Refertilising Wester Ross 8th April 2016

Chairman: Prof Dave Barclay

10:10 Peter Cunningham (WRFT) ***'Fertility sources & nutrient cycling in Wester Ross'***

10:40 Dr James Merryweather (WREN & SLEF) ***'Now you see it? No you don't!'***

Tea break

11:30 Dr Scott Newey (Hutton Institute) ***'Deer Carcasses, scavengers, soil nutrients & invertebrates'***

12:00 Dr Adam Smith (GWCT) ***'Moorland fertilisation: a wild grouse chase?'***

Lunch (12:30 to 13:15)

13:20 Simon McKelvey (Cromarty FT) ***'Nutrient Restoration in Upland Streams'***

13:50 Prof Davy McCracken (SRUC) ***'What future for hill farming and crofting?'***

Tea break & Workshop session

15:00 Possible presentation(s) from youngsters. . . *[titles to follow!]*

15:30 Conclusions of workshop session & general discussion

16:15 Summing up.

Field trip at Beinn Eighe NNR, 7th April 2016 (photo by Peter Cunningham)

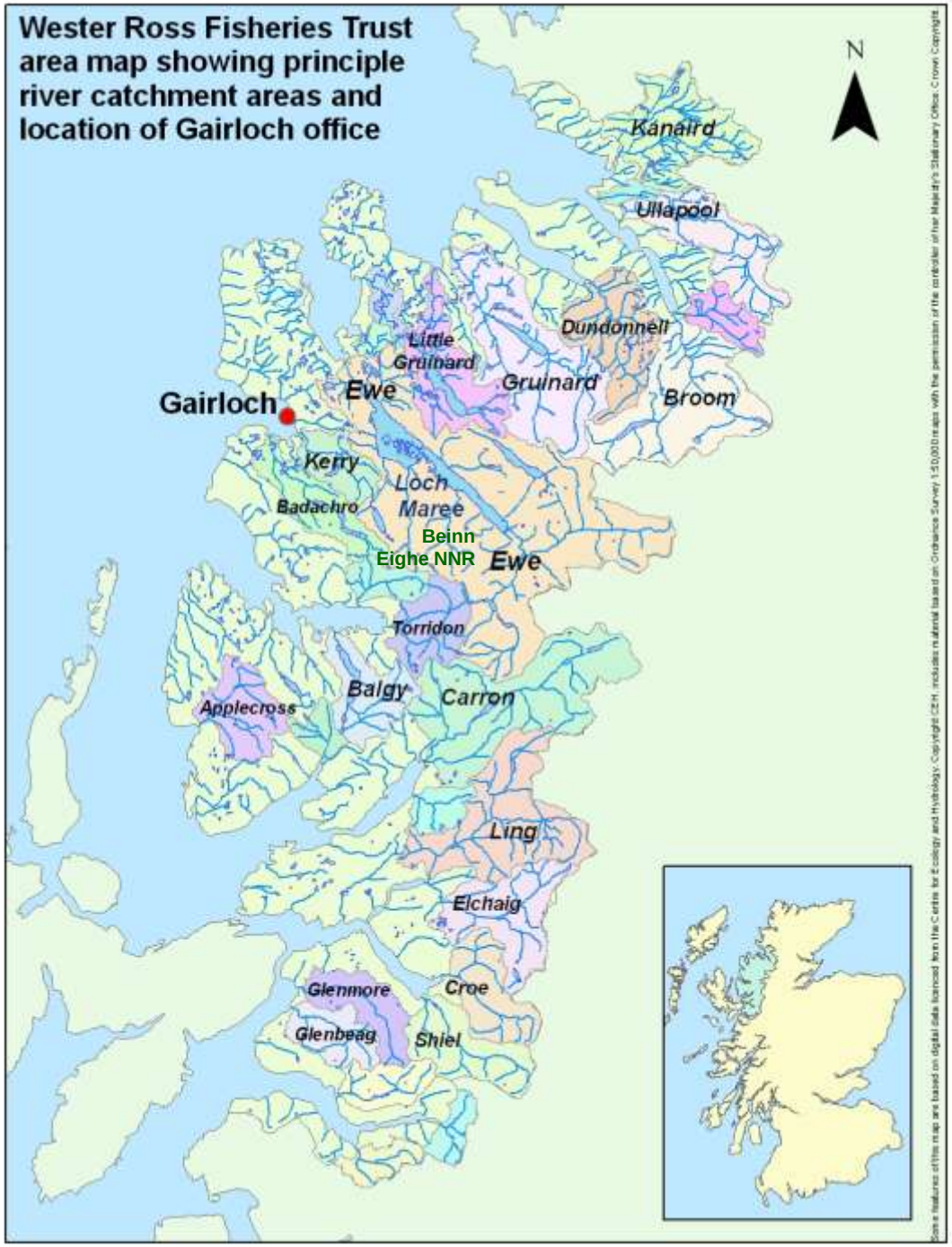
Fertility sources and nutrient cycling in Wester Ross

Peter D. Cunningham
Wester Ross Fisheries Trust
8th April 2016

Raptor perch in Beinn Eighe NNR

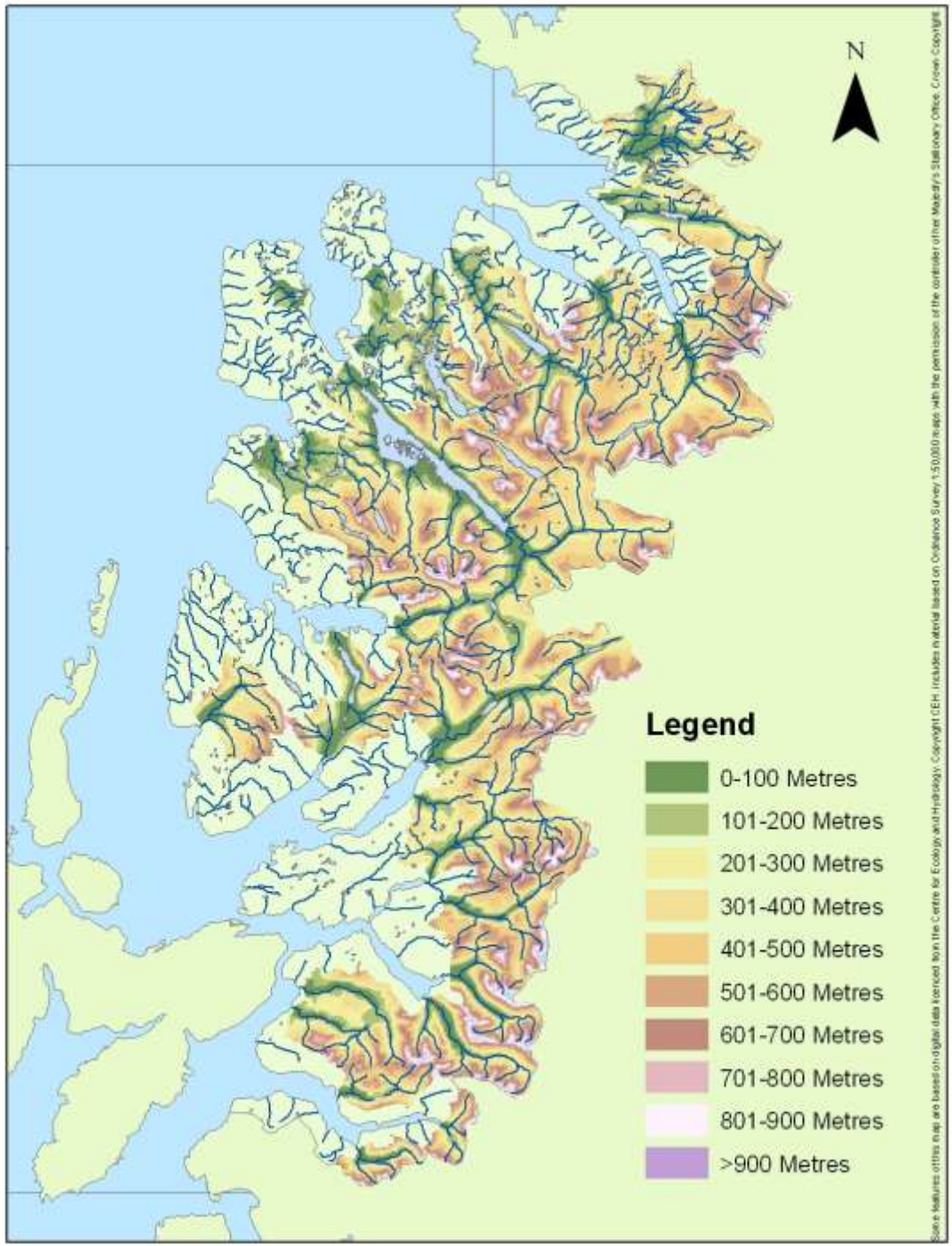
The overall **Purpose** of the Wester Ross Fisheries Trust is:

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



Outline of talk

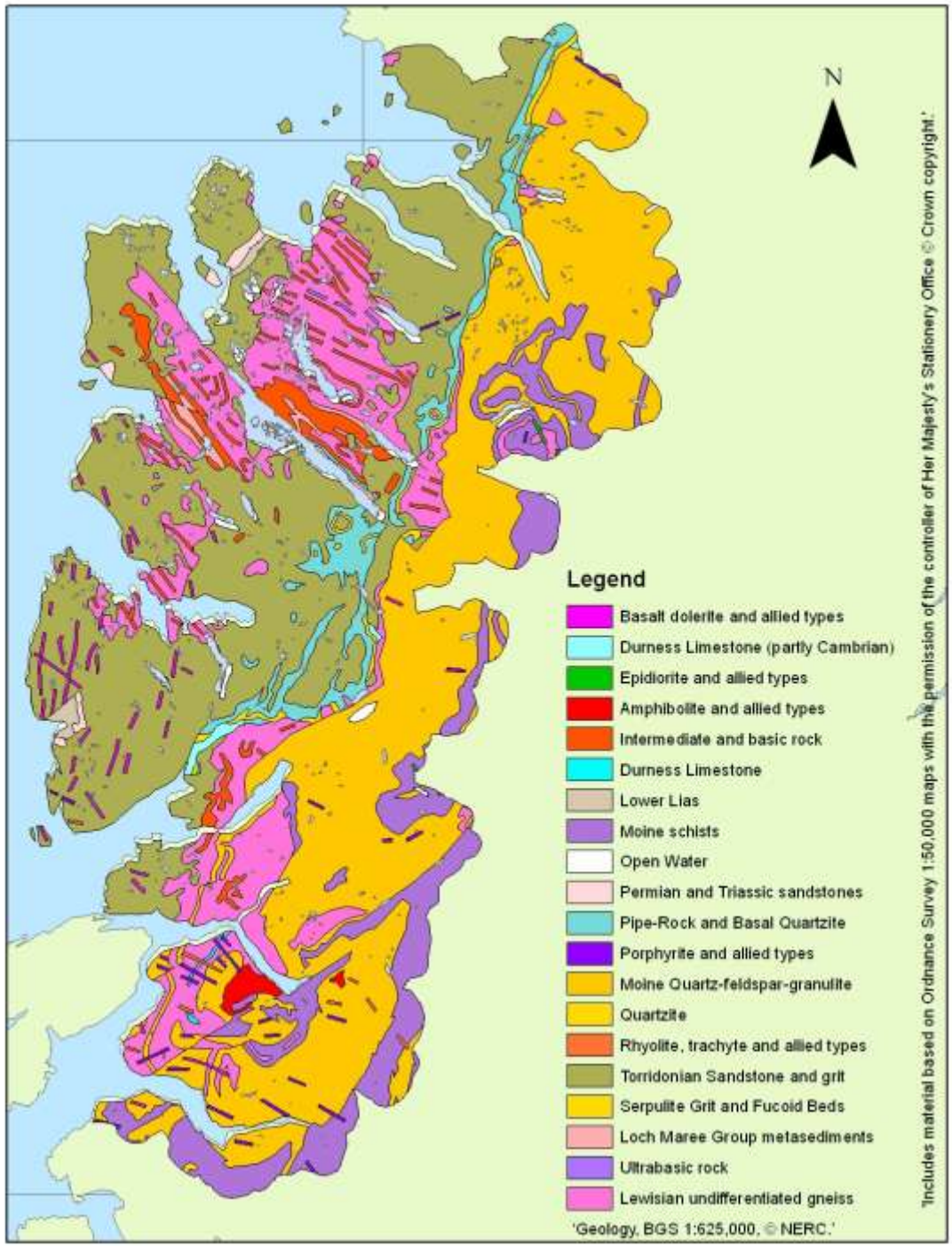
1. What is fertility?
2. Phosphorus as a limiting nutrient
3. Fertile places in Wester Ross
4. Ecosystems and nutrient cycling
5. Fire
6. Animal export
7. Recap and restoration proposal



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.


Lewisian gneiss and Torridonian sandstone: hard, resistant to weathering, un-yielding rock.


Barren mountains . . .
Beinn Eighe NNR: how natural?


Sparsely vegetated slopes
Beinn Damh forest: where are the trees?

Unstable rivers

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


Trees cling to inaccessible ledges
Abhainn Dearg

Uninhabited ‘wilderness’ . . .

Fionn loch and Dubh loch from Beinn Airigh charr


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

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.

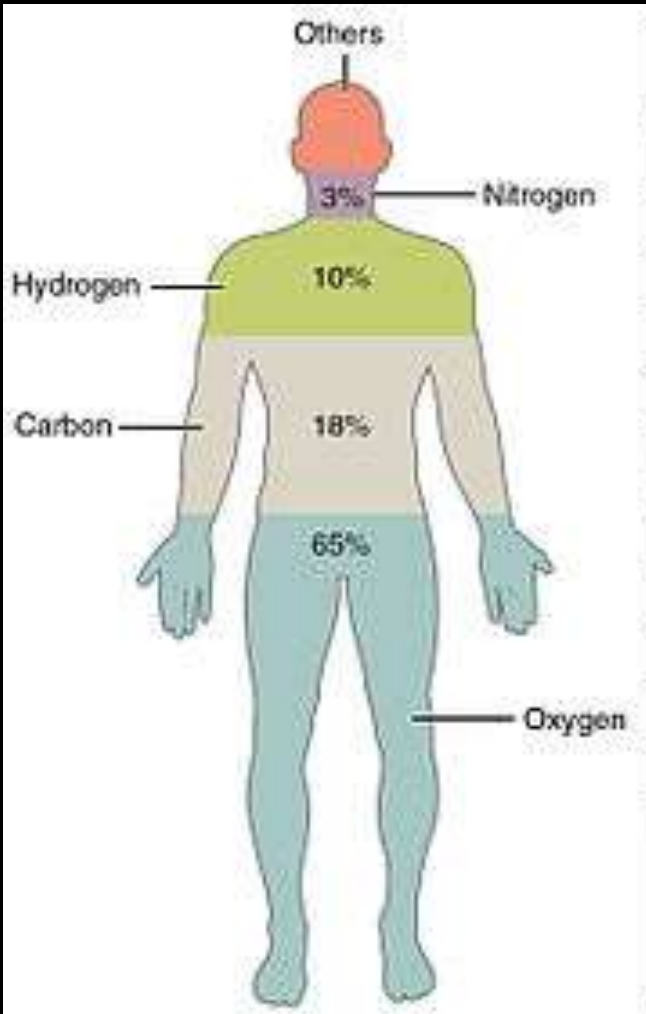
https://en.wikipedia.org/wiki/Soil_fertility

2. Phosphorus

Phosphorus is essential to all life forms.

Assorted bones, Aultgrishan shore 3rd April 2016

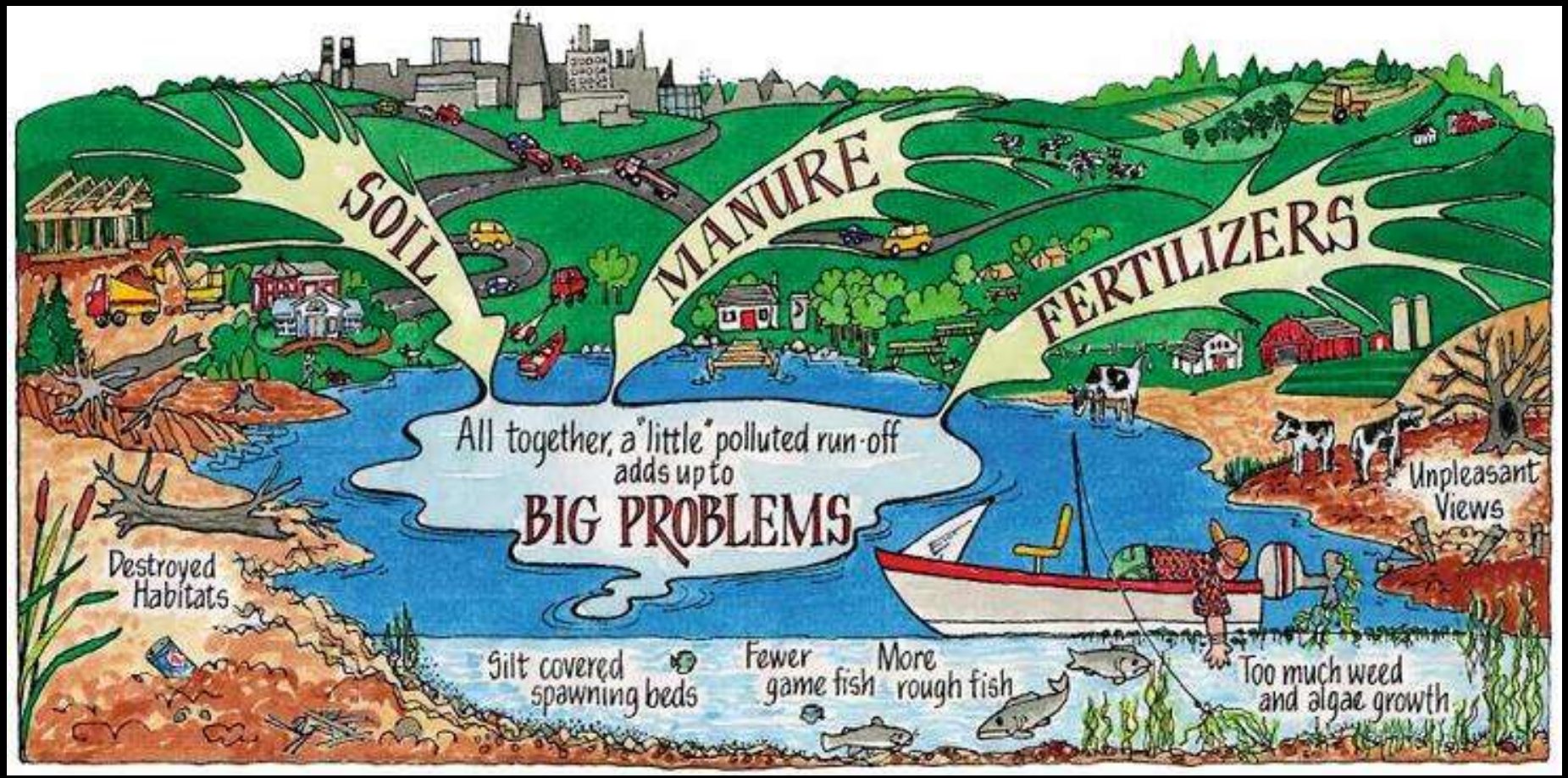
Humans are approximately 1% Phosphorus



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

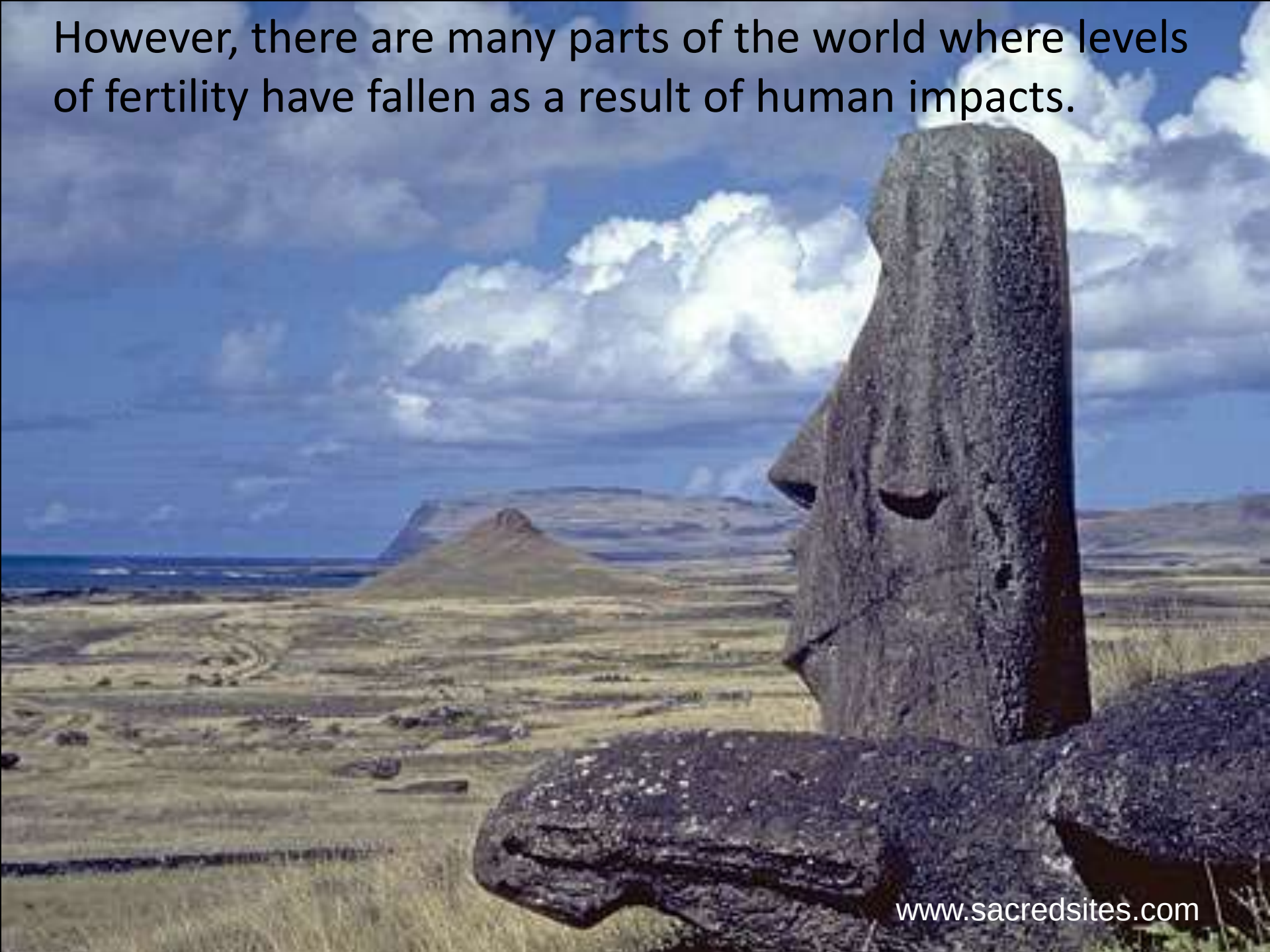
Too much phosphorus causes *eutrophication*



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

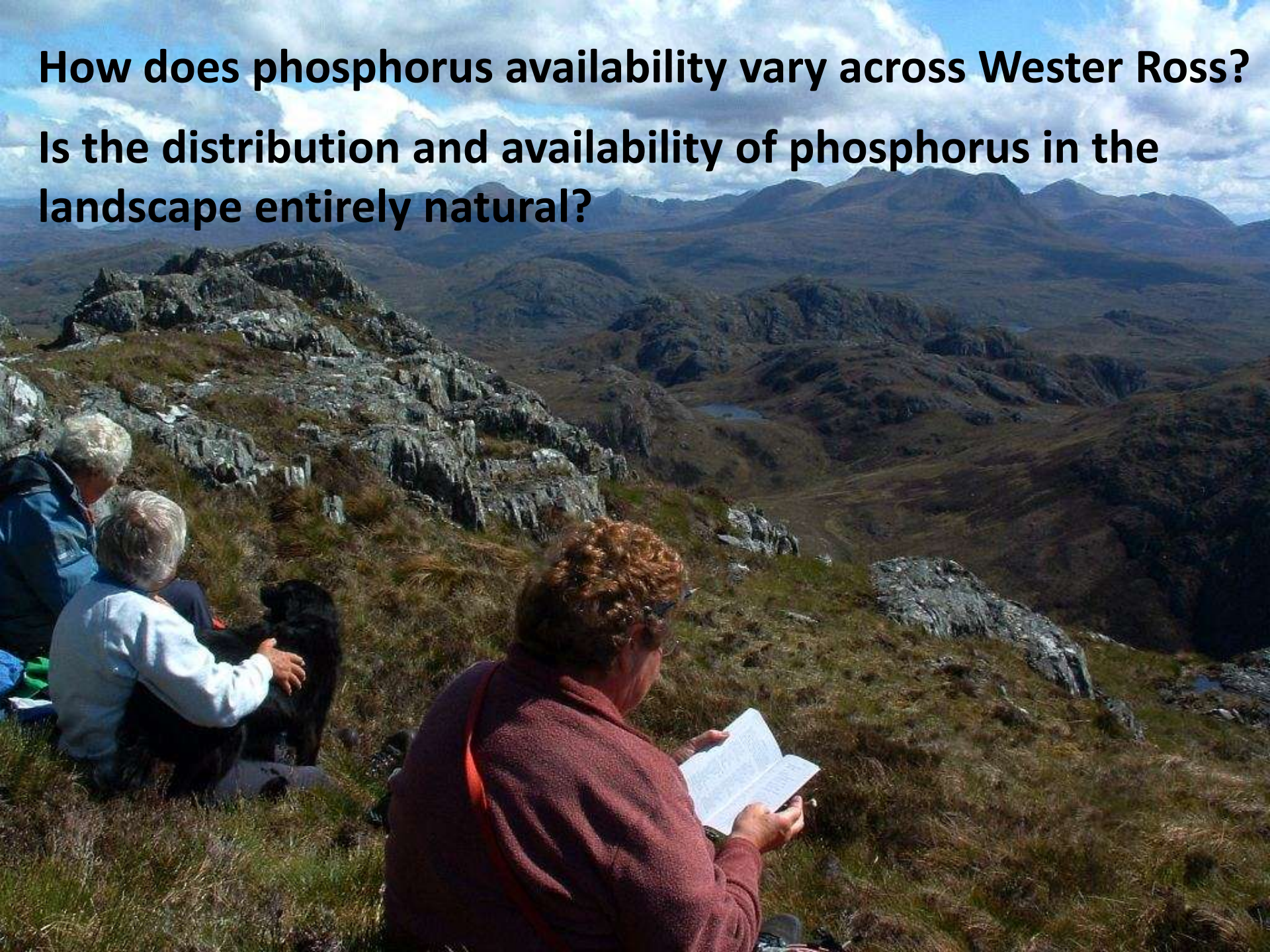
One of our greatest government-led achievements for the environment, to date, has been the cleaning-up of 'eutrophied' waters.

However, there are many parts of the world where levels of fertility have fallen as a result of human impacts.



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?

3. 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


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

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?"

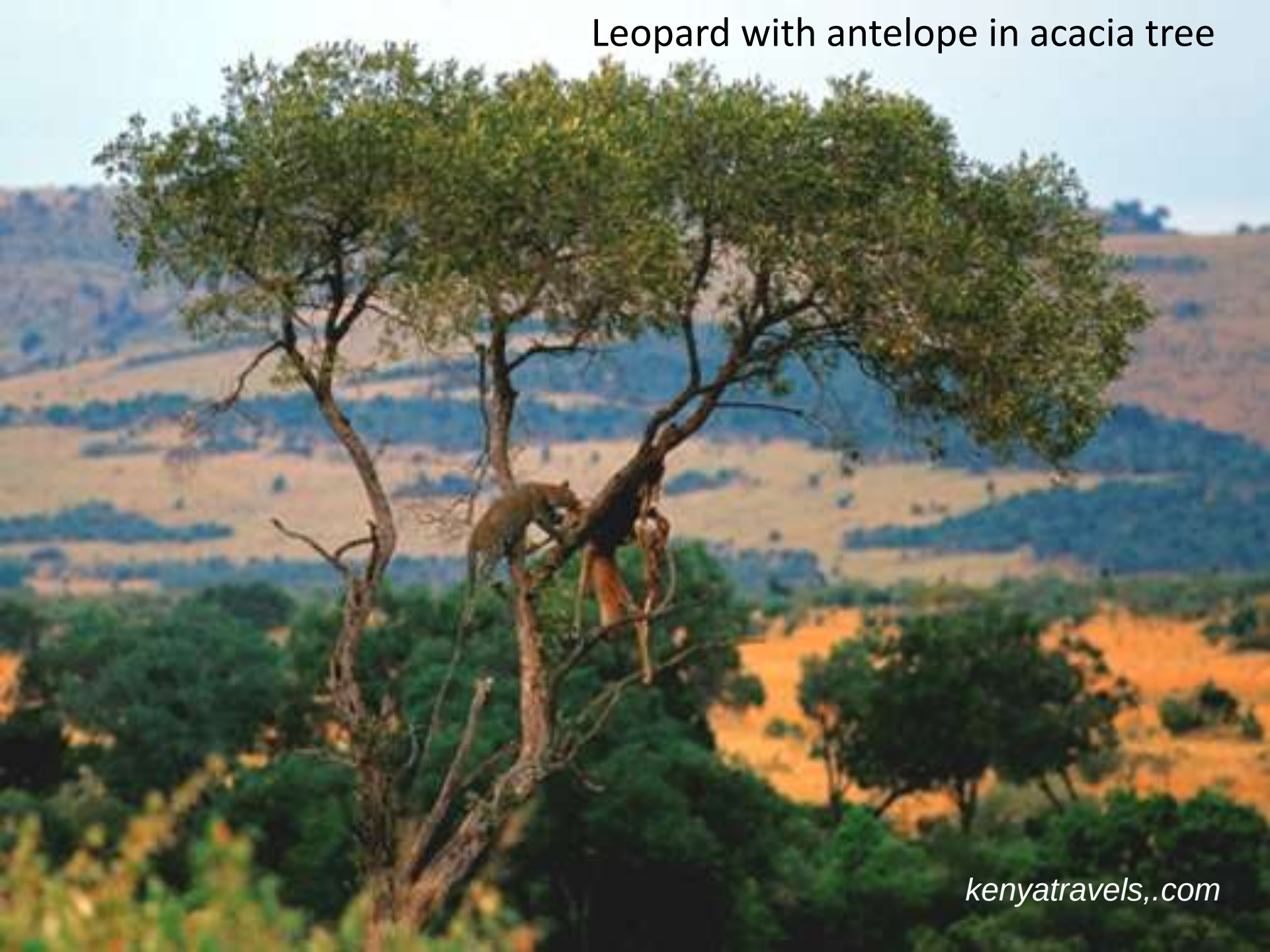
-- Carl Safina, essayist for *Salmon in the Trees*

photos by Amy Gulick


Fionn Loch islands, Little Gruinard catchment.


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

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

4. Ecosystems and nutrient cycles

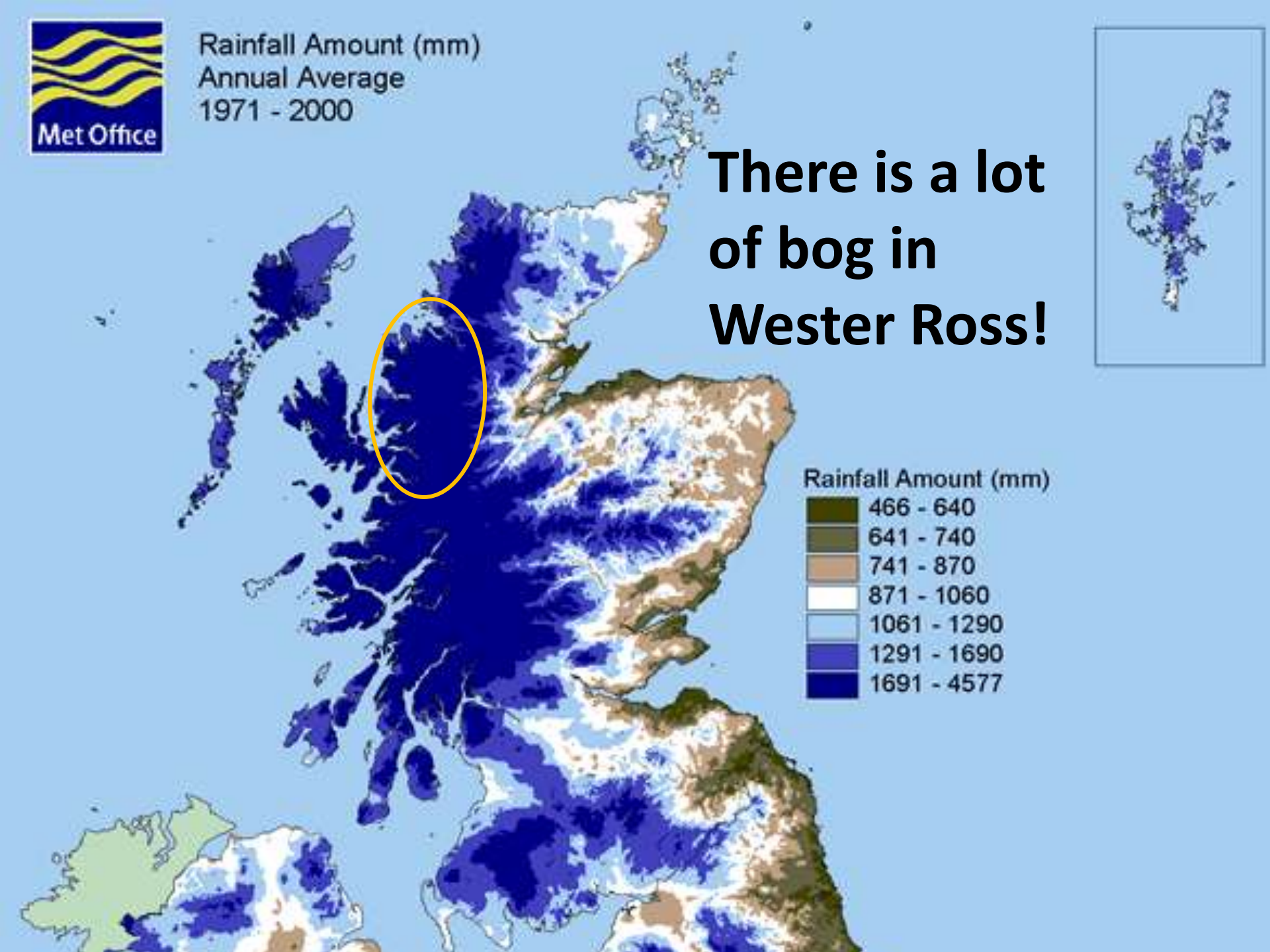
Why is there a greener patch in the bog?

Bog near Redpoint (2002)

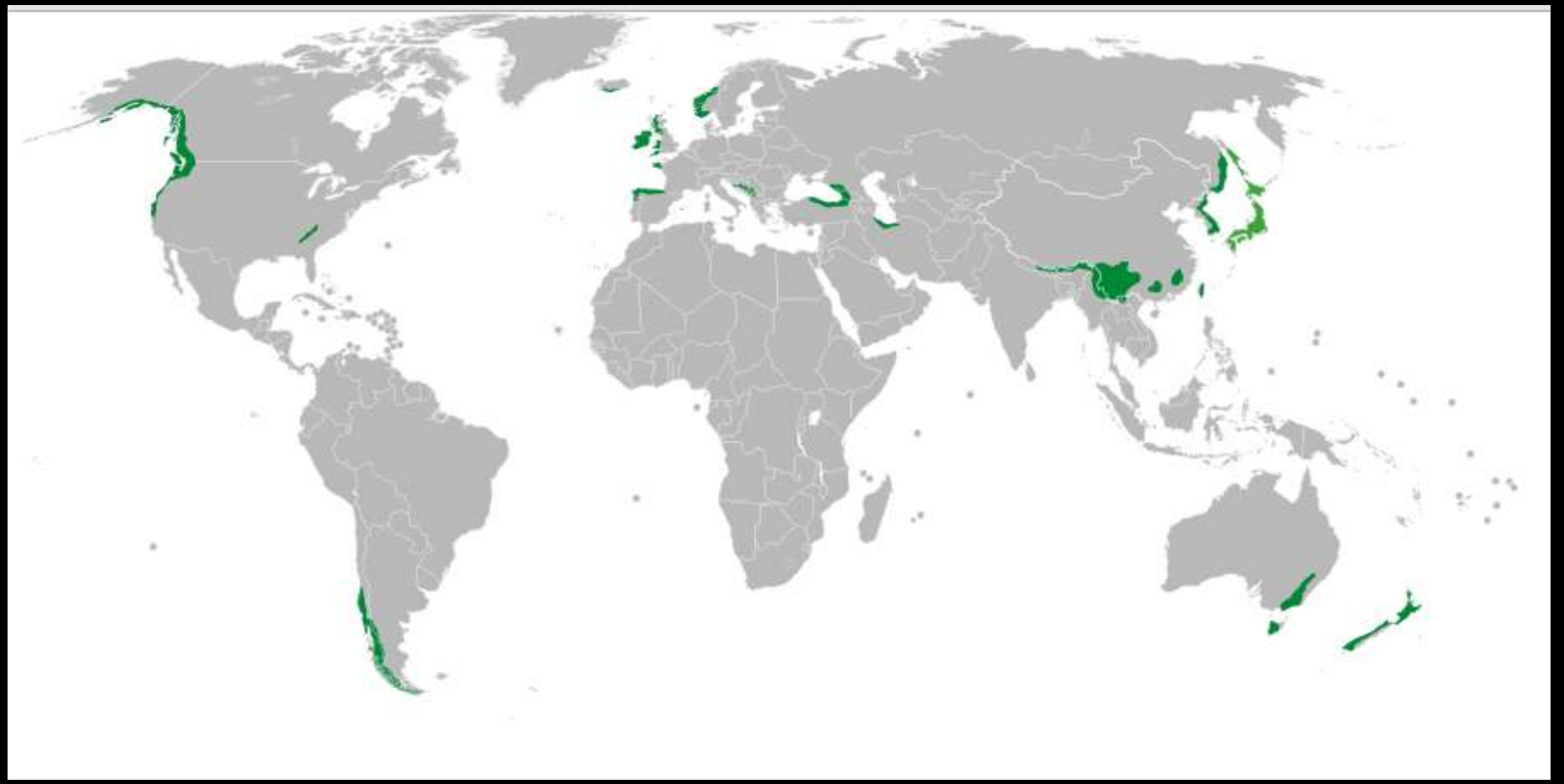
Where nutrients are recycled . . .

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

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


Met Office
Rainfall Amount (mm)
Annual Average
1971 - 2000
There is a lot of bog in Wester Ross!
Rainfall Amount (mm)
466 - 640
641 - 740
741 - 870
871 - 1060
1061 - 1290
1291 - 1690
1691 - 4577

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.

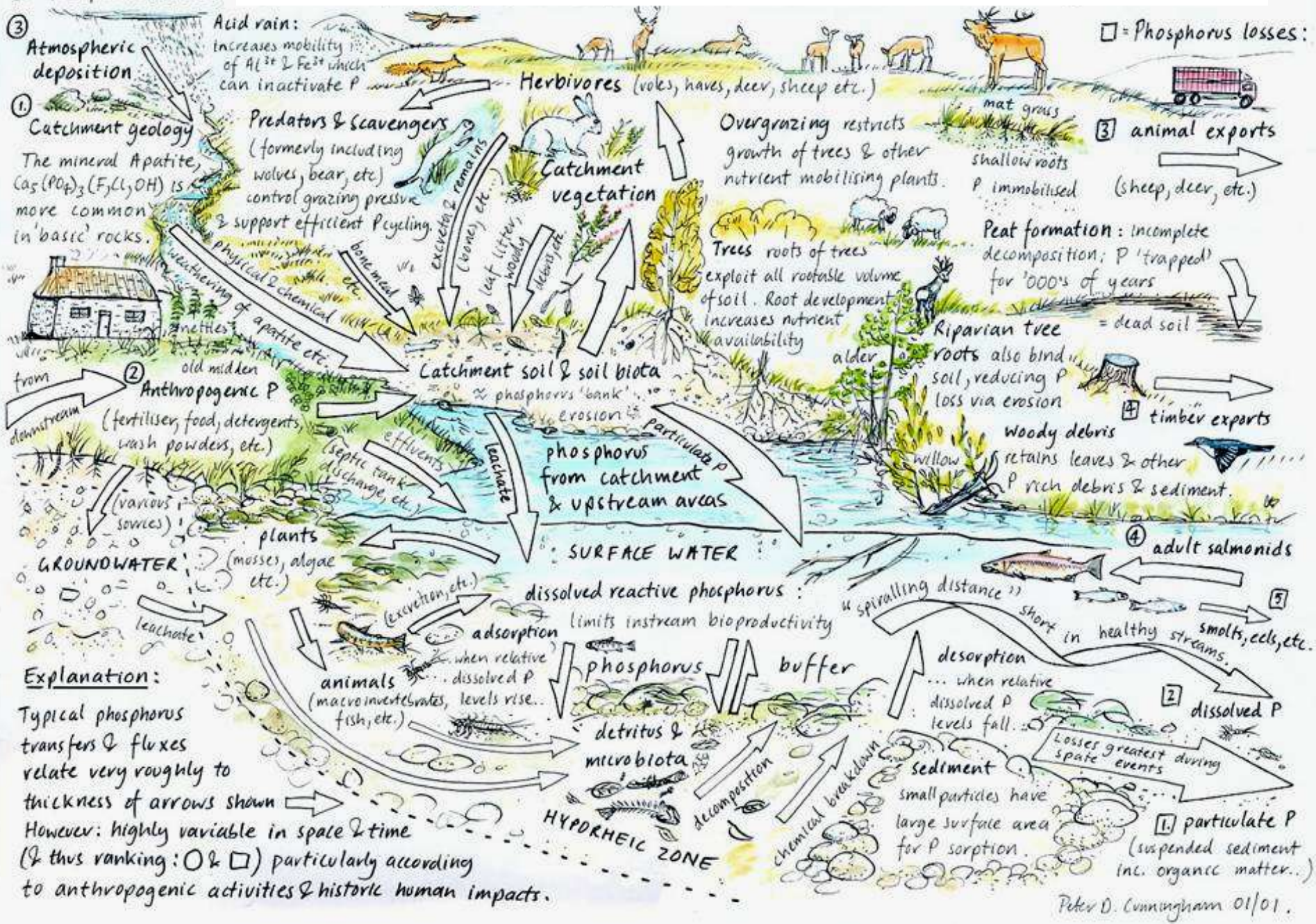
Soil fertility: the ability of a soil to supply plant nutrient

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

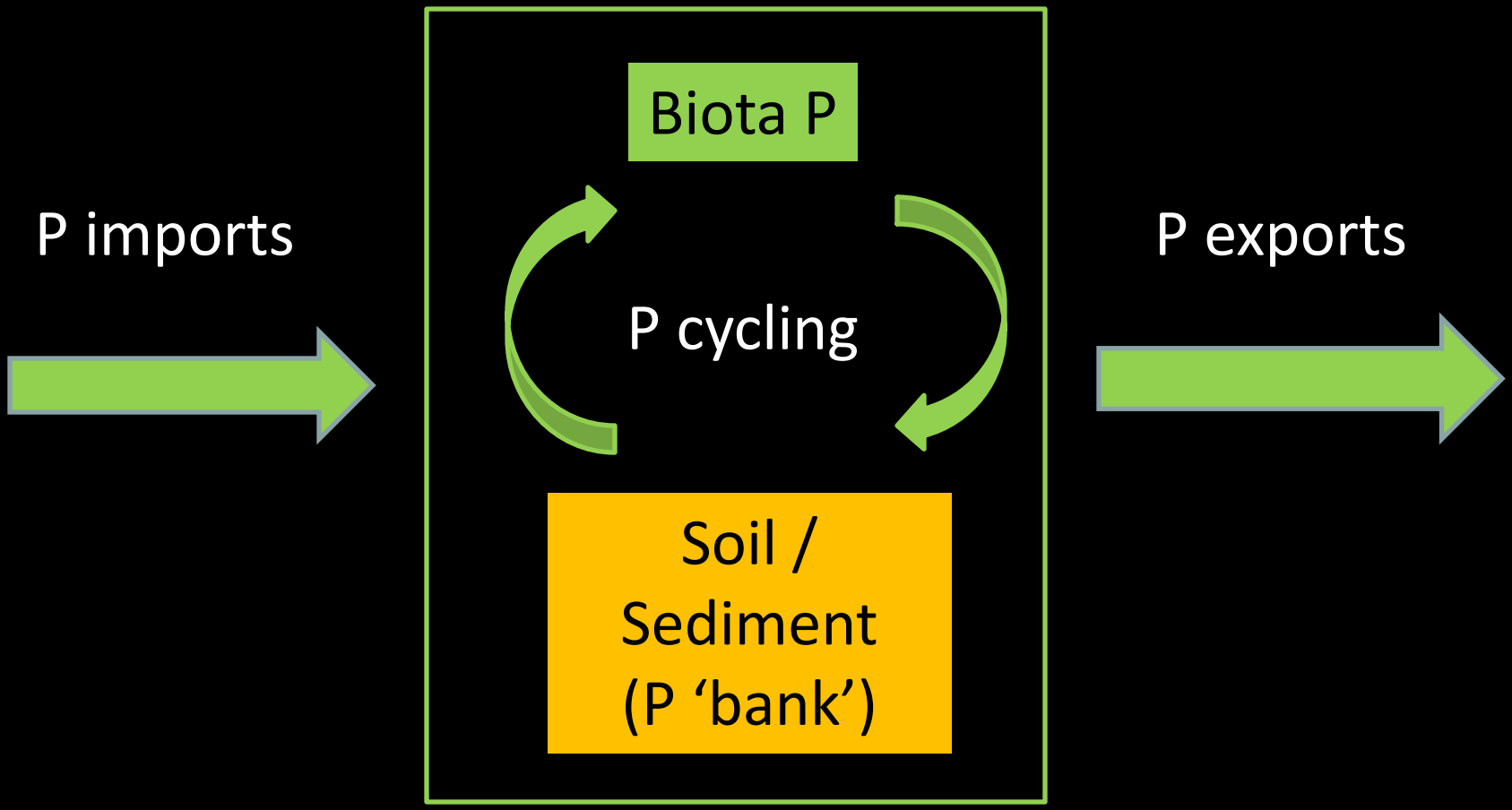
(from 'Refertilising Scotland' presentation at 'Reforesting Scotland' meeting in Torridon Community Centre, September 2010)

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

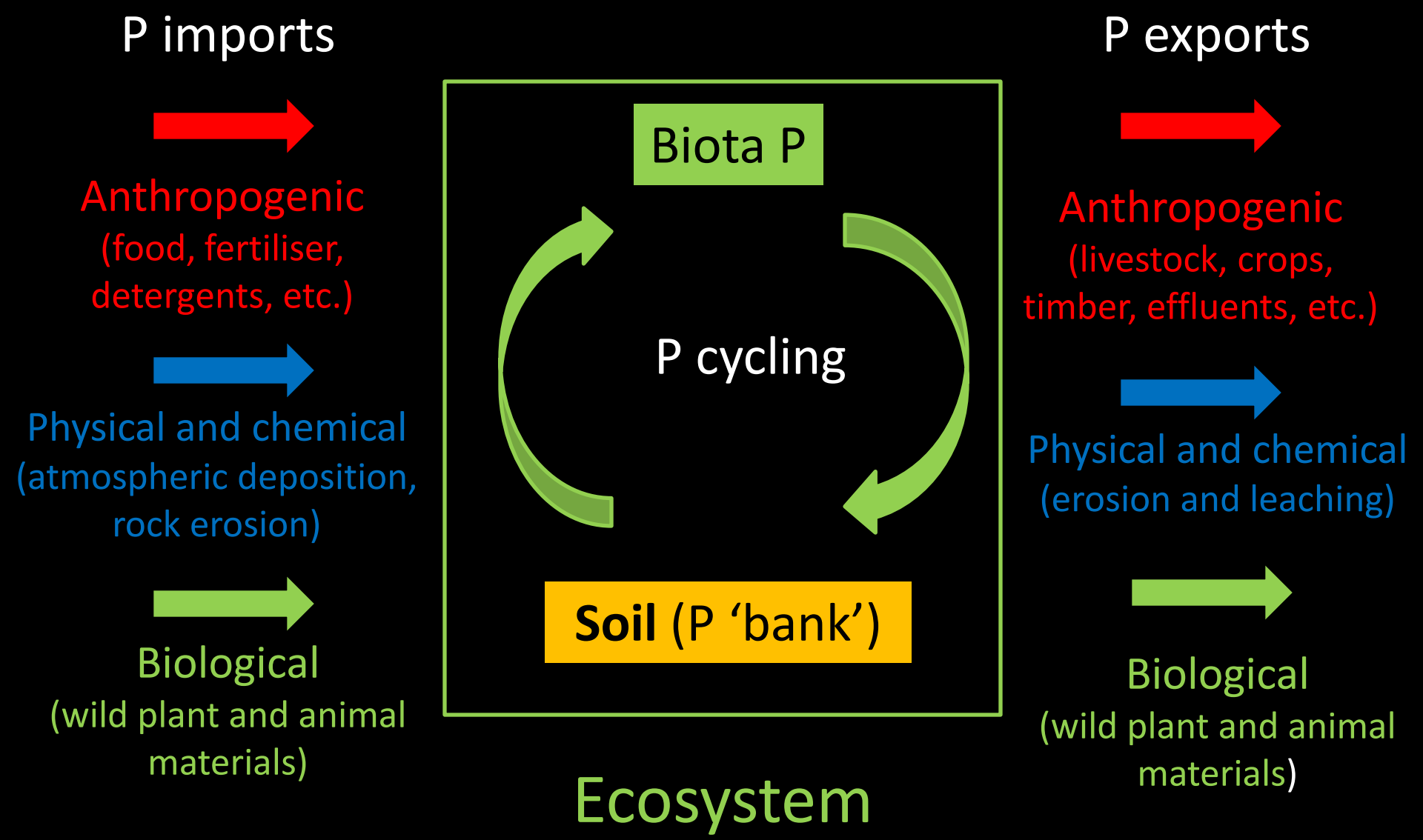
Phosphorus availability is dependent upon ecosystem processes



Simplified Phosphorus budget model!

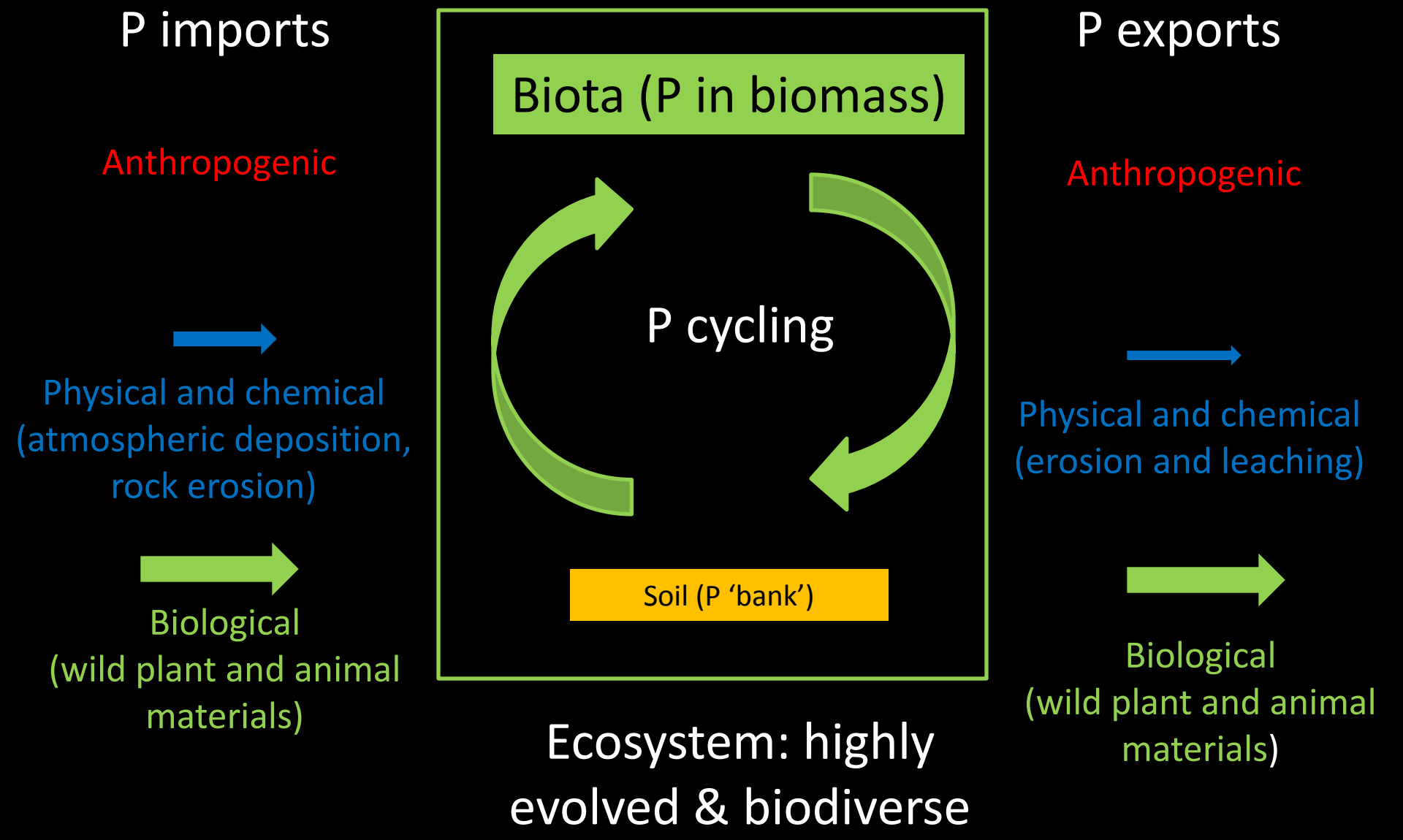


Phosphorus budget




Tropical rainforest
Rainforests are forests characterized by high rainfall, with between 2500mm and 4500mm of rain per year.
© Alfred Molon
www.molon.de

Tropical Rainforest

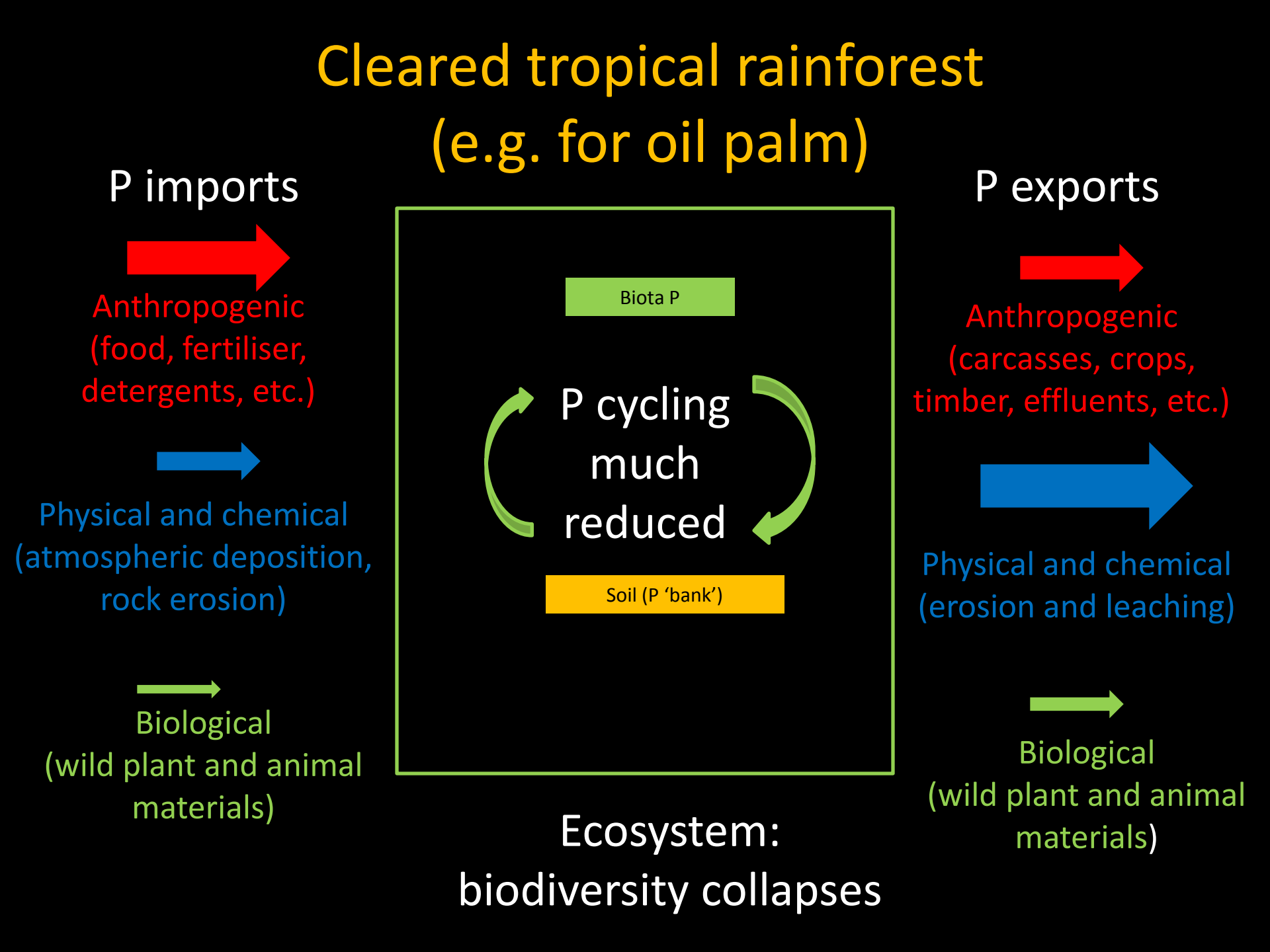


Deforested hills in Madagascar . . .

Cleared tropical Rainforest

Jungle clearance Sarawak

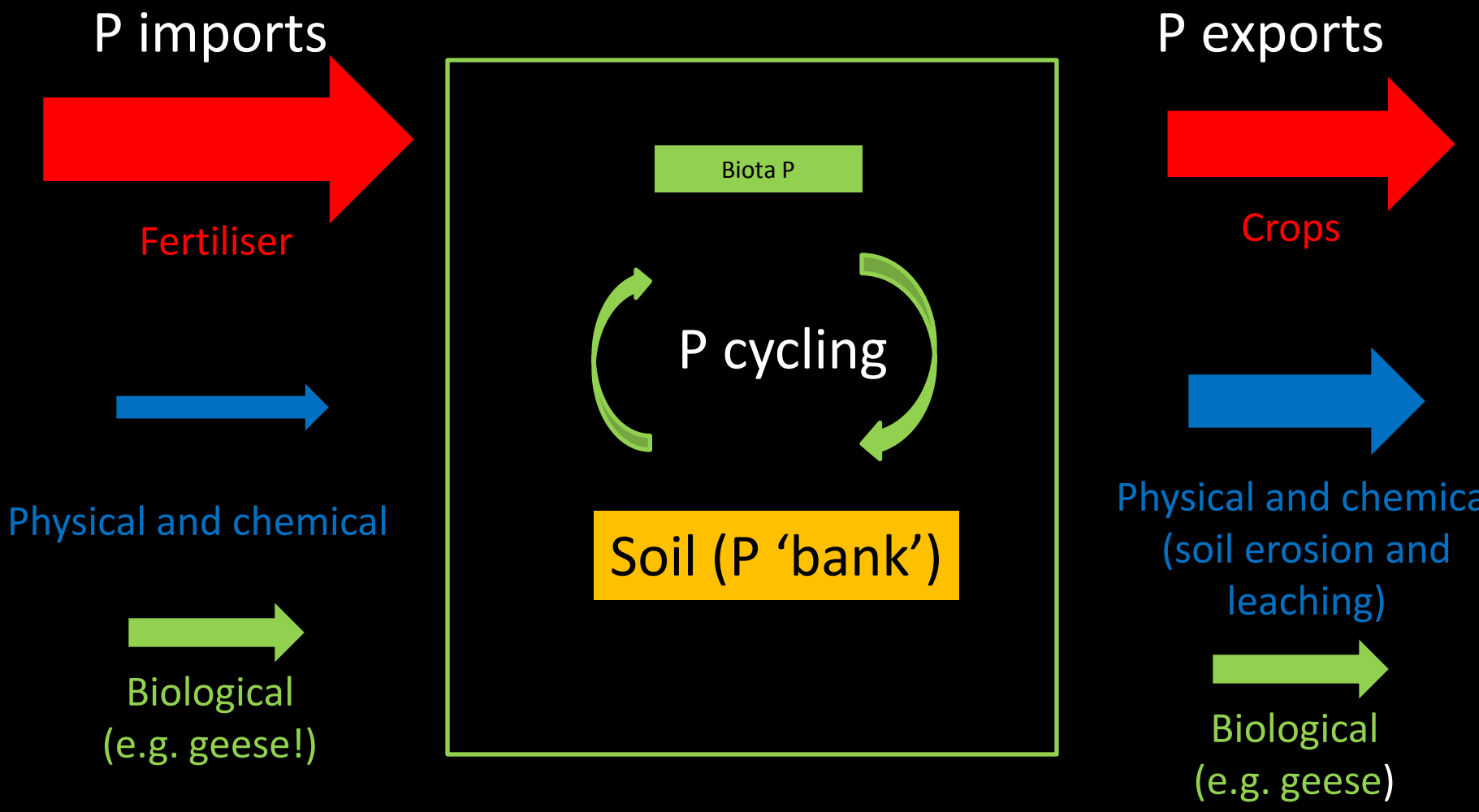
Cleared tropical rainforest (e.g. for oil palm)



Intensive agricultural area

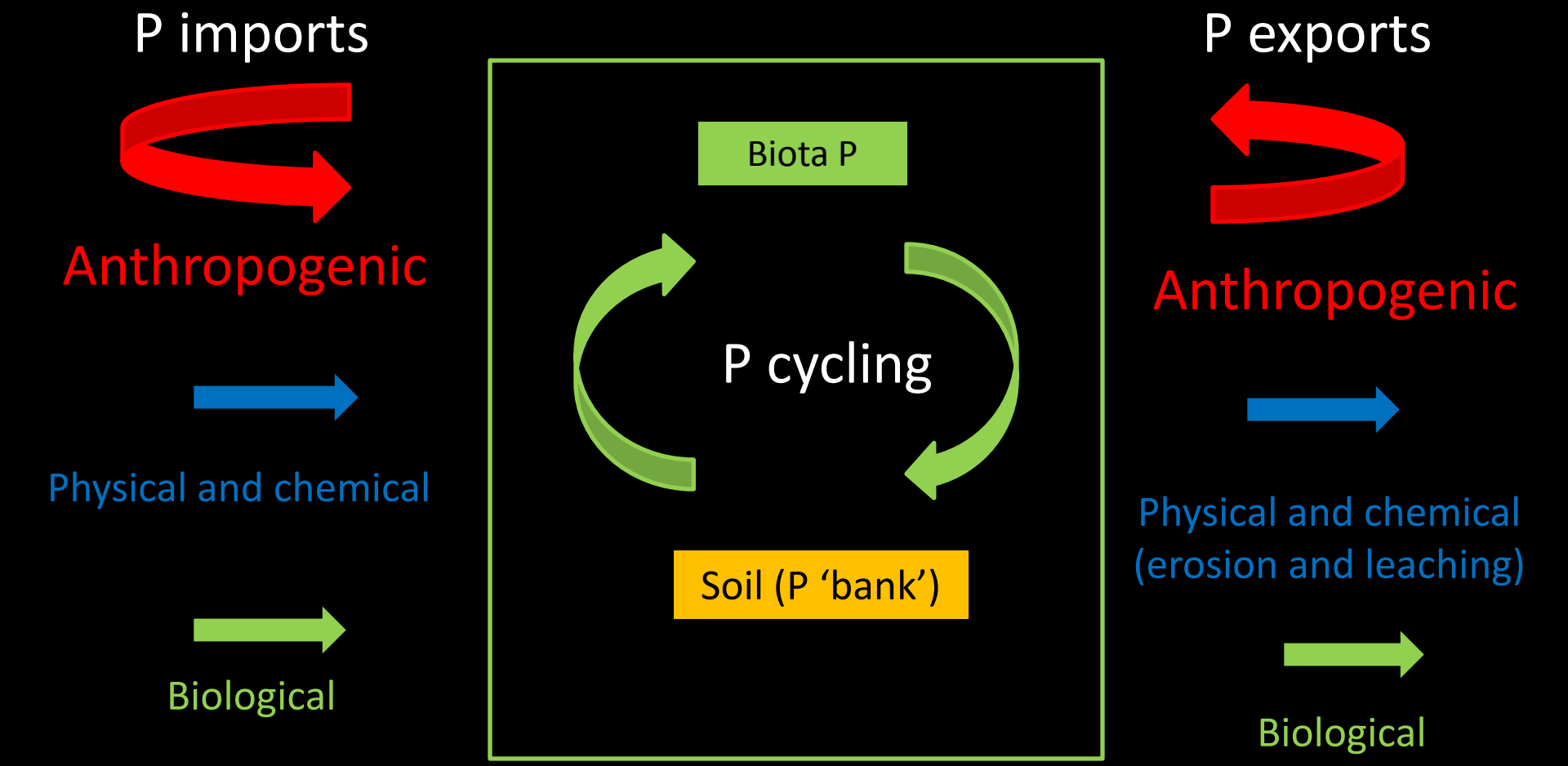
Andy Hay (rspb-images.com)

Intensive agricultural area



Ecosystem?

Traditional agricultural area



Agricultural Ecosystem: people are a part of the system

Crofting townships around the coast

Melvaig and Alltgrishan in 2004

Traditional agriculture

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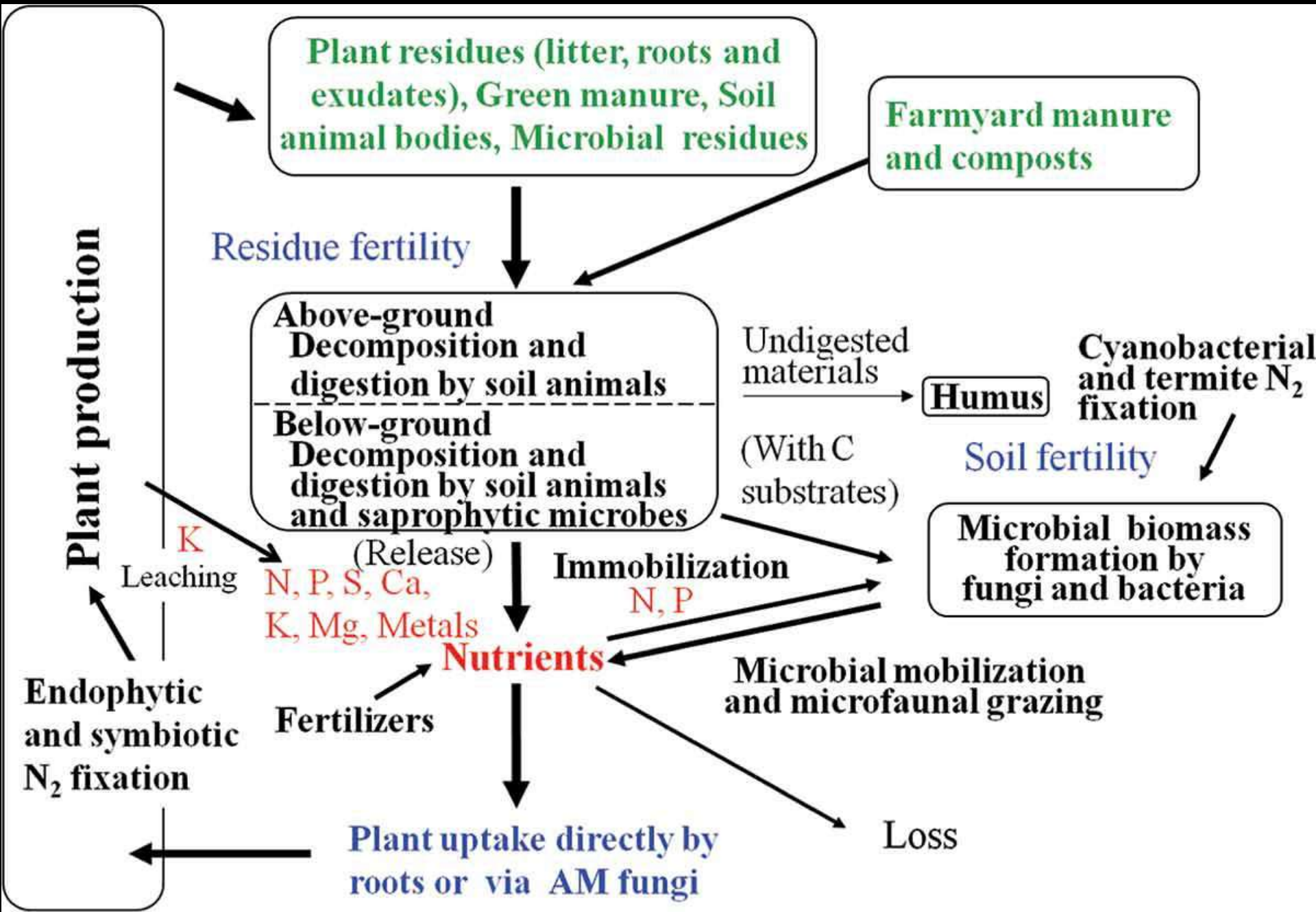
Abstract

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.


Plant production
Plant residues (litter, roots and exudates), Green manure, Soil animal bodies, Microbial residues
Farmyard manure and composts
Residue fertility
Above-ground Decomposition and digestion by soil animals
Below-ground Decomposition and digestion by soil animals and saprophytic microbes
Undigested materials
Humus
(With C substrates)
Cyanobacterial and termite N_2 fixation
Soil fertility
Microbial biomass formation by fungi and bacteria
K
Leaching
(Release)
N, P, S, Ca, K, Mg, Metals
Immobilization
N, P
Nutrients
Microbial mobilization and microfaunal grazing
Endophytic and symbiotic N_2 fixation
Fertilizers
Plant uptake directly by roots or via AM fungi
Loss

5. Fire

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

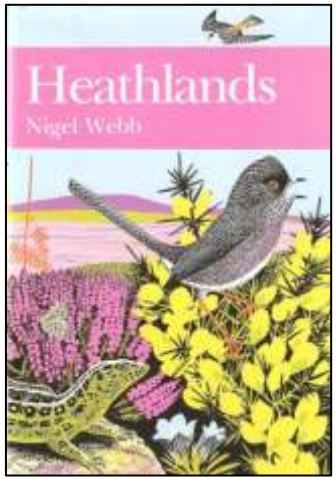

Little Gruinard River, May 2010 (inside fenced enclosure)
Wildfire in 2007

A forest on a boulder

Hillsides are burnt to promote fresh growth.

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						



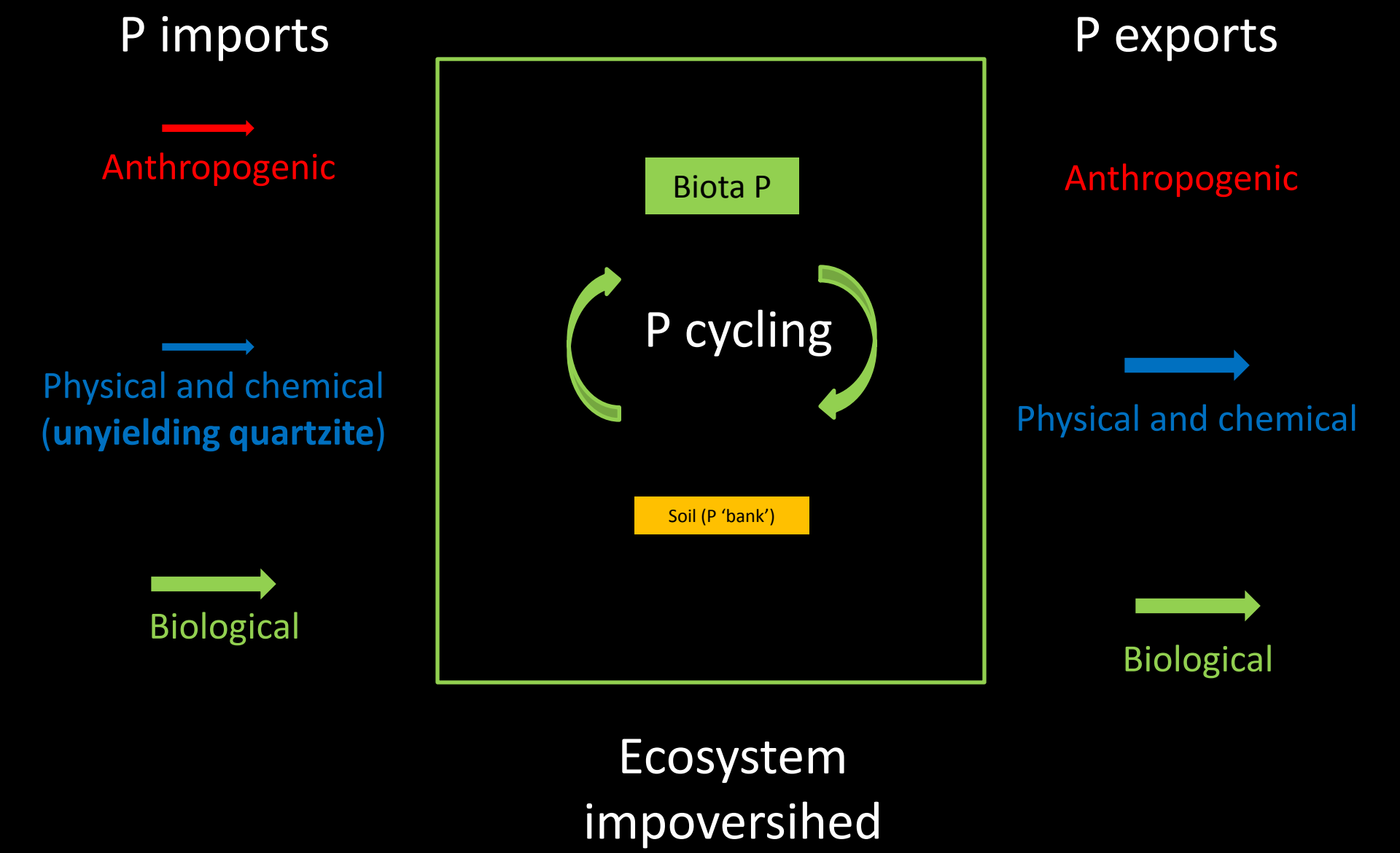
25% of the P in vegetation and leaf litter was lost on burning and not recovered within 10 years, representing a loss of over 2kg of P per ha.

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

Beinn Eighe National Nature Reserve

How ‘natural’?

Beinn Eighe mountainside



Fertilisation trials were carried out on Beinn Eighe NNR in the 1950s by Donald McVean to find out how to enhance soil fertility and establish tree seedlings.

Details are sketchy, but 50 yrs on, results could still be clearly seen.

Looks like the trial was successful??


. . . c. green knoll

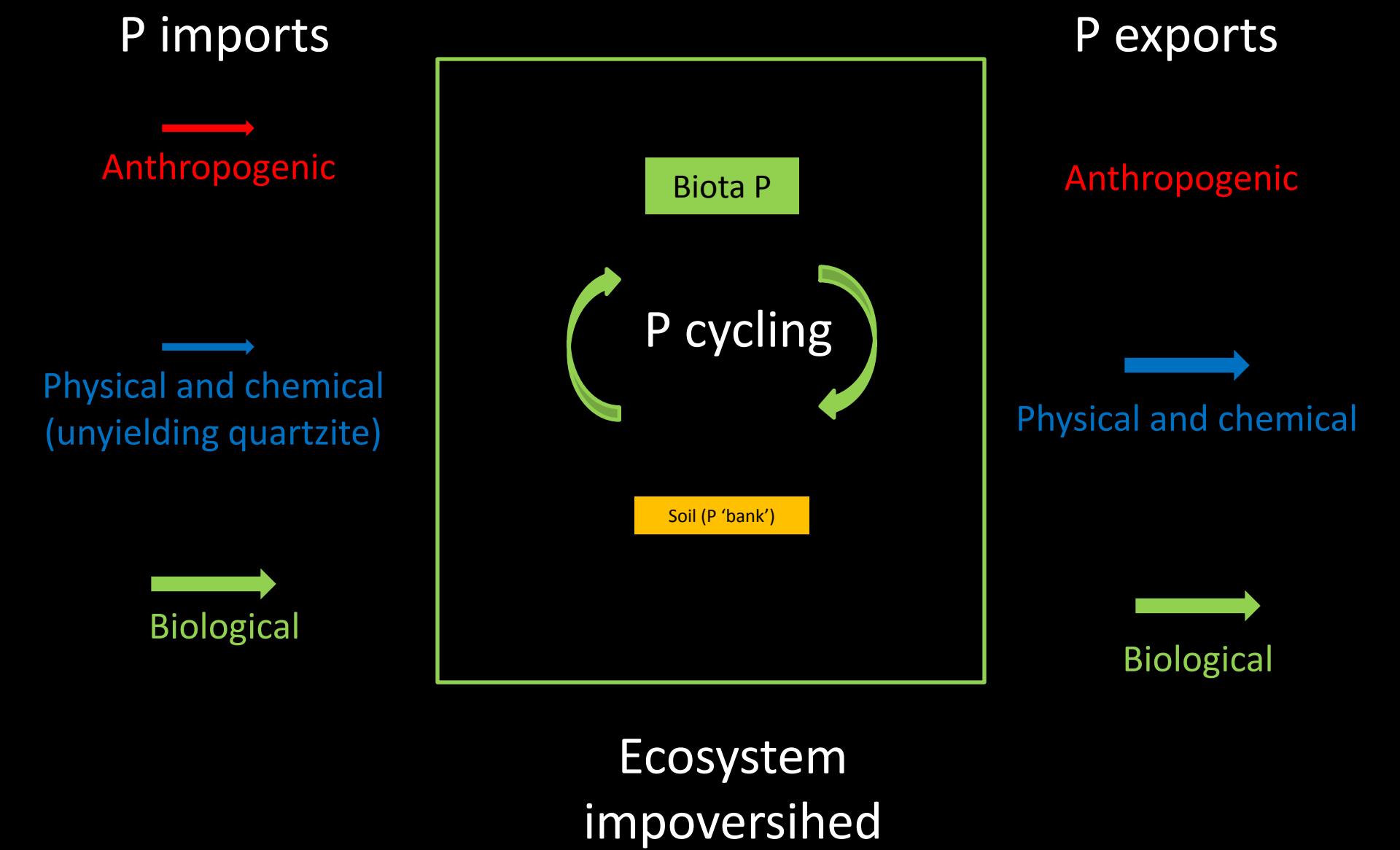
Inside area fertilised

- 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

Outside fertilised area

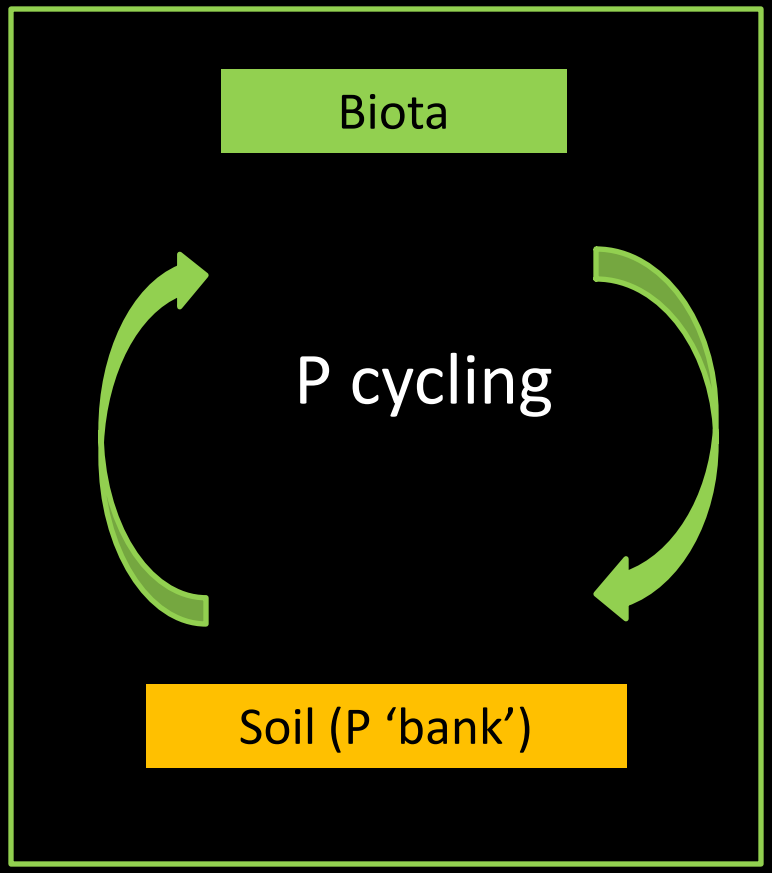


Inside fertilised area

(50+ years following fertiliser application)

P imports

P exports



Anthropogenic (2008)

Physical and chemical

Biological (e.g. grouse droppings)

Anthropogenic

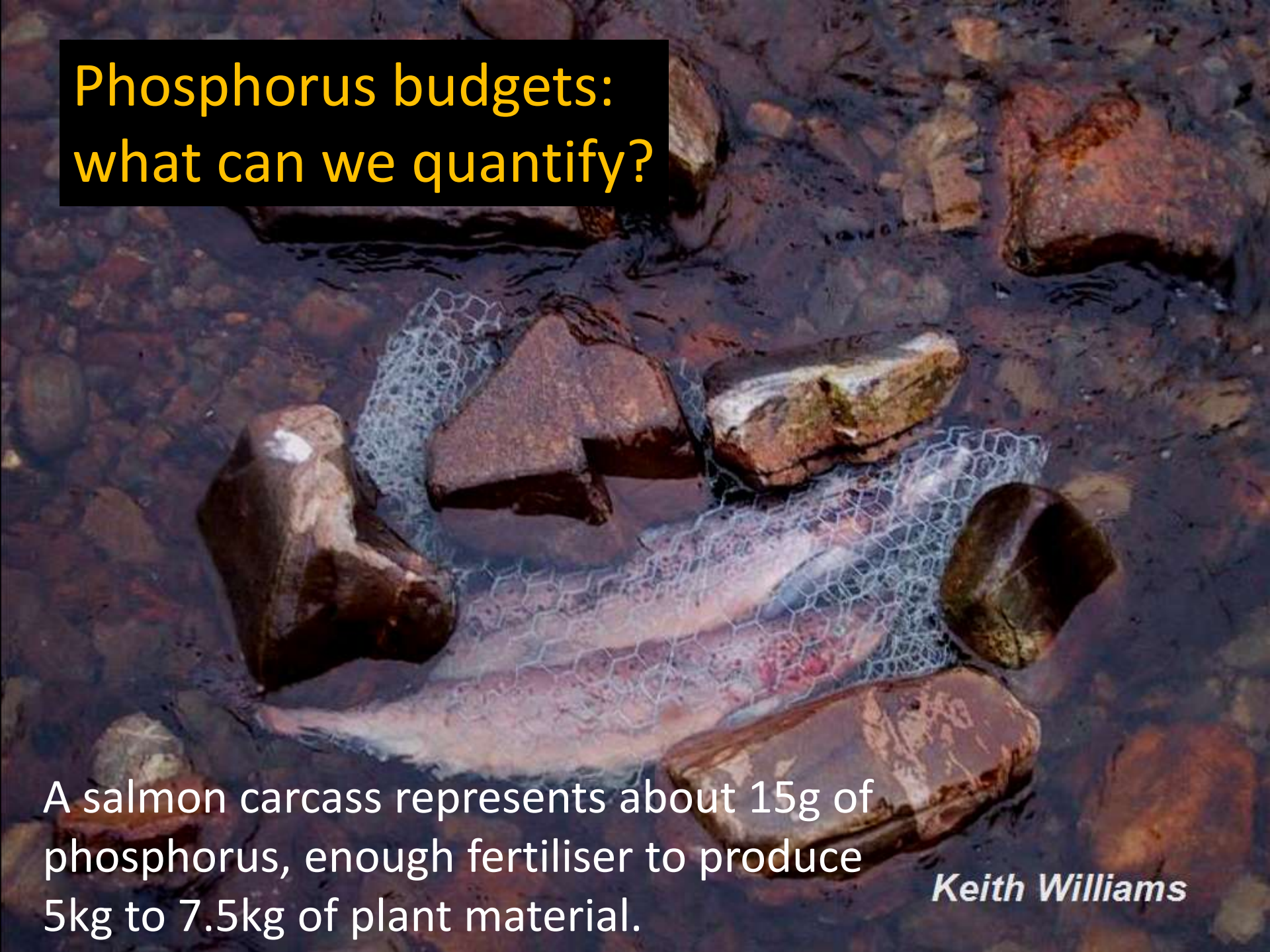
Physical and chemical

Biological (e.g. insects)

Ecosystem enriched:

higher productivity and higher biodiversity . . .

Phosphorus budgets: what can we quantify?



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

Keith Williams

Phosphorus budgets

200 salmon carcasses contain 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

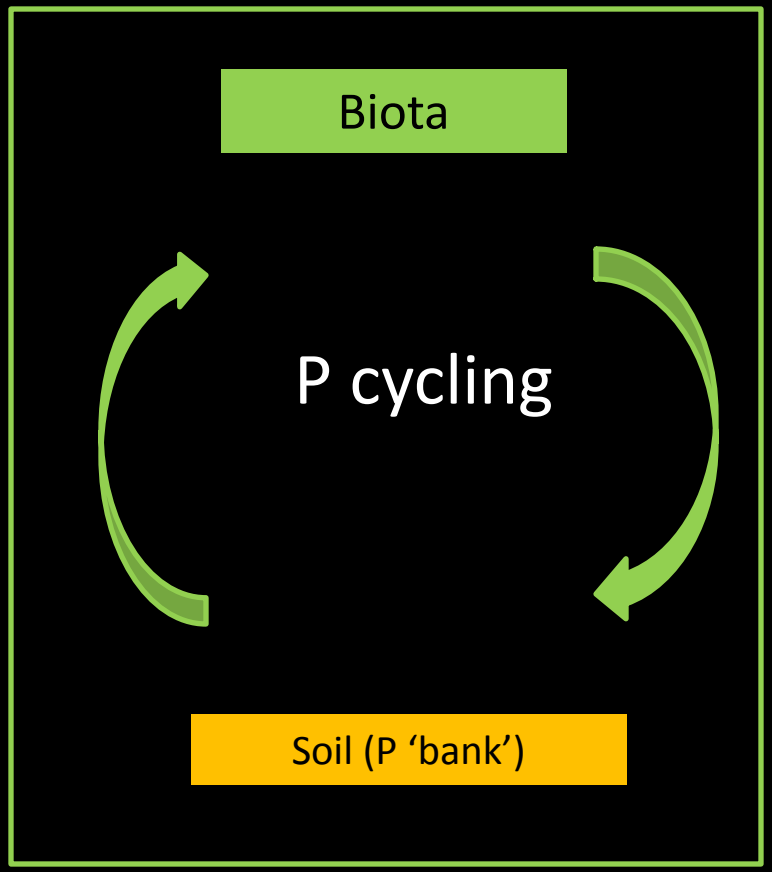
x 3

= ~ 3kg of Phosphorus

balanced ‘biological’ P budget model, e.g.

P imports

Biological
400 salmon / year
(6kg P)



P exports

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

catchment area

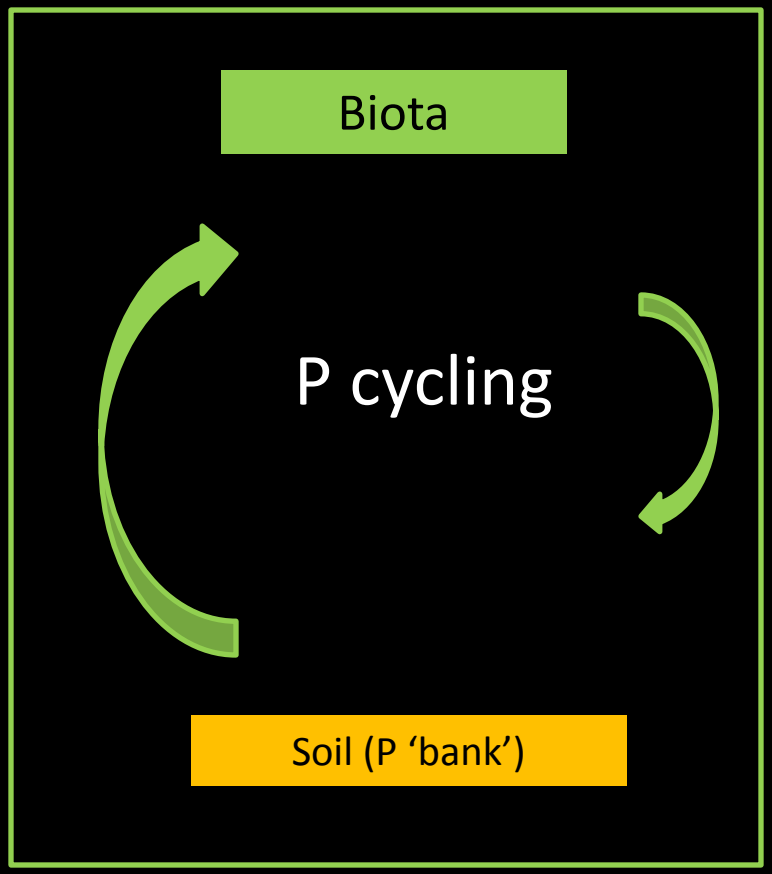
If deer carcasses are taken off the hill and phosphorus is not replaced. .

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

imbalanced system

P imports

Biological
200 salmon / year
(3kg P)

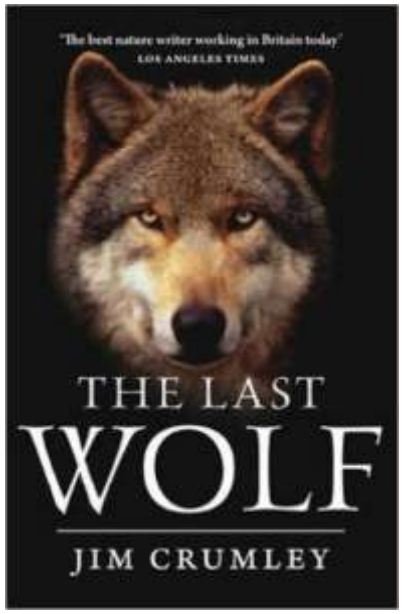


P exports

Biological
20 deer removed from
catchment area (20kg P)

.

catchment area becomes
phosphorus depleted



6. Animal export

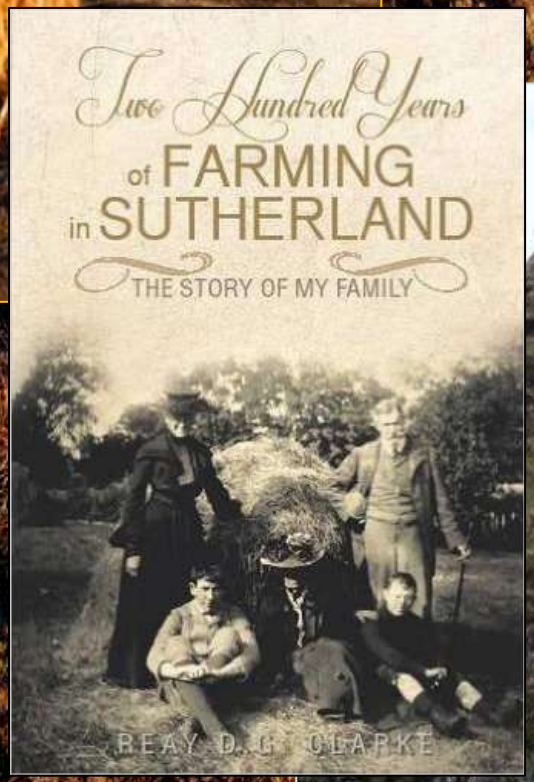
How many animals have been removed from headwater catchment areas over the past 100++ years?

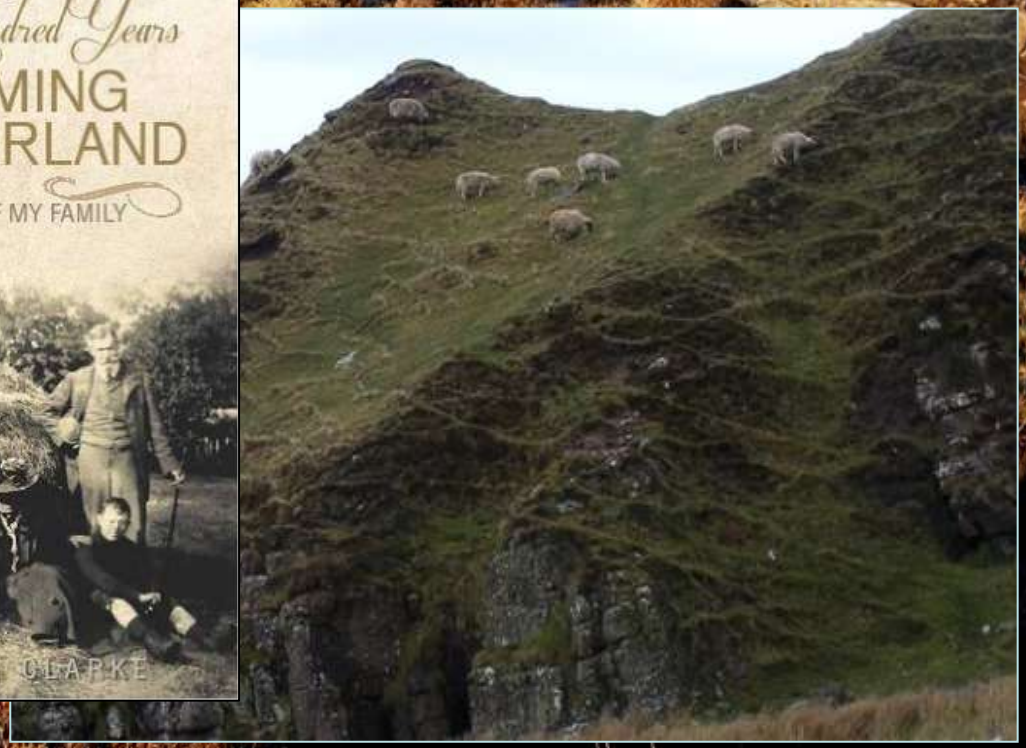
How much phosphorus does this represent?

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

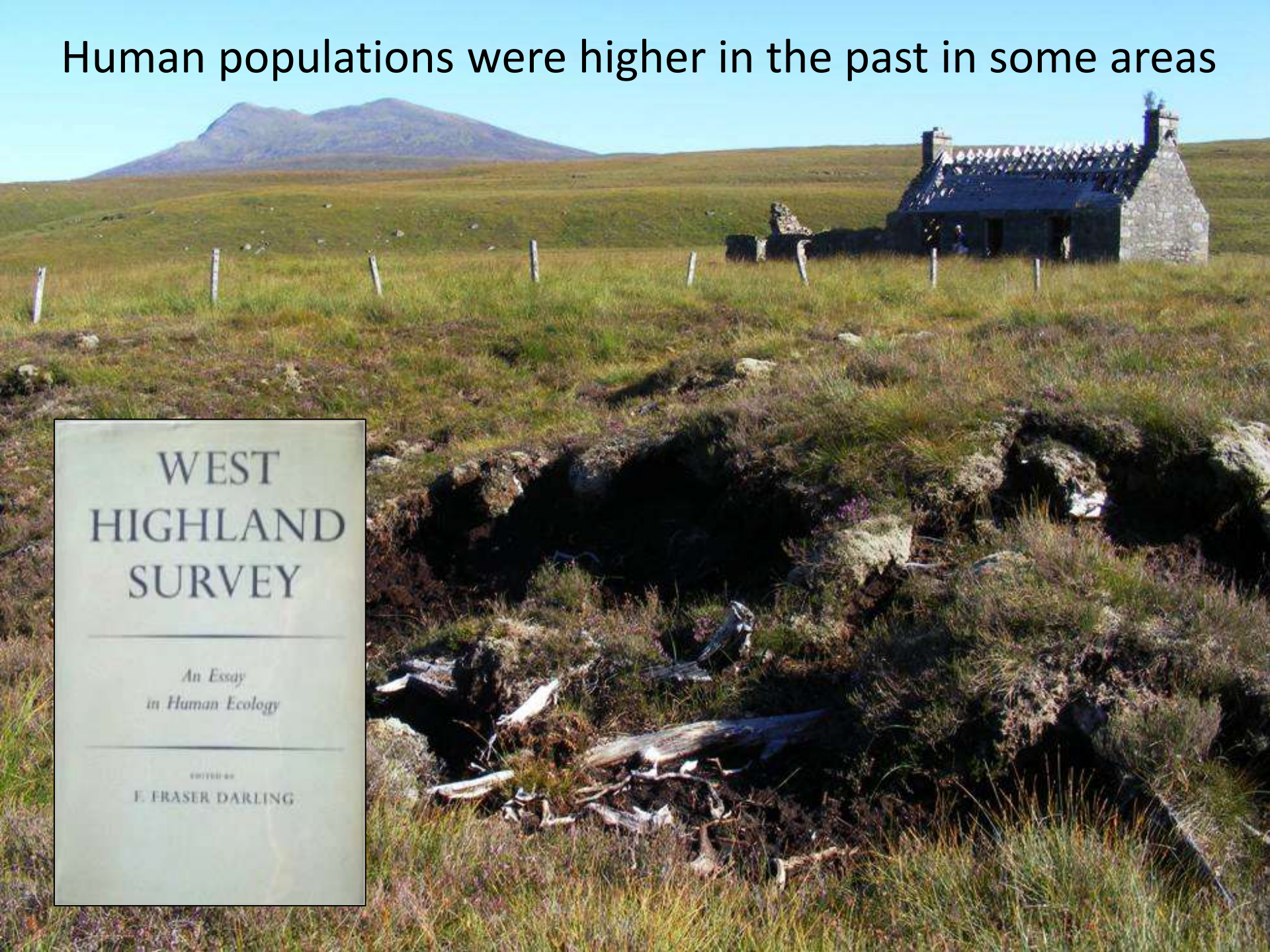
The removal of deer, sheep or cattle from upland catchment areas represents an unnatural loss of phosphorus from the ecosystem.

Have grazing areas in Wester Ross become less fertile?





Human populations were higher in the past in some areas



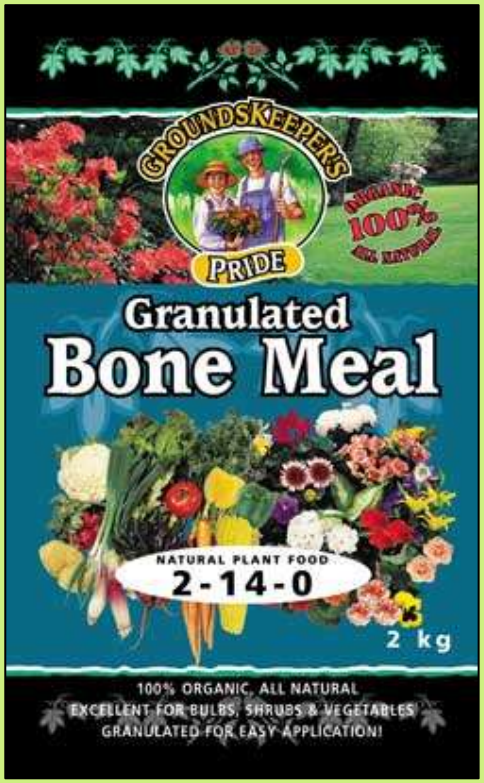
Human factors which affect fertiltiy of land (over 1,000s of years)

- extirpation of top predators (wolves, bear)
- destruction of forests
- burning vegetation
- heavy grazing pressure (cattle, sheep, deer)
- migration of people from Straths

= cultural oligotrophication ?


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?



or other P rich fertiliser?

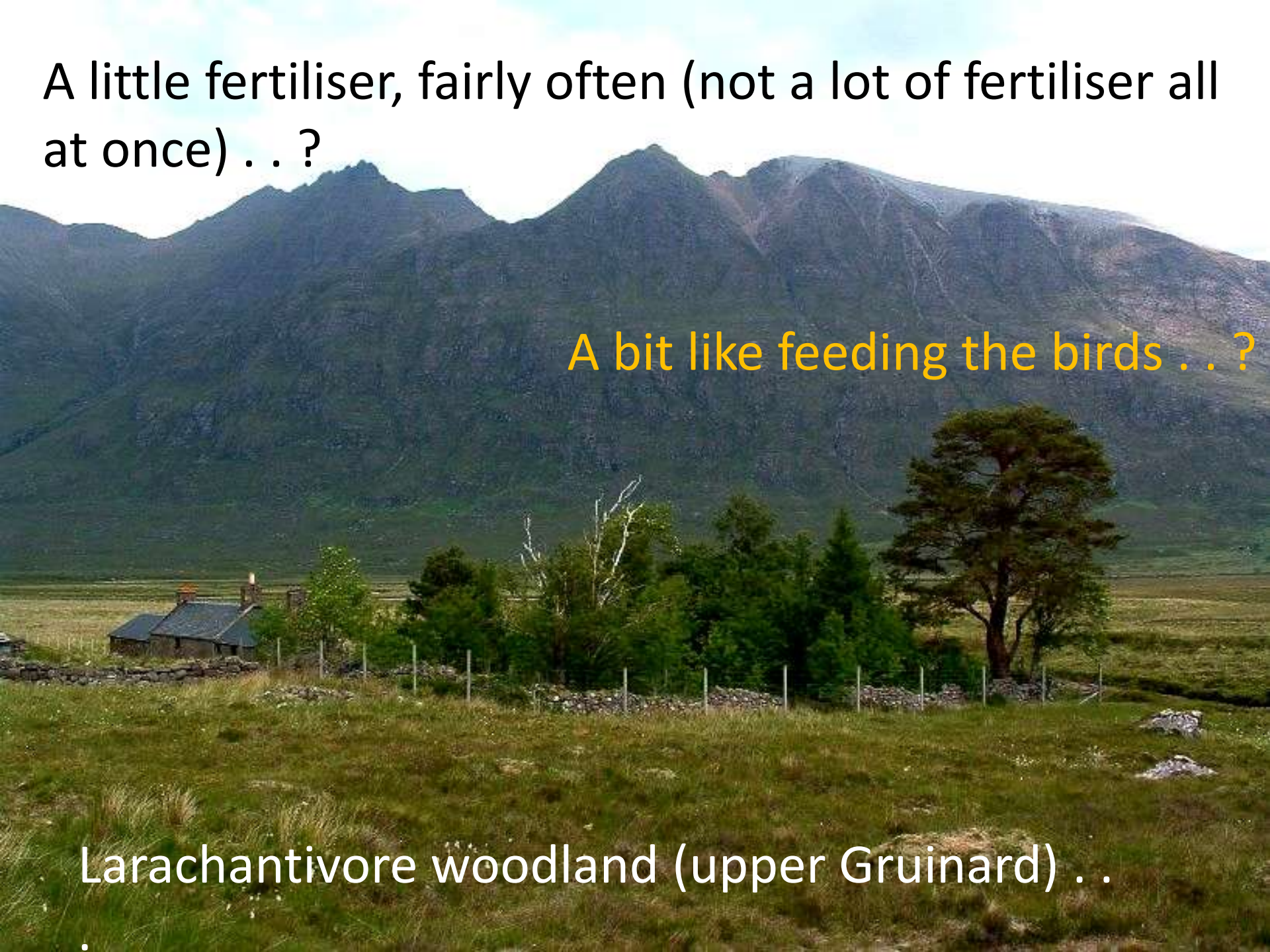
Recommendation

If fertility levels have fallen . . .

. . . can a case be made for ‘ecological fertilisation’: the gradual restoration of nutrients to areas from where nutrients have been lost, to restore soils, 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) . .
.

Many estates have developed enclosed woodlands to stabilise streams and enhance food availability.

WGS enclosure, Coulin Estate (headwaters of River Ewe)


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

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


Gairloch Estate: Balle Mor
native woodland restoration

Conclusions 1

- There is considerable variation in ecosystem fertility in space and time.
- Human impacts greatly affect ecosystem fertility both directly (e.g. application of fertiliser) and indirectly (e.g. extinction of top carnivores, export of livestock).
- Impacts can be positive and negative.

Conclusions 2

- Some parts of Wester Ross were more fertile, more biodiverse, and more productive in the past than they are at present.
- So should we focus more on restoring fertility to these places?

Refertilisation could help to support and revive fragile crofting communities.

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

‘Ecological refertilisation'

Thank you