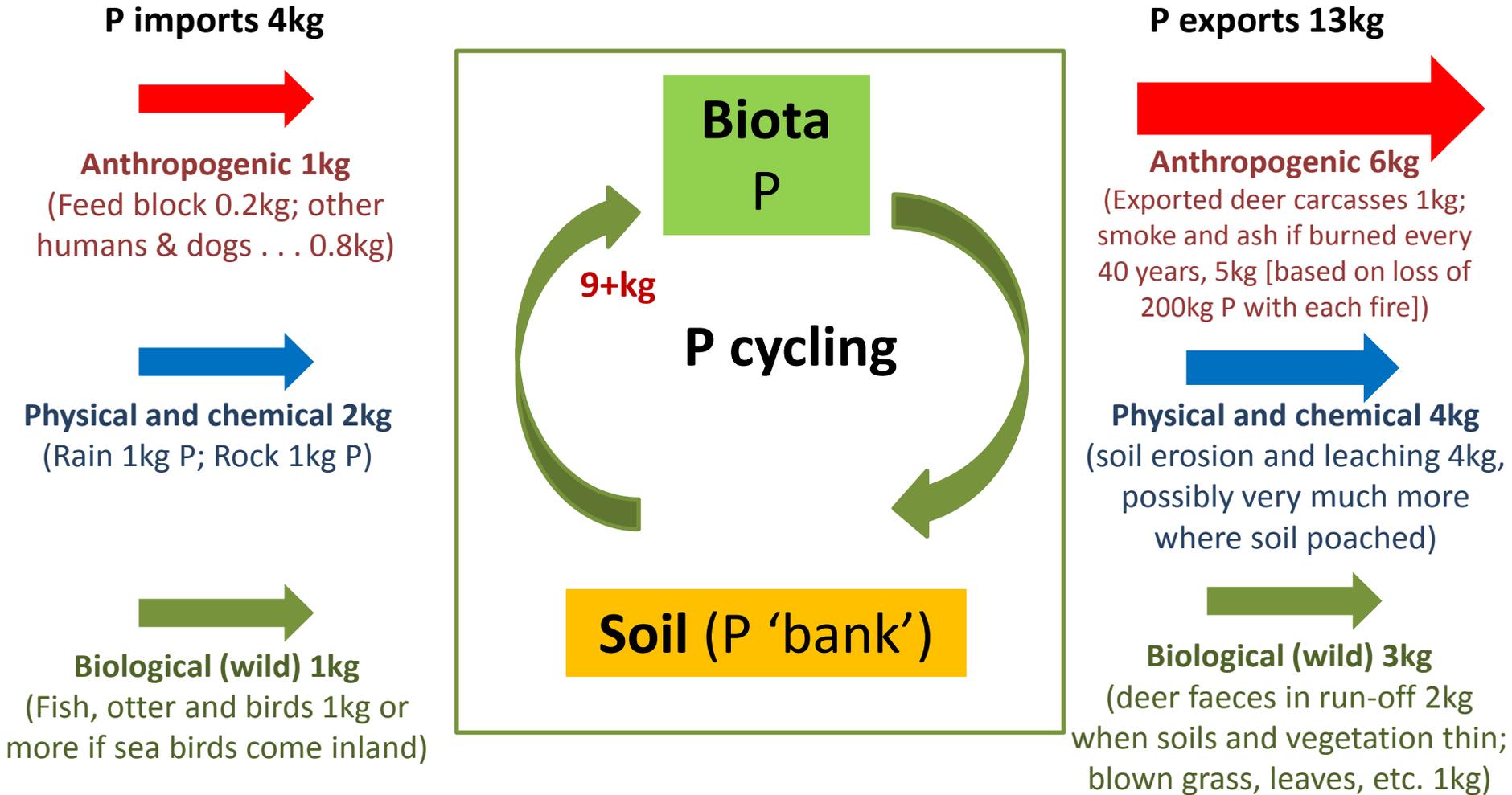
³ Swiss Tropical Institute, University Basel, 4002 Basel, Switzerland

Received: 23 February 2009 / Accepted: 7 April 2009 / Published: 14 April 2009

Abstract: Biogeochemical cycles are cornerstones of biological evolution. Mature terrestrial ecosystems efficiently trap nutrients and certain ones are largely recycled internally. Preserving natural fluxes of nutrients is an important mission of protected areas, but artificially leaky systems remain common. Native red deer (*Cervus elaphus*) in the Swiss National Park (SNP) are known to reduce phosphorus (P) in preferred feeding sites by removing more P than is returned with feces. At larger scales it becomes apparent that losses are occurring due to seasonal deer movements out of the SNP where most deer end up perishing. Thus, the SNP contributes to producing deer which translocate P to sink areas outside the SNP due to several artificial factors. An adult female dying outside of SNP exports about 1.8 kg of P, whereas a male dying outside of SNP at 8 years of age exports 7.2 kg of P due also to annual shedding of antlers. Averaged over the vegetated part of the SNP, the about 2,000 deer export 0.32 kg/ha/yr of P. Other ungulate species using the SNP and dying principally outside of its borders would result in additional exports of P. Leakiness in this case is induced by: a) absence of the predator community and thus a lack of summer mortalities and absence of several relevant non-lethal predator effects, b) hunting-accelerated population turnover rate, and c) deaths outside of SNP principally from hunting. The estimated export rate for P compares to rates measured in extensive production systems which receive 10–50 kg/ha/yr of P as fertilizer to compensate the losses from biomass exports. Assumptions were made regarding red deer body weight or population turnover rate, yet substituting my estimates with actual values from the SNP would only affect somewhat the magnitude of the effect, but not its direction. The rate of P loss is a proxy for losses of other elements, the most critical ones being those not essential to autotrophs, but essential to heterotrophs. High deer turnover rates combined with accelerated biomass export warrants detailed mass balances of macro and micro nutrients, and studies of biogeochemical cycles in protected areas are essential if preserving natural processes is a mandate.

Keywords: *Cervus elaphus*; Phosphorus; Biogeochemical cycle; Protected areas; Biomass export.

Hypothetical annual P budget example for 1km² of uninhabited unfertilised Wester Ross deer forest (i.e. open hill) burned every 40 years and stocked at 8 deer per km² where 1 deer is culled and carcass removed each year



Ecosystem: possible net loss of >9kg P per km² 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.



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[HOME](#) [DEER MANAGEMENT GROUP MAP](#)

Deer Management Group Map

Deer Management Groups comprise groups of estates or other landholdings that share access to a discrete population or herd of deer that is managed as a common resource. DMGs have been set up over the last 30 years with encouragement from the Government agency, now Scottish Natural Heritage, with the responsibility for the conservation and control of all four species of deer presently found in Scotland.

Click on the map to view individual DMG websites. All DMGs are listed alphabetically below the map, with links to their respective sites.



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 it 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 sporting 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 overhanging streams 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 (*Nardus stricta*) and purple moor grass (*Molinia caerulea*). Sheep and deer are selective grazers so 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
- • peat 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 mountainous terrain but has a different political and land-use history. Switzerland, Austria, Germany and many Eastern European countries also hold useful lessons.

<http://www.reforestingscotland.org/what-we-do/influencing-policy/the-impact-and-management-of-deer-in-scotland/>

Scottish Natural Heritage
**Code of Practice
on Deer Management**

The Deer Management
plans follow guidance from
SNH.



West Sutherland
Deer Management Group

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Home



Canisp, Suilven and Cui Mor, with Lochinver in the foreground.

Location

WSDMG lies in the north west of the country and is one of a number of deer groups in Sutherland. The boundaries of the area are:

- To the north, a line following the Laxford River from Laxford Bridge and along Lochs Stack, More, Merkland, Ghrama and Shin (A837)
- The A839 from Lairg, then the A837 from Rosehall via Oykel Bridge to Ledmore junction, then following the A835 south to Ardmail, and then west along the coastline to Achiltibuie.
- The coastlines of Coigach and Assynt, round Enard Bay then Edrachillis Bay to Laxford Bridge.

The area includes iconic mountains such as Suilven, Canisp and Stac Pollaidh. The villages of Scourie, Lochinver, Drumbeg and Achiltibuie are located within the area.

Click on the link below for map of the West Sutherland DMG area:

Recent Posts

- East area sub-group DMP final plan now adopted
- North area Sub-group Deer Management Plan revised July 2016, available to download on Deer Management Plan page.
- East area Deer Management Plan now available for consultation
- North sub-group Deer Management Plan available for consultation

<http://wsutherlanddmg.deer-management.co.uk/>

Home



The West Ross Deer Management Group (WRDMG) is situated in the north-west Highlands. Between Loch Broom to the north east and Loch Maree to the south west, it extends to over 96,000 ha (238,000 acres). From sea level on the west coast the area rises to 1,060m at the summit of An Teallach.

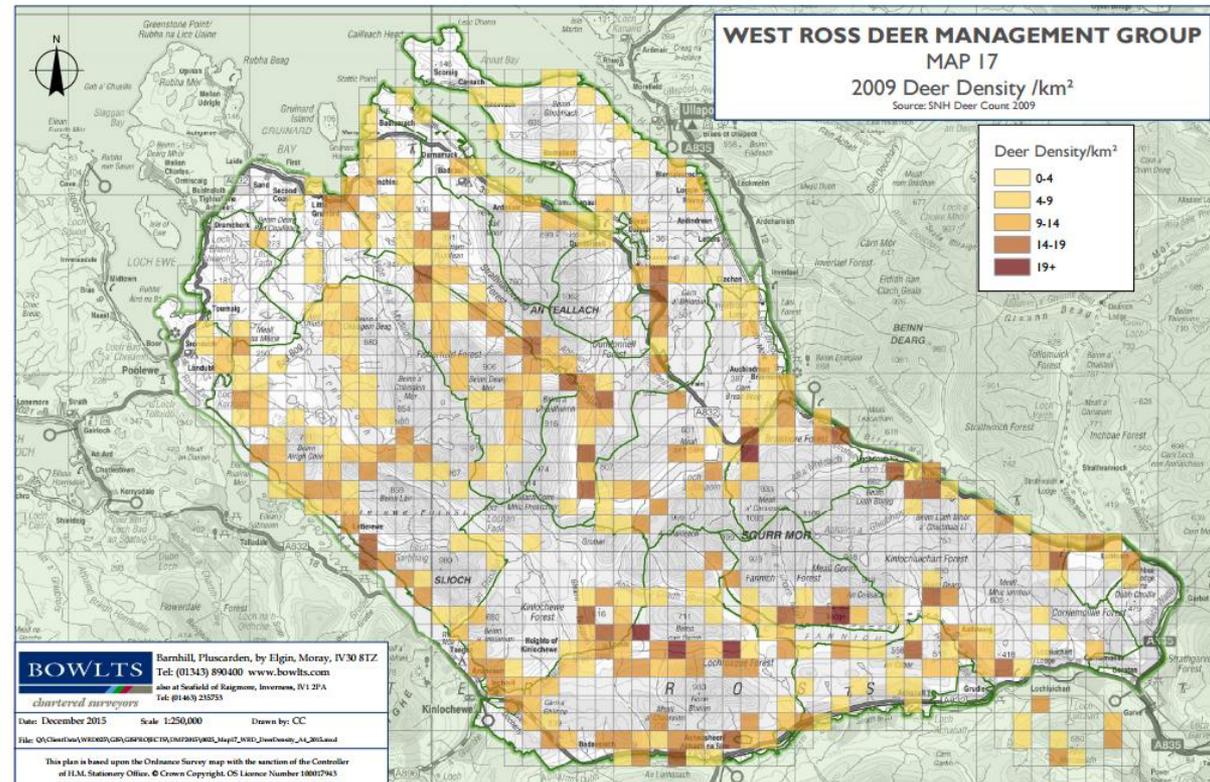
It is a beautiful and remote part of the north western Highlands, with limited road access with the A832 running almost entirely round it's perimeter.

Popular with tourists, in particular hill walkers, there are 18 Munros and many walking routes.

The aim of the group is to collaborate on deer management issues and in particular to:

- share a commitment to a sustainable and economically viable Scottish countryside;
- maintain a sporting stag cull and associated socio-economic benefits;
- maintain designated features in favourable condition and work towards favourable/unfavourable recovering status;
- liaise with SNH to protect all designated features;
- control the spread of non-native deer and other species;
- consider public interest elements relevant to local circumstances;
- identify native woodland condition and potential woodland expansion;
- encourage members to undertake skills and training assessment and maintain a record of skills;
- promote awareness of appropriate bio-security measures;
- encourage responsible access via the outdoor access code.

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.



NORTH WEST SUTHERLAND DEER MANAGEMENT GROUP

MARCH 2015 DRAFT

DEER MANAGEMENT PLAN

2015 – 2025

Background Information

PREFACE

This Deer Management Plan has been developed for the North West Sutherland Deer Management Group (NWS DMG) and also includes issues relating to domestic livestock. The Plan is funded both by the deer group and by Scottish Natural Heritage. It replaces a previous DMP that was partially drawn up in 2006, aiming to take account of changing circumstances with the group area. The Plan runs from 2015 until 2025 and has been formally endorsed by all the Members of the Group. It has been designed to be readily updated as needs arise and will be reviewed on a six-monthly basis or as required, with a systematic review taking place at the end of the first five year period in 2020.

This Plan has been compiled by:

Victor Clements: Native Woodland Advice, Mamie's Cottage, Taybridge Terrace,
Aberfeldy, PH15 2BS

Tel (01887) 829 361 victor@nativewoods.co.uk

... 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>

Part Two - OVERALL AIMS & OBJECTIVES

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 fulfil the annual sporting and venison production objectives of individual Members. During this plan this will amount to some **487 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 ration 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.

NORTH ROSS DEER MANAGEMENT GROUP

(VERSION May 2016)



DEER MANAGEMENT PLAN
2014 - 2019

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?

<http://nrossdmg.deer-management.co.uk/wp-content/uploads/2016/06/Deer-Management-Plan-2014-2019.pdf>

2. AIMS & OBJECTIVES

2.1 Guiding Principles

The Members have adopted the Principles of Collaboration created by the ADMG which are as follows:-

- to acknowledge what we have in common - namely a shared commitment to a sustainable and economically viable Scottish countryside;
- to make a commitment to work together to achieve that;
- to accept that we have a diversity of management objectives and that we respect each other's objectives;
- to undertake to communicate openly with all relevant parties;
- to commit to negotiate and where necessary compromise in order to accommodate the reasonable land management requirements of our neighbours;
- to undertake that where there are areas of disagreement, we will work to resolve these.

In addition Members have adopted the Code of Practice on Deer Management (Appendix II) and aim to deliver the terms of the code through the Groups policies and objectives.

2.2 The Group's Objectives:-

- To foster best practice in all aspects of deer management.
- To adopt a constitution suitable for the running of the NRDMG
- To ensure full participation throughout the Group area
- To ensure that ownership objectives (be they sporting, forestry, agricultural, fishing, conservation, etc) are achievable whilst maintaining designated features in favourable condition or working towards favourable/unfavourable recovering condition.
- To maintain a sustainable Group sporting stag cull and associated socio-economic benefits.
- Minimise spread of sika and any other non-native deer species within the DMG area and report sightings to SNH
- Minimise the incidents of deer poaching.
- Minimise negative impacts associated with access legislation.
- To adhere to the Deer Management Group benchmark (Appendix III)
- to achieve a relatively stable deer population capable of sustaining sporting requirements along with other land uses and habitat requirements of the area;
- to ensure sufficient on going training is carried out to enable the aims and objectives of the Group to be met
- to ensure an effective system of communications is in place both within the Group and with the general public and to engage positively and actively.
- to ensure such there are sufficient resources carry out the aims and objectives of the Group

If deer carcasses are taken off the hill and phosphorus is not replaced. .

Diet compensates for mineral deficiencies

https://asknature.org/strategy/diet-compensates-for-mineral-deficiencies/#.WCBVpS2LSUk

BIOLOGICAL STRATEGIES INSPIRED IDEAS RESOURCES COLLECTIONS

Diet compensates for mineral deficiencies

Red Deer

AskNature Team May 4, 2016

ADAPT BEHAVIORS

The dietary behavior of some red deer compensates for periods of mineral deficiencies by eating bones of small birds.



REFERENCES

"On one of Scotland's western outposts, the island of Rhum in the Inner Hebrides, there are more than 300 red deer (*Cervus elaphus*). Although they are the same species as those found on the Scottish mainland, the red deer of Rhum exhibit a macabre dietary deviation that sets them far apart from others of their species.

"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.

"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." (Shuker 2001:118)

BOOK

The Hidden Powers of Animals: Uncovering the Secrets of Nature

January 1, 1970
Dr. Karl P. N. Shuker

ORGANISM

Wapiti

Cervus elaphus Subspecies

Break – any questions (or answers)?



Do any estates manage the fertility and productivity of the areas where deer may graze?

Phosphorus budgets: what else can we quantify?

A salmon carcass represents about 15g of phosphorus, enough fertiliser to produce 5kg to 7.5kg of dried plant material.

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



x 200

or



x 1,000kg

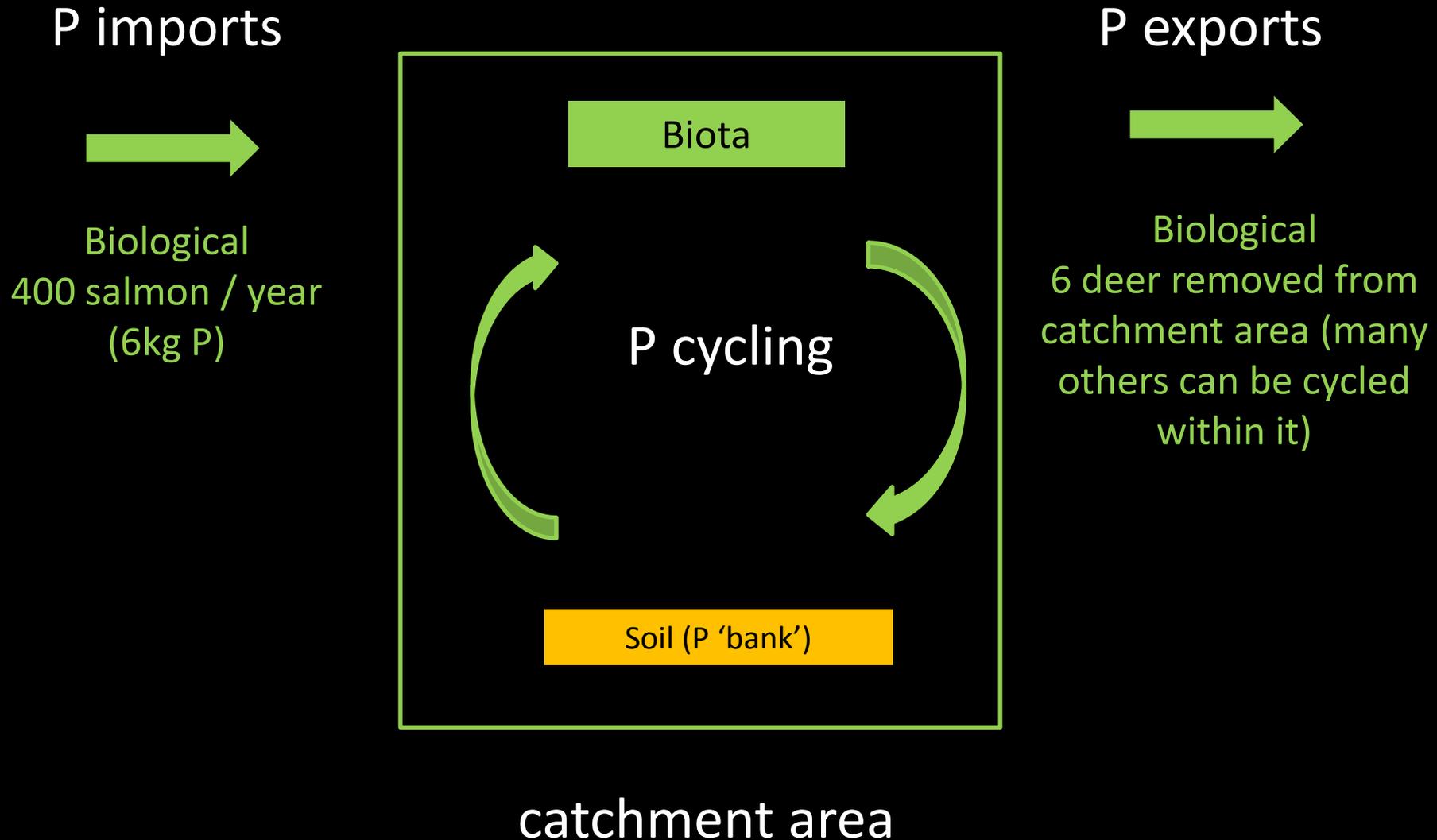
or



x 3

= ~ 3kg of
Phosphorus

balanced 'biological' P budget model, e.g.



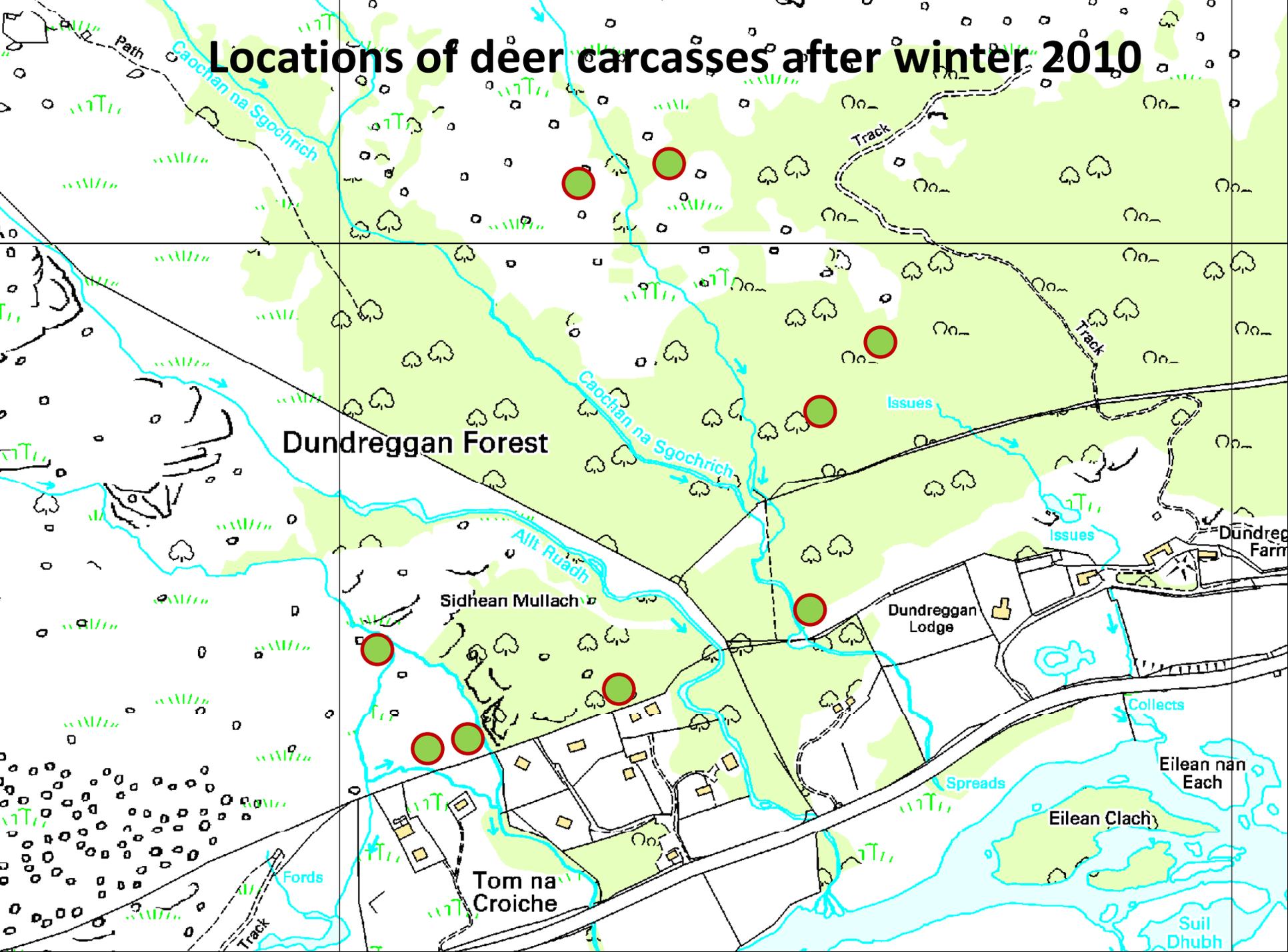


What would happen
to deer populations
if they were not
culled?

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 more natural situation?

Where predators are present, nutrients from carcasses are recycled back into the ecosystem.

Ecology, 00(0), 0000, pp. 000–000
© 0000 by the Ecological Society of America

Wolves modulate soil nutrient heterogeneity and foliar nitrogen by configuring the distribution of ungulate carcasses

JOSEPH K. BUMP,¹ ROLF O. PETERSON, AND JOHN A. VUCETICH

School of Forest Resources and Environmental Science, 1400 Townsend Drive, Michigan Technological University, Houghton, Michigan 49931 USA

Abstract. Mechanistic links between top terrestrial predators and biogeochemical processes remain poorly understood. Here we demonstrate that large carnivores configure landscape heterogeneity through prey carcass distribution. A 50-year record composed of >3600 moose carcasses from Isle Royale National Park, Michigan, USA, showed that wolves modulate heterogeneity in soil nutrients, soil microbes, and plant quality by clustering prey carcasses over space. Despite being well utilized by predators, moose carcasses resulted in elevated soil macronutrients and microbial biomass, shifts in soil microbial composition, and elevated leaf nitrogen for at least 2–3 years at kill sites. Wolf-killed moose were deposited in some regions of the study landscape at up to 12× the rate of deposition in other regions. Carcass density also varied temporally, changing as much as 19-fold in some locations during the 50-year study period. This variation arises, in part, directly from variation in wolf hunting behavior. This study identifies a top terrestrial predator as a mechanism generating landscape heterogeneity, demonstrating reciprocal links between large carnivore behavior and ecosystem function.

Key words: animal–ecosystem links; carcass; carnivore; ecosystem function; heterogeneity; indirect effect; Isle Royale; moose; predator–prey; resource patch; spatial pattern; wolves.

INTRODUCTION

wolves configure soil and plant resource hotspots by directly influencing prey carcass distribution.

Soil heterogeneity is an important determinant of soil diversity (Tilman 1999, Ettema and Wardle 2002, Wardle 2002, Wardle et al. 2004, De Deyn and Van der Putten 2005), which causes patchiness of soil resources, influencing aboveground biodiversity and ecosystem function (Hutchings et al. 2000, Lovett et al. 2003). Biotic interactions affect the heterogeneity of soil resources frequently through plant–soil associations and invertebrate soil fauna (Wardle 2002, 2006). The effects of large herbivores on soil heterogeneity are typically characterized by indirect feedbacks between selective herbivory and leaf litter quality, and nutrient-rich patch generation through feces and urine deposition (Danell et al. 2006). Recently however, the nutrient-rich and highly labile carcasses of large ungulates have been recognized as being consequential in the generation of landscape heterogeneity (reviewed in Carter et al. 2007). In the absence of predators, bison (*Bos bison*), cattle (*B. taurus*), and deer (*Odocoileus virginianus*) carcasses can provide local nutrient pulses at intensities that exceed other natural processes, thus influencing plant composition and biomass (Towne 2000). However, the effects of predators and scavengers on carcass spatial distribution, temporal deposition, and the magnitude of nutrients released due to variable carcass consumption are unknown.

While carcasses produced by means other than predation (e.g., starvation, disease, vehicle collisions,

*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.*



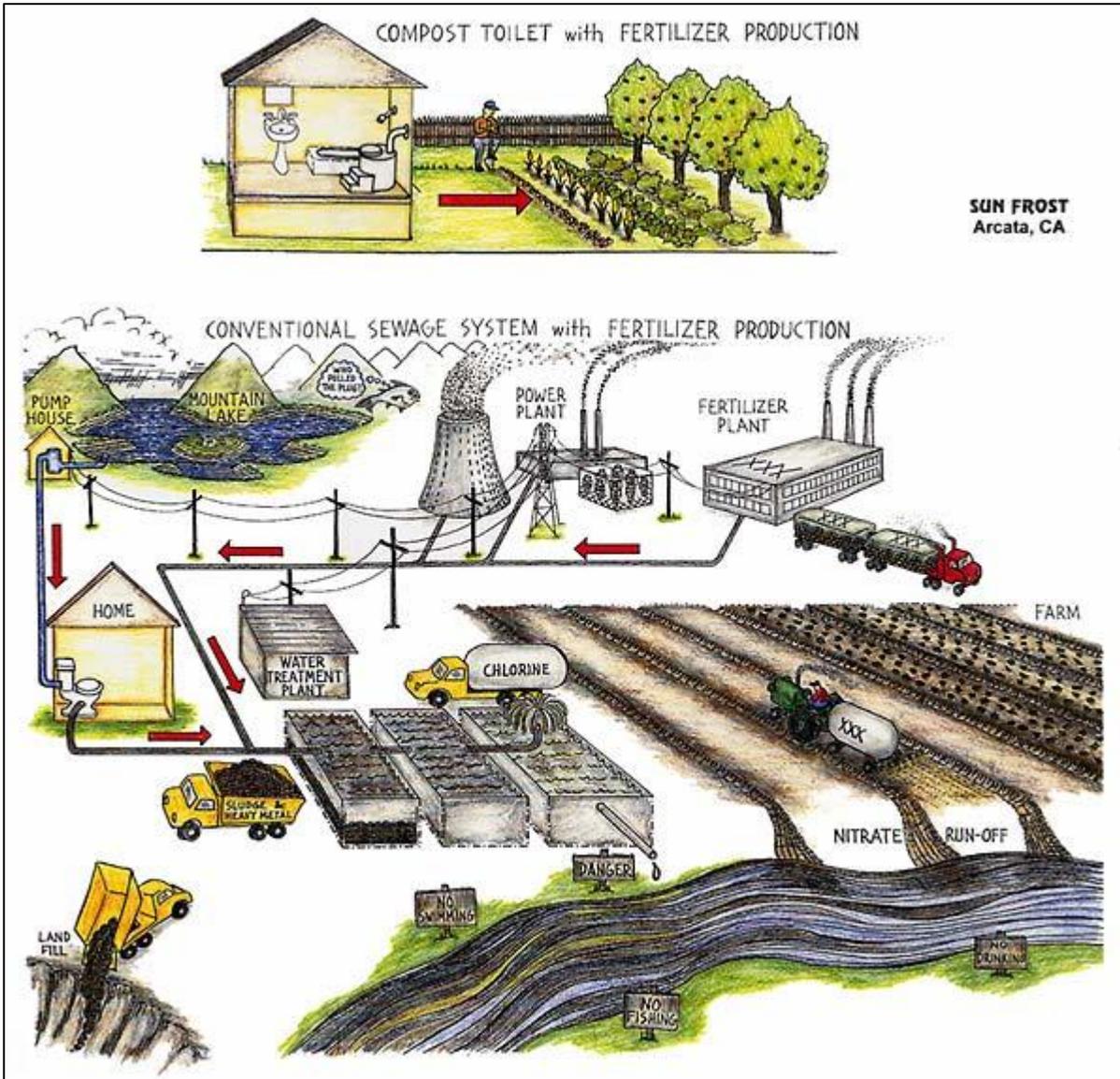
<http://www.indefenseofplants.com/blog/2015/12/11/arctic-bone-nurseries>

Break – any questions (or answers)?



Green knoll: phosphorus & biodiversity hot spot?

6. How to conserve and replenish phosphorus . . .



SUN FROST
Arcata, CA

?

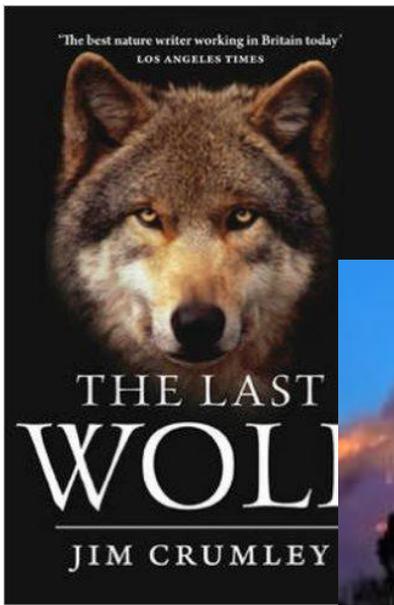
http://www.sunfrost.com/images/compost_toilet_full_size.jpg

Recap:

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.

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

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.

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

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

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.

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

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

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

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

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

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



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

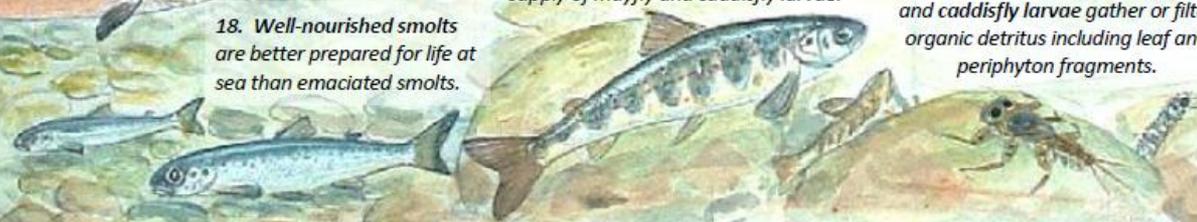
18. Well-nourished smolts are better prepared for life at sea than emaciated smolts.

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.

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

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

In some areas invasive New Zealand flatworms have reduced earthworm populations, displacing moles with adverse consequences for soils.



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.



WGS enclosure, Coulin Estate (headwaters of River Ewe)

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 . . .

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



Trees were planted in ~2006

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

Thank you to Colin Simpson.

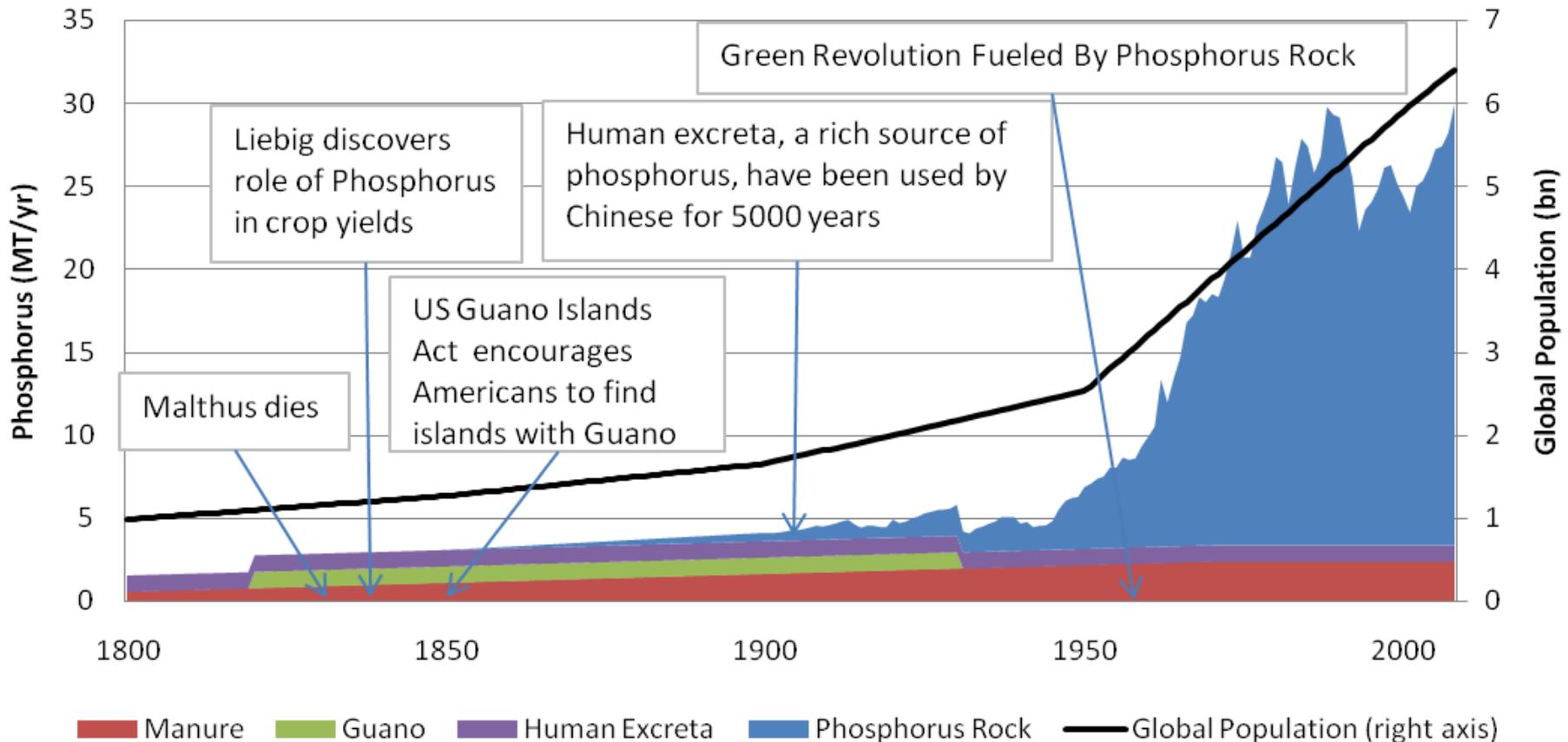
However; note that application rates should be carefully considered . . !!



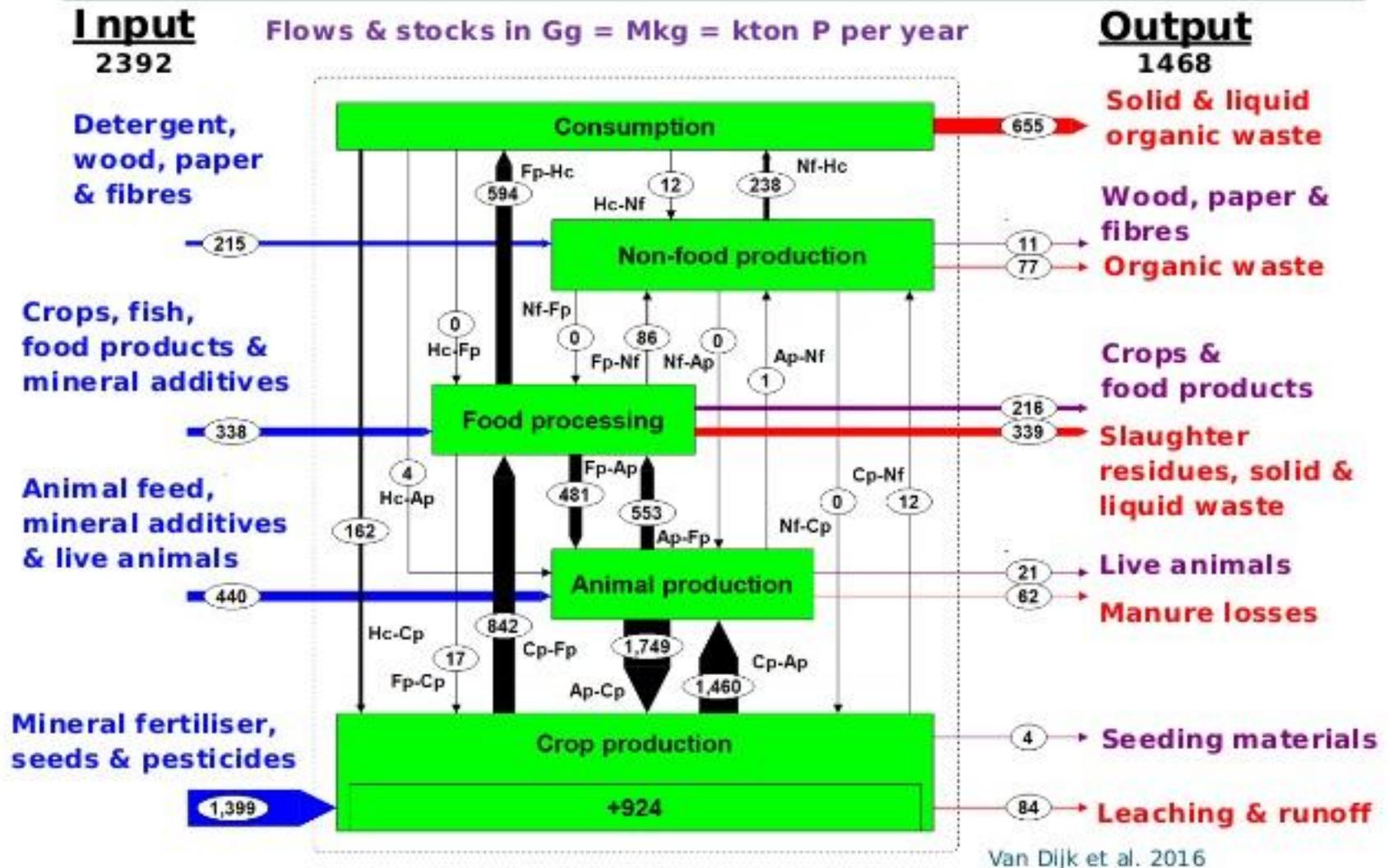
Filamentous algal matt below WGS scheme, Balgy catchment, Sept 2010

We may run short of phosphorus in future years.

Historical Sources of Phosphorus Fertilizer



Phosphorus use in the EU-27 in 2005





Phosphorus: a limiting nutrient for humanity?

James J Elser 

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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.

Phosphorous & rice production



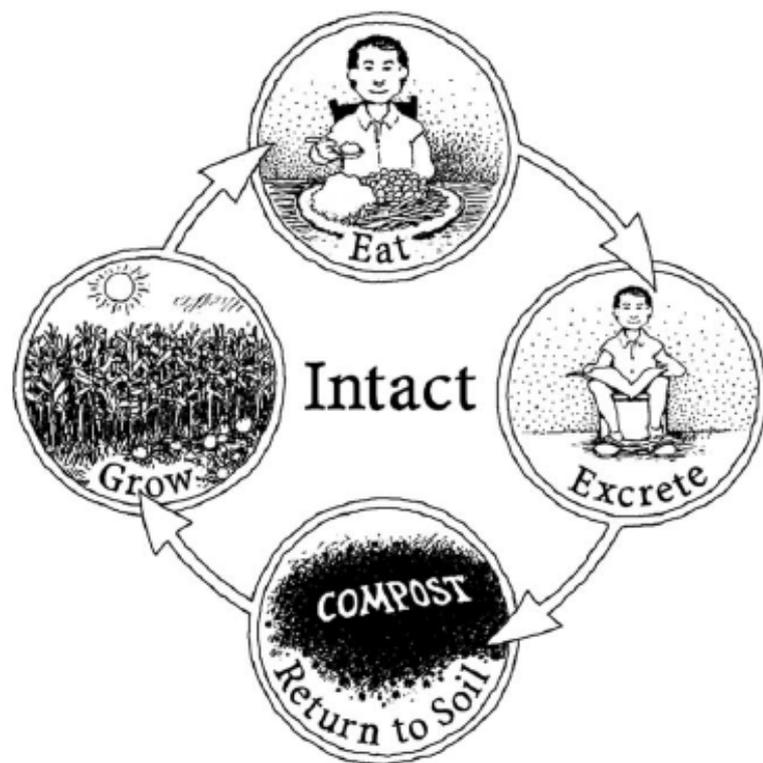
<http://www.knowledgebank.irri.org/images/stories/phosphorus-deficiency-field.jpg>

Phosphorous deficiency in Groundnut

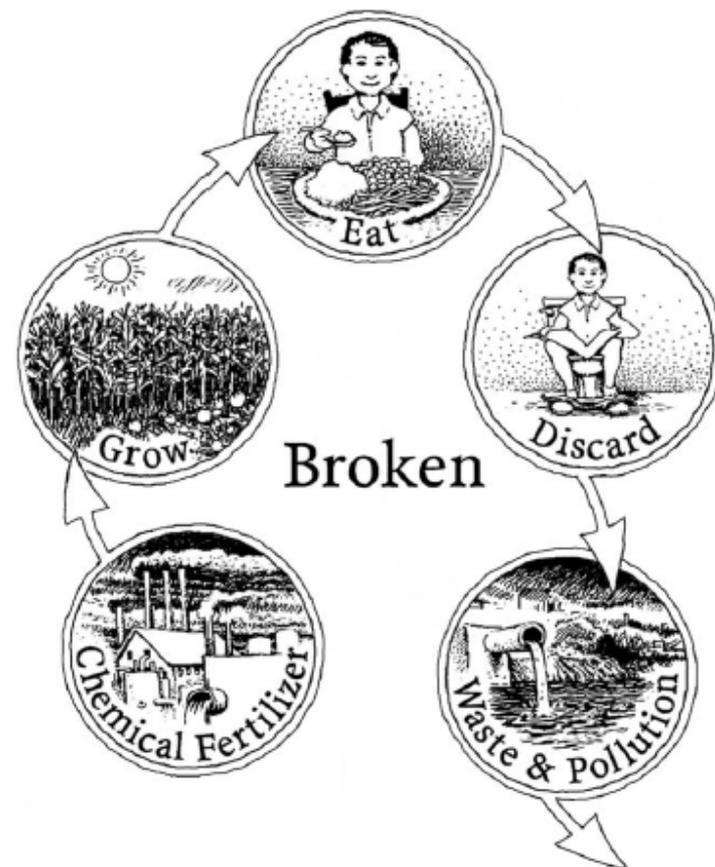


<http://agropedia.iitk.ac.in/content/phosphorous-deficiency-groundnut>

The *HUMAN* *NUTRIENT CYCLE*



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.

Opportunities for the brightest and the best on the
Oxford University Press *Journals Career Network*



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.

Key words phosphorus • food security • sustainability • human phosphorus cycle
• phosphorus limitation

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BioScience (2011) 61 (2): 117-124.
doi: 10.1525/bio.2011.61.2.6

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Commentary

Transition towards Circular Economy in the Food System

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† These authors contributed equally to this work.

Academic Editor: Helmut Haberl

Received: 9 October 2015 / Accepted: 7 January 2016 / Published: 10 January 2016

Abstract: Growing population and increased demand for food, along with environmental impacts, and high rates of food wasted towards more sustainable practices. In this article we explore the transition theory towards sustainability. We discuss (focusing on nutrient flow), the consumption stage (food waste management and prevention).

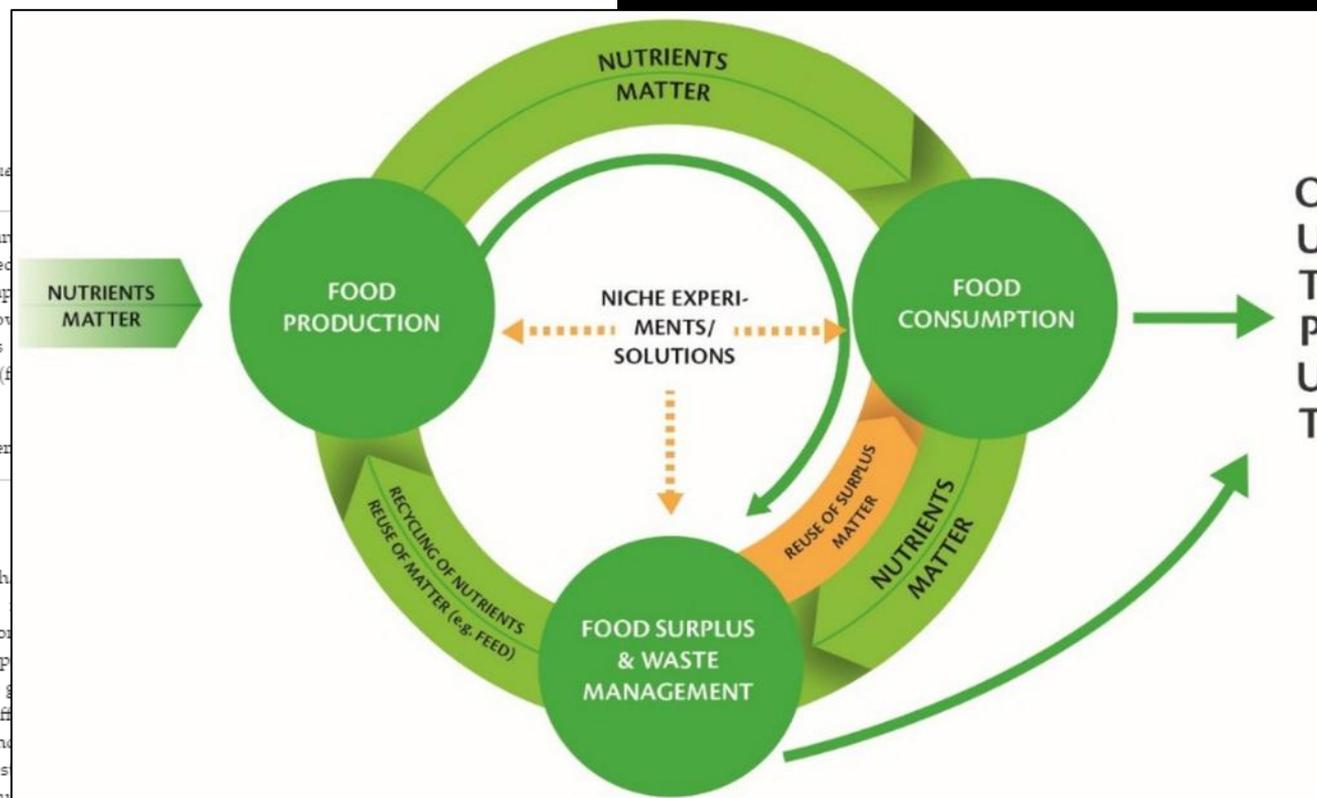
Keywords: circular economy; sustainability; food system

1. Introduction

Our current food production and consumption has significant environmental impacts, such as eutrophication and climate change. Approximately 30%–50% of food intended for human consumption is lost or wasted. Current inefficiency in the food economy means we lose potential of throwing food away. More pollution and greenhouse gas emissions. The UN's Food and Agriculture Organization [5], the inefficiency costs the world \$450 billion a year, or even two trillion dollars when social and environmental costs are included. To enhance and optimize for sustainability within the Western world, we need to transition towards a circular economy.

Circular economy uses theory and principles from industrial ecology, which aims to 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 [6]. Circular economy is an industrial economy that is restorative by design and mirrors nature in actively enhancing and optimizing the systems. It applies several principles from nature: production out of waste, resilience through diversity, the use of renewable energy sources, systems thinking, and cascading flows of materials and energy [7]. Circular economy

Figure 1. Three stages of the food system in a circular economy. Circular economy regarding the food system implies reducing the amount of waste generated in the food system, reuse of food, utilization of byproducts and food waste, and nutrient recycling. The measures must be implemented both at the producer and consumer levels, and finally in the food waste and surplus management.



<http://www.mdpi.com/2071-1050/8/1/69/htm>

Conclusions 1

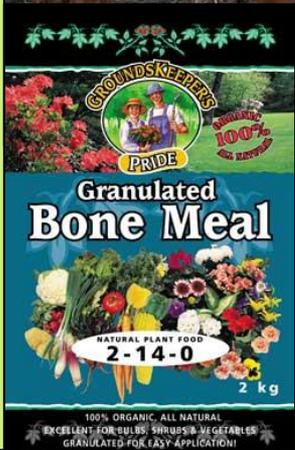
- There is considerable variation in the fertility of ecosystems across Wester Ross in space and time.
- Human impacts have greatly affected ecosystem fertility and phosphorus availability; both directly (e.g. via harvesting of trees, sheep and cattle) and indirectly (e.g. extinction of top carnivores, 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.

<http://www.actionhub.com/news/2012/10/24/electricity-to-power-vermont-ski-lift-will-be-generated-from-cow-manure/>



<http://honestfood.net/2009/07/17/six-days-of-salmon/>



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 . . . ?

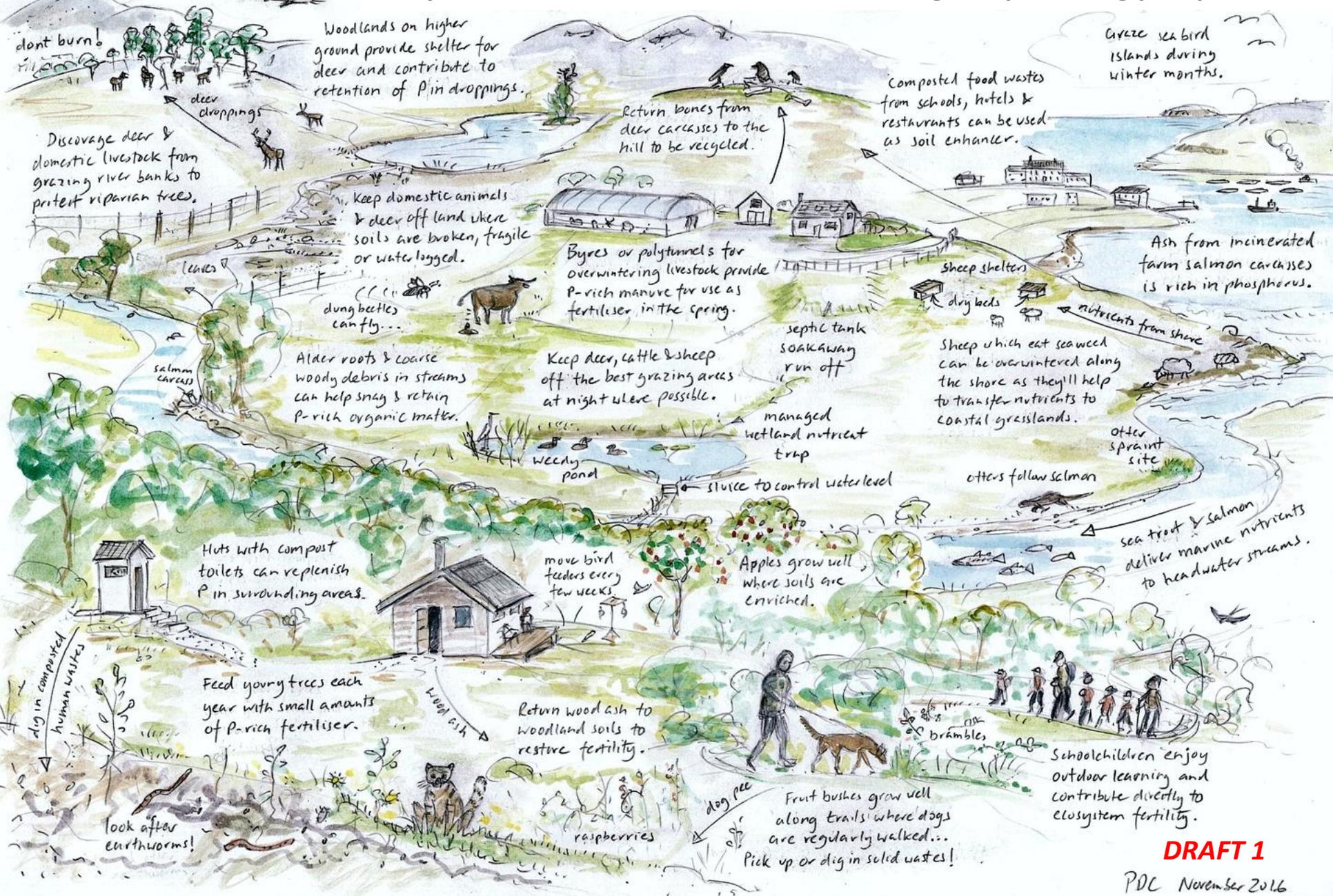
A little fertiliser, fairly often (not a lot of fertiliser all at once) . . . ?

A bit like feeding the birds . . . ?

Larachantivore woodland (upper Gruinard) . .



Ecosystem nutrition in Wester Ross: conserving & replenishing phosphorus



DRAFT 1

PDC November 2016

Refertilisation
can help to
support and
revive fragile
communities.

Inverasdale school



http://www.ross-shirejournal.co.uk/imageLibrary/Client_Images/Client00007/02001800/02001802.jpg



Melvaig School, 1952/3

Back: Mrs Catherine Macrae; Roddie MacKenzie, Duncan Macrae, Chrissie Mackenzie, Elizabeth Urquhart, Cathabel Macrae, Farquhar Macrae, Murdo MacKenzie, Donald Macrae
Front: Kenny Macrae, Roddie MacKenzie, Frances Urquhart, Janette Macrae, Elizabeth Chisholm, Alice MacKenzie, Isabel Urquhart, Roddy Macrae, Alisdair Millan

*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'.*



https://www.hutton.ac.uk/sites/default/files/images/research/Hare4Web_345x250.jpg?1544266952

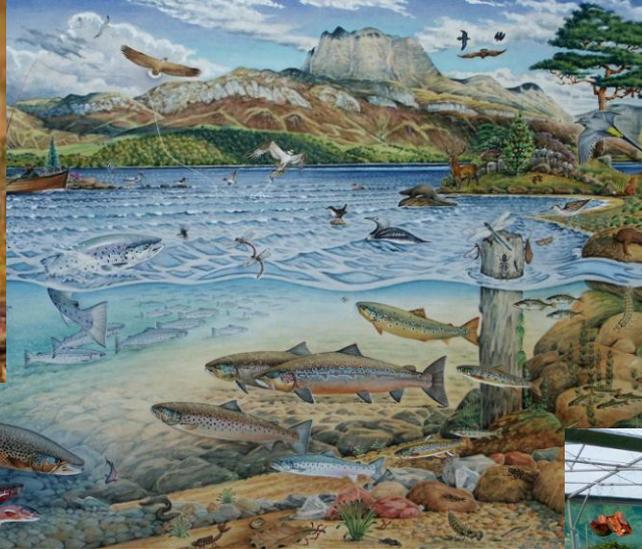


https://www.rspb.org.uk/images/1019686_tcm9130731.jpg?width=118&height=89&crop=auto



<http://wild-scotland.org.uk/wp-content/uploads/2011/05/Black-Grouse-taking-flight.jpg>





Thank you



