Grazing, trees and trout 24th June 2017

Feed the land . . .

Peter Cunningham

Skye & Wester Ross Fisheries Trust

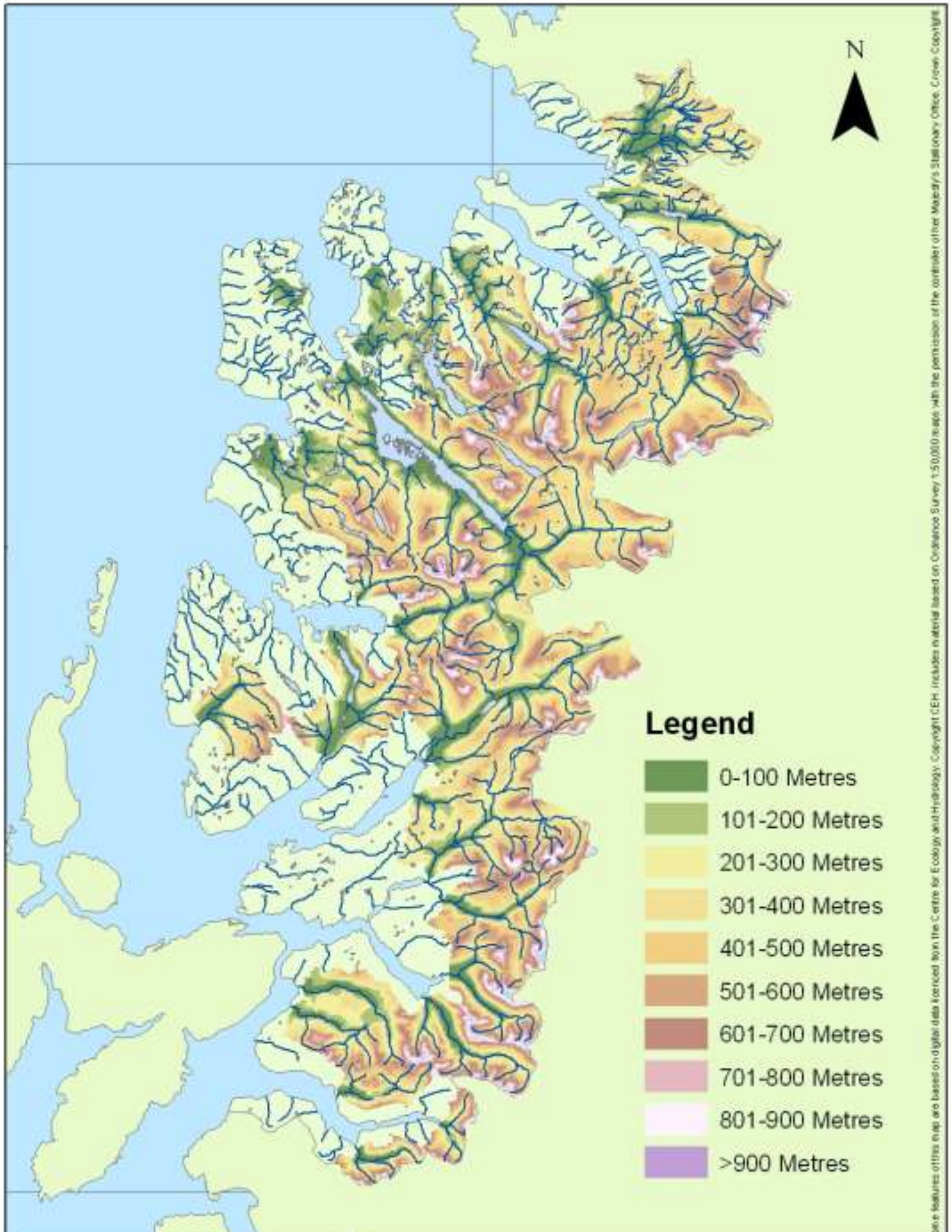
info@wrft.org.uk

WOODLAND TRUST

Coimisean na Coilltearachd Alba | Forestry Commission Scotland

Feed the land . . .

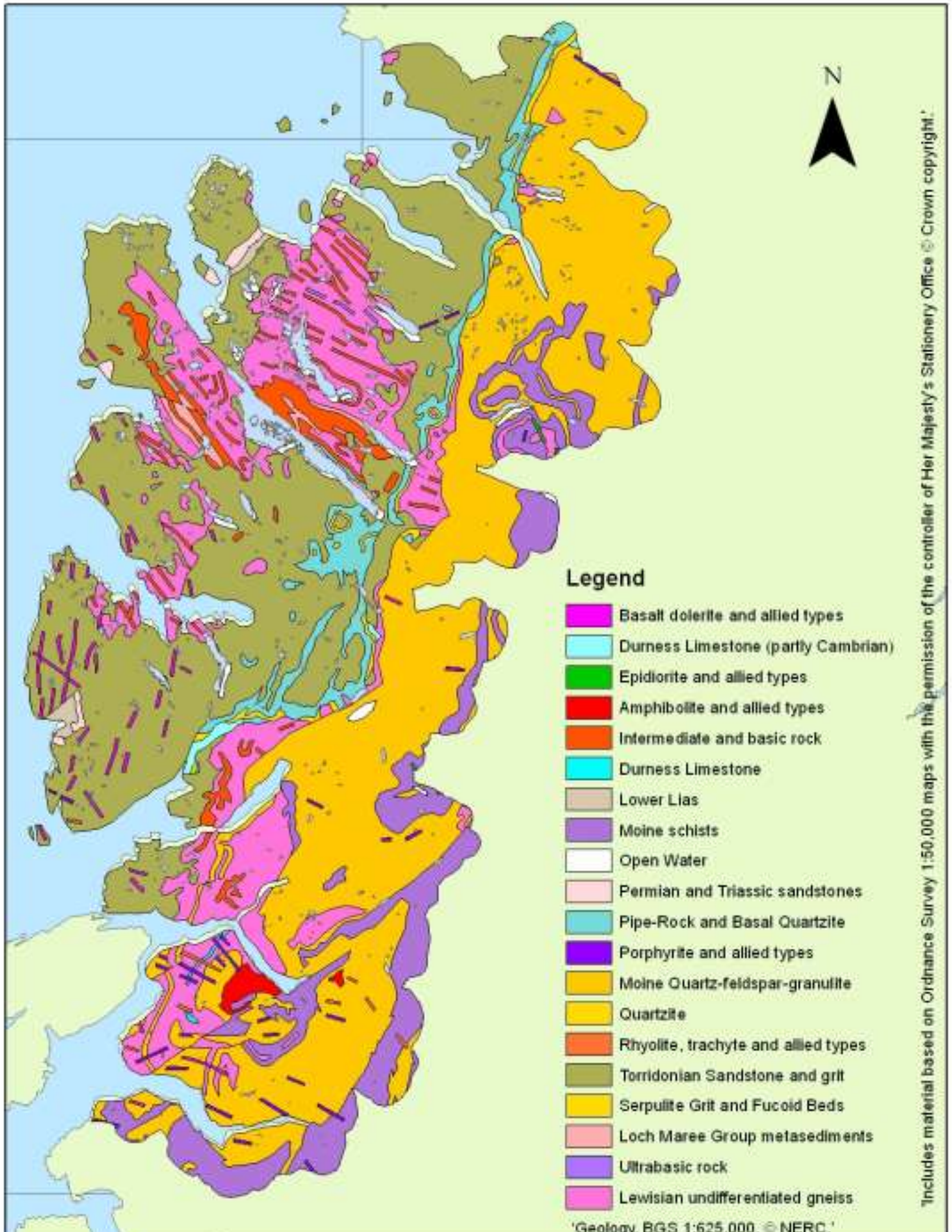
1. What is fertility?
2. Fertile places in Wester Ross
3. Ecosystems and nutrient flow
4. Deforestation, fire and loss of fertility
5. Animals and phosphorus export
6. How to conserve and replenish phosphorus?



In Wester Ross, soils are thin and generally infertile:

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

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?


Trees cling to
inaccessible ledges
Abhainn Dearg

Unstable rivers

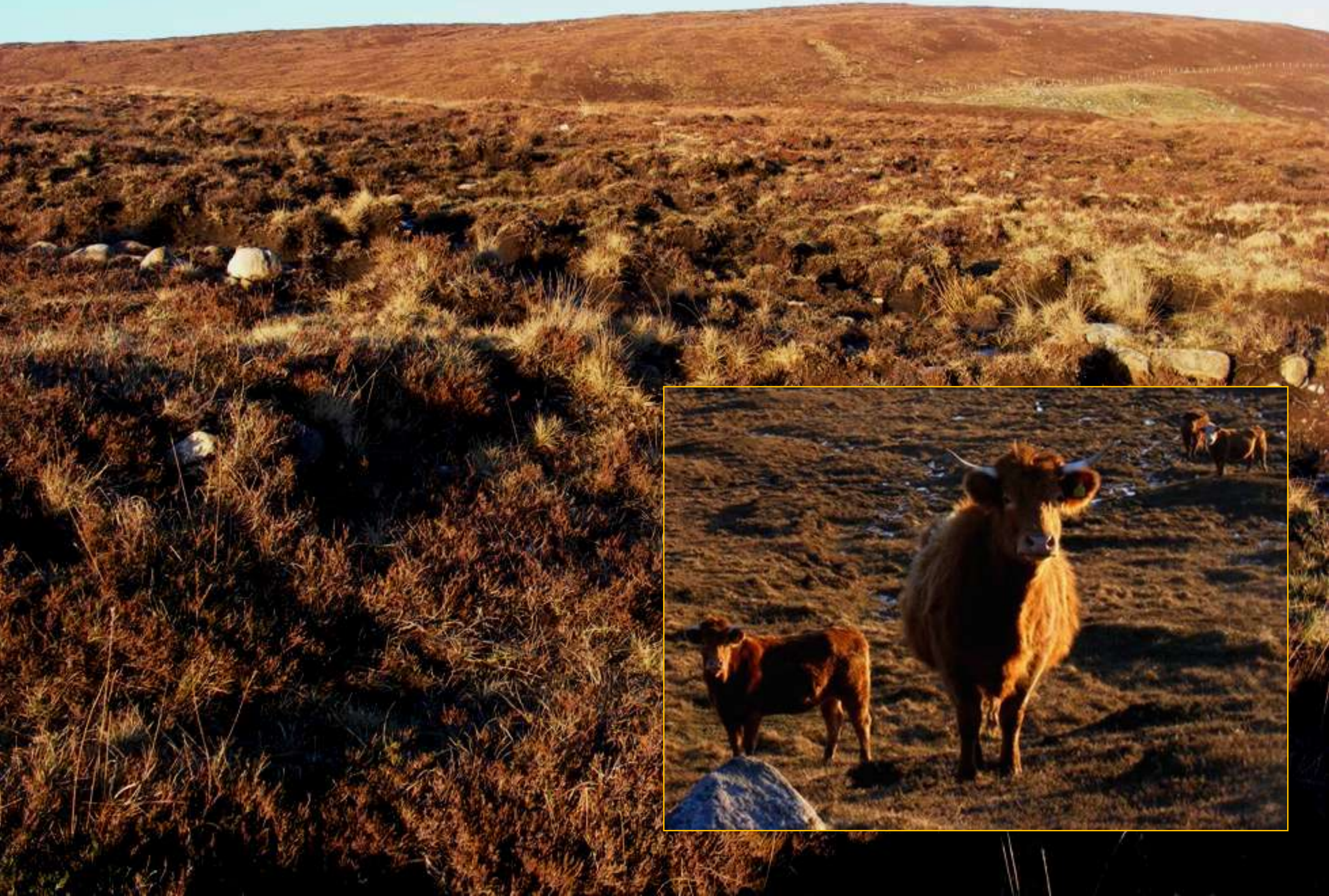
Strath na Sealga, upper Gruinard: note alder woodland along floodplain

Uninhabited ‘wilderness’ . . .

Fionn loch and Dubh loch from Beinn Airigh charr


with ‘near pristine’ oligotrophic lochs . . .
Loch Maree . . . .

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.

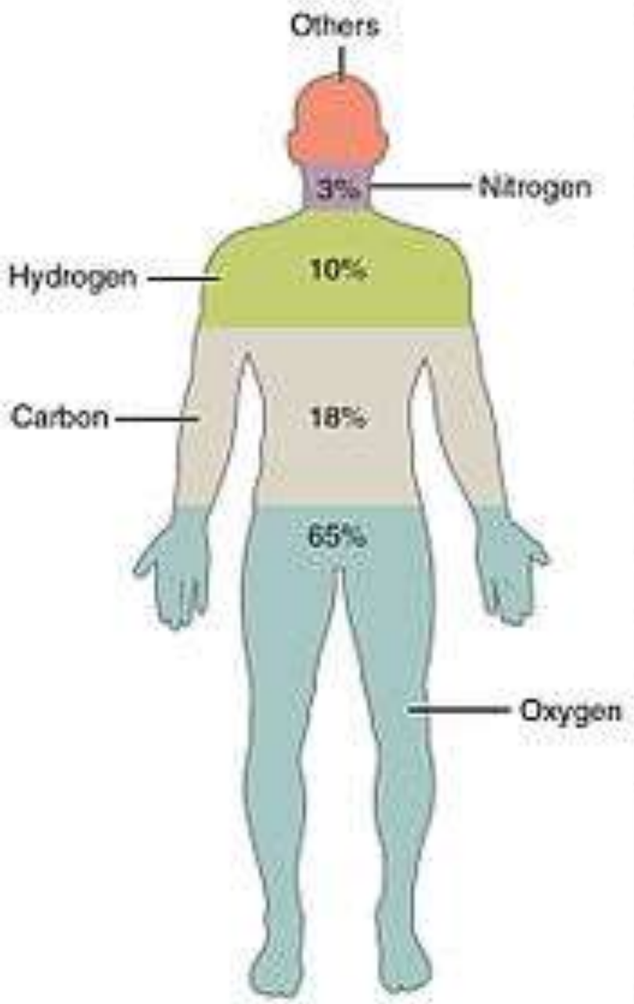
https://en.wikipedia.org/wiki/Soil_fertility

Phosphorus

Phosphorus is essential to all life forms.

Assorted bones, Aultgrishan shore 3rd April 2016

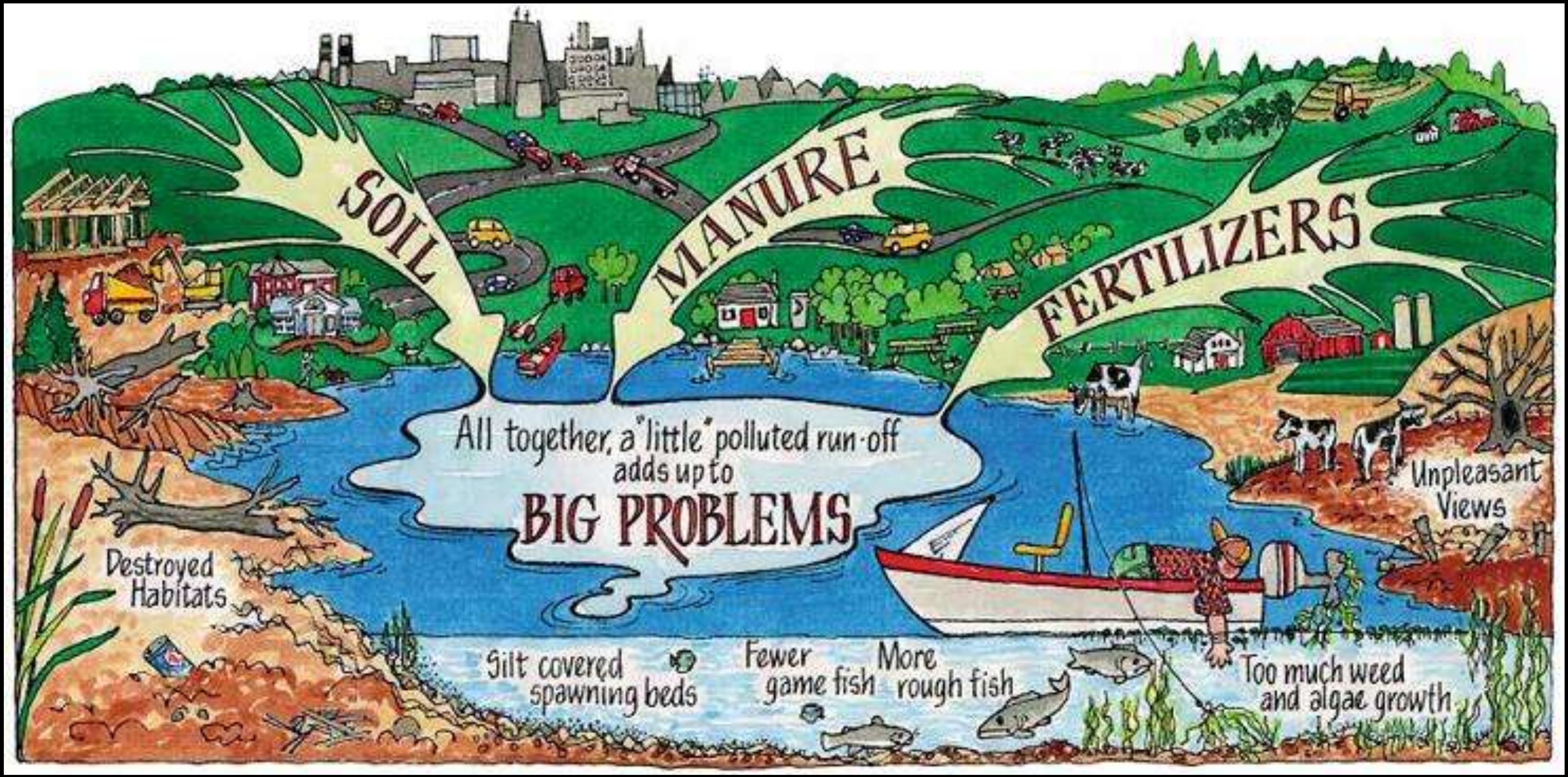
Humans are approximately 1% Phosphorus



Element	Symbol	Percentage in Body
Oxygen	O	65.0
Carbon	C	18.5
Hydrogen	H	9.5
Nitrogen	N	3.2
Calcium	Ca	1.5
Phosphorus	P	1.0
Potassium	K	0.4
Sulfur	S	0.3
Sodium	Na	0.2
Chlorine	Cl	0.2
Magnesium	Mg	0.1
Trace elements include boron (B), chromium (Cr), cobalt (Co), copper (Cu), fluorine (F), iodine (I), iron (Fe), manganese (Mn), molybdenum (Mo), selenium (Se), silicon (Si), tin (Sn), vanadium (V), and zinc (Zn).		less than 1.0

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

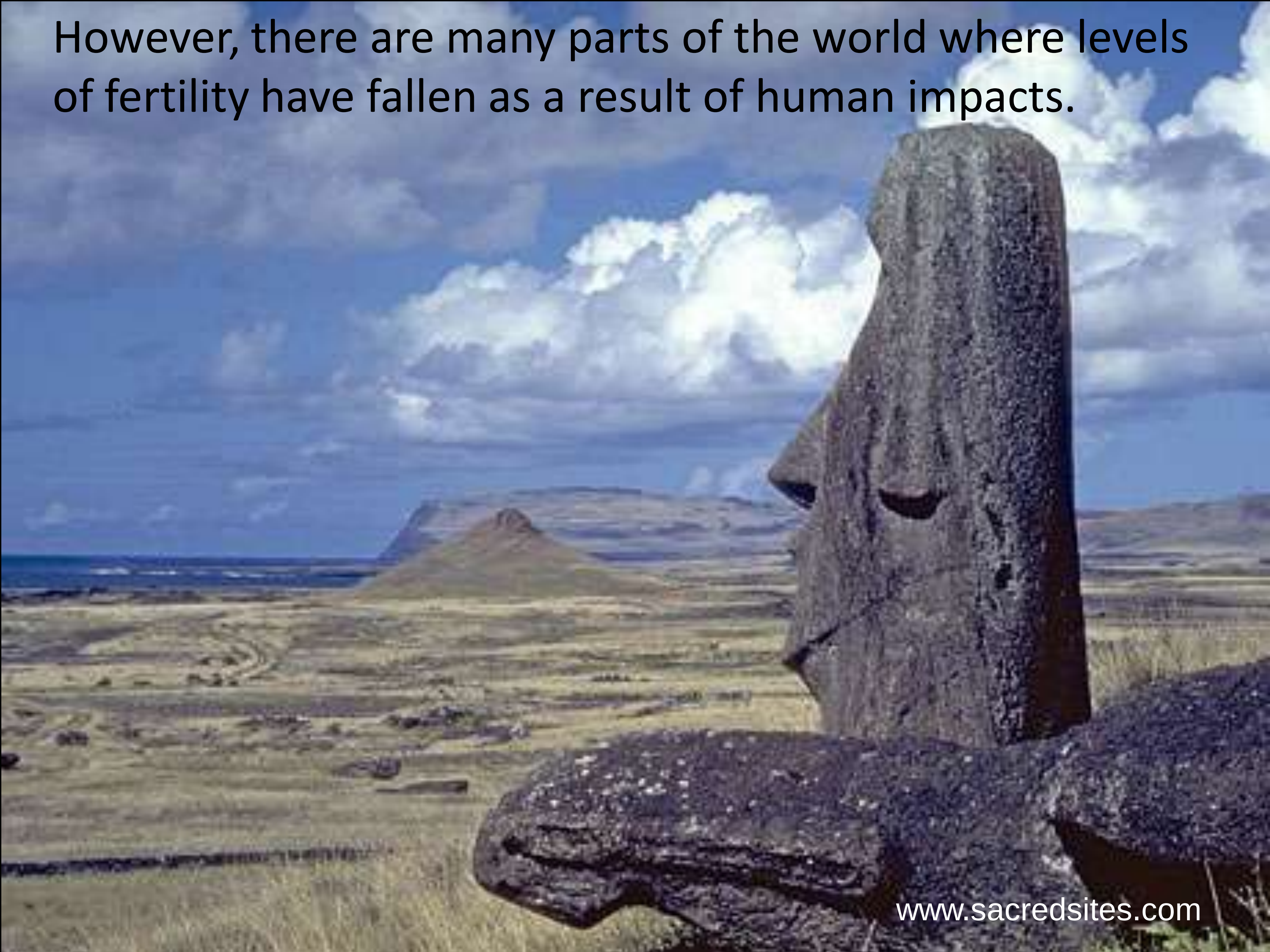
Too much phosphorus causes *eutrophication*



http://lawncarecompanymn.com/blog/minnesota-lawn-and-yard-lawn-care-fertilizing-services-mn/

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.



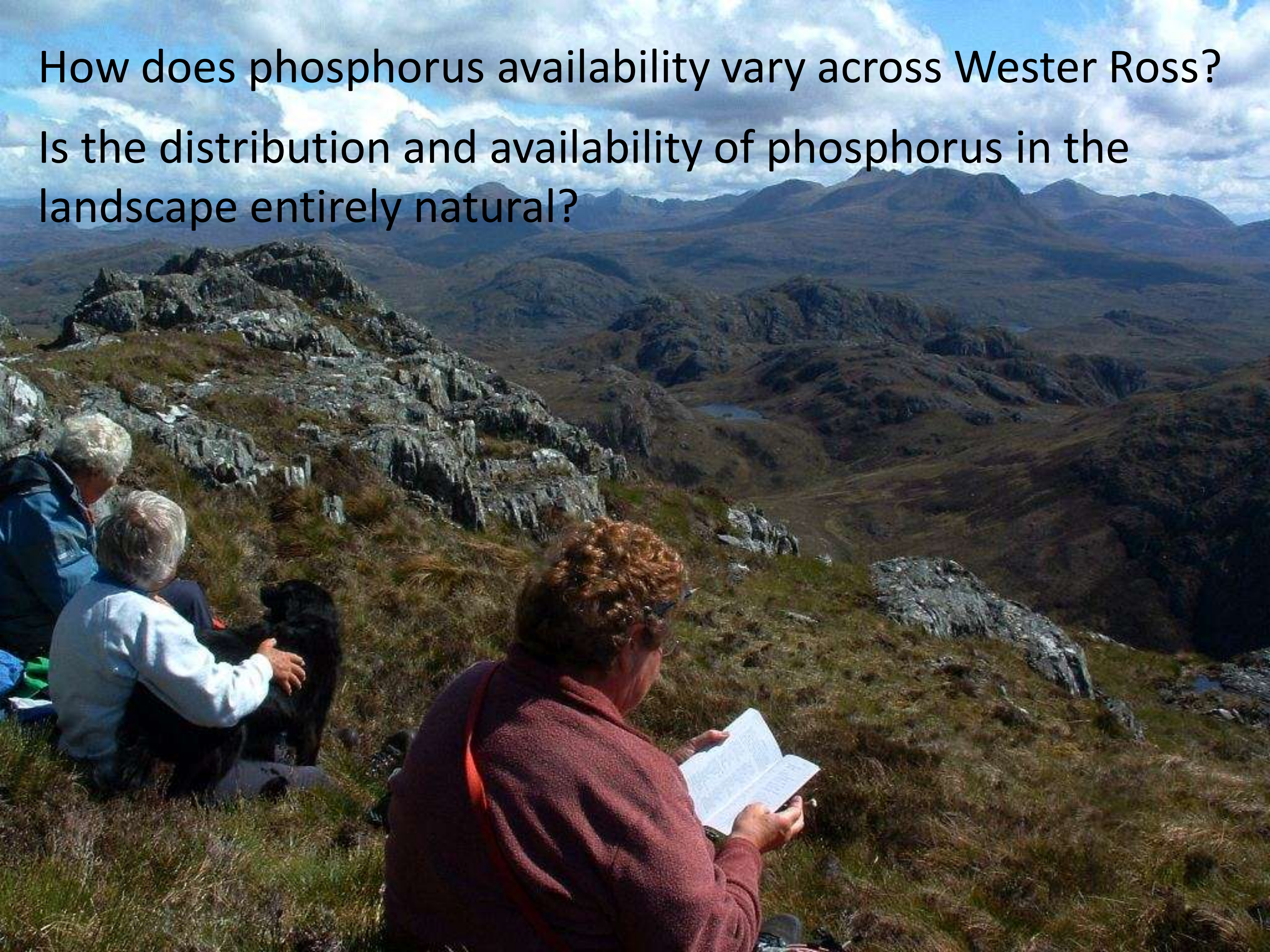
https://www.youtube.com/watch?v=RNUSgY2NbFM

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 . . .

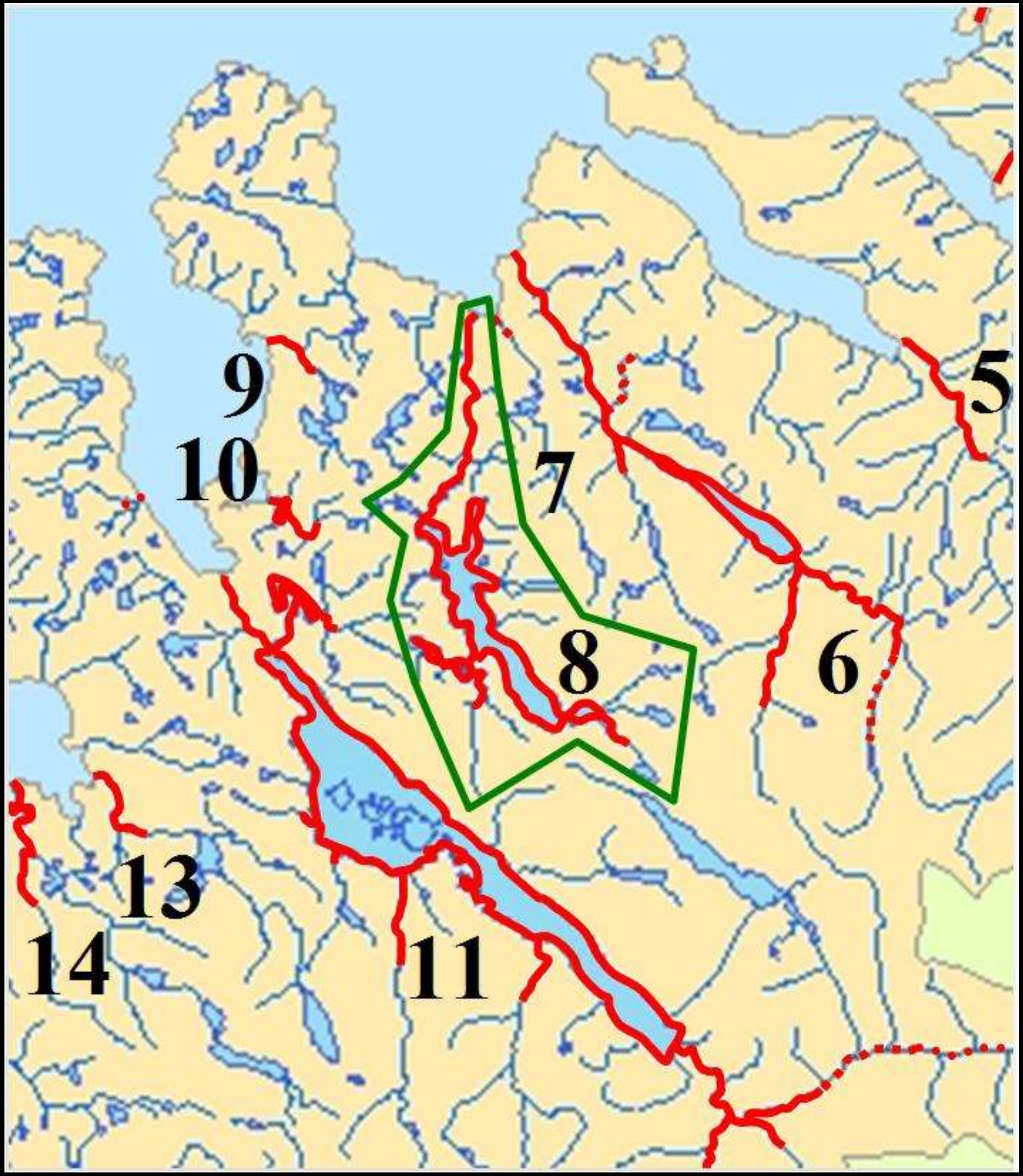
Watching an eagle above Beinn Eighe NNR

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

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 . . .
Little Gruinard River


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

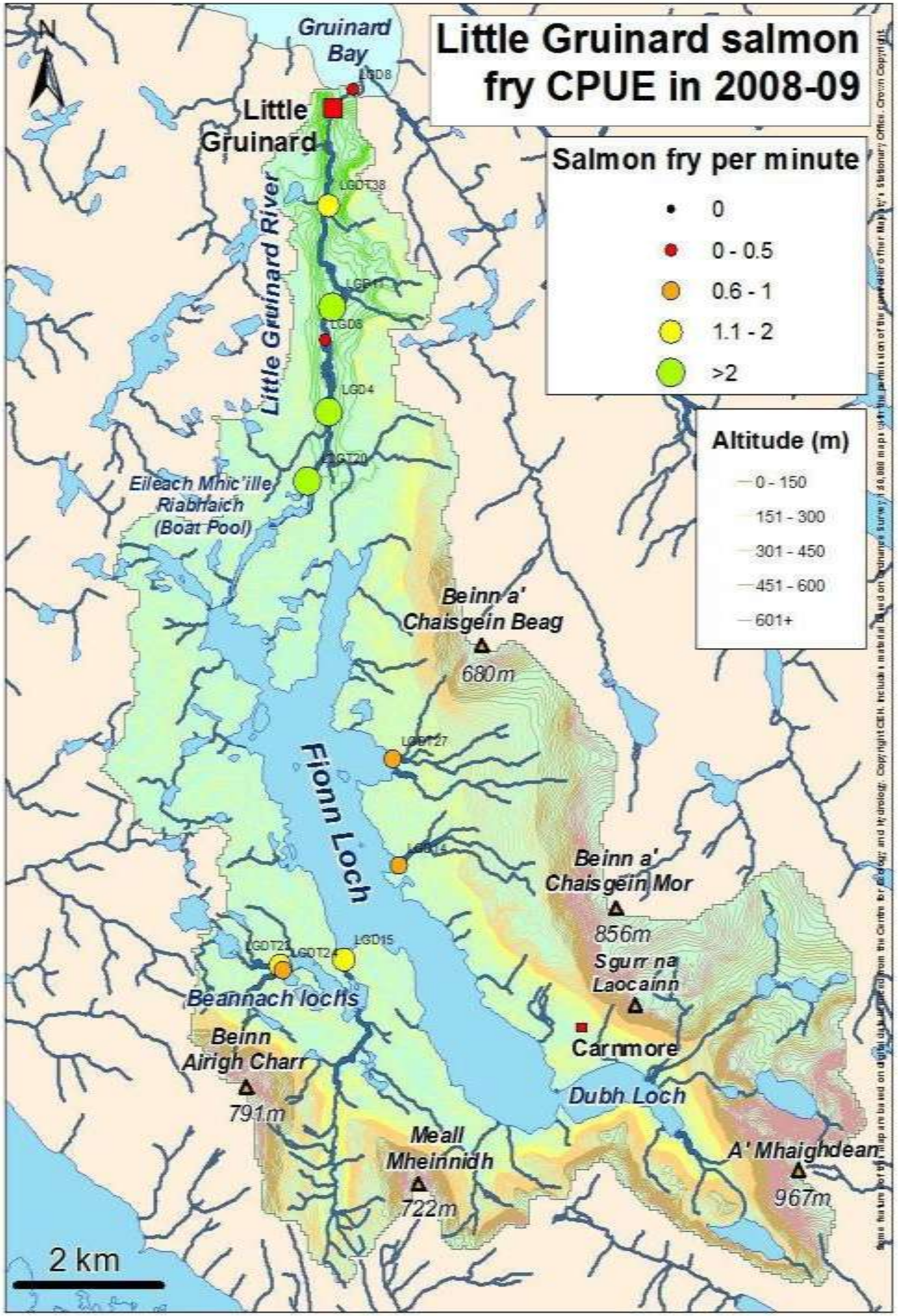
In the past, many more salmon returned to Scottish rivers from the sea each year.

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*

photos by Amy Gulick

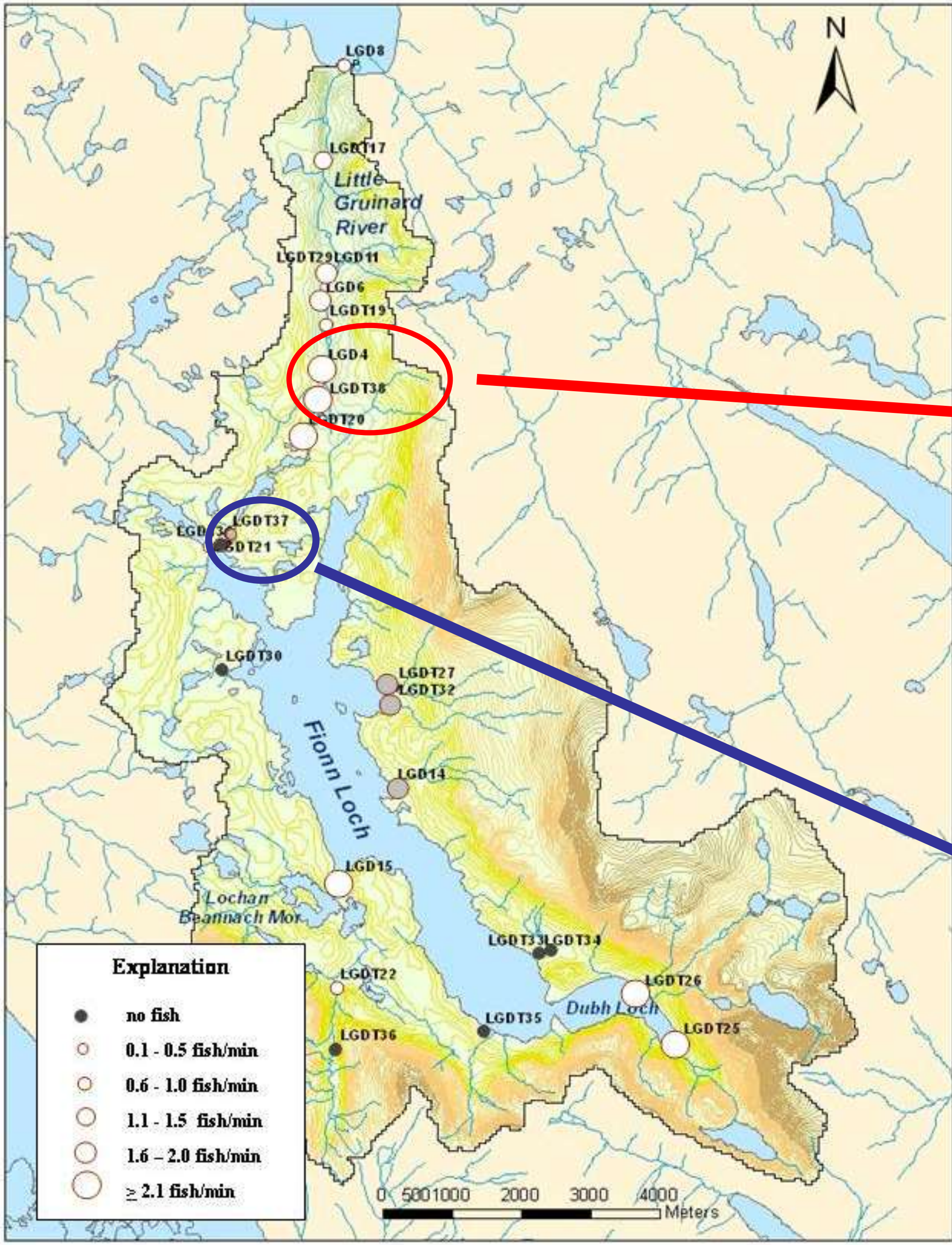


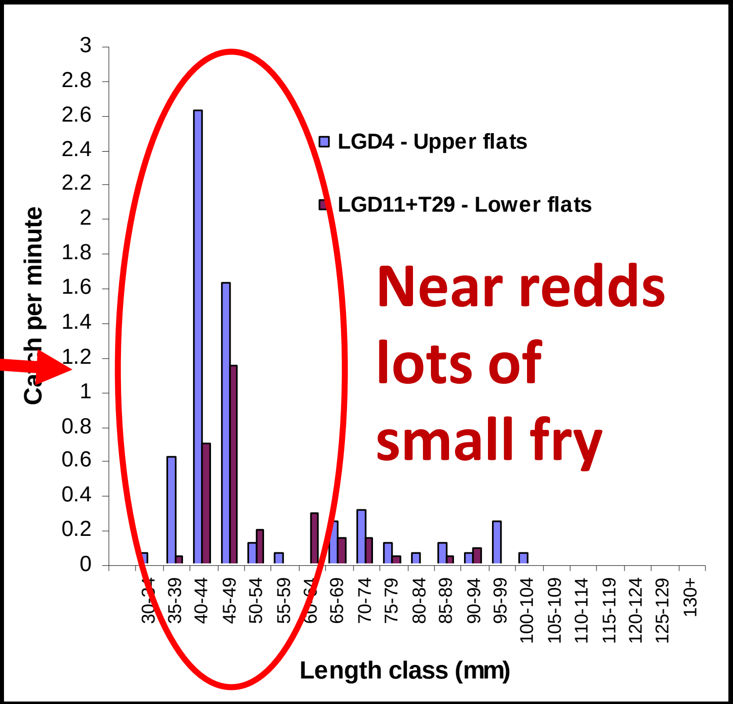
Juvenile salmon survey

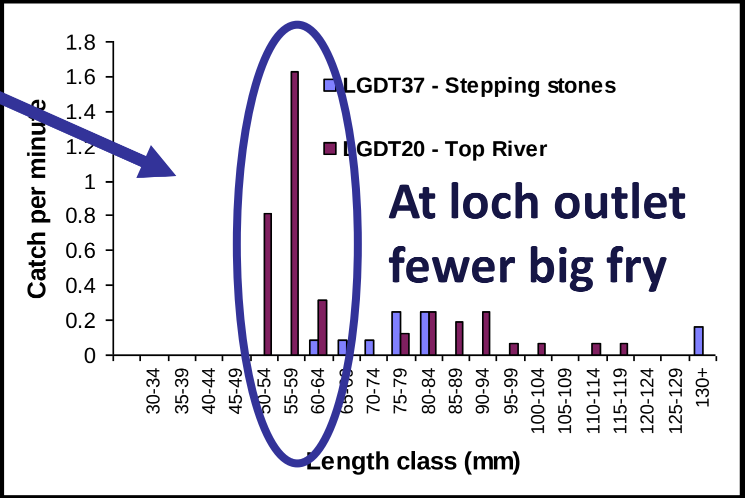
Plenty of salmon fry and parr in the main river . . .

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

Juvenile salmon 2006





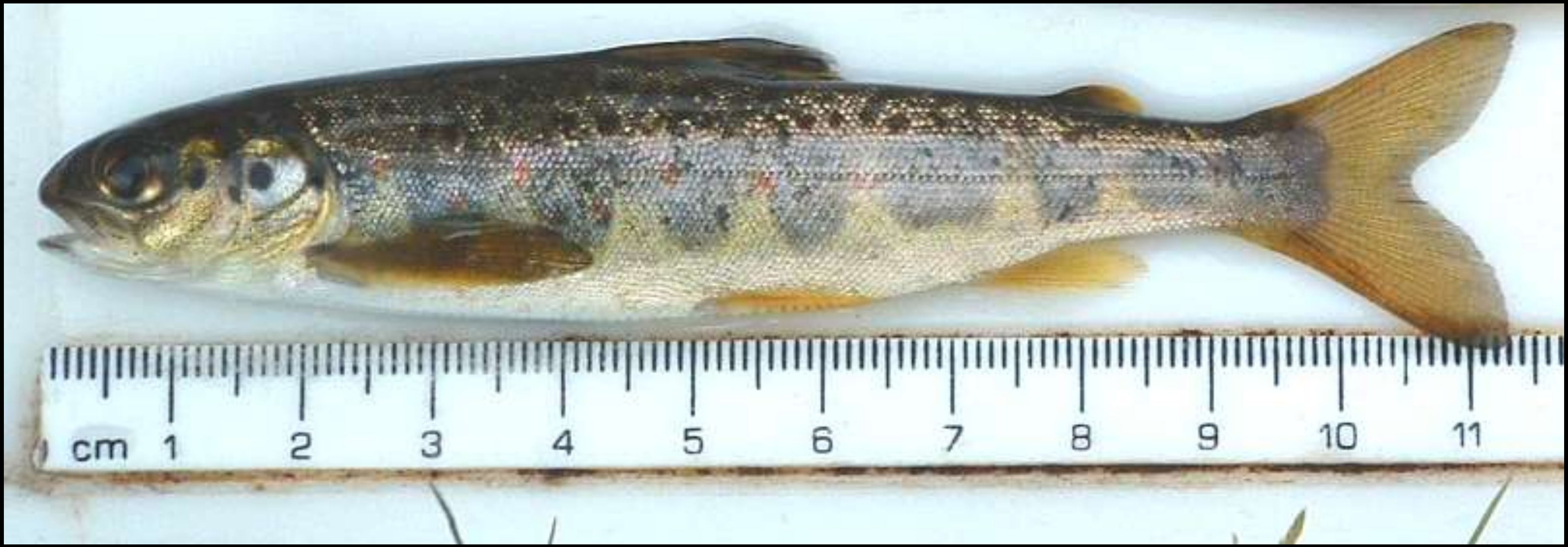



Lower Flats of
Little Gruinard


Small fry . . . . and small parr
cm 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25

Below Fionn Loch outlet

Big, faster growing, one year old parr

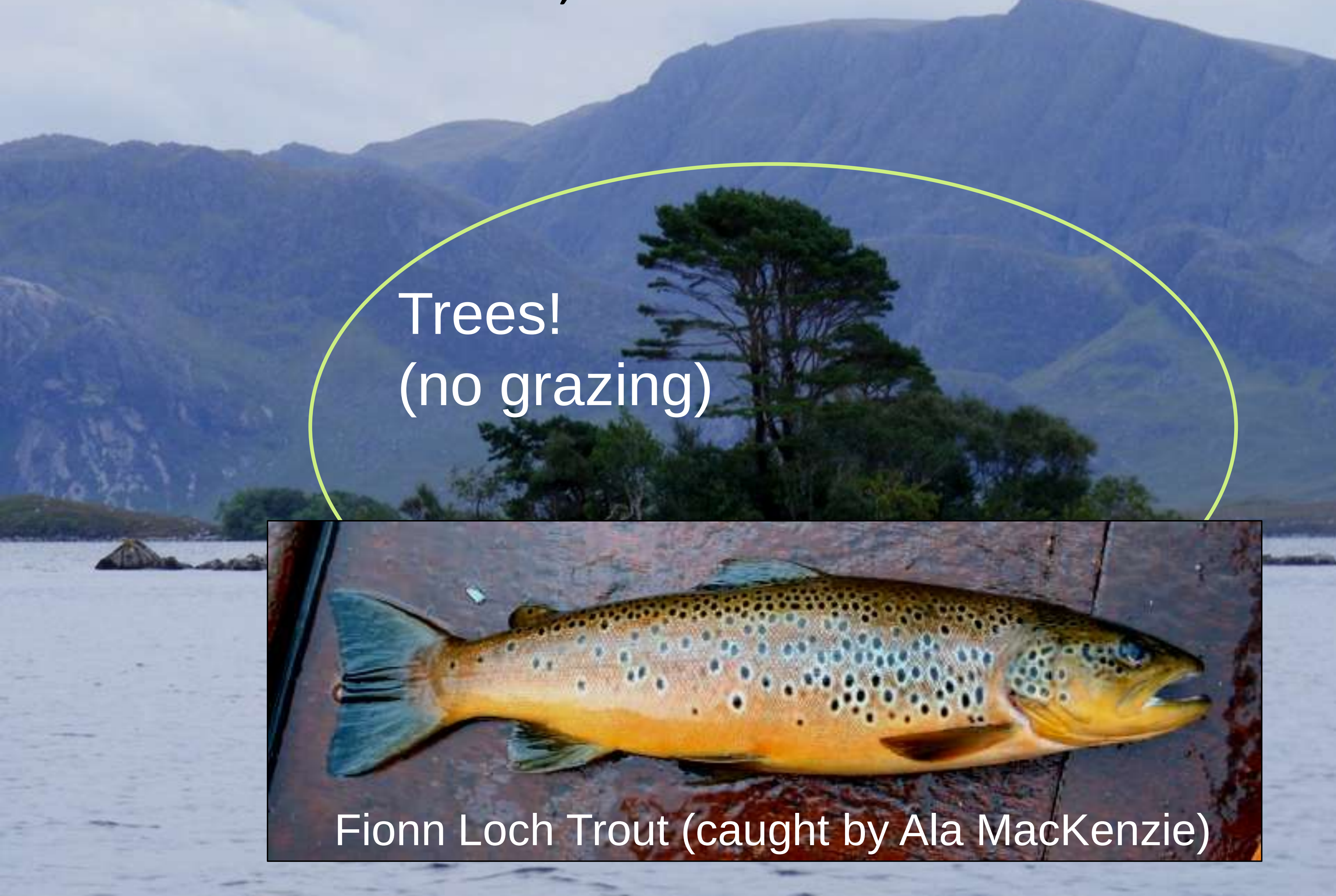


- Juvenile salmon production is determined by habitat area, food availability and stream fertility

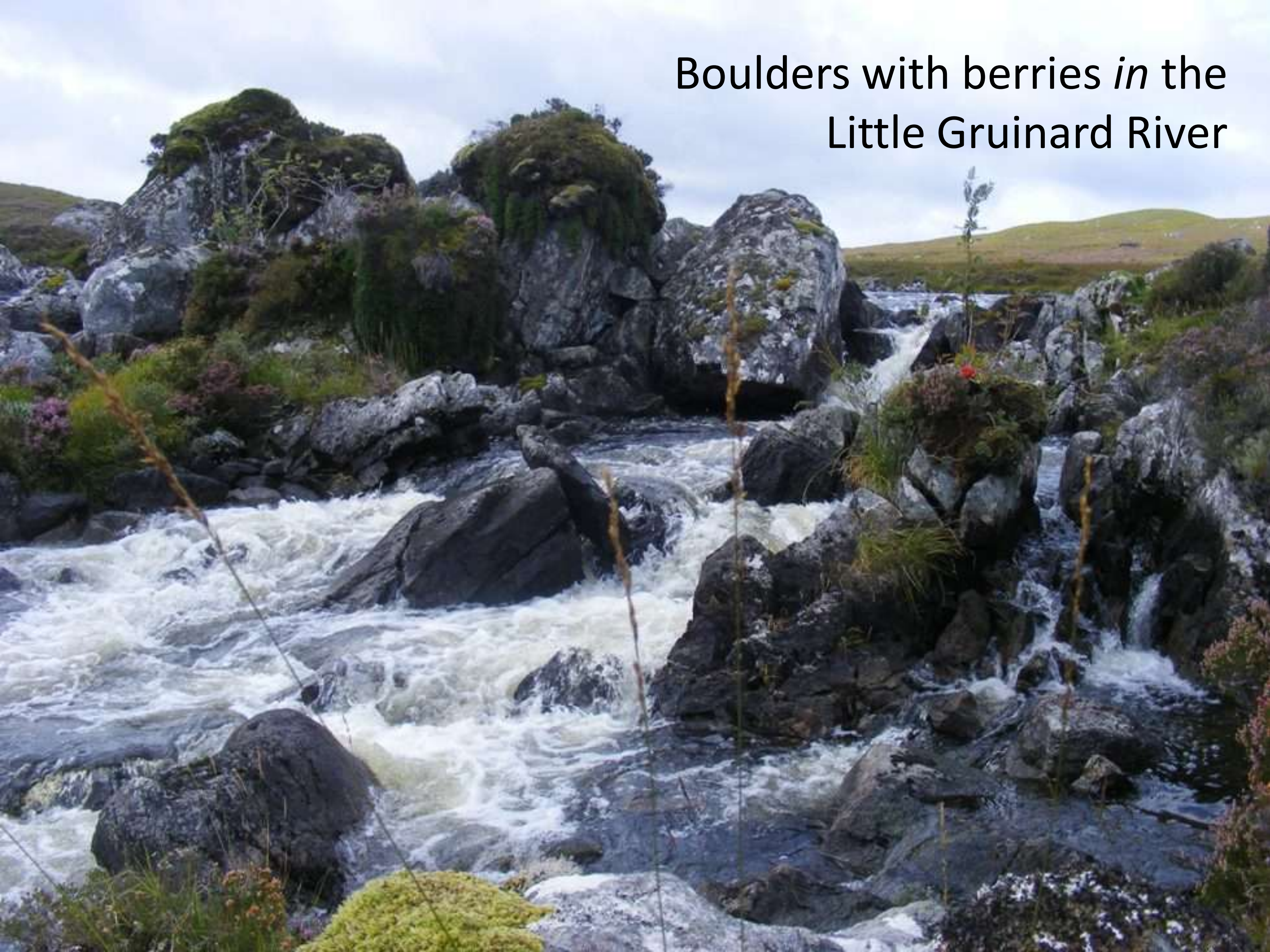

Food for trout and juvenile salmon


Fionn Loch
Beannach lochs
from Beinn Airigh charr

Fionn Loch islands, Little Gruinard catchment.



Fionn Loch Trout (caught by Ala MacKenzie)


Boulders with berries *in* the Little Gruinard River

Boulders with berries *in* the Little Gruinard River


Boulders by the Little Gruinard River,
September 2016

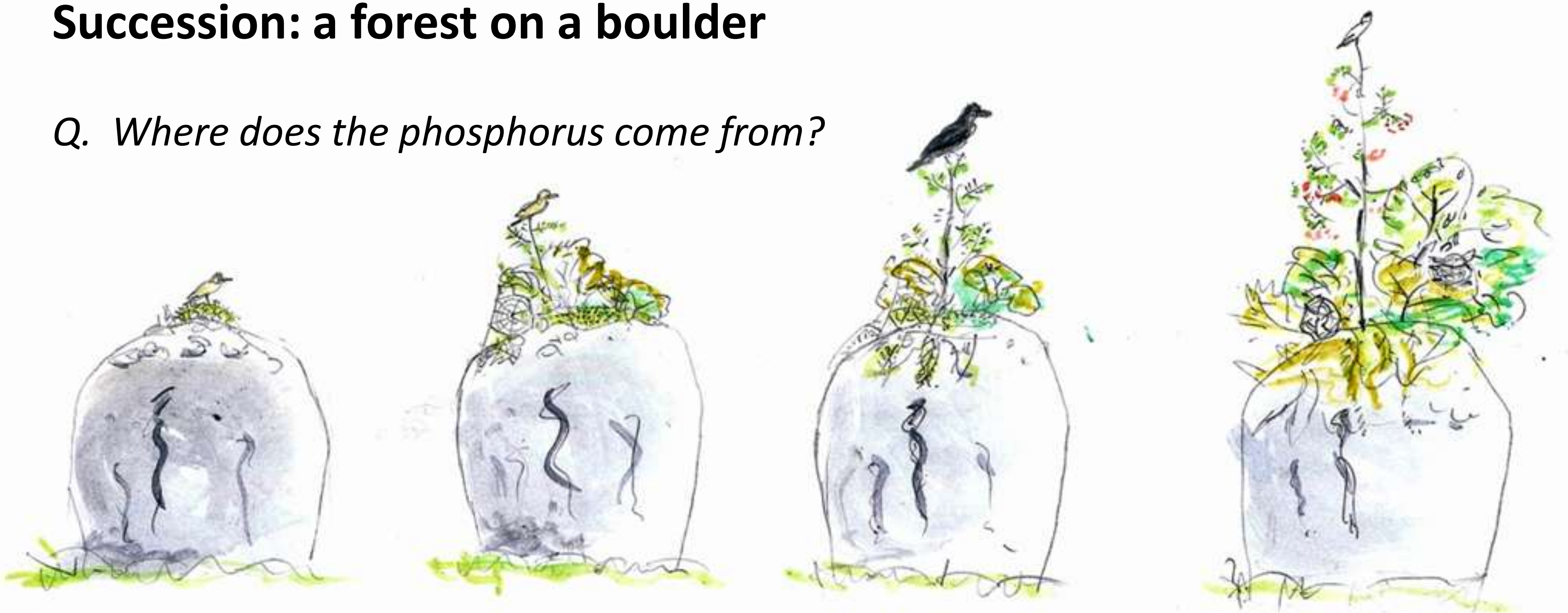
A forest on a boulder?

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, blaeberry, rowan tree; spider's web, crow perch

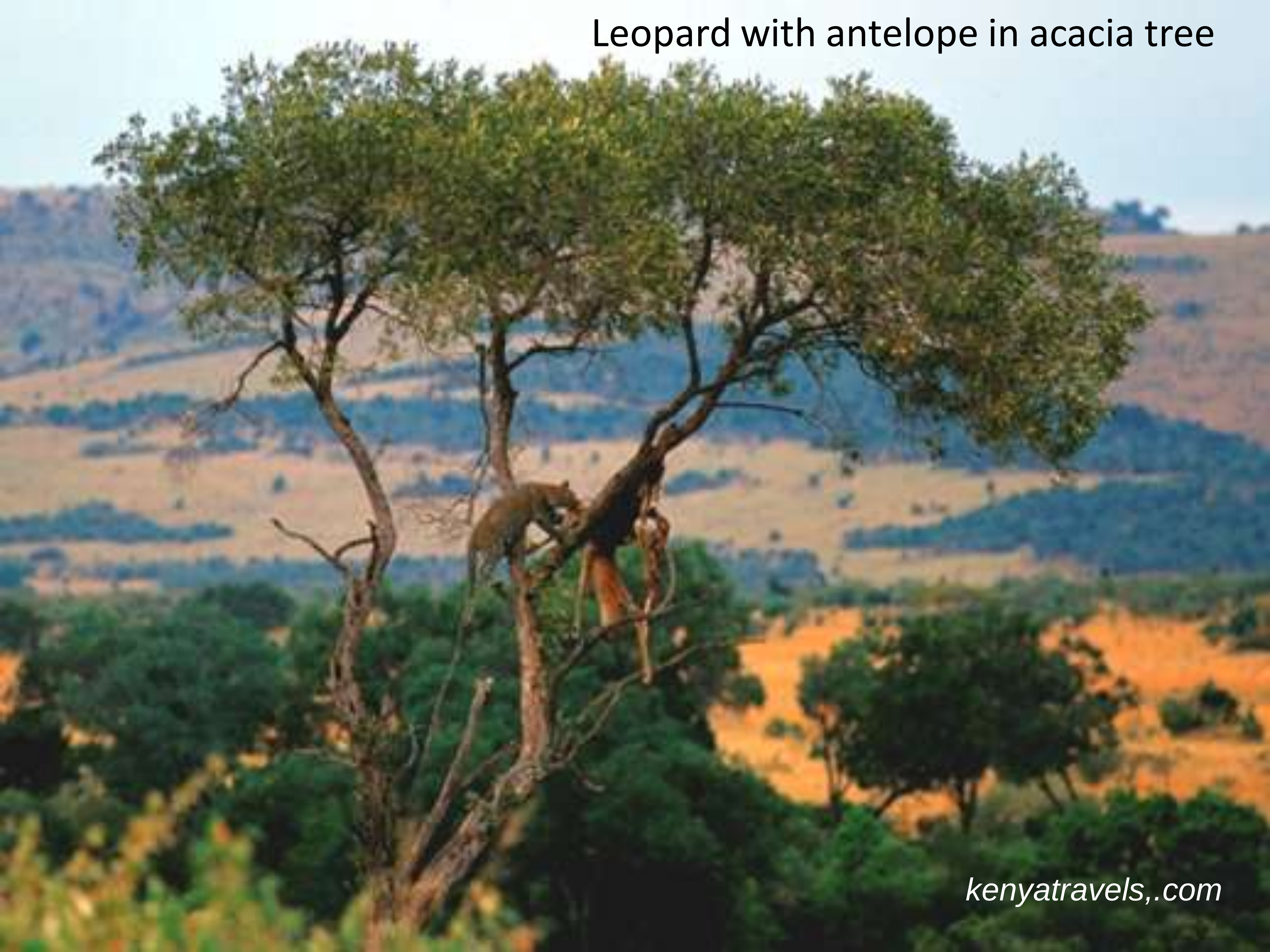
Bird droppings: crow, thrushes, pipits, wren; spider droppings; dead insects . .

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



kenyatravels,.com

Fertile places can be found around houses

Glen Torridon September 2010


nettles
ARKive
© www.osfimages.com

http://www.mountainbothies.org.uk/cust_images/bothy%20images/Shenavall---Alan-Bellis.jpg

(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!!

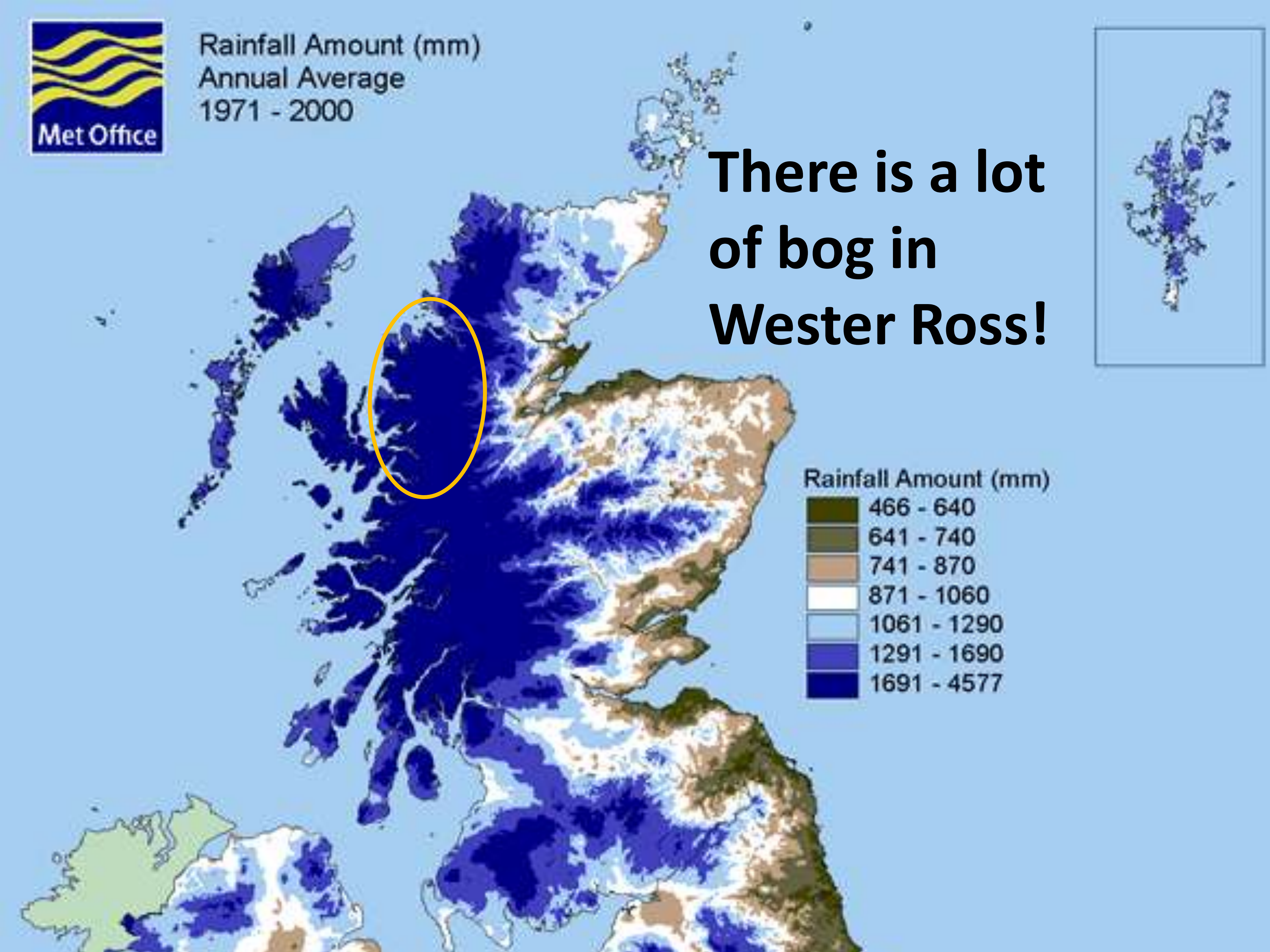
Break – any questions?

Succession . . . sustained by P imports?

3. Ecosystems and nutrient flow

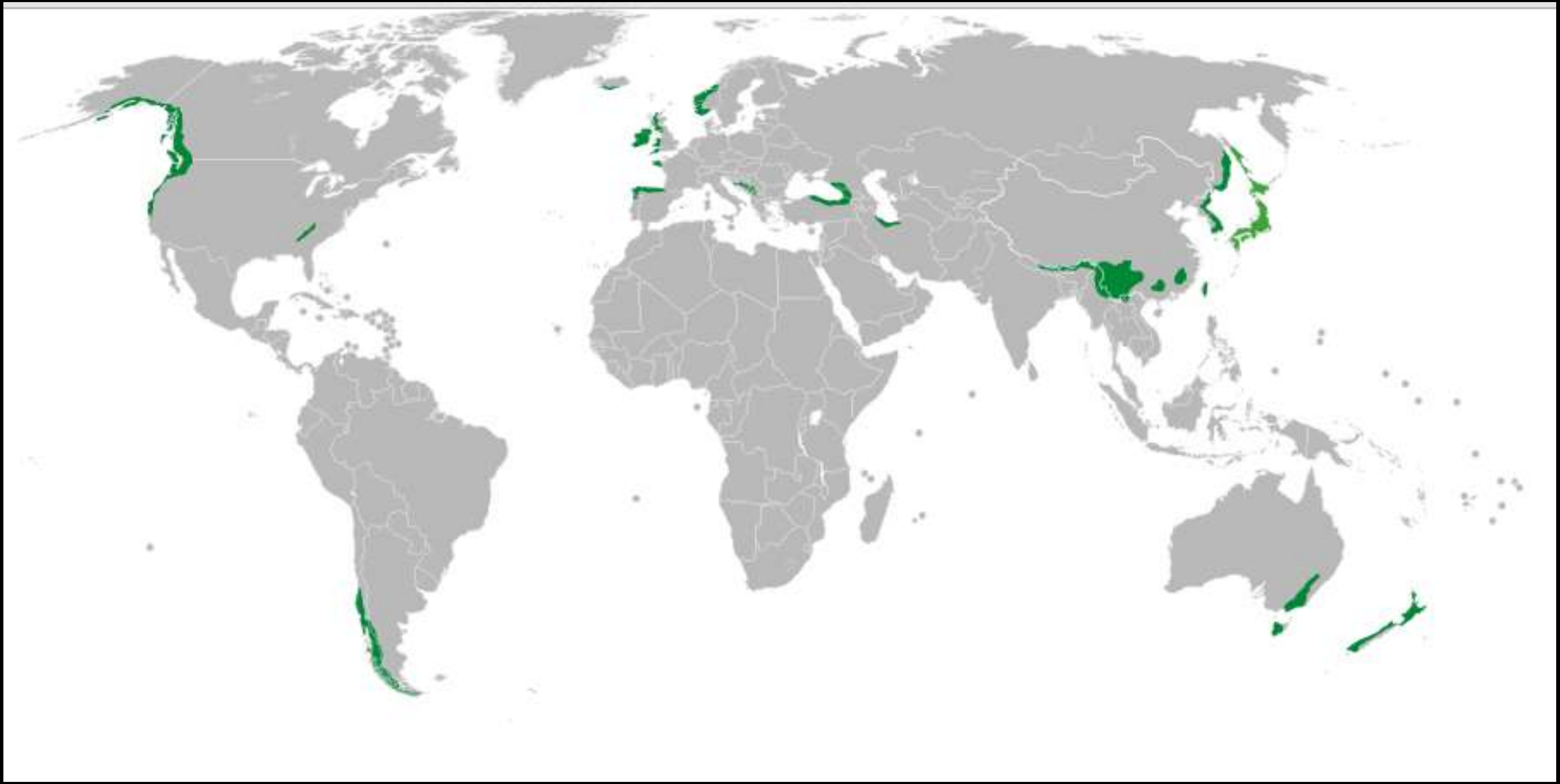
Why is there a greener patch in the bog . . .?

Bog near Redpoint (2002)



There is a lot of bog in Wester Ross!

Temperate rainforest



Temperate rainforest . . .

[. . . or rain**wood** (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)

Reforesting Scotland

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

Soil Science and Plant Nutrition (2015), **61**, 698–703 http://dx.doi.org/10.1080/00380768.2015.1017439

http://www.tandfonline.com/doi/full/10.1080/00380768.2015.1017439

REVIEW ARTICLE

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

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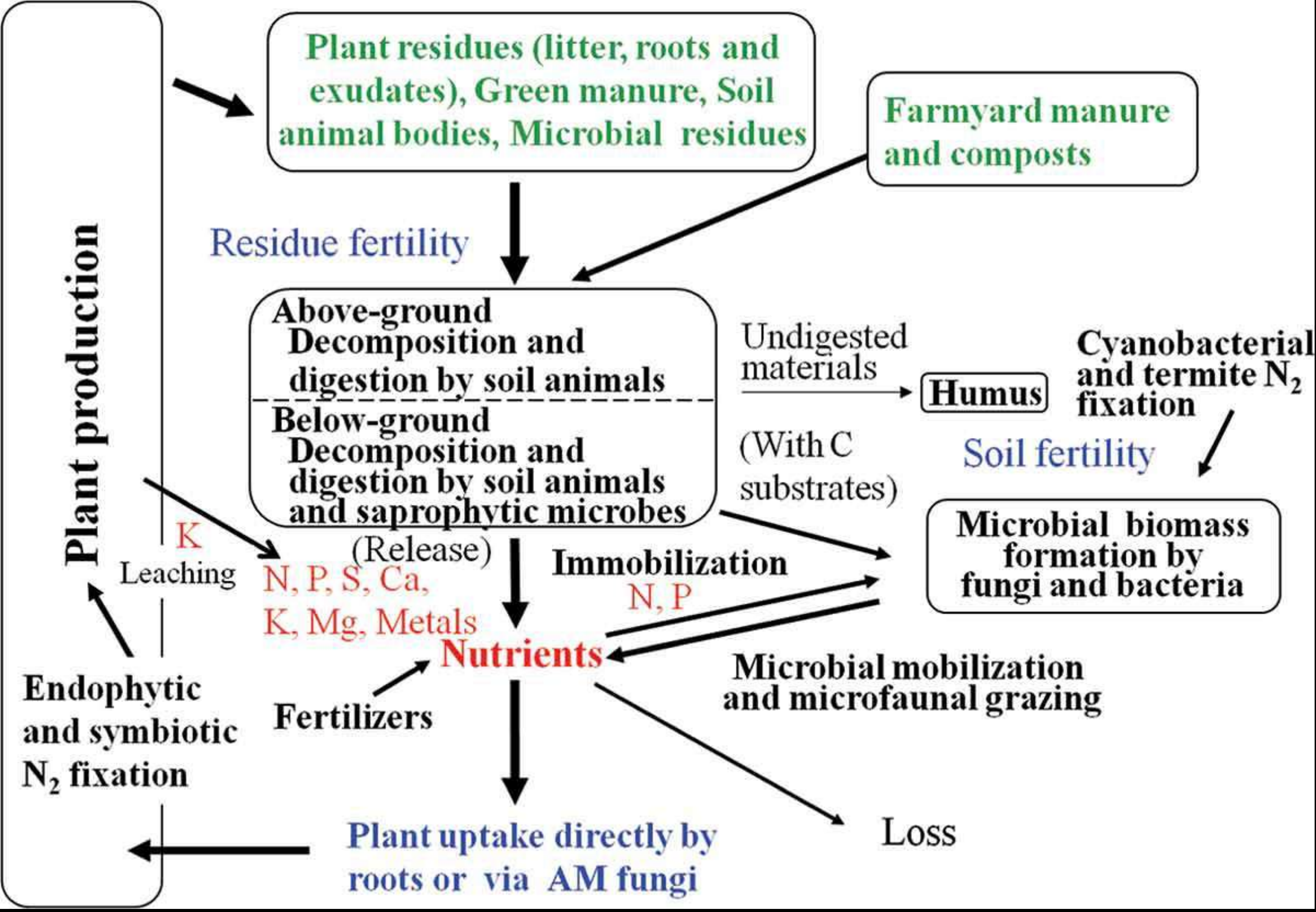
Abstract

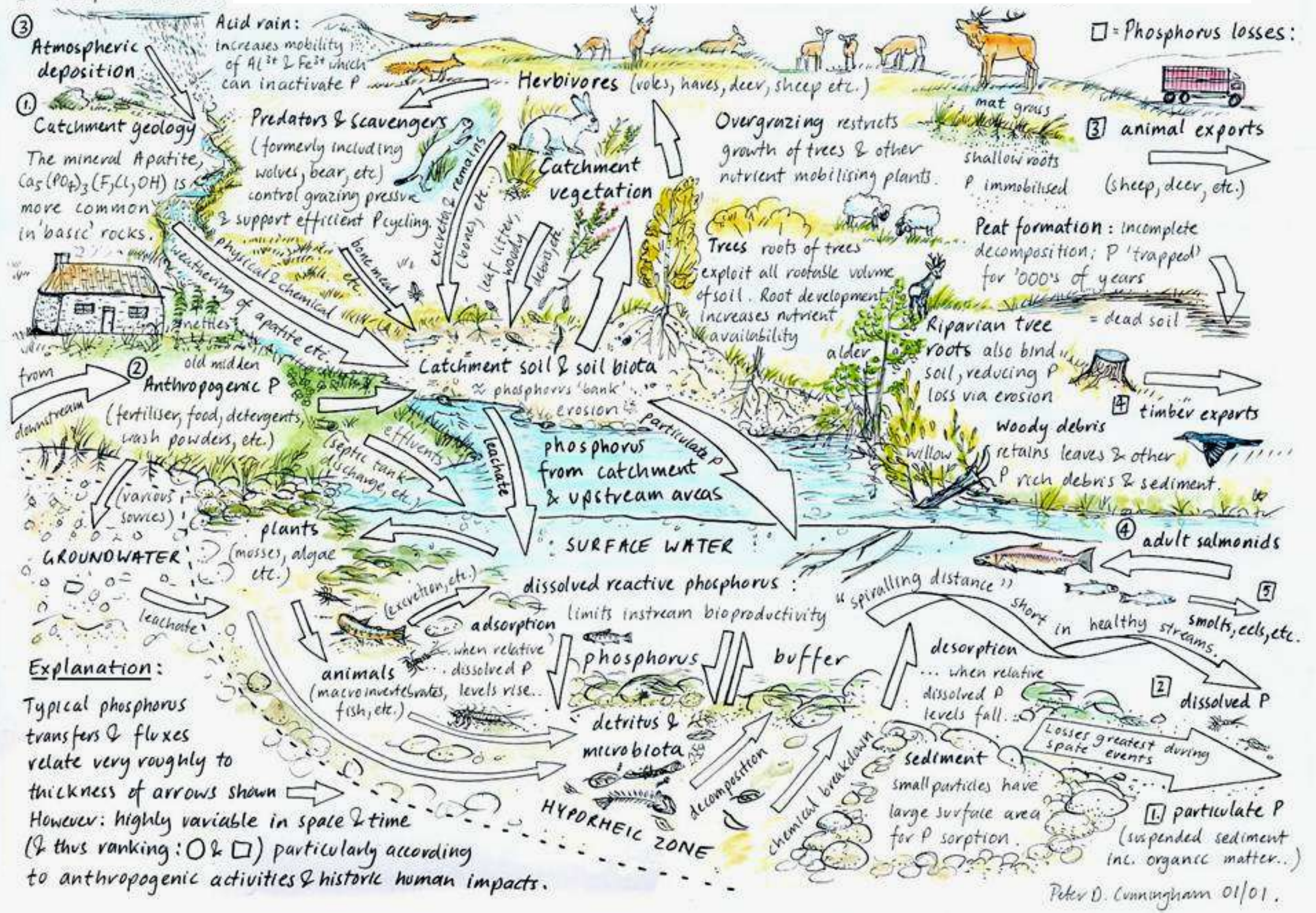
Soil fertility has been an important factor in sustainable plant production in native and agricultural fields in temperate climates such as that in Japan. Soil fertility is assessed based on the availability of nutrients, in particular inorganic nitrogen (N) and phosphorus (P), from soil-accumulated 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.

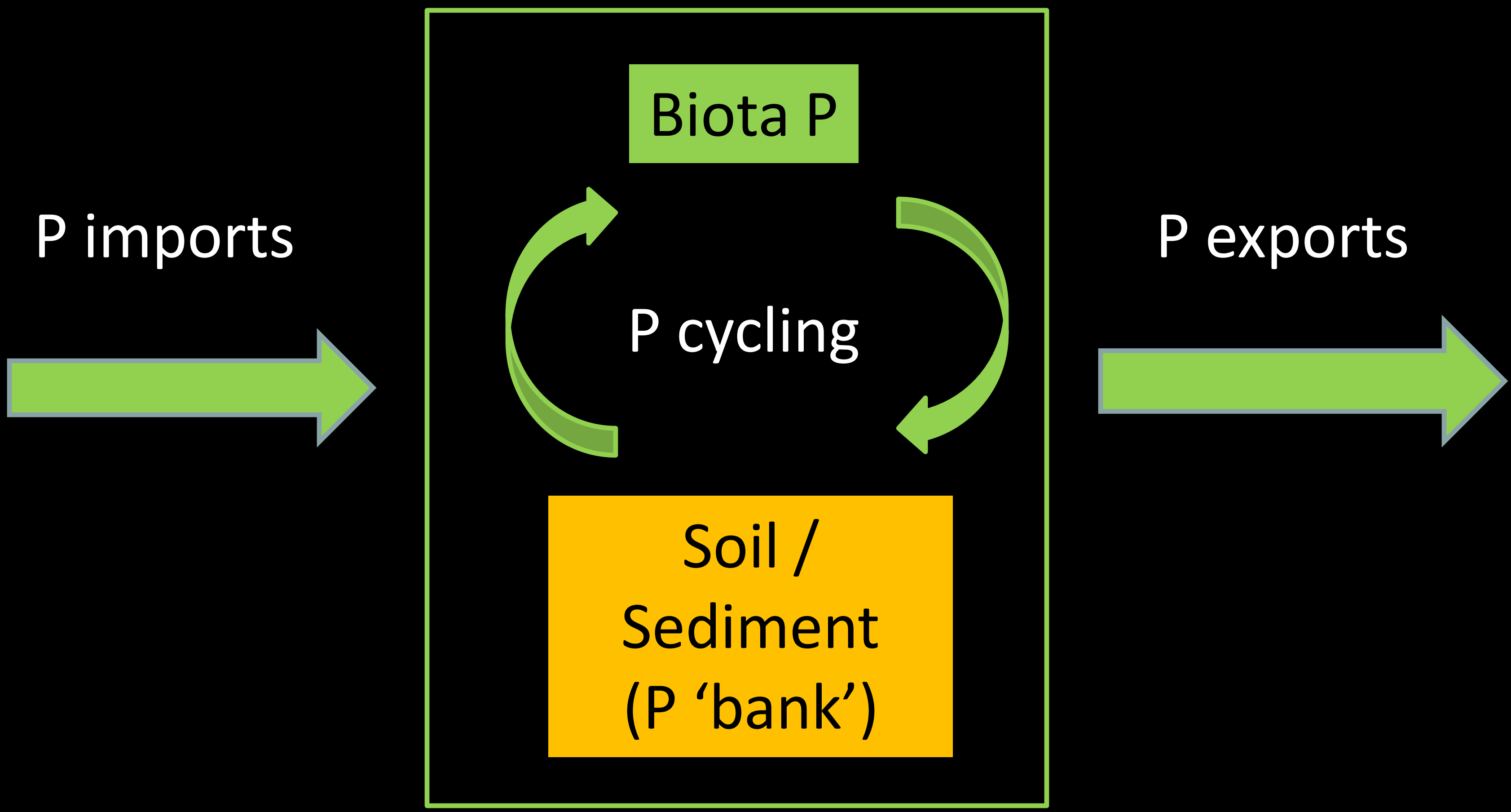


http://www.tandfonline.com/doi/full/10.1080/00380768.2015.1017439

Phosphorus availability is dependent upon ecosystem processes



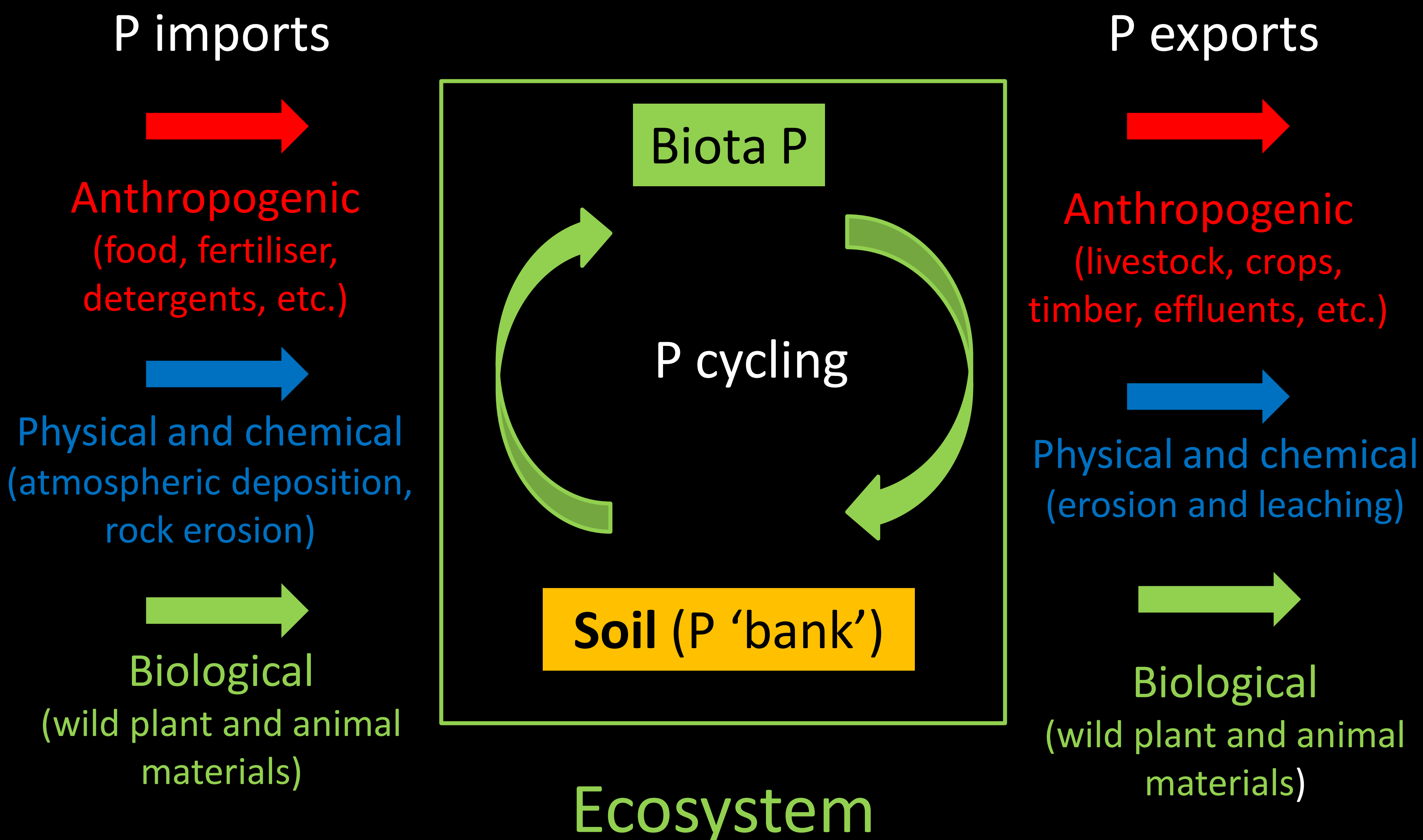
Simplified Phosphorus budget model!



Ecosystem

(can be what ever scale you choose)

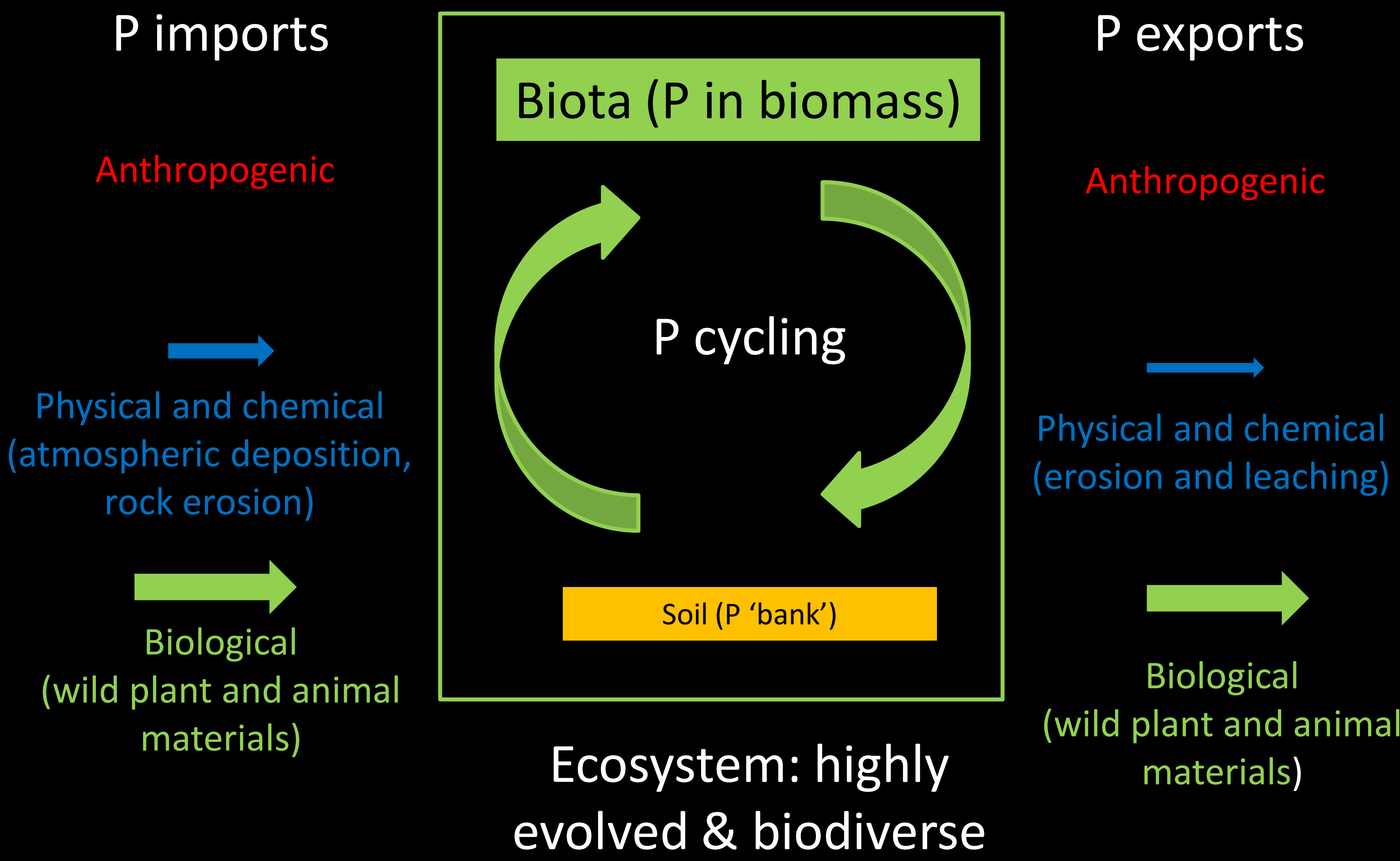
Phosphorus budget



Tropical rainforest

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

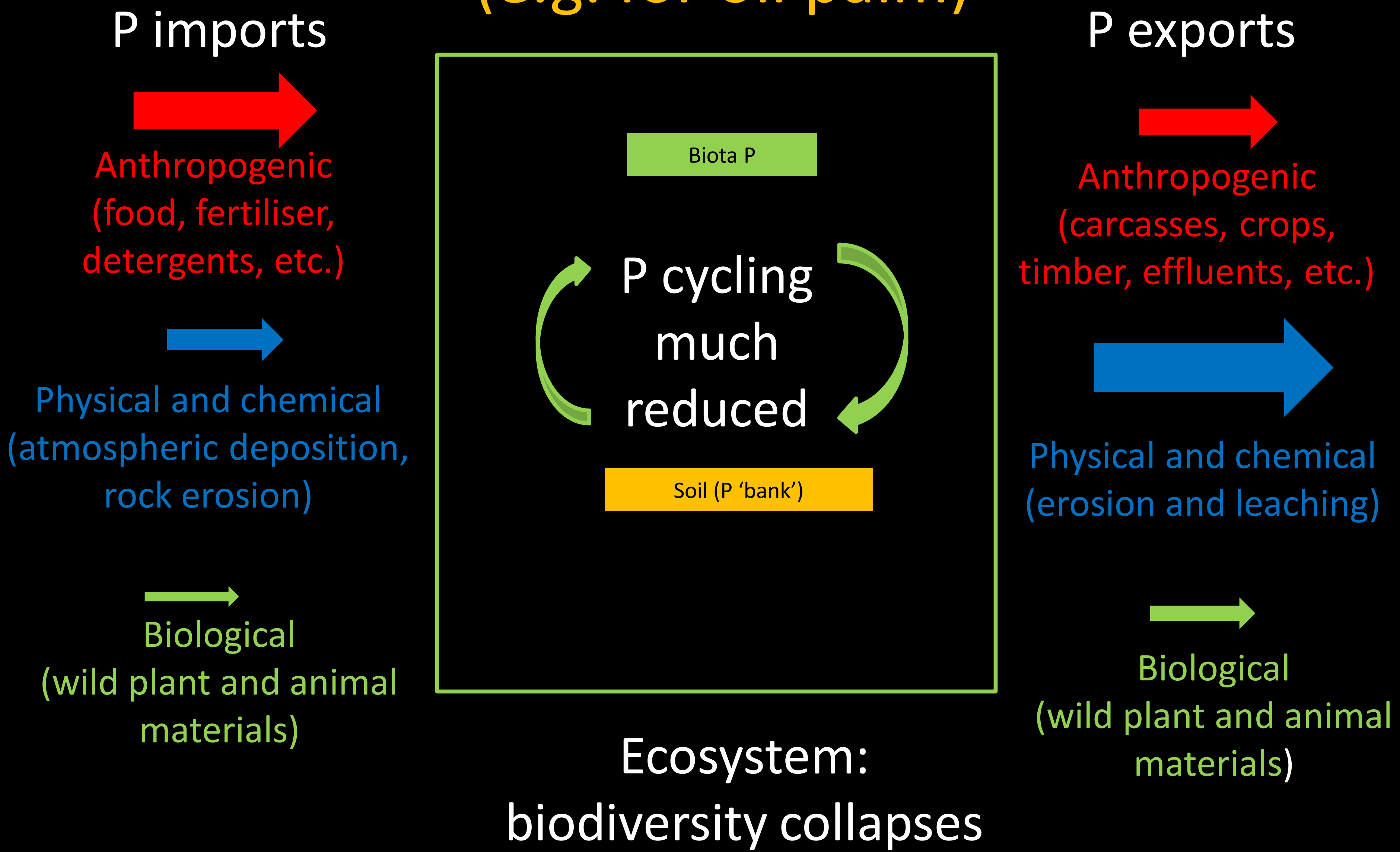
Tropical Rainforest



Deforested hills in Madagascar . . .

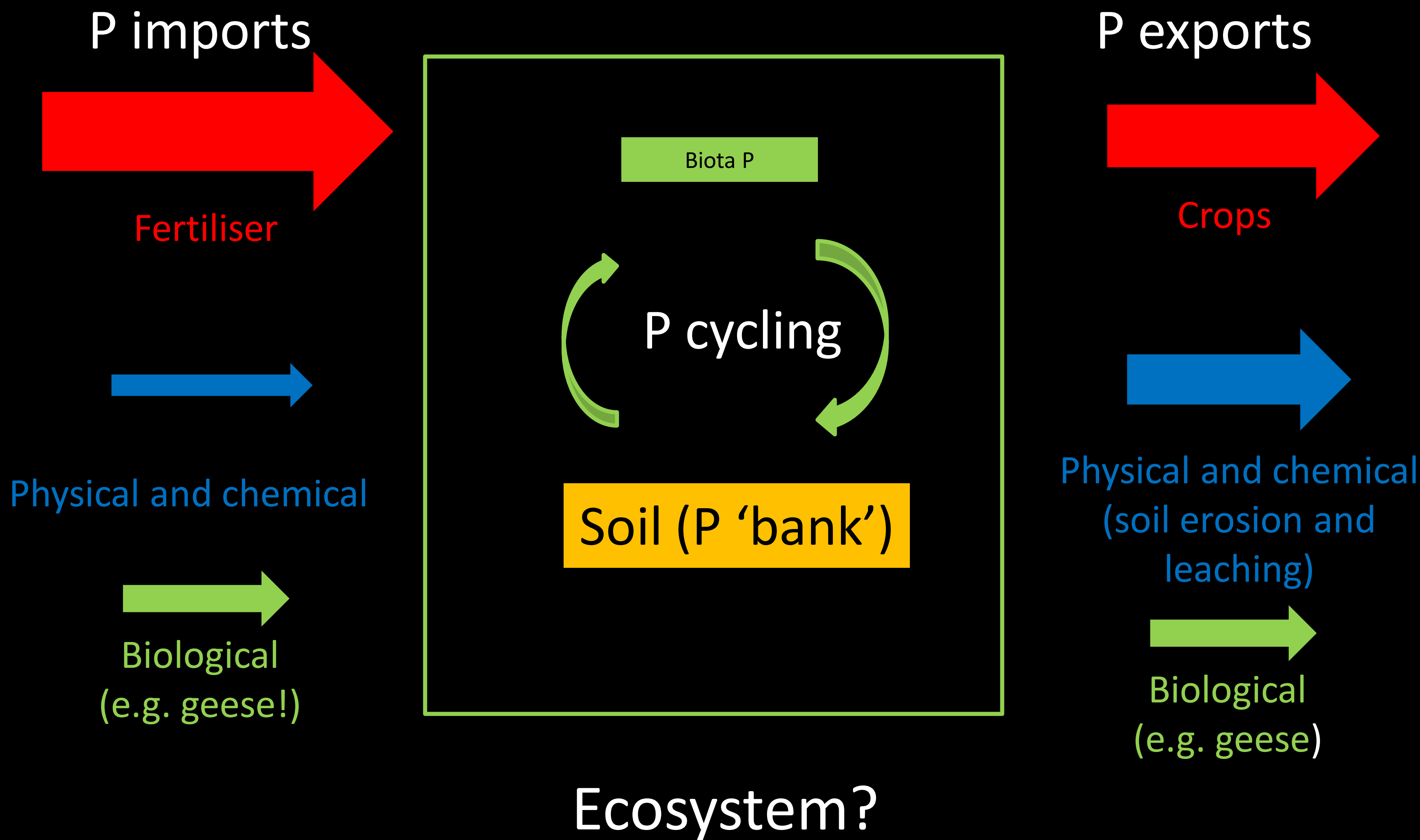
Cleared tropical Rainforest

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



Intensive agricultural area

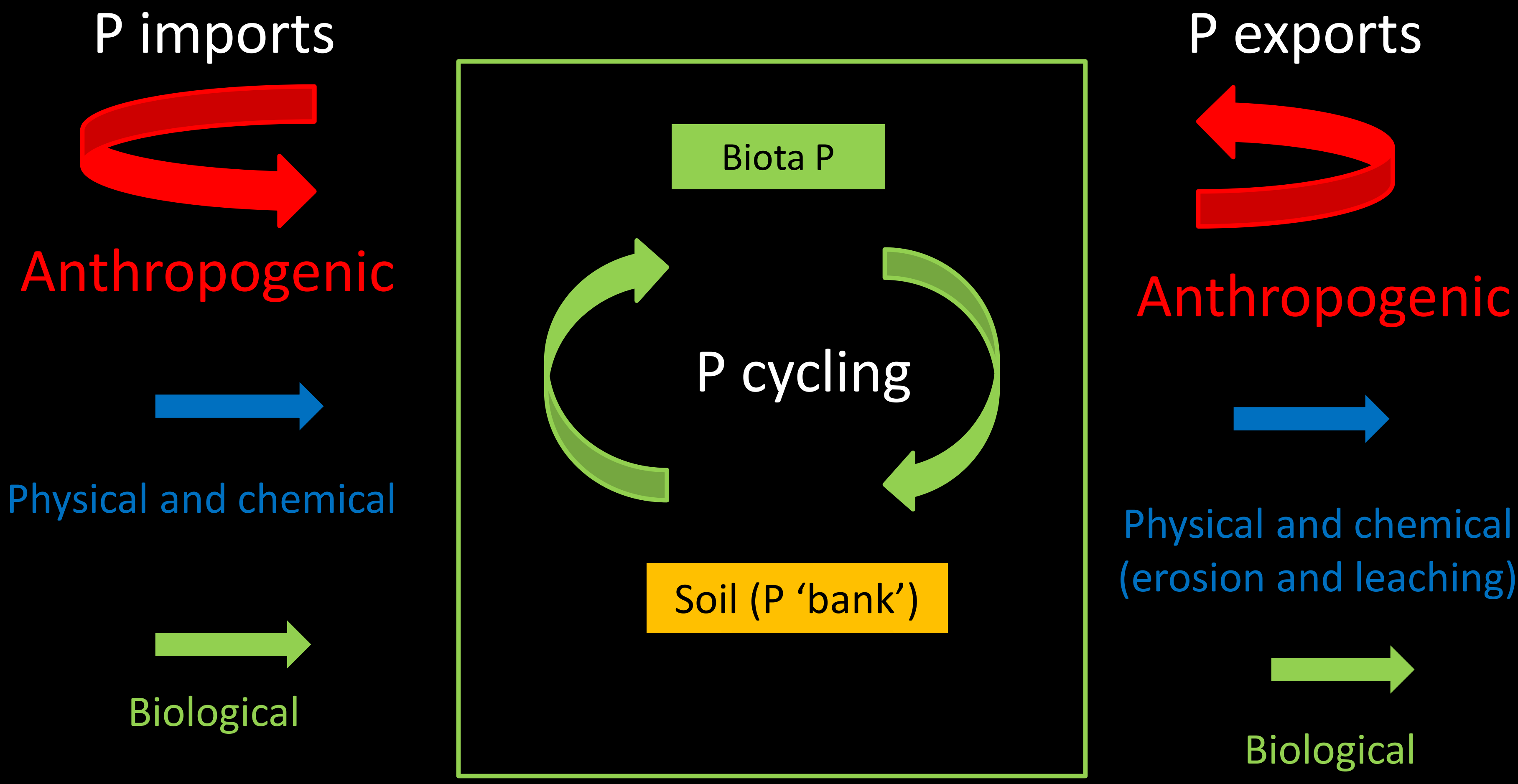
Intensive agricultural area



Traditional agriculture

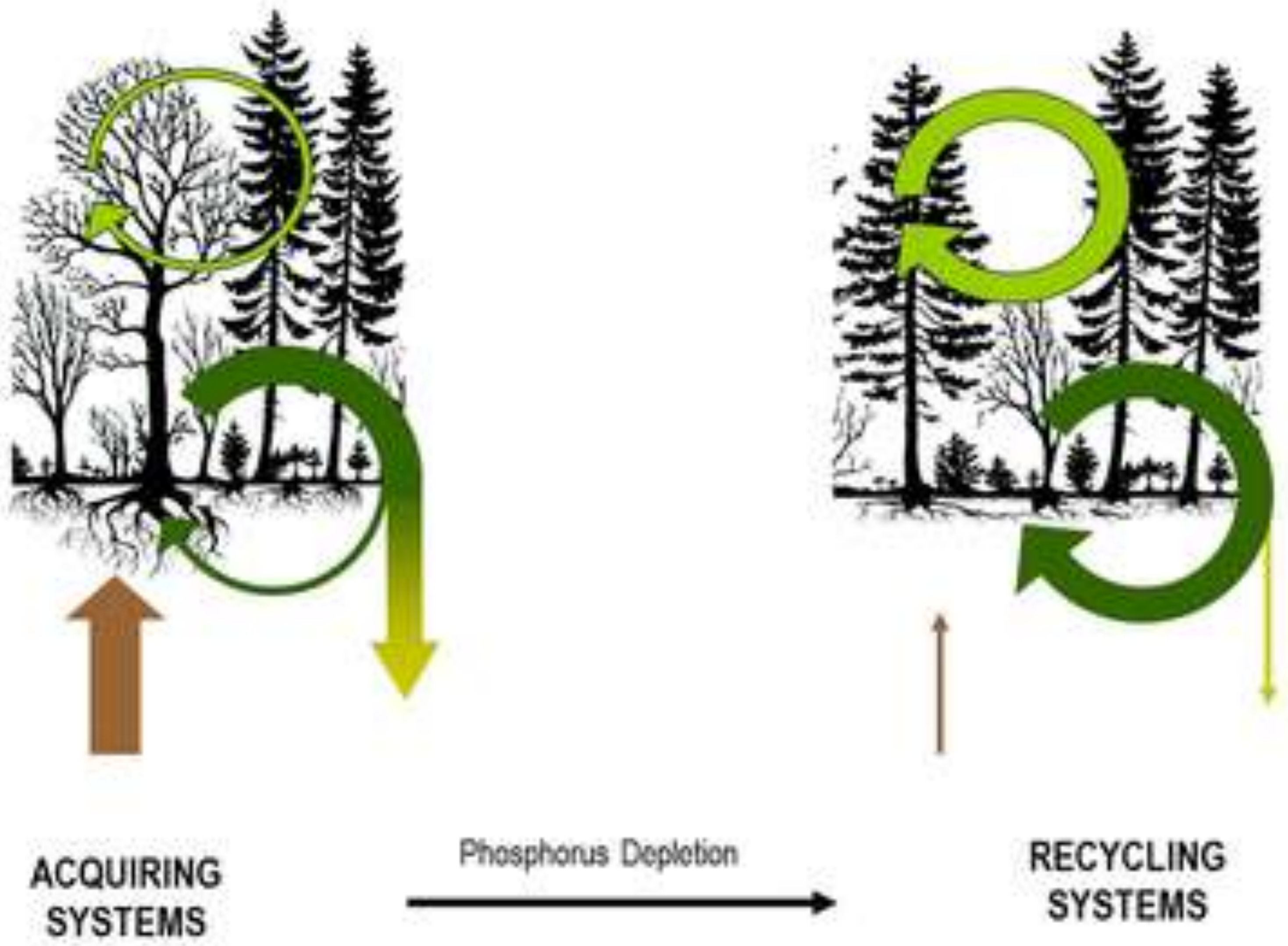

Crofting townships around the coast
Melvaig and Alltgrishan in 2004

Traditional agricultural area



Agricultural Ecosystem: people are a part of the system

Ecosystem nutrition: forest strategies for limited phosphorus resources



https://www.bodenkunde.uni-freiburg.de/forschung/SPP1685

Break – any questions (or answers)?

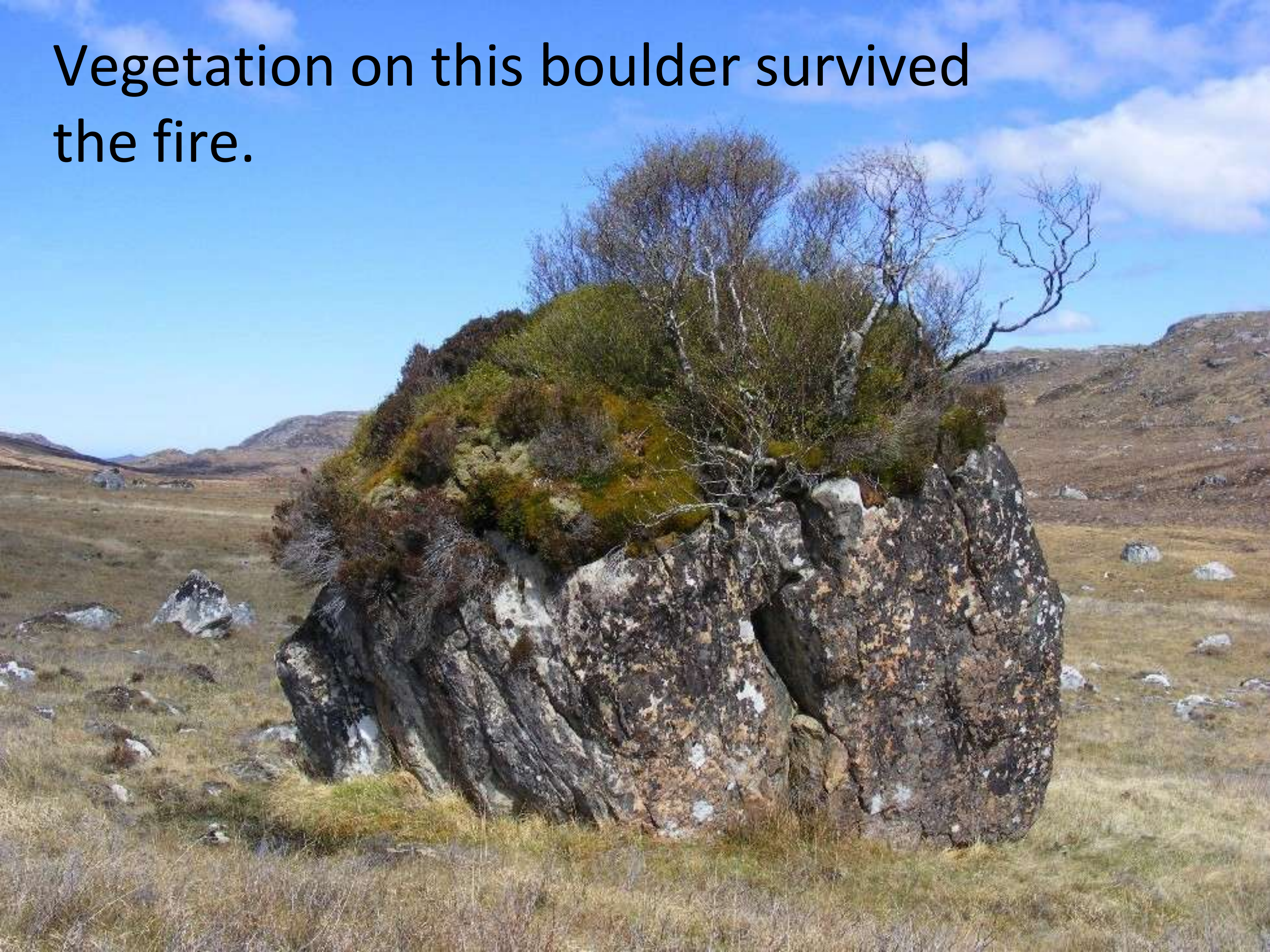
4. Loss of vegetation, fire & phosphorus export

http://www.ross-shirejournal.co.uk/News/Fresh-spate-of-Ross-wildfires-spark-muirburn-warning-01042013.htm

Hillsides are burnt to promote fresh growth.

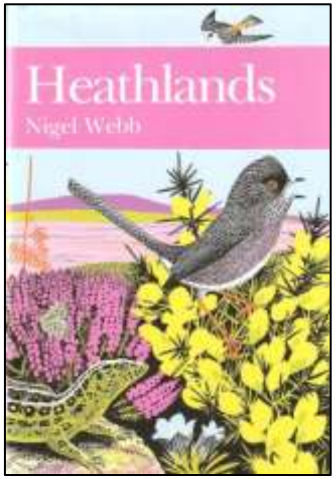
Little Gruinard River, May 2010 (inside fenced enclosure)

Wildfire in 2007


Vegetation on this boulder survived the fire.

How much phosphorus is lost in a moor burn?

Nutrient Balance Sheet for an Area of Lowland Heath (expressed as kg per ha)						
from Webb, 1986						
	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
Figures are in kg per ha						



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

Wester Ross Fisheries Trust

Link to meeting reports: http://www.wrft.org.uk/downloads/files.cfm?id=39

The James Hutton Institute
SRUC
Forestry Commission Scotland
Coimisean na Coilltearachd Alba
Cromarty Fisheries
rspb giving nature a home
SEPA Scottish Environment Protection Agency
John Muir Trust for wild land & wild places
Scottish Natural Heritage
All of nature for all of Scotland
Ben Damph Estate
the National Trust for Scotland
a place for everyone
Game & Wildlife Conservation Trust
Skye & Lochalsh Environment Forum
a Bridge to Biodiversity
Drochaid gu Iomadachd Nàdair

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 nutrtient 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

VEGETATION SURVEY OF
BEINN EIGHE, WESTER ROSS, 1997

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

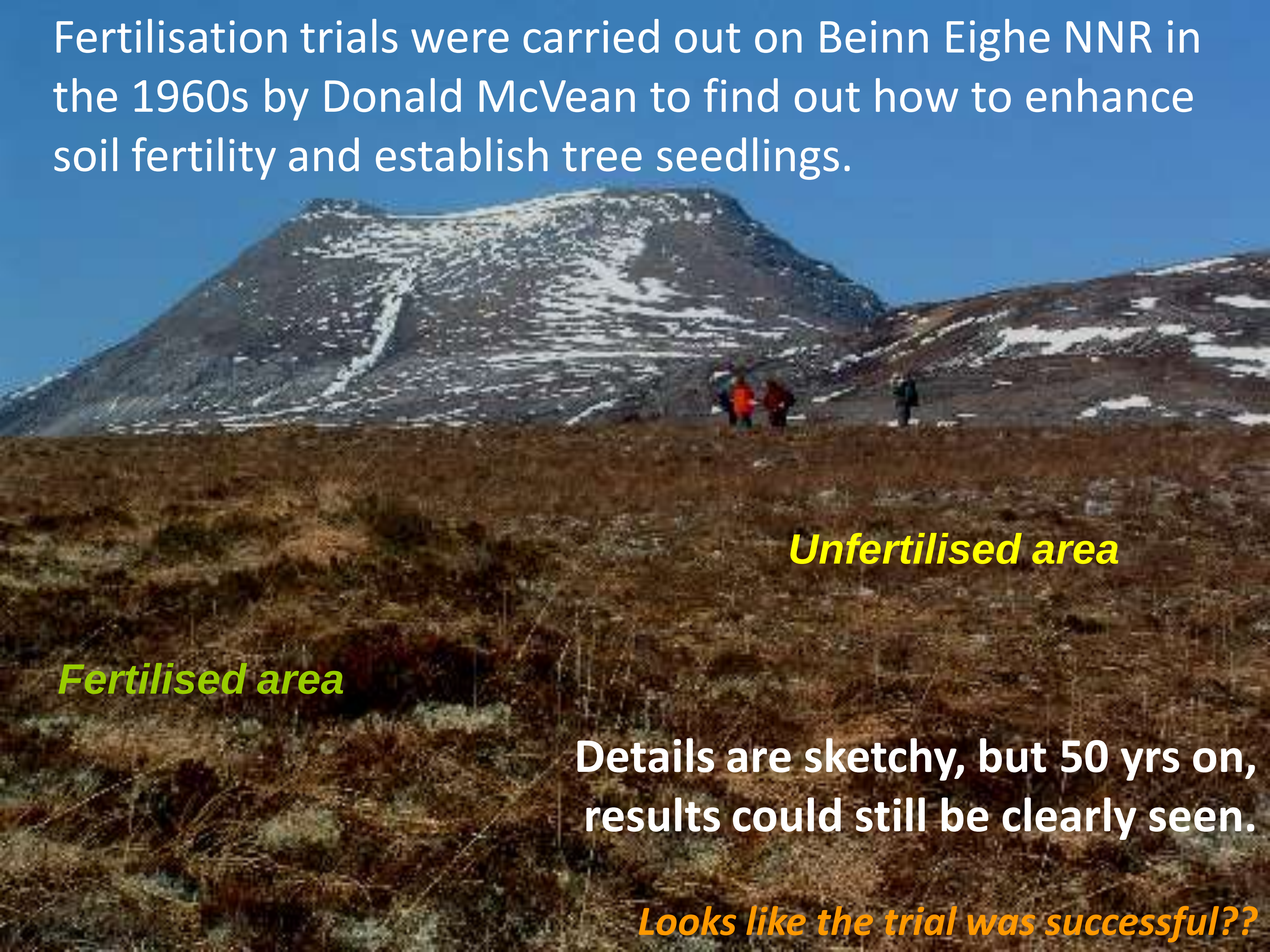
January 1998

Scottish Natural Heritage contract HT/97/98/13

'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.
Unfertilised area
Fertilised 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 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.

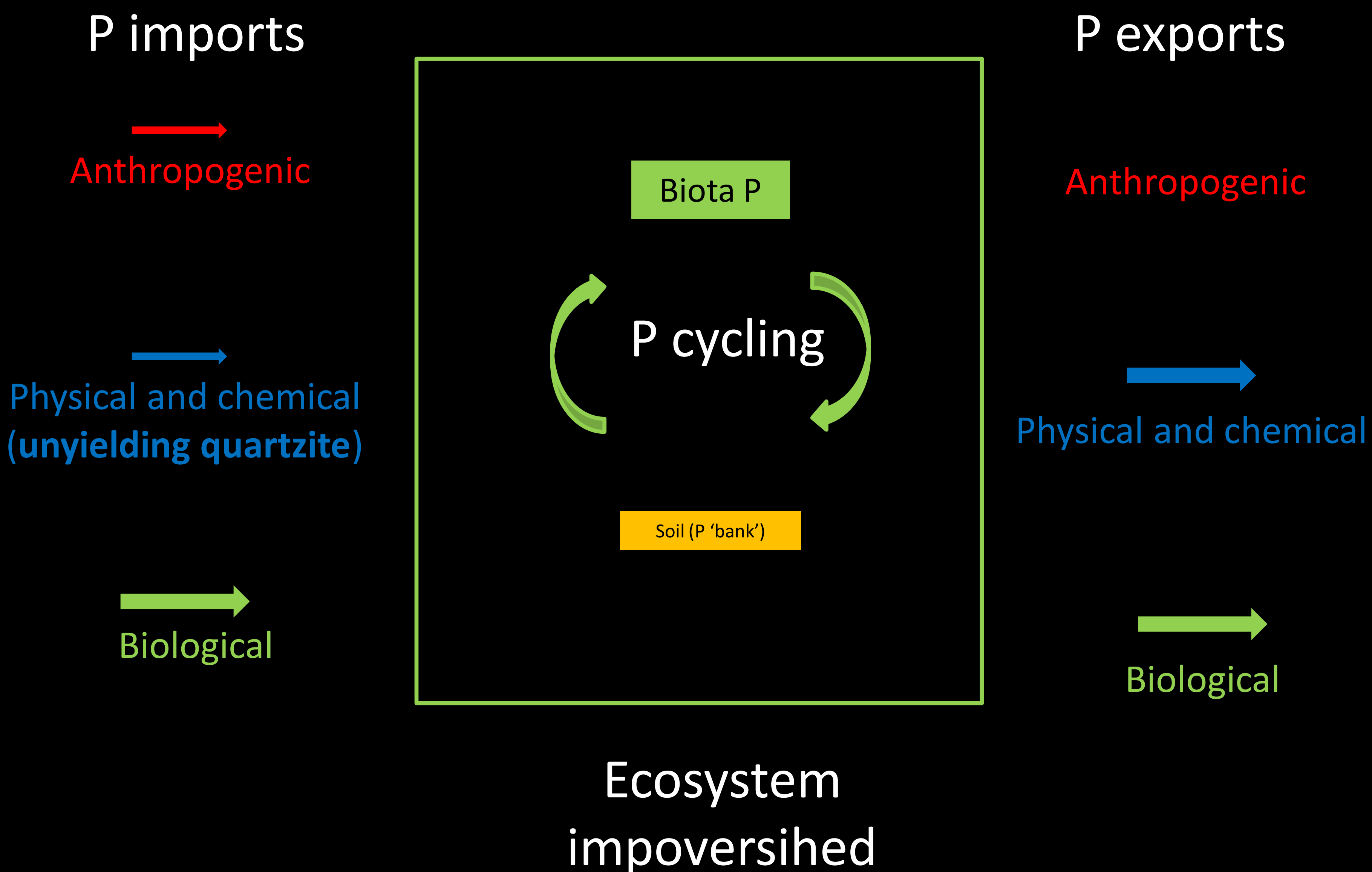
•It has a noticeably greater cover of the moss *Racomitrium lanuginosum* (50-75%) and the lichens *Cladonia portentosa, C.arbuscula* and *C.uncialis* (30-50%) than does the surrounding heath.

•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



Inside fertilised area

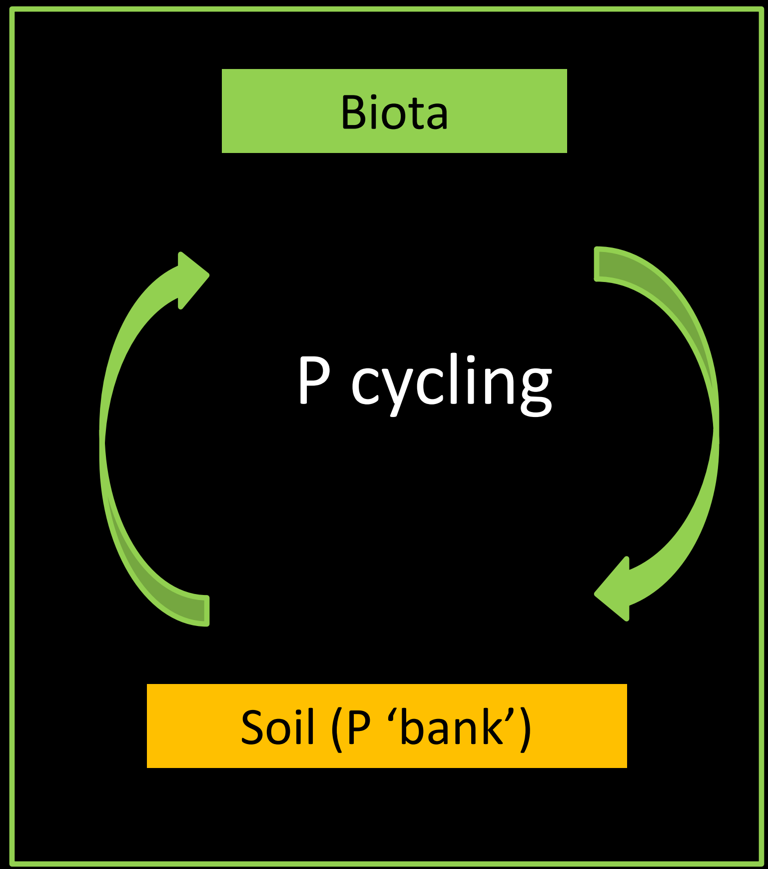
(50+ years following fertiliser application)

P imports

Anthropogenic (2008)

Physical and chemical

Biological
(e.g. grouse droppings)



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?)

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

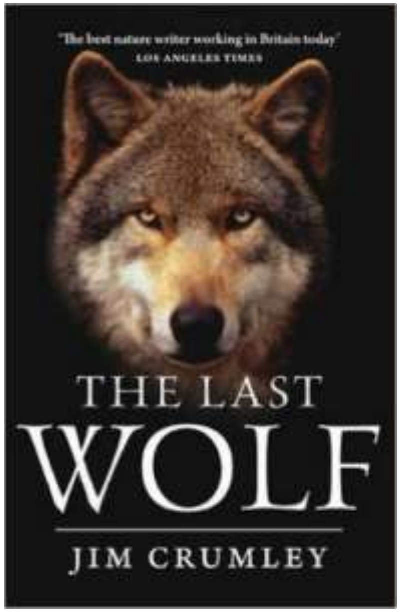
A.B.G. Averis and A.M. Averis

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

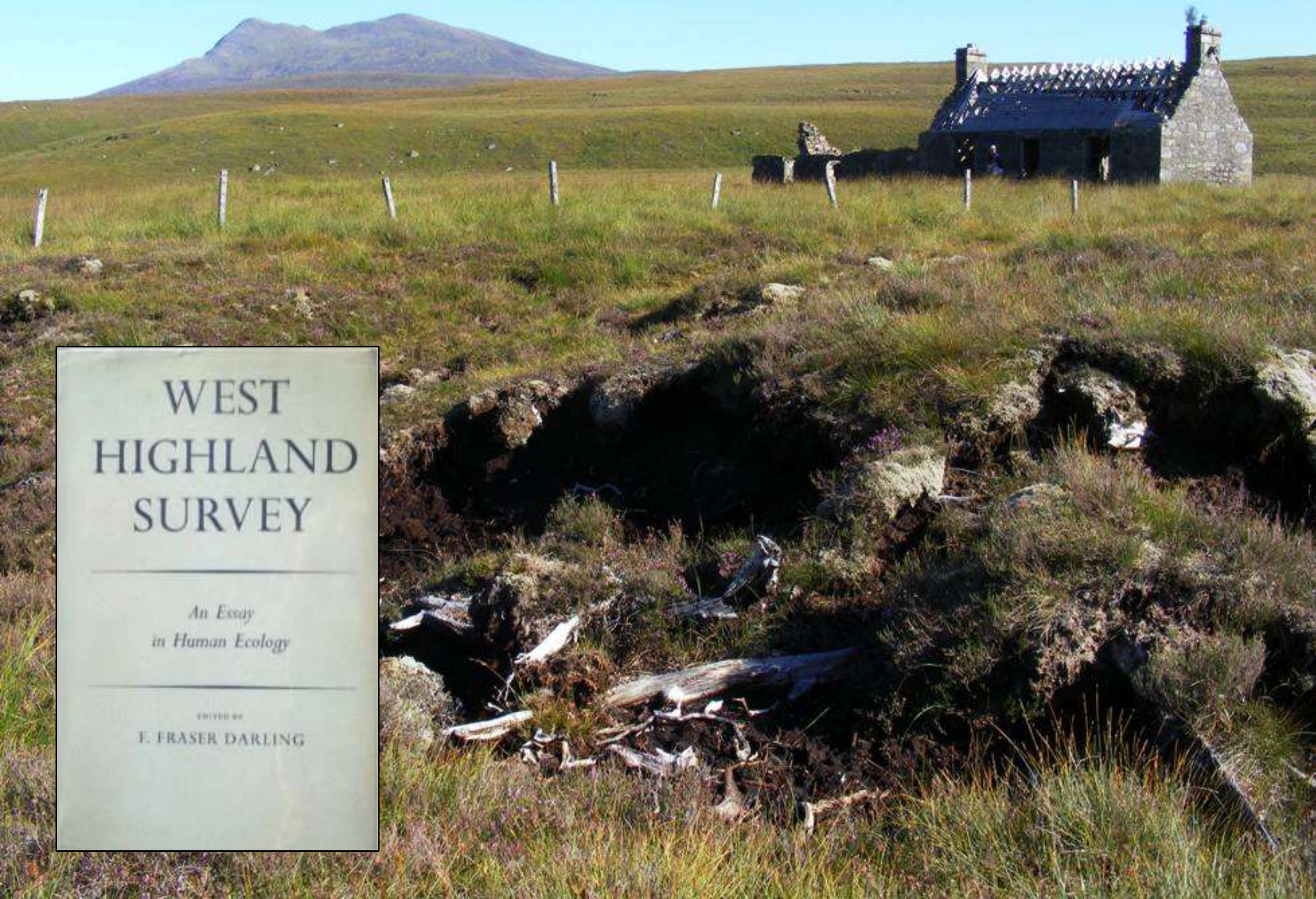
- *The removal of deer, sheep or cattle from upland catchment areas represents an unnatural loss of phosphorus from the ecosystem*.

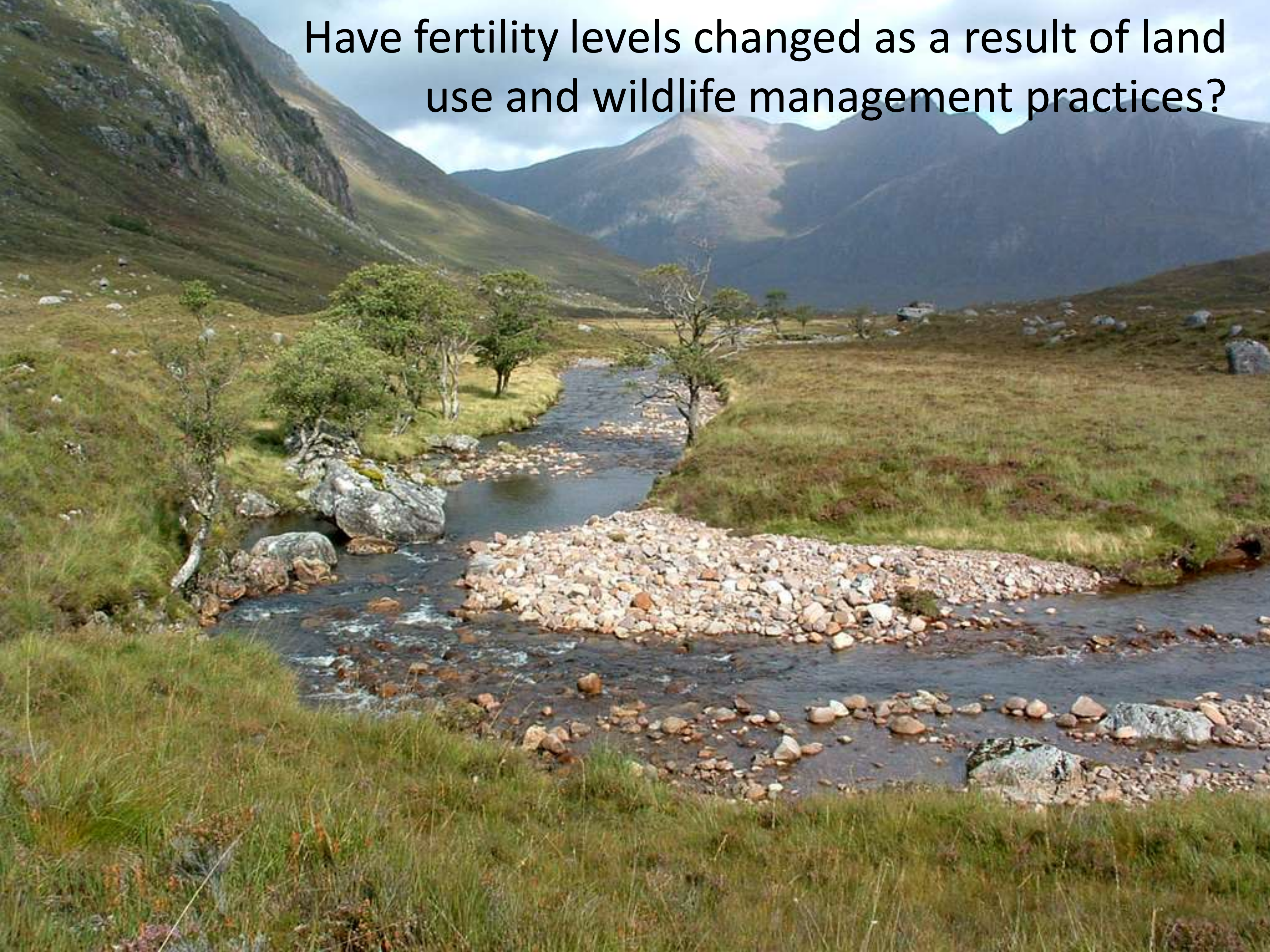
- *How many cattle sheep and deer have been removed from headwater catchment areas over the past 100++ years?*

- *How much phosphorus does this represent?*

- *How much phosphorus has been returned to the areas where the animals grazed?*

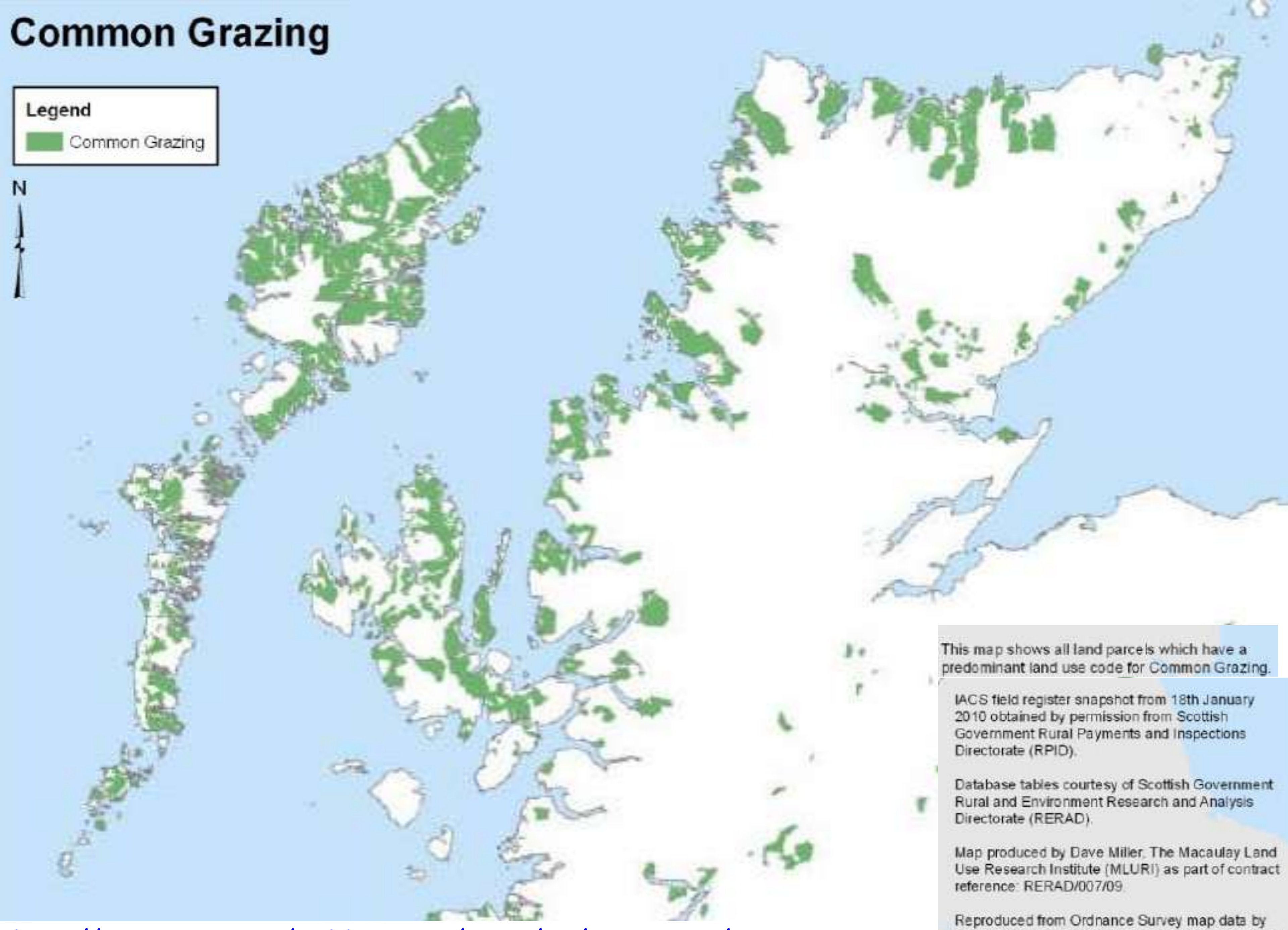
Human populations were higher in the past in some areas




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?

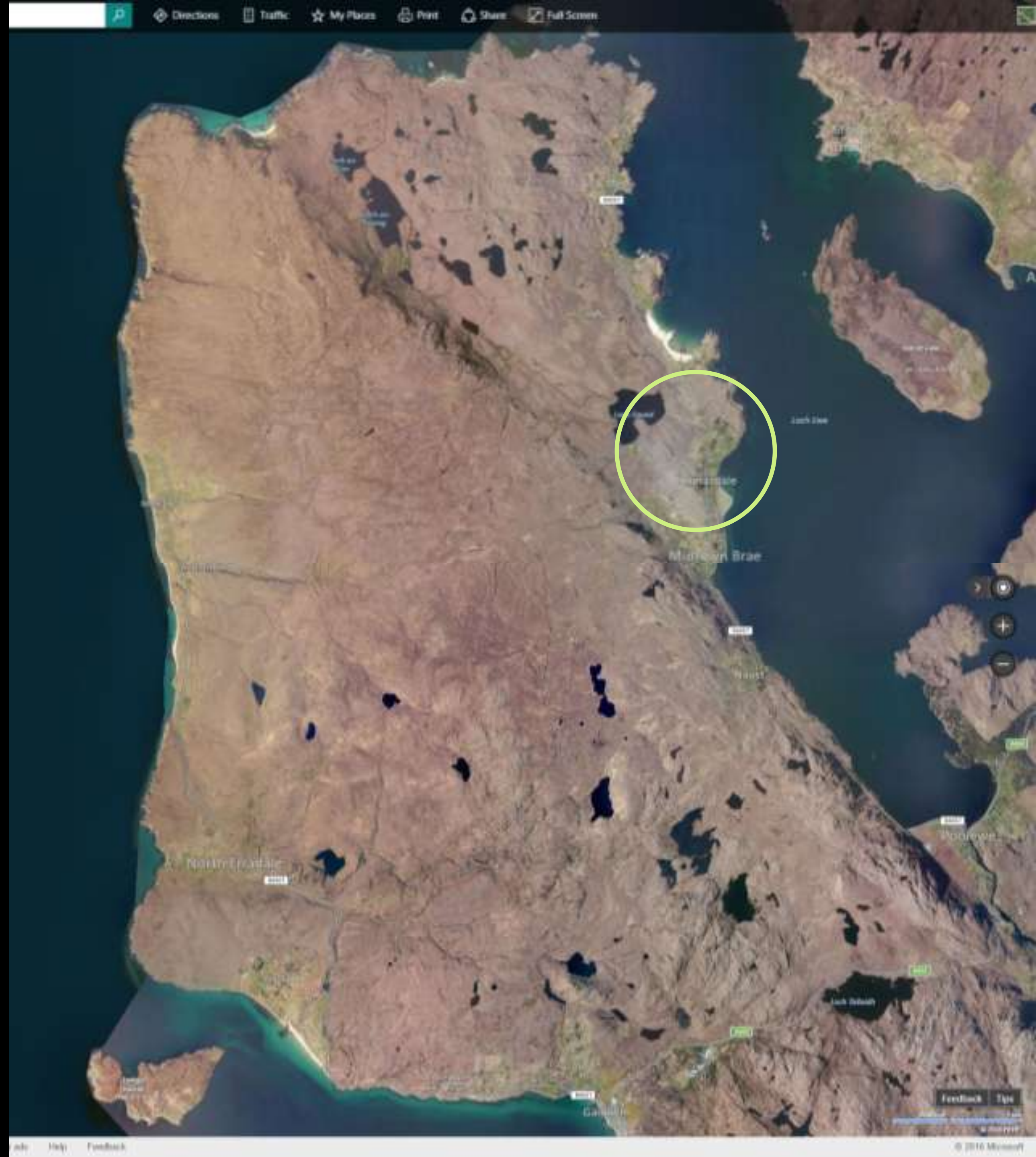
Common Grazing



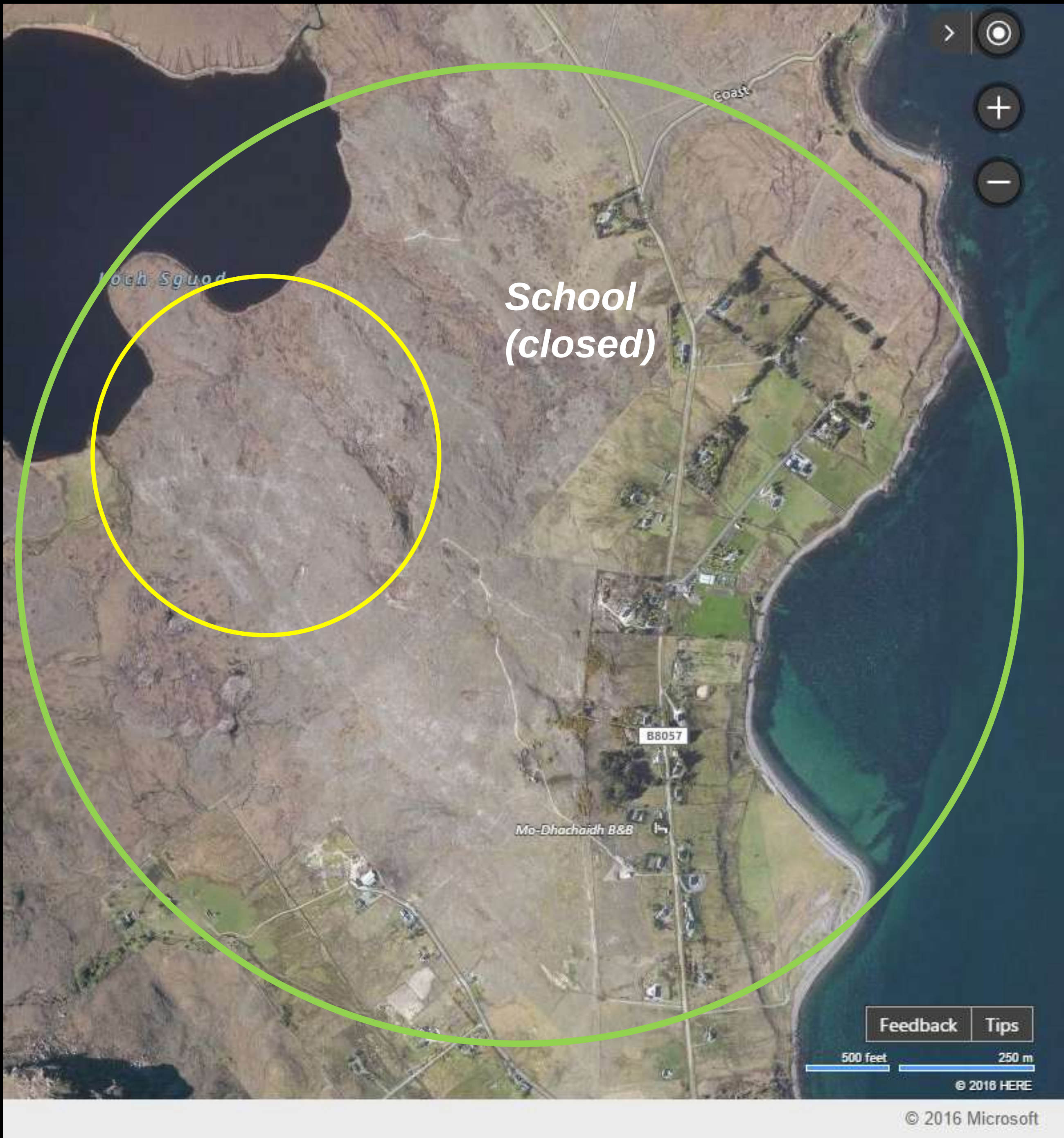
http://www.gov.scot/Publications/2010/11/01153620/13

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.

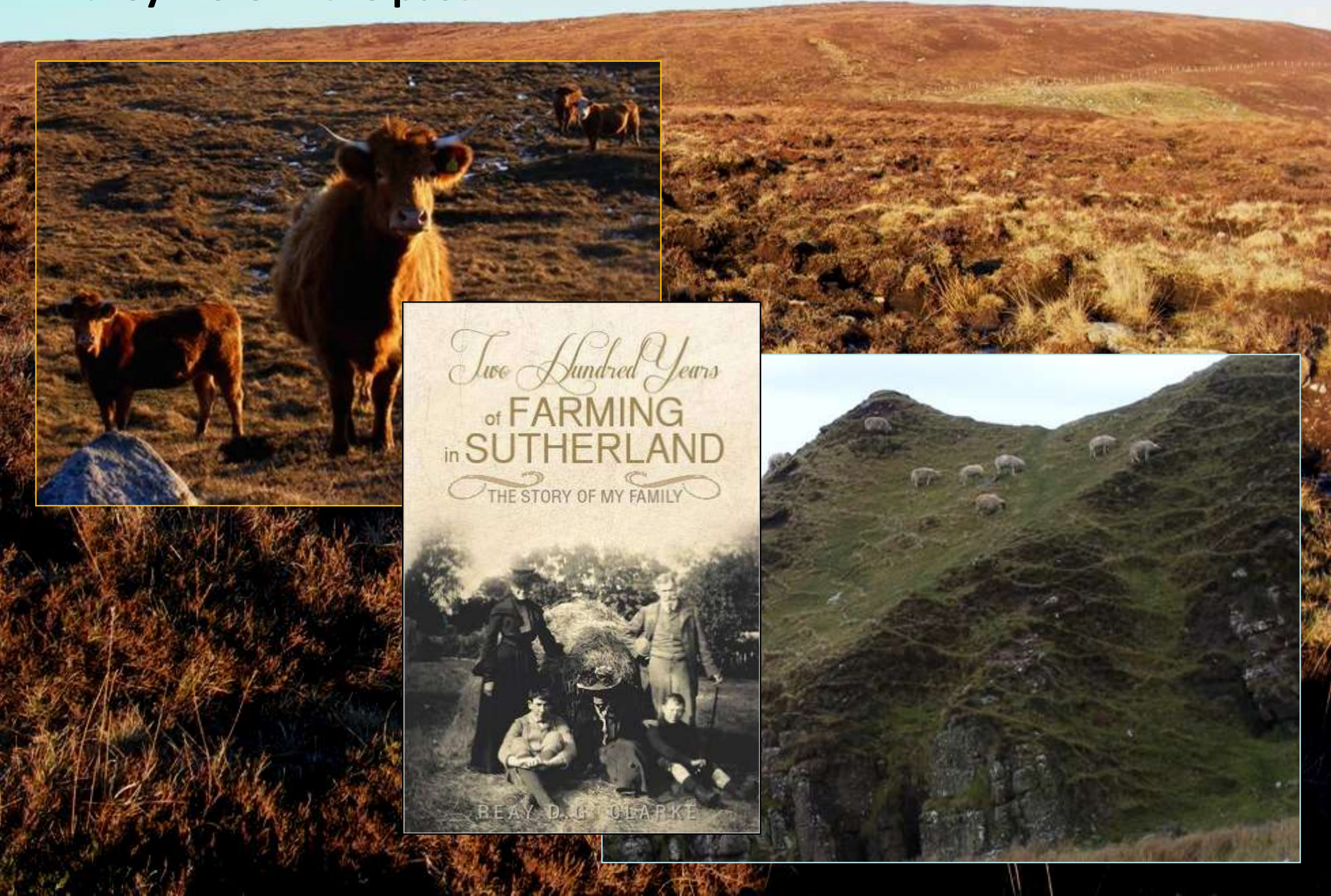


Peat cut and removed?

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?



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 . . .’

http://www.crofting.scotland.gov.uk/userfiles/file/Act_and_Policy/Crofting-Commission-Policy-Plan.pdf

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. . .’

http://www.crofting.scotland.gov.uk/userfiles/file/Act_and_Policy/Crofting-Commission-Policy-Plan.pdf

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 (?).

http://www.crofting.scotland.gov.uk/userfiles/file/Act_and_Policy/Crofting-Commission-Policy-Plan.pdf

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. .

http://www.thefield.co.uk/stalking-2/where-to-go-stalking-in-scotland-in-2016-29934

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=vc9uv8I9

http://img.myswitzerland.com/mys/7398/images/buehne/STS2740-1.jpg

Ecosystems (2006) 9: 624–633
DOI: 10.1007/s10021-006-0091-4

ECOSYSTEMS

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. Edwards[6]

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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


00:02

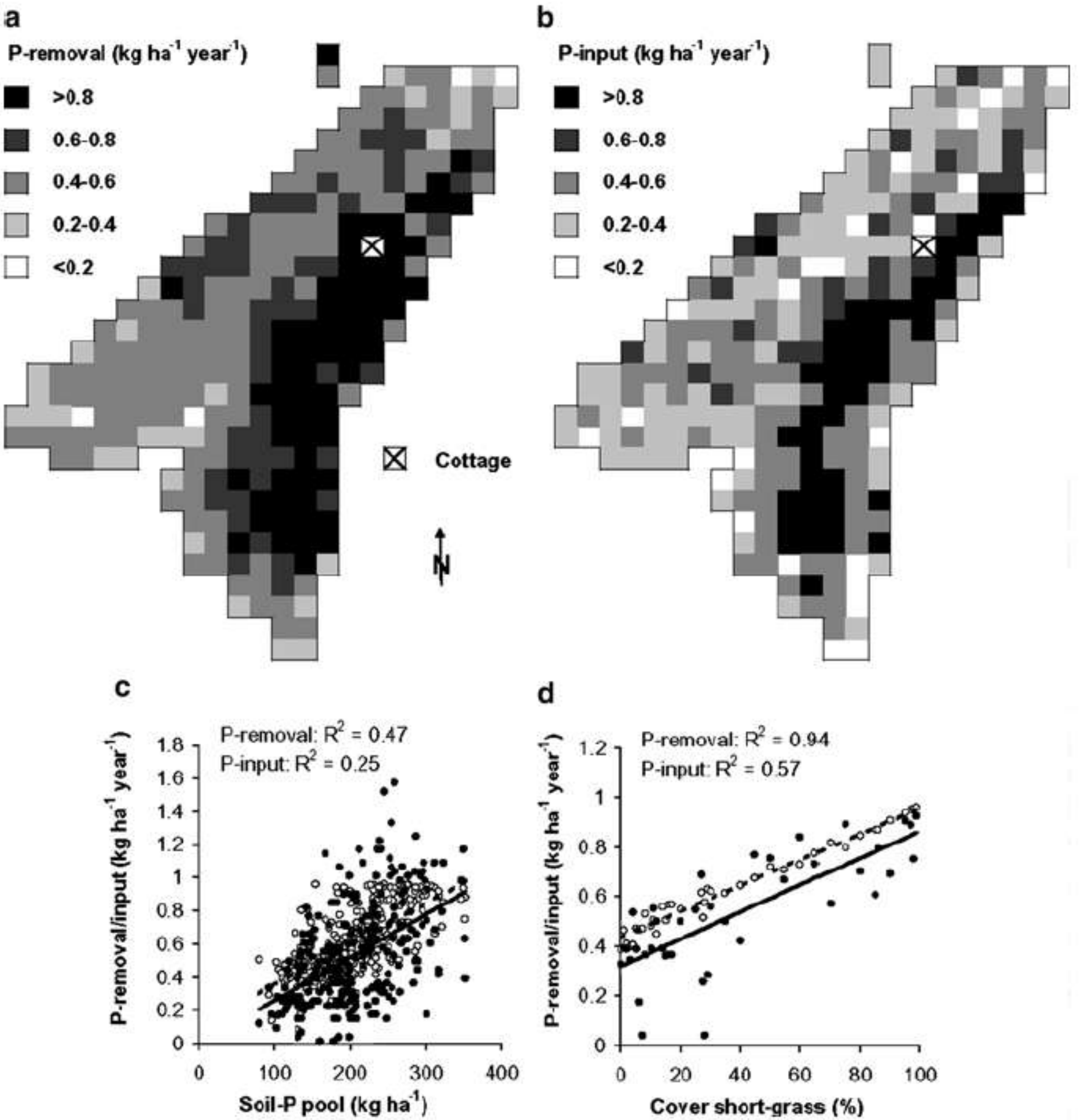


Figure 3. Spatial patterns of **A** phosphorus (P) removal by red deer grazing offtake, and **B** P input by red deer dung deposition on the subalpine grassland of Alp Stabelchod **C** Relationship between P removal/P input and soil-P pool. **D** Relation between P removal/P input and short-grass cover.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

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

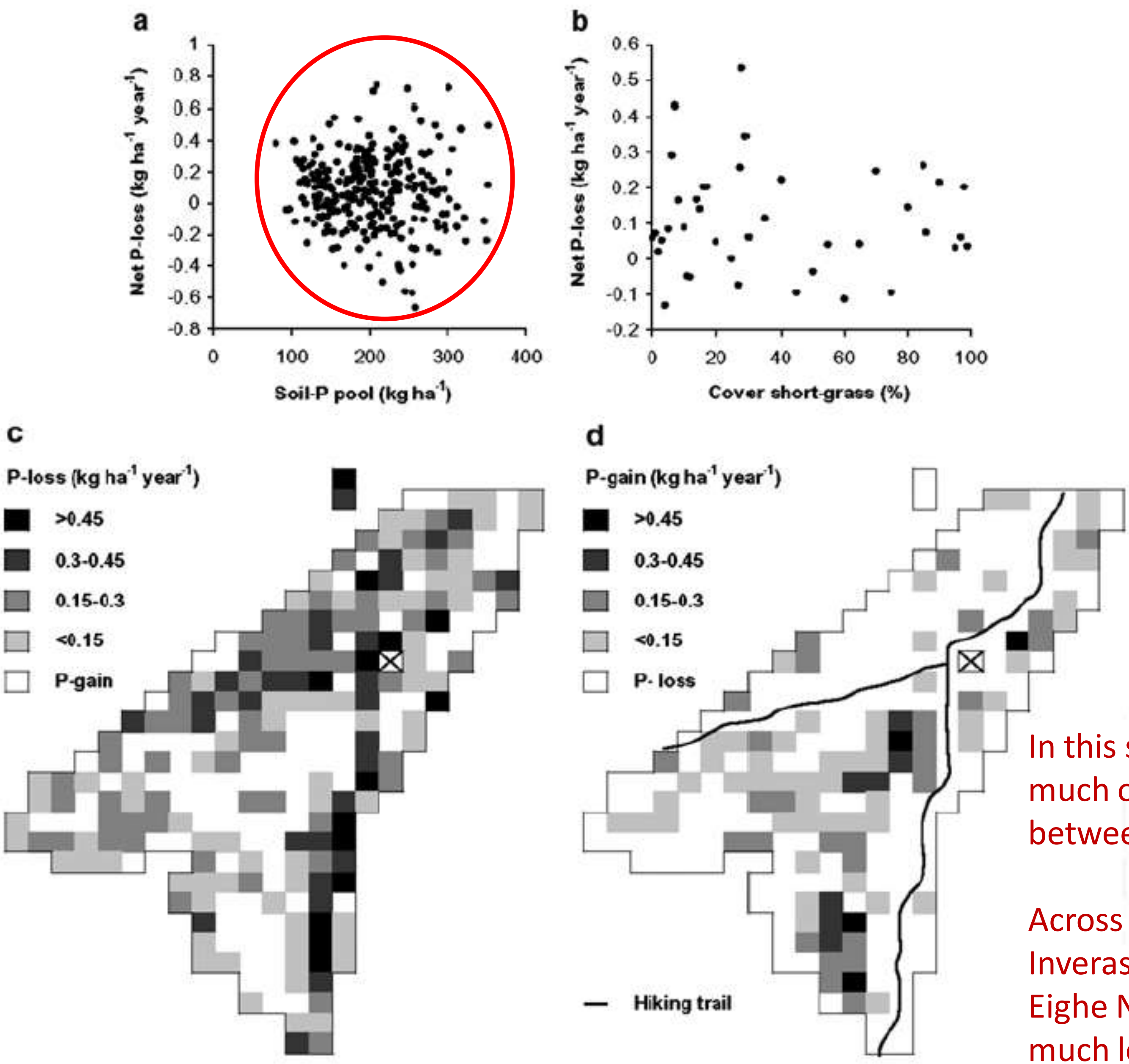


Figure 4. Relationship between **a** net phosphorus (P) loss and soil-P pool, **b** net P loss and cover of short-grass vegetation. Spatial patterns of **c** net P loss (removal > input) and **d** net P gain (input > removal) on the subalpine grassland of Alp Stabelchod.

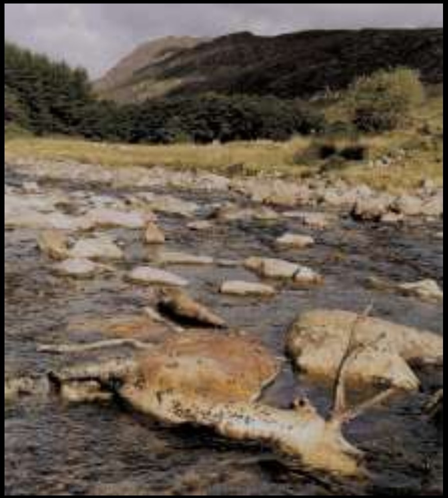
In this study, the **soil P pool** over much of the study area was typically between 200 and 300 kg P /ha.

Across much of Wester Ross (e.g. Inverasdale grazings area; Beinn Eighe NNR) it is probably usually much less than that . . .

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

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?



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Article

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

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

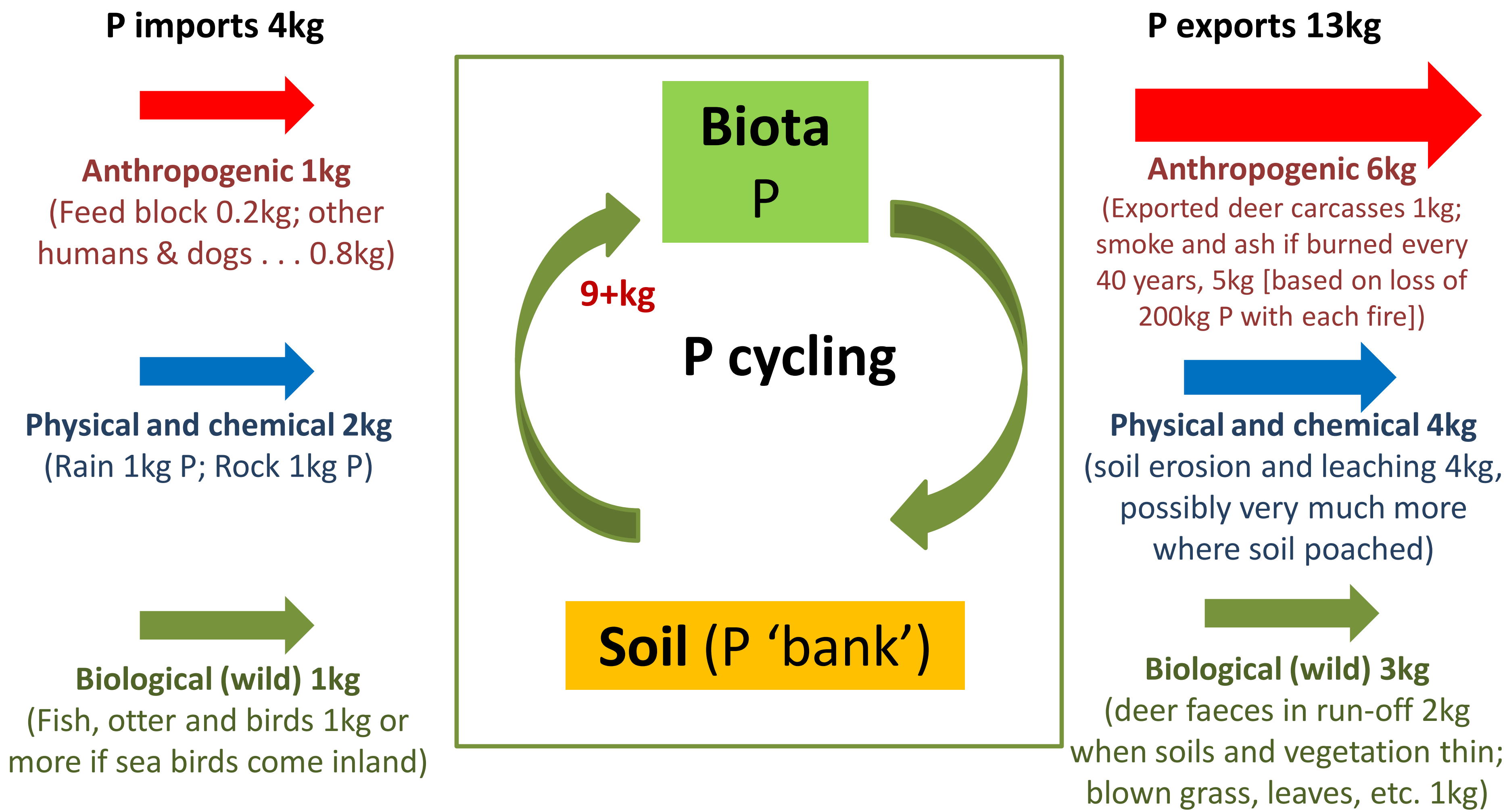
Abstract: Biogeochemical cycles are cornerstones of biological evolution. Mature terrestrial ecosystems efficiently trap nutrients and certain ones are largely recycled internally. Preserving natural fluxes of nutrients is an important mission of protected areas, but artificially leaky systems remain 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.

Phosphorus loss of ~0.1 kg /Ha/yr of P . . . = 10kg /km^2/yr of P

http://www.thefield.co.uk/stalking-2/where-to-go-stalking-in-scotland-in-2016-29934

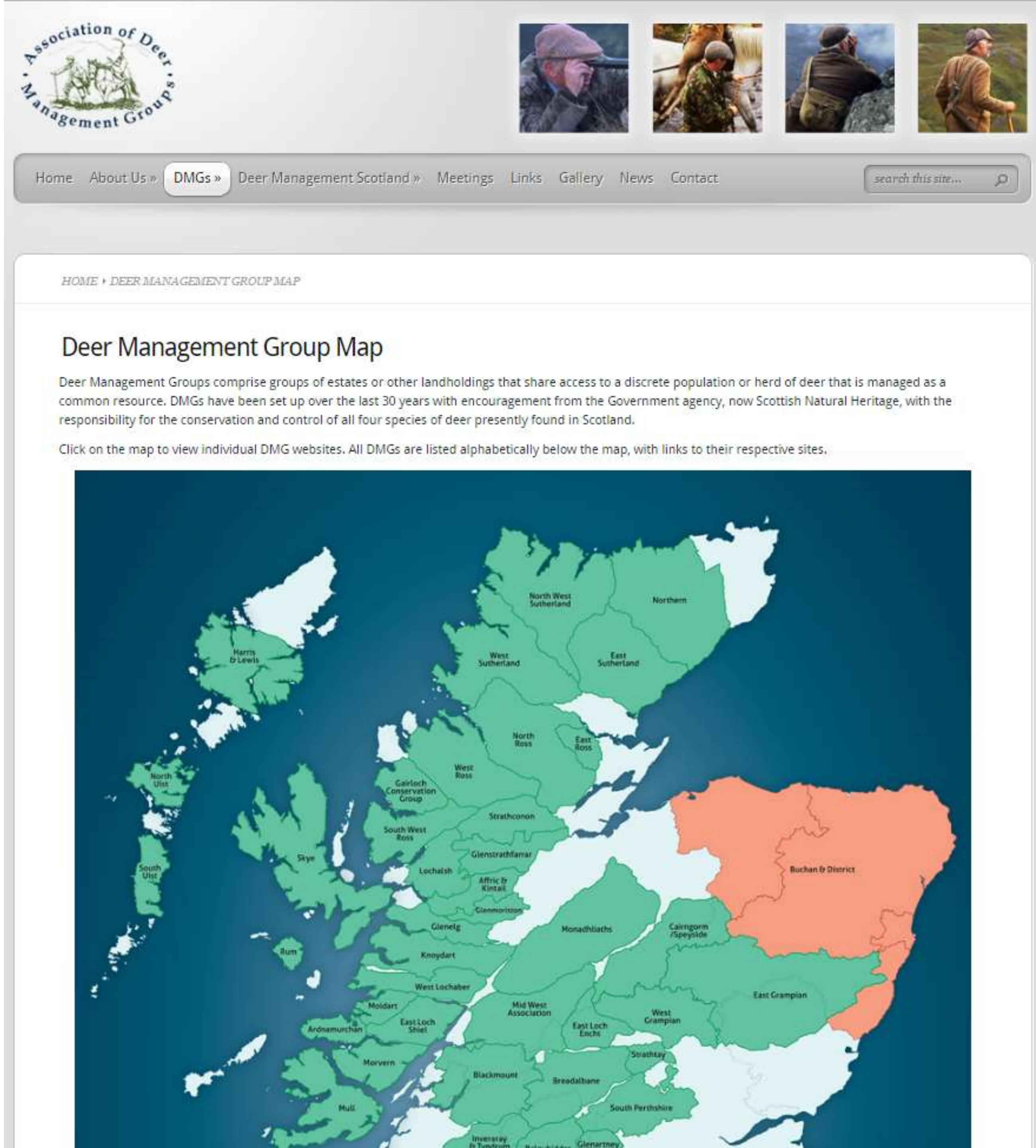
Hypothetical annual P budget example for $1km^2$ of uninhabited unfertilised Wester Ross deer forest (i.e. open hill) burned every 40 years and stocked at 8 deer per km^2 where 1 deer is culled and carcass removed each year



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 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.

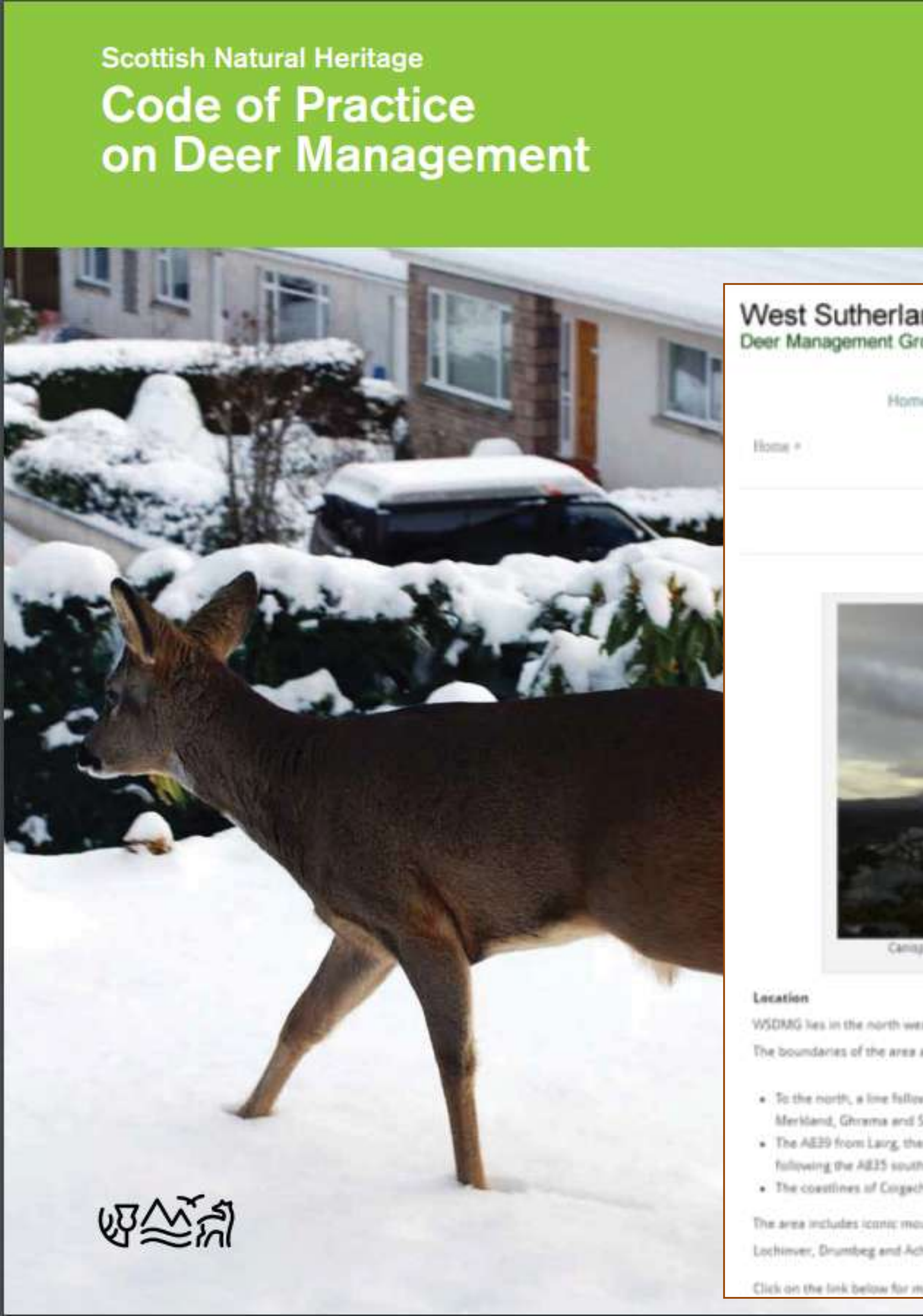
The impacts of herbivores and the consequent decline in the condition and extent of woodland, together with changes in land use and land management, has resulted in:

- 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

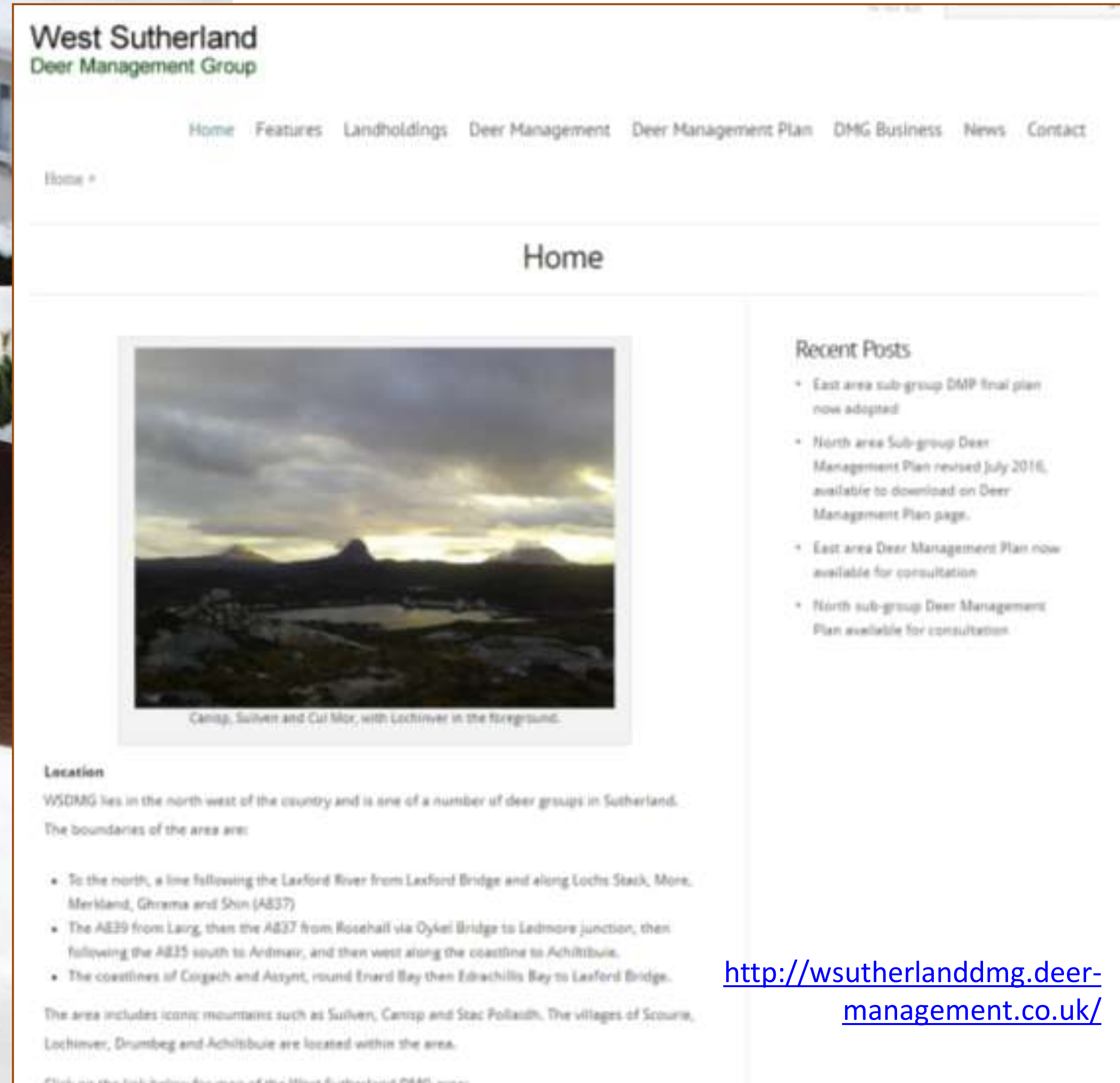
Benefits of a forested landscape

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.

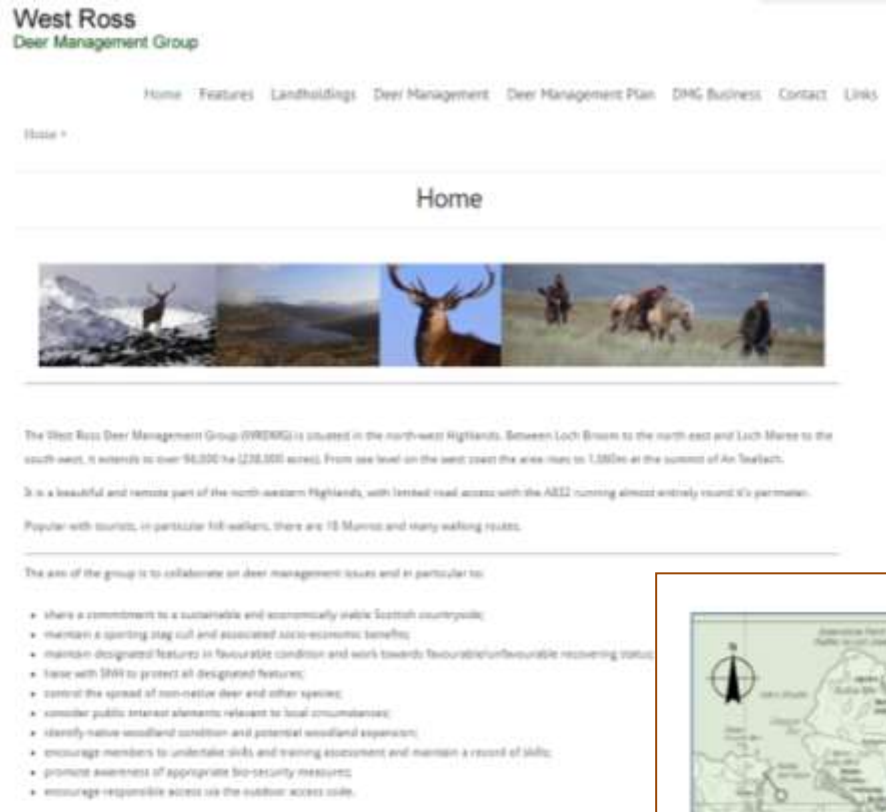
http://www.reforestingscotland.org/what-we-do/influencing-policy/the-impact-and-management-of-deer-in-scotland/



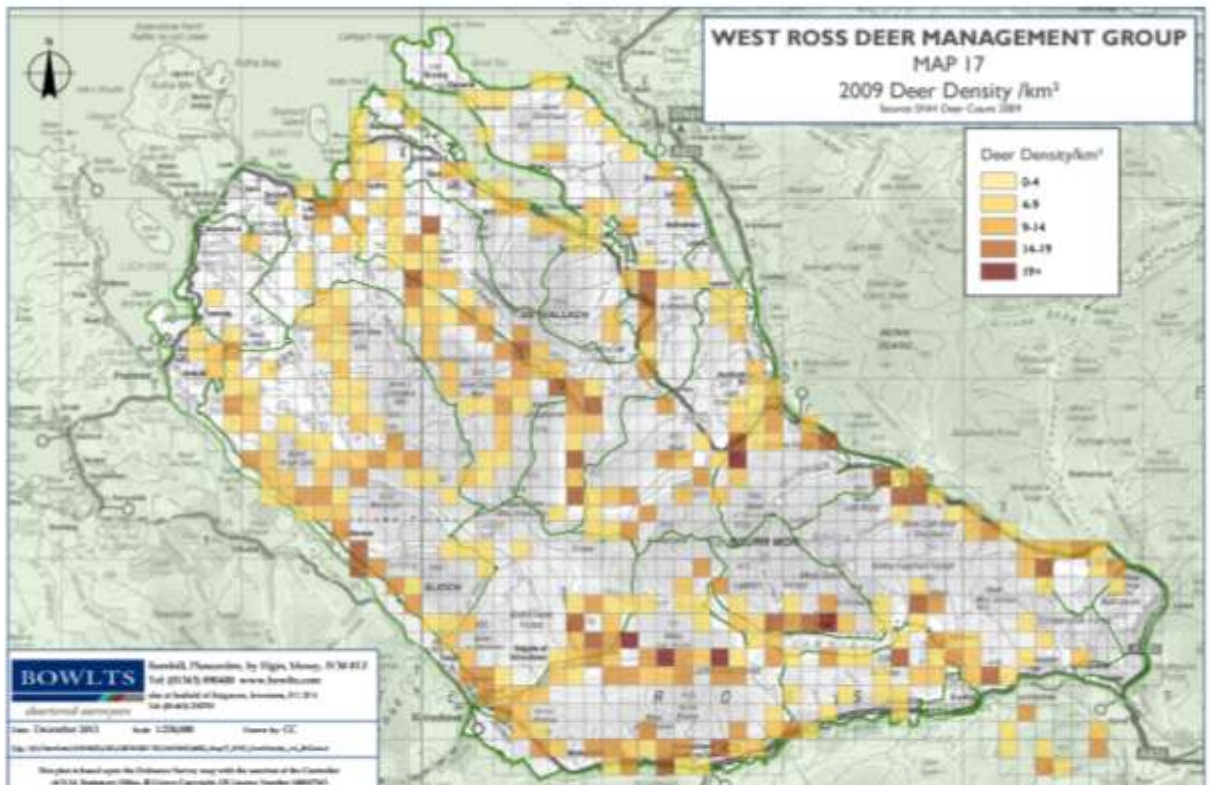
The Deer Management plans follow guidance from SNH.



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.



http://wrossdmg.deer-management.co.uk/

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

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

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. . .

Diet compensates for m...

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

STRATEGY

Diet compensates for mineral deficiencies

Red Deer

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

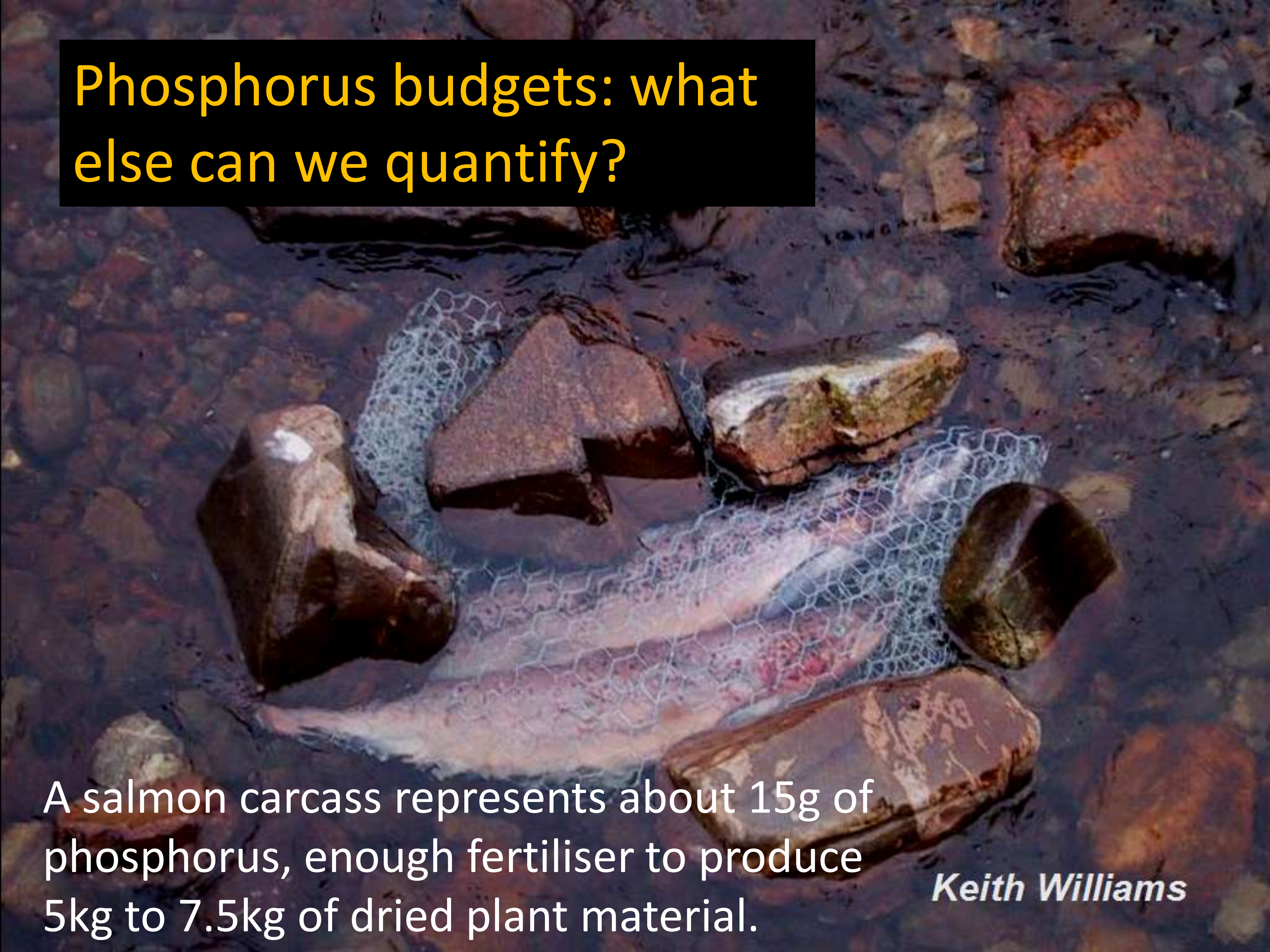
Wapiti

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.

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

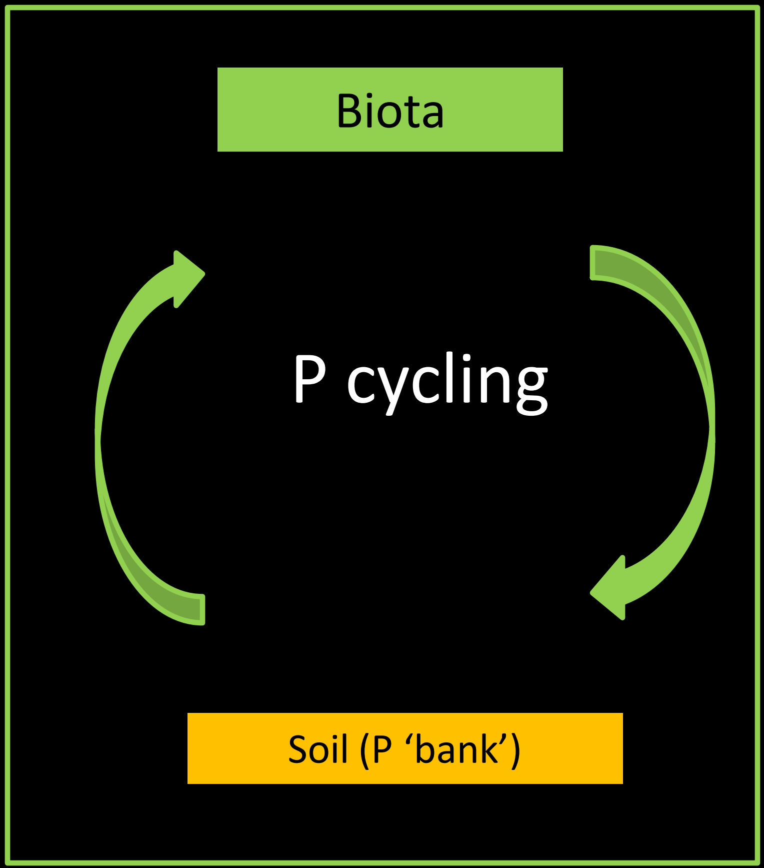
x 200 or x 1,000kg or x 3

= ~ 3kg of Phosphorus

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

P imports

Biological
400 salmon / year
(6kg P)



catchment area

P exports

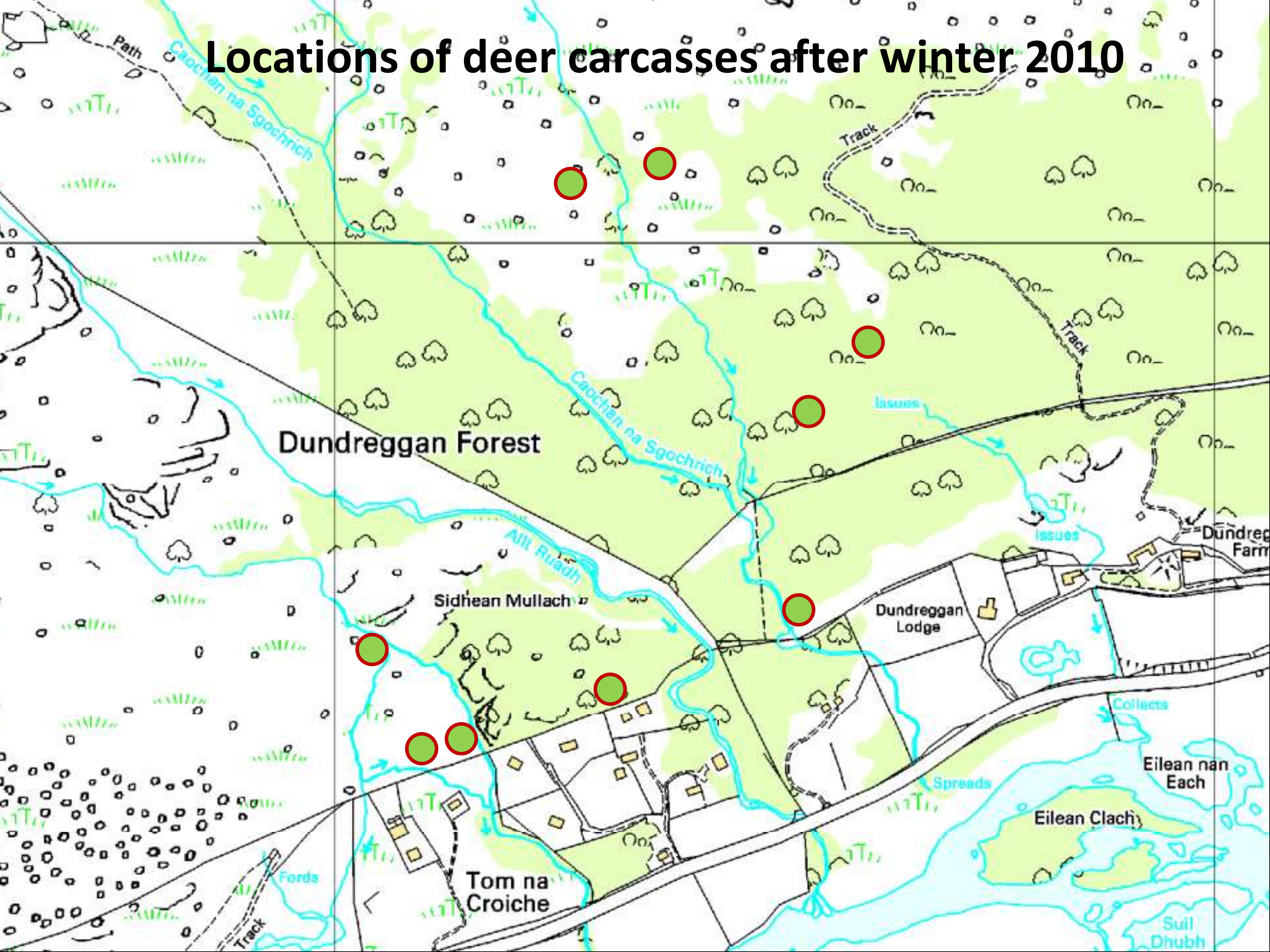
Biological
6 deer removed from catchment area (many others can be cycled within it)

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


elite-view.com
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

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

Theory and empirical examples indicate that when carnivores affect ecosystem processes and biodiversity it is generally thought that they do so primarily by their effects on the population dynamics and behavior of large herbivores (Estes 1995, Terborgh et al. 2001, Ives et al. 2005, Ray et al. 2005, Soule et al. 2005). However, large, terrestrial carnivores might affect ecosystem function in an entirely different way by impacting landscape heterogeneity. If carnivores influence the distribution of carcasses that result from predation, they would also affect the spatiotemporal heterogeneity of soil and plant properties. To be true, carcasses produced via predation would have to be important to above- and belowground communities, and predation would have to occur in some locations at rates that are different than the rates for other causes of mortality (e.g., starvation, hunting). Data supporting such effects would provide empirical evidence for a mechanistic link between large carnivores and heterogeneity in terrestrial ecosystems. This would be important because it would identify a key mechanism that potentially explains a positive correlation between the presence of large, terrestrial carnivores and the maintenance of biodiversity (Ray et al. 2005). Here, we provide evidence that 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,

Manuscript received 19 February 2009; accepted 3 March 2009. Corresponding Editor: R. W. Ruess.

[1] E-mail: jkbump@mtu.edu

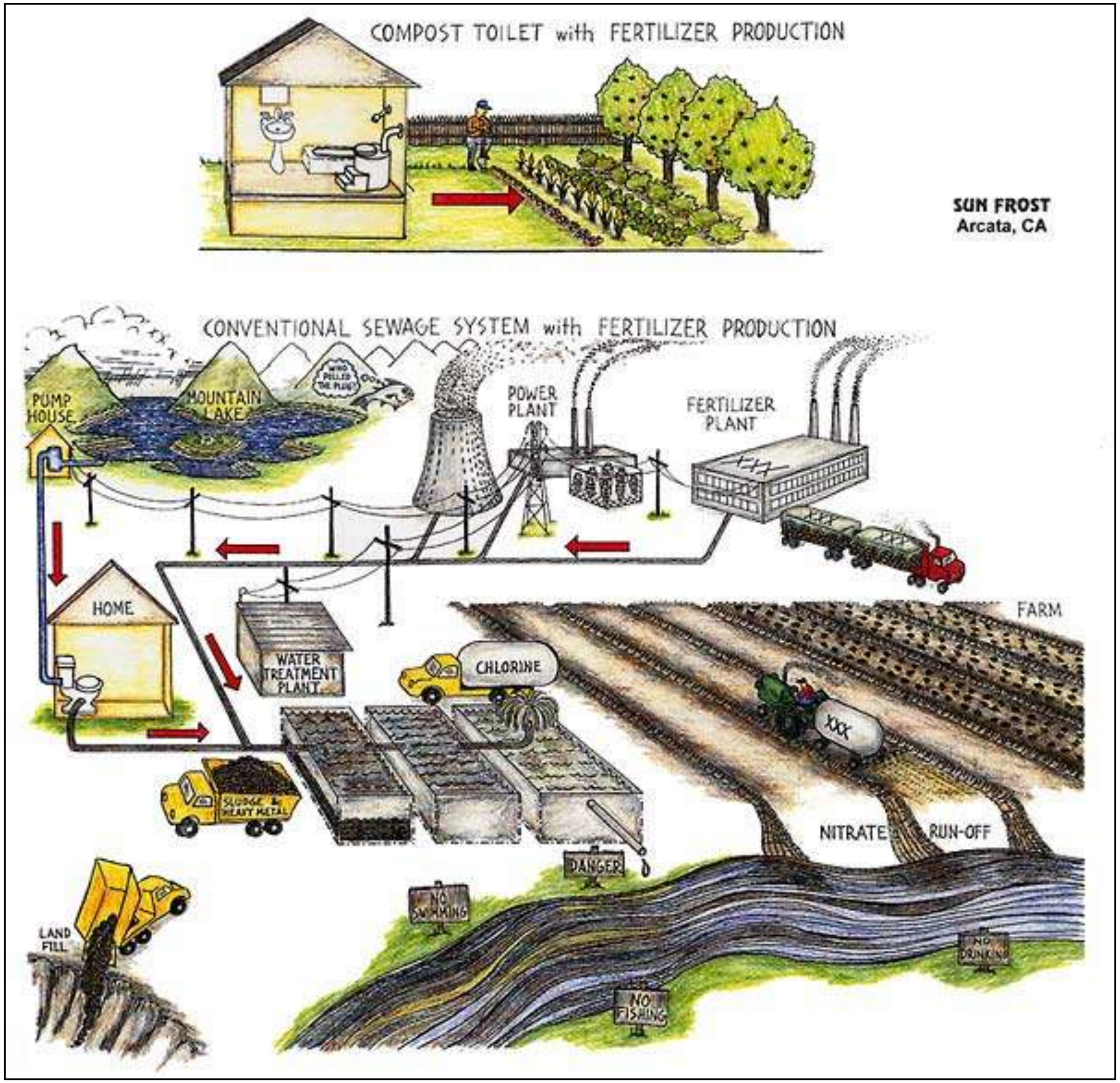
In the low resource environment of the Arctic tundra, the impact of a muskox (Ovibos moschatus) carcass on surrounding vegetation was still dramatic after 10 years (Danell et al. 2002), which emphasizes that carcass effects may last longer in some systems.

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

Break – any questions (or answers)?

Green knoll: phosphorus & biodiversity hot spot?

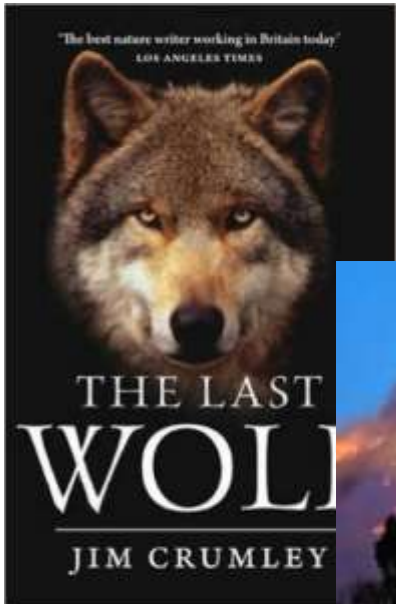
6. How to conserve and replenish phosphorus . . .



?

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

Recap:

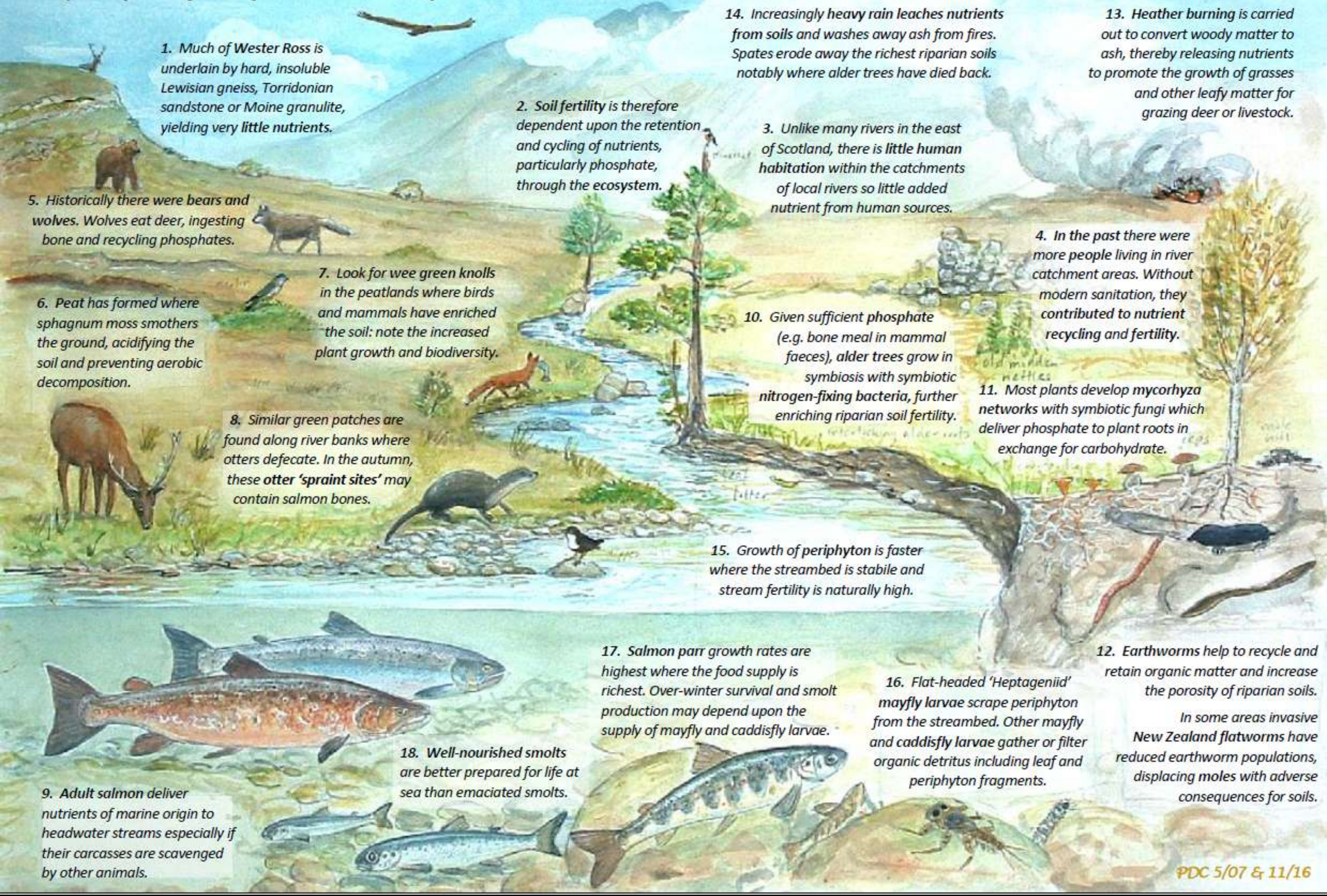


Some human factors which affect the fertility of ecosystems

- 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

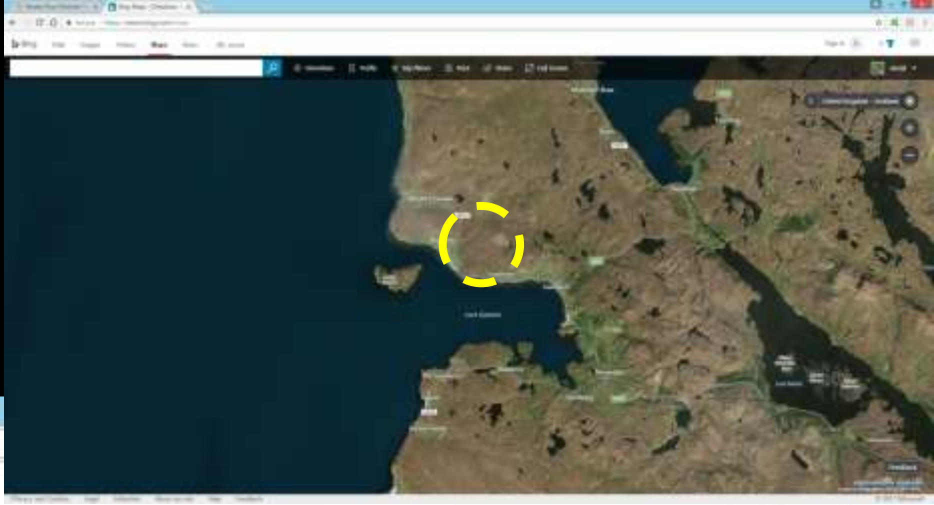


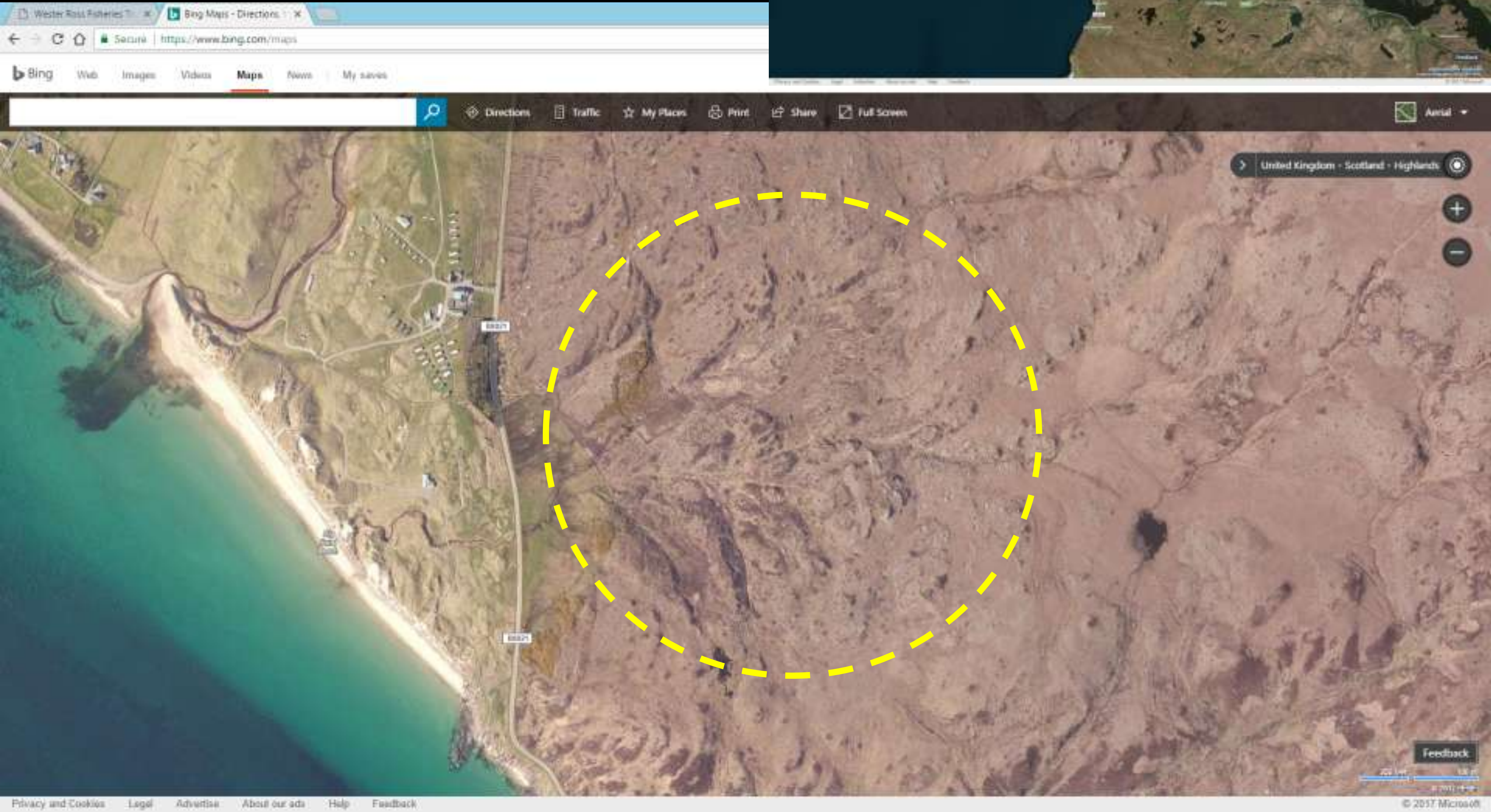

Solution: apply P fertiliser?
Ground Rock Phosphate fertiliser
applied initially at 125g / tree
Gairloch Estate: Balle Mor
native woodland restoration
Note grass growth


Many estates have developed enclosed woodlands to stabilise streams and enhance food availability.
WGS enclosure, Coulin Estate (headwaters of River Ewe)


Gairloch Estate: Balle Mor
native woodland restoration

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.

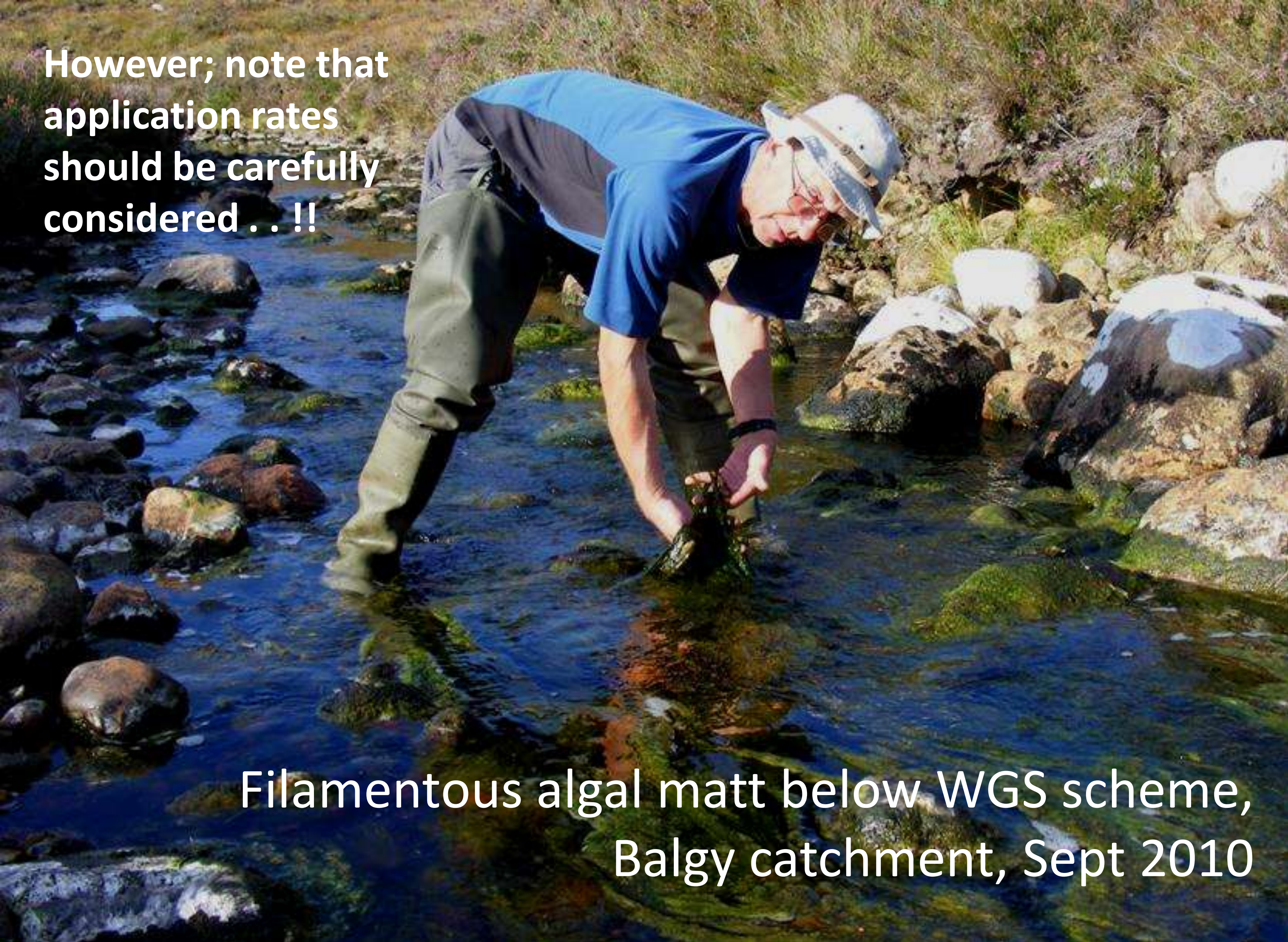
However, this tree was planted on a whole bag of fertiliser (1.5kg) to see what would happen . . .

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

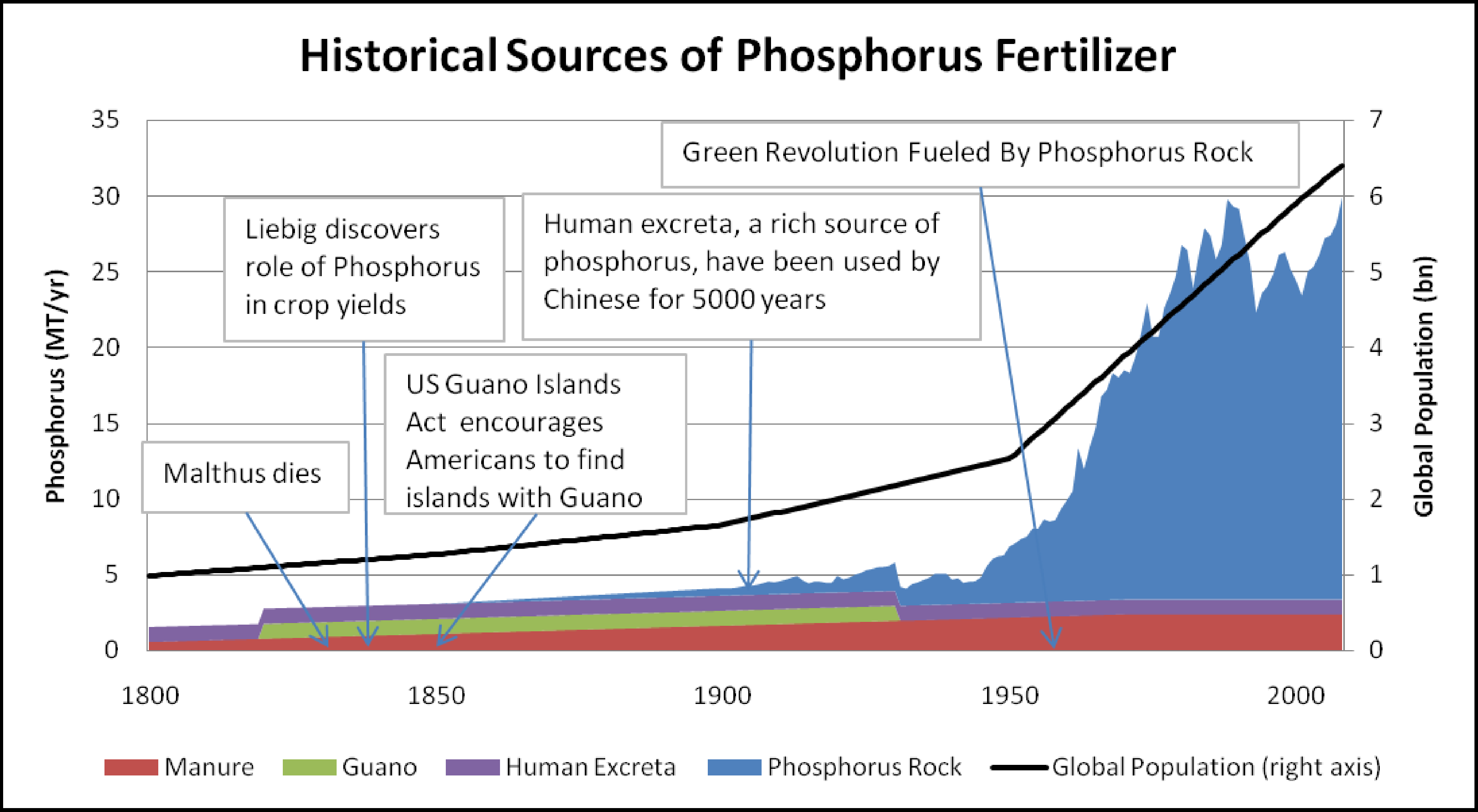
Gairloch Estate: Balle Mor native woodland restoration – photos taken October 2016

Thank you to Colin Simpson.



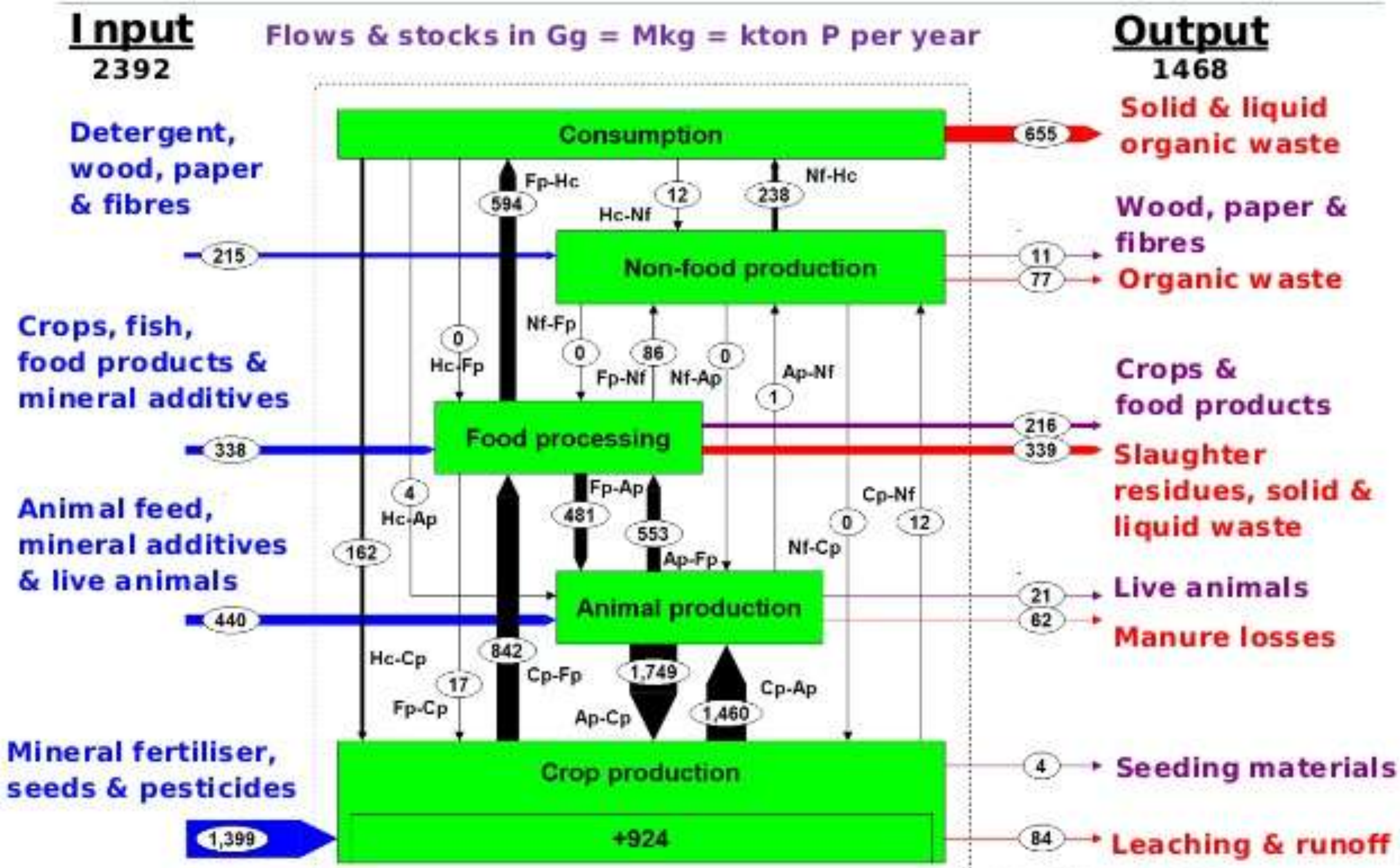
Filamentous algal matt below WGS scheme, Balgy catchment, Sept 2010

We may run short of phosphorus in future years.



http://seekingalpha.com/article/182522-taking-stock-of-phosphorus-and-biofuels

Phosphorus use in the EU-27 in 2005



Van Dijk et al. 2016

http://image.slidesharecdn.com/20160610cas-lmuphosphorusworkshopvandijkv2-160612085109/95/past-present-and-future-phosphorus-use-and-management-in-europe-12-638.jpg?cb=1465721867

ELSEVIER

Current Opinion in Biotechnology

Volume 23, Issue 6, December 2012, Pages 833–838

Phosphorus biotechnology • Pharmaceutical biotechnology

Phosphorus: a limiting nutrient for humanity?

James J Elser

Show more

http://dx.doi.org/10.1016/j.copbio.2012.03.001

http://www.sciencedirect.com/science/article/pii/S0958166912000481

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.

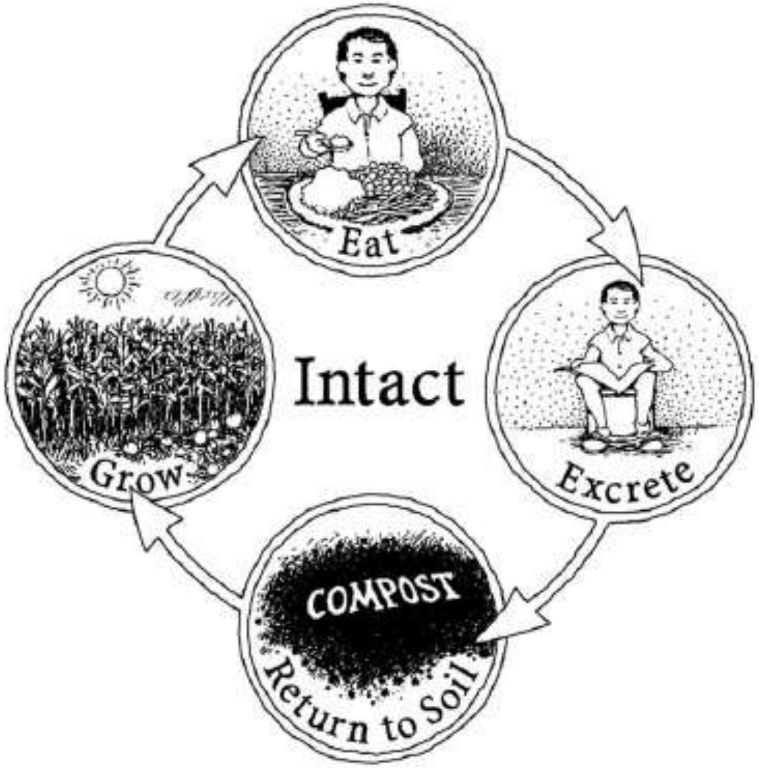
Phosphorous & rice production

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

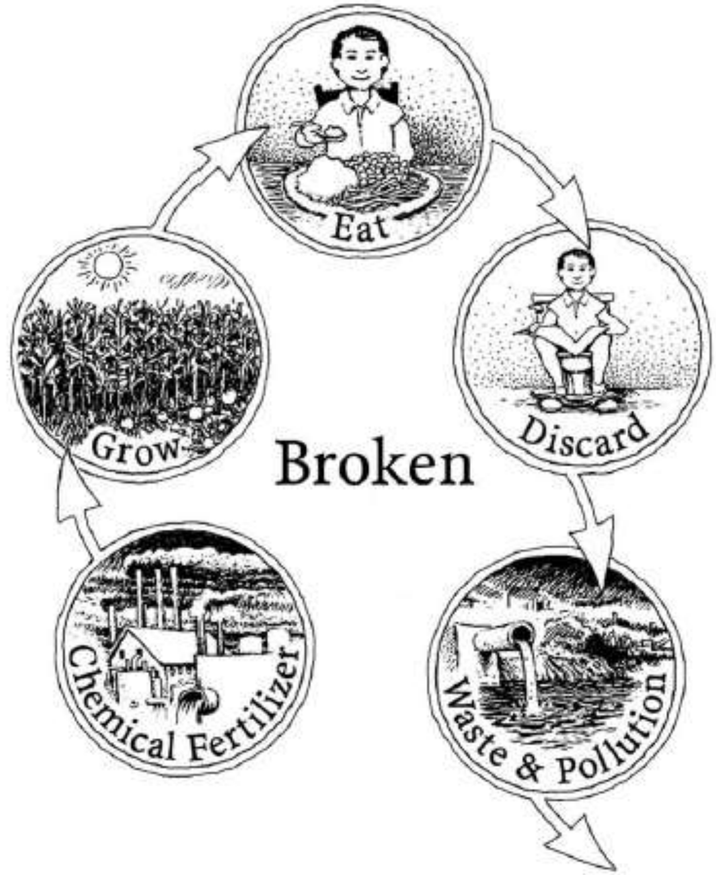
Phosphorous deficiency in Groundnut

http://agropedia.iitk.ac.in/content/phosphorous-deficiency-groundnut http://www.humanurehandbook.com/

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.

BioScience

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Oxford Journals › Science & Mathematics › BioScience › Volume 61, Issue 2 › Pp. 117-124.

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

This Article

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doi: 10.1525/bio.2011.61.2.6

http://bioscience.oxfordjournals.org/content/61/2/117.short

Sustainability **2016**, *8*(1), 69; doi:10.3390/su8010069 Open Access

Commentary

Transition towards Circular Economy in the Food System

Alexandra Jurgilevich [1,*], Traci Birge [2,†], Johanna Kentala-Lehtonen [3,†], Kaisa Korhonen-Kurki [1,†], Janna Pietikäinen [1,†], Laura Saikku [4,†] and Hanna Schösler [5,†]

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† These authors contributed equally to this work.

Academic Editor: Helmut Haberl

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Abstract: Growing population and increased deman
environmental impacts, and high rates of food wasted
towards more sustainable practices. In this article we ap
food system. Furthermore, we explore the transition tov
transition theory towards sustainability. We discuss
(focusing on nutrient flow), the consumption stage (f
management and prevention.

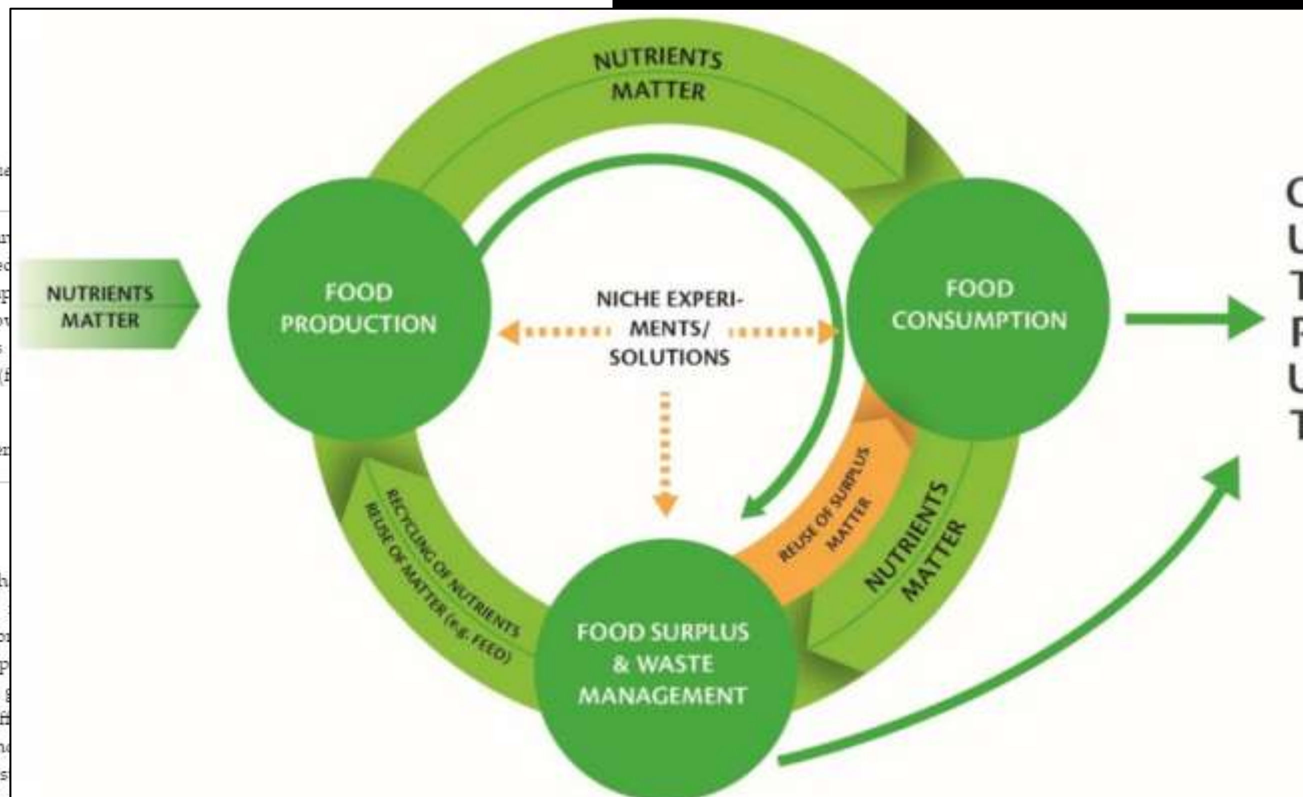
Keywords: circular economy; sustainability; food systen

1. Introduction

Our current food production and consumption h
environmental impacts, such as eutrophication and
approximately 30%–50% of food intended for human co
Current inefficiency in the food economy means we lose p
of throwing food away. More pollution and greenhouse g
the UN's Food and Agriculture Organization [5], the ineff
dollars a year, or even two trillion dollars when social an
to enhance and optimize for sustainability within the Wes

Circular economy uses theory and principles from indu
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 [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?)

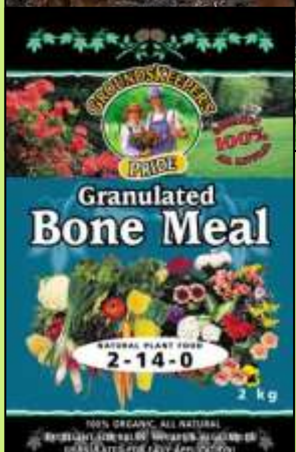
Conclusions 2

- 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://honest-food.net/2009/07/17/six-days-of-salmon/

or other P rich fertiliser . . . ?

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 fertiltiy, 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.

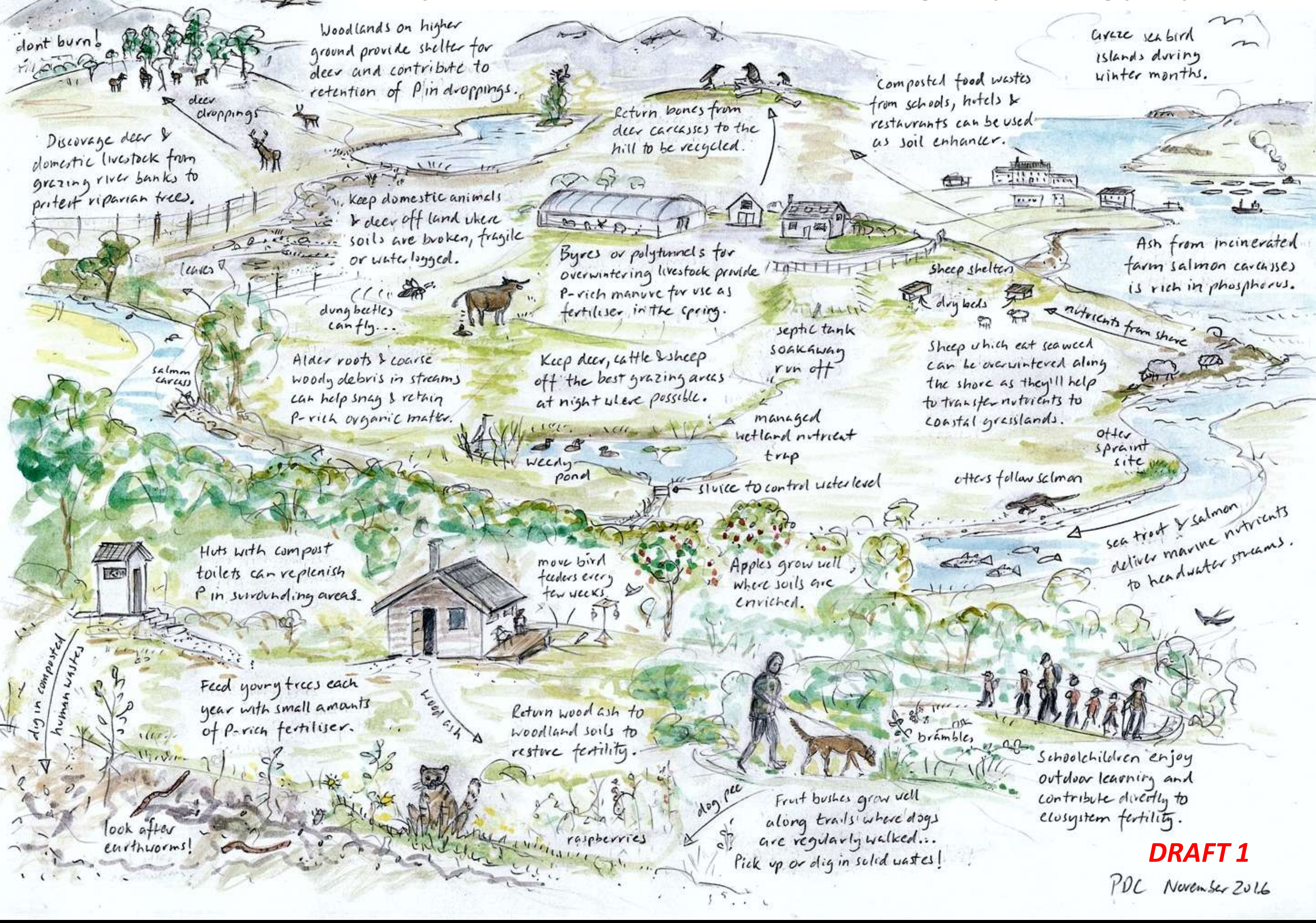
A little fertiliser, fairly often (not a lot of fertiliser all at once) . . ?

A bit like feeding the birds . . ?

Larachantivore woodland (upper Gruinard) . . .

http://l7.alamy.com/zooms/db5ee27981cc47e59486d73529045ff4/bush-toilet-loo-with-a-view-s15x3n.jpg

Ecosystem nutrition in Wester Ross: conserving & replenishing phosphorus



Refertilisation can help to support and revive fragile communities.

Inverasdale school

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

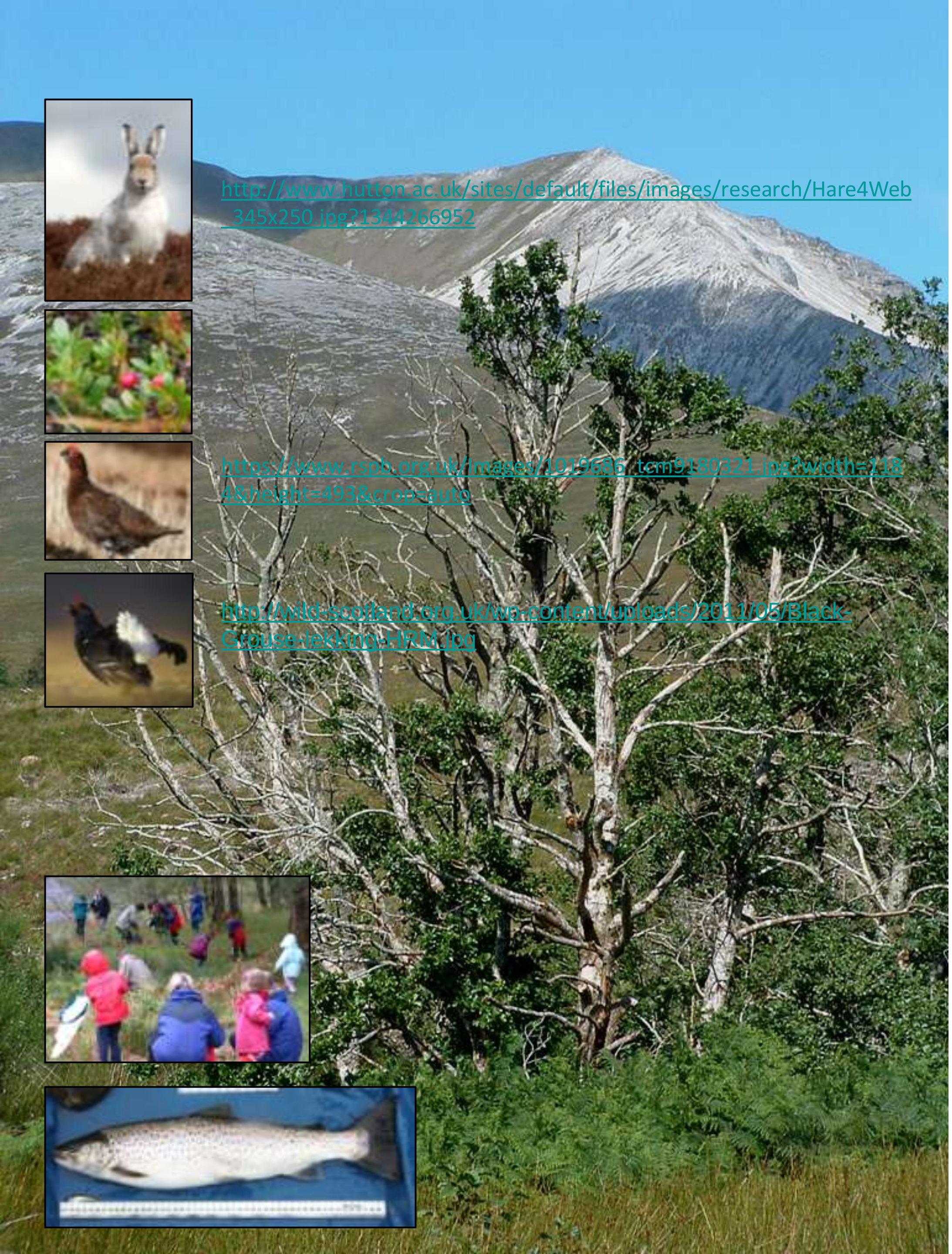
Front: Kenny Macrae, Roddie MacKenzie, Frances Urquhart, Janette Macrae, Elizabeth Chisholm, Alice MacKenzie, Isabel Urquhart, Roddy Macrae, Alisdair Millan

Picture from Gairloch Heritage Museum Calendar, 2015

Opportunities for new Wester Ross Biosphere?

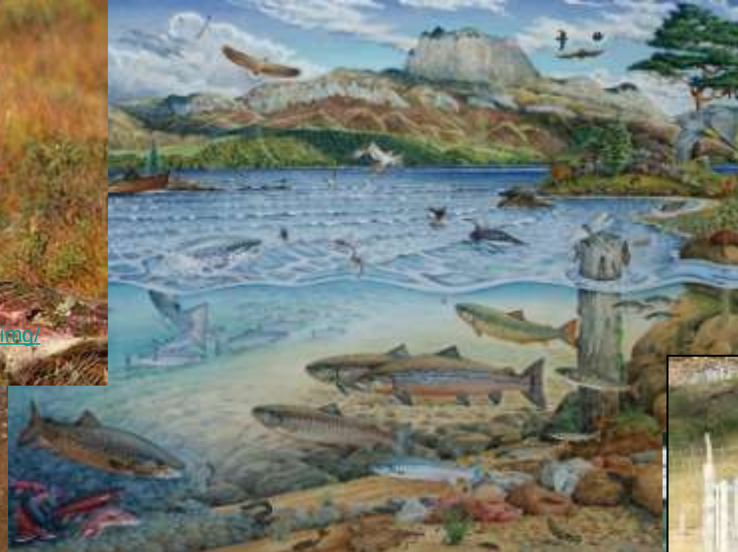
United Nations
Educational, Scientific and
Cultural Organization

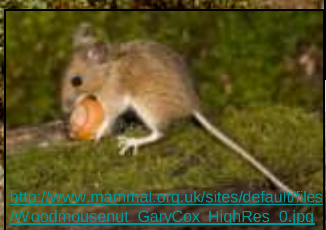
- ***Develop a clearer understanding of ecosystem nutrition;***
- ***Ecosystem fertility restoration and management studies;***
- ***Demonstration projects to learn and extend information about managing fertility.***
- ***'Think globally . . . (productive landscapes), . . . act locally'.***



Beinn Eighe NNR

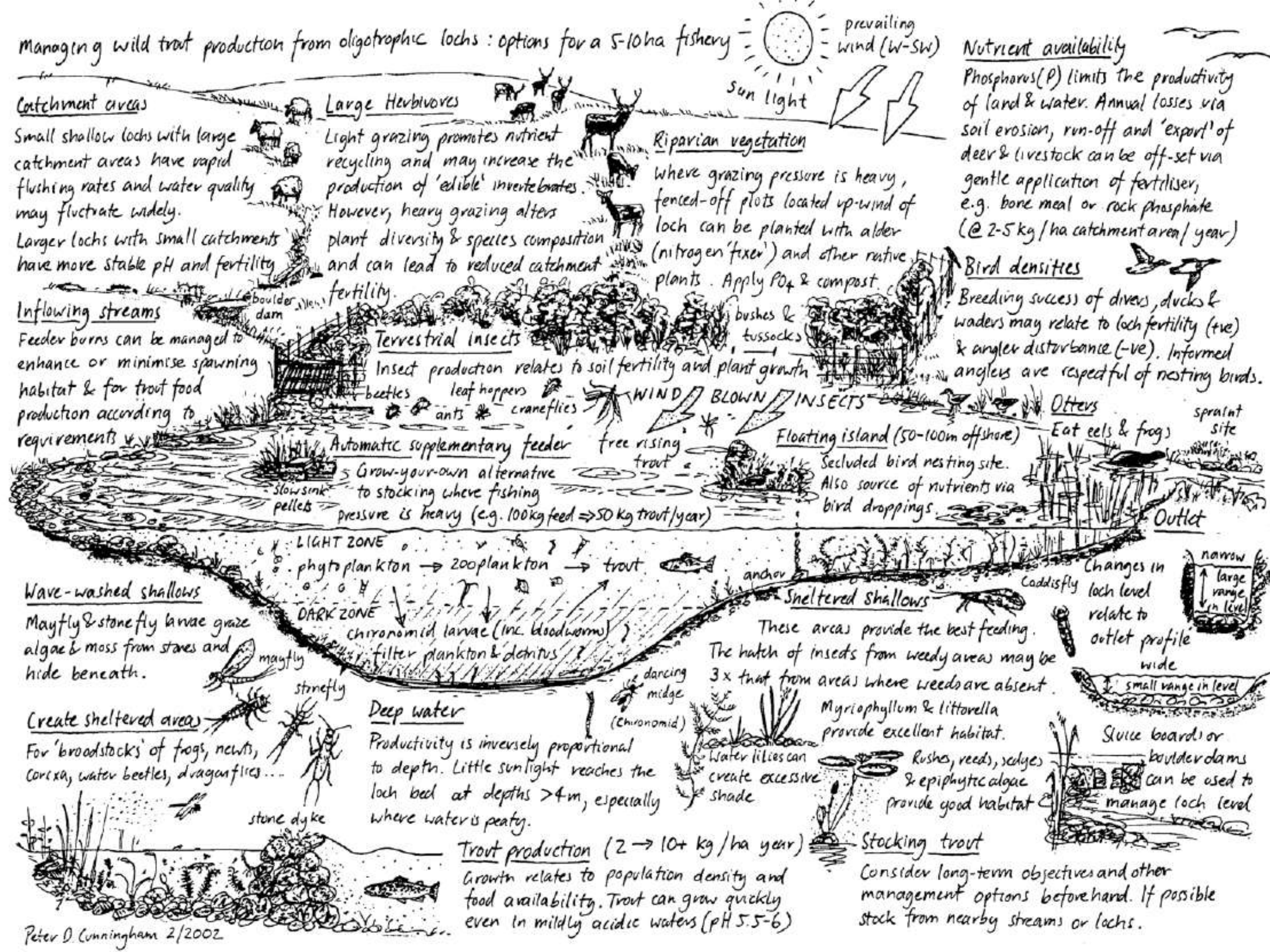

http://www.wildlifeextra.com/resources/listimg/
news/golden-eagle_carcass@body.JPG




http://www.mammal.org.uk/sites/default/files
/Woodmousenut_GaryCox_HighRes_0.jpg

Thank you


http://www.thevitruvianman.org/metaphor-on-a-wild-
raspberry/


Managing wild trout production from oligotrophic lochs: options for a 5-10ha fishery
prevailing wind (W-SW)
Sun light
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
Large Herbivores
Light grazing promotes nutrient recycling and may increase the production of 'edible' invertebrates. However, heavy grazing alters plant diversity & species composition and can lead to reduced catchment fertility.
Riparian vegetation
Where grazing pressure is heavy, fenced-off plots located up-wind of loch can be planted with alder (nitrogen 'fixer') and other native plants. Apply PO4 & compost.
Nutrient availability
Phosphorus (P) limits the productivity of land & water. Annual losses via soil erosion, run-off and 'export' of deer & livestock can be off-set 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 (+ve) & angler disturbance (-ve). Informed anglers are respectful of nesting birds.
boulder dam
bushes & tussocks
Inflowing streams
Feeder burns can be managed to enhance or minimise spawning habitat & for trout food production according to requirements
Terrestrial insects
Insect production relates to soil fertility and plant growth
beetles
leaf hoppers
ants
craneflies
WIND BLOWN INSECTS
Otters
Eat eels & frogs
spraint site
Automatic supplementary feeder
Grow-your-own alternative to stocking where fishing pressure is heavy (e.g. 100kg feed ⇒ 50 kg trout/year)
slow sink pellets
free rising trout
Floating island (50-100m offshore)
Secluded bird nesting site. Also source of nutrients via bird droppings.
Outlet
LIGHT ZONE
phytoplankton → zooplankton → trout
DARK ZONE
chironomid larvae (inc. bloodworms) filter plankton & detritus
anchor
Caddisfly
Wave-washed shallows
Mayfly & stonefly larvae graze algae & moss from stones and hide beneath.
mayfly
stonefly
Sheltered Shallows
These areas provide the best feeding. The hatch of insects from weedy areas may be 3 x that from areas where weeds are absent.
Changes in loch level relate to outlet profile
narrow
large range in level
wide
small range in level
darcing midge (Chironomid)
Create sheltered areas
For 'broodstocks' of frogs, newts, corixa, 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.
Myriophyllum & littorella provide excellent habitat.
Water lilies can create excessive shade
Rushes, reeds, sedges & epiphytic algae provide good habitat
Sluice boards or boulder dams can be used to manage loch level
stone dyke
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)
Stocking trout
Consider long-term objectives and other management options beforehand. If possible stock from nearby streams or lochs.
Peter D. Cunningham 2/2002