

CURSO DE POSGRADO • 3ª EDICIÓN

Eutrofización *y biogeoquímica* ambiental del fósforo.



LIMNO.CUENCAS.UY

INICIO

15 de junio
2026

MODALIDAD

Intensivo
Presencial / Distancia

RESPONSABLES

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BIOLOGÍA
GEOCIENCIAS



UPEP
Unidad Pedagógica y Académica



P en la Biósfera



Guillermo Goyenola
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Laboratorio de
**Ciencia de Cuencas
y Limnología**
del Antropoceno
CATCHMENT SCIENCE · ANTHROPOGENE LIMNOLOGY



“La historia de la ciencia
es la ciencia misma.”

Von Goethe (1749-1832)



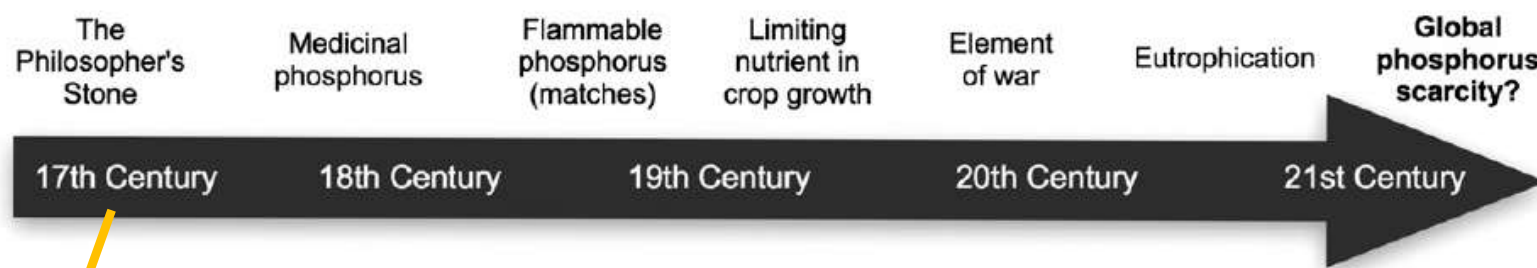
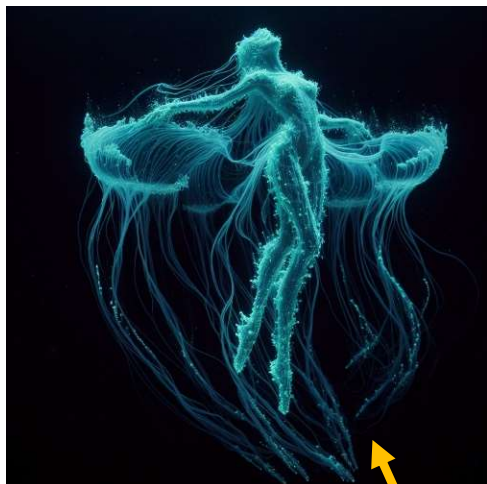


Fig. 1. The evolution of phosphorus use and abuse: from the Philosopher's Stone to use in war, food production, and more recently implicated in water pollution. A new emerging discourse of the 21st century may be global phosphorus scarcity. *Source: Cordell (2010).*



Ashley, K., D. Cordell and D. Mavinic (2011). "A brief history of phosphorus: From the philosopher's stone to nutrient recovery and reuse." *Chemosphere* 84(6): 737-746.



K. Ashley et al / Chemosphere 84 (2011) 737–746

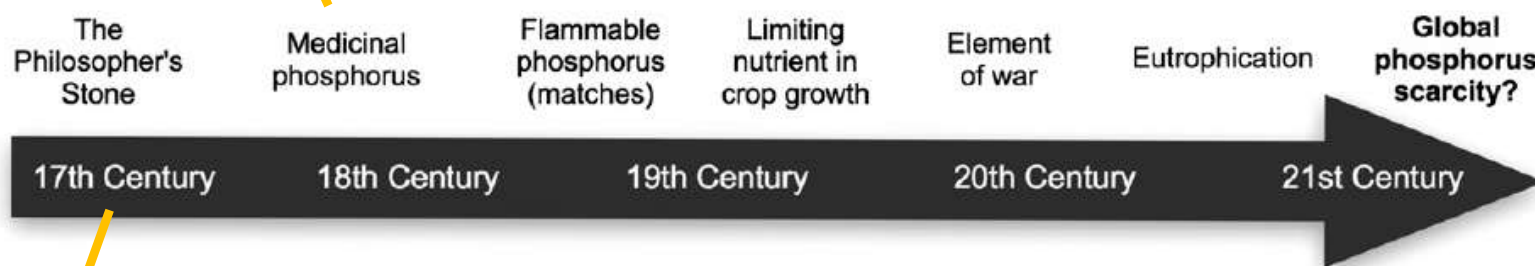


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1802
von Humboldt

738

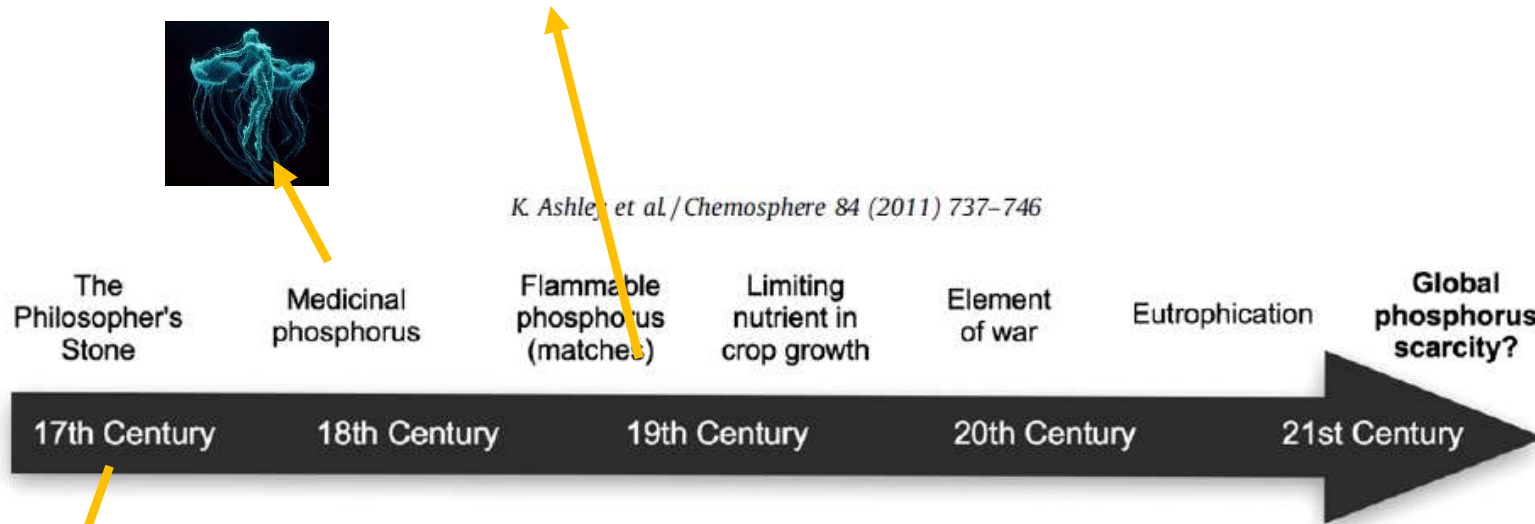


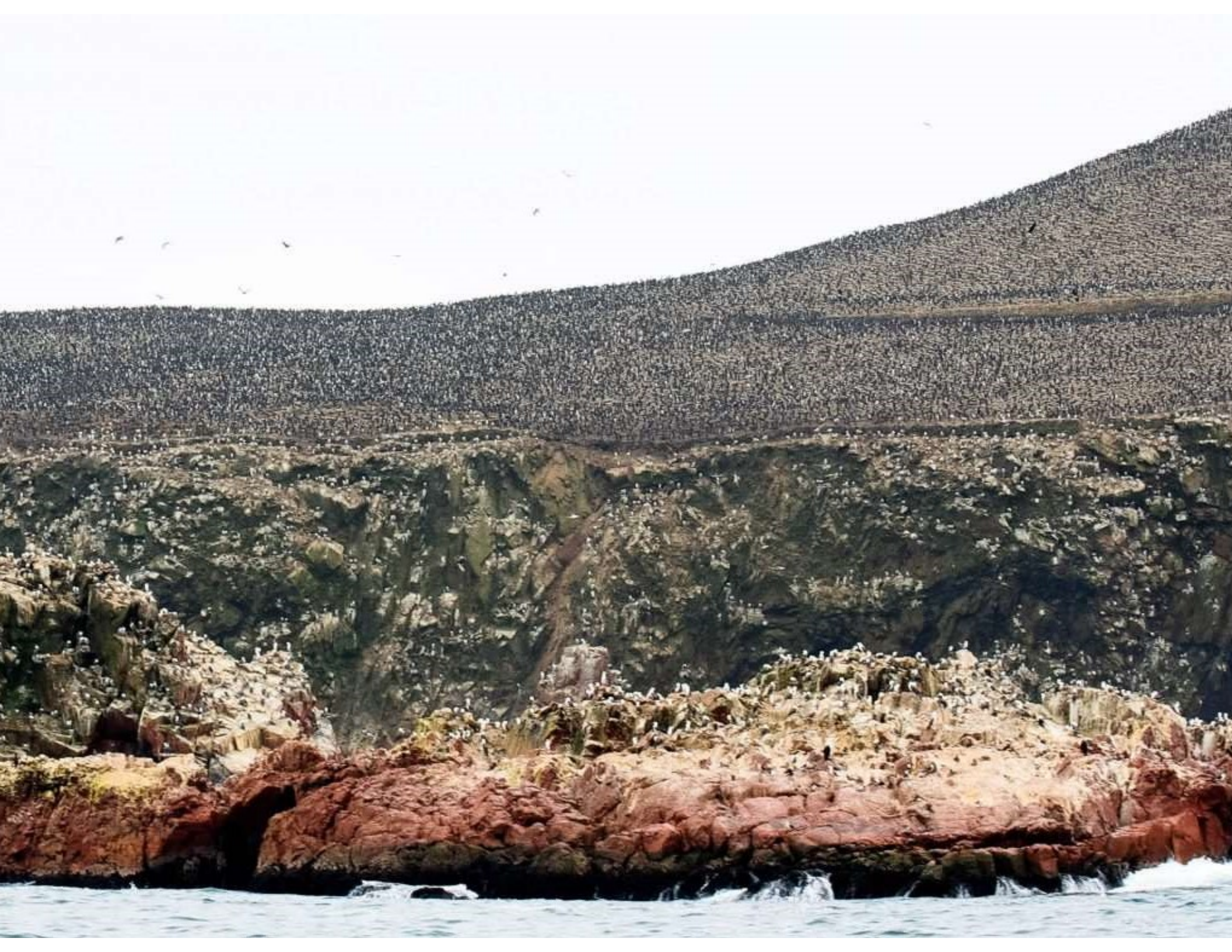
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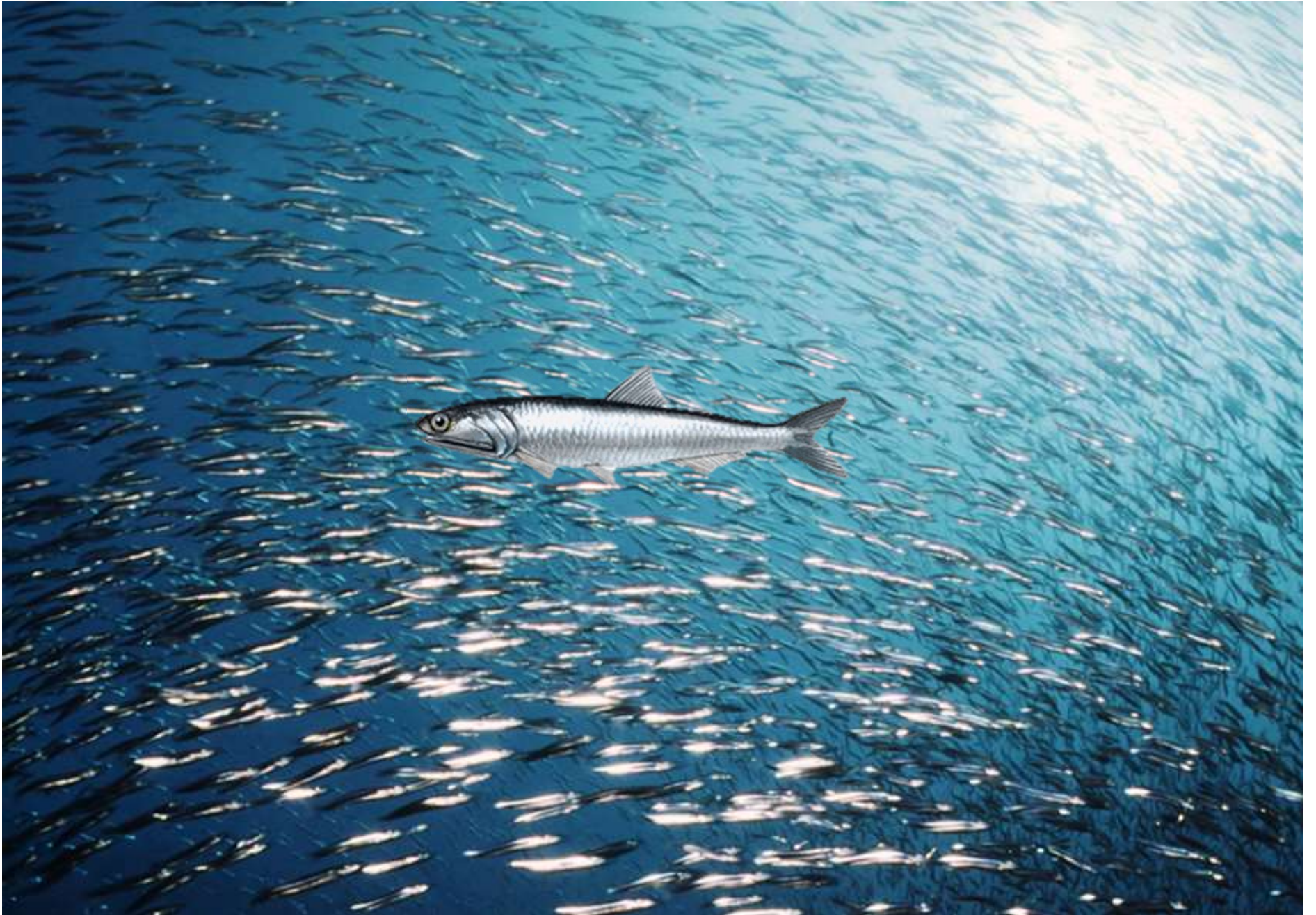








Cormorant guanay
(*Leucocarbo bougainvillii*)

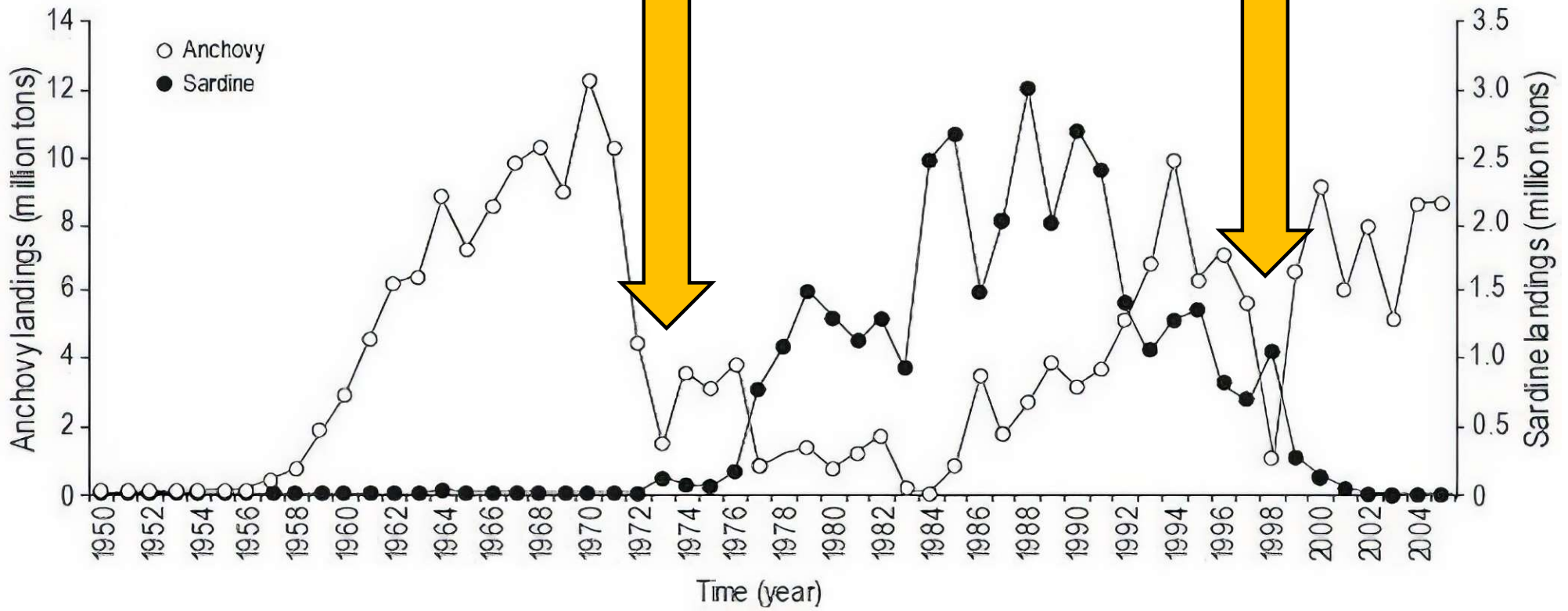


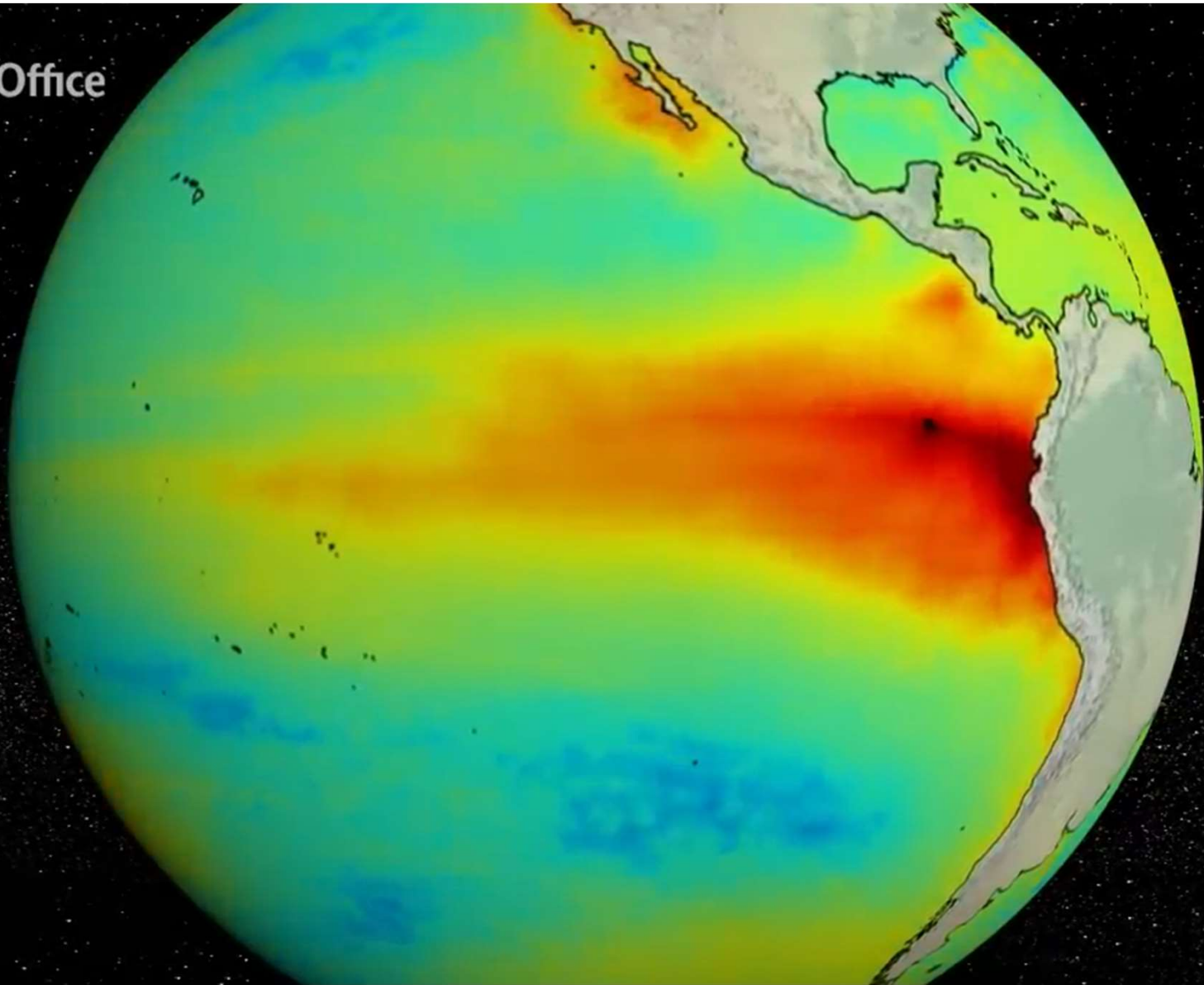
Engraulis ringens

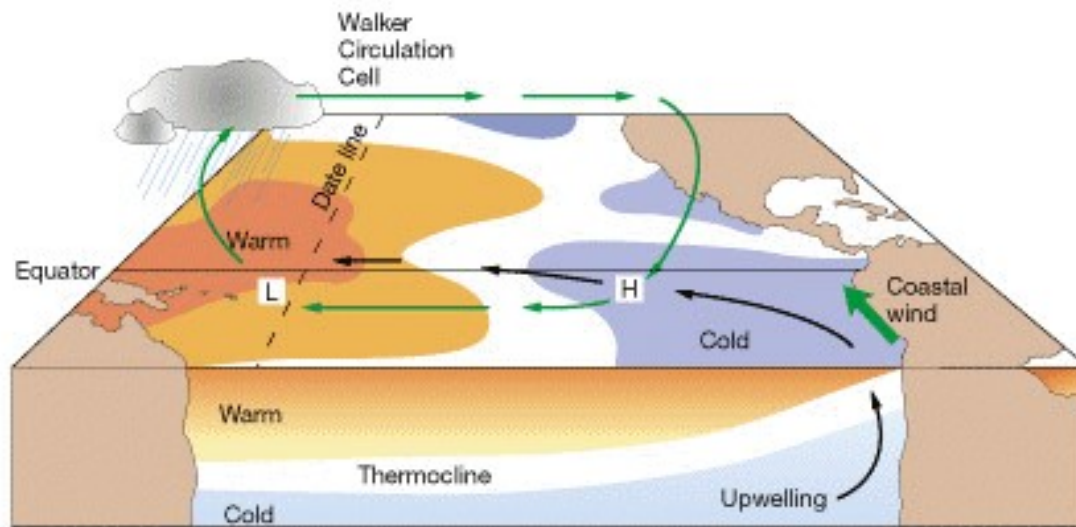


Sardinops sagax

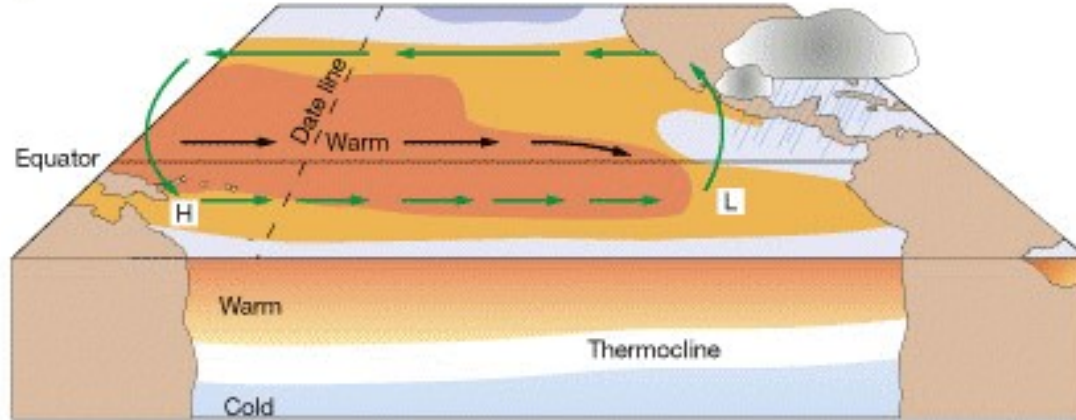




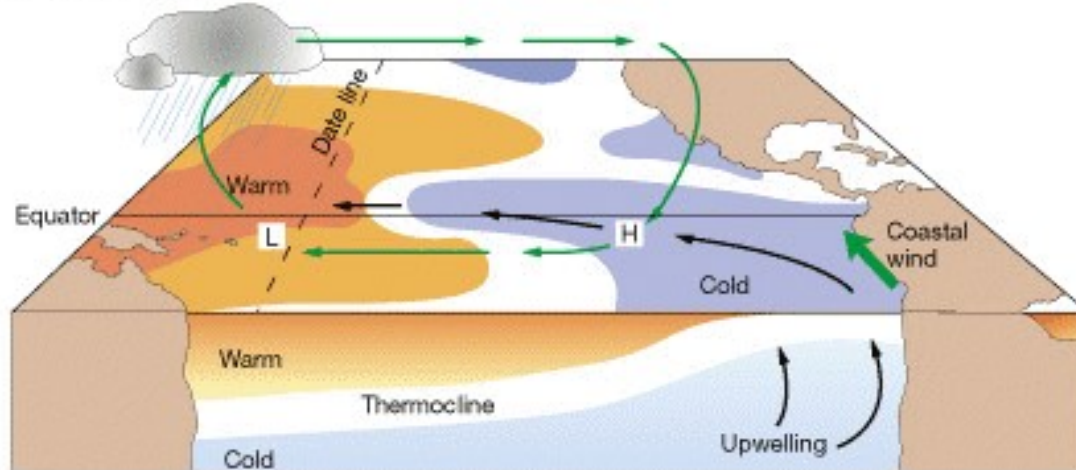




(a) Normal conditions

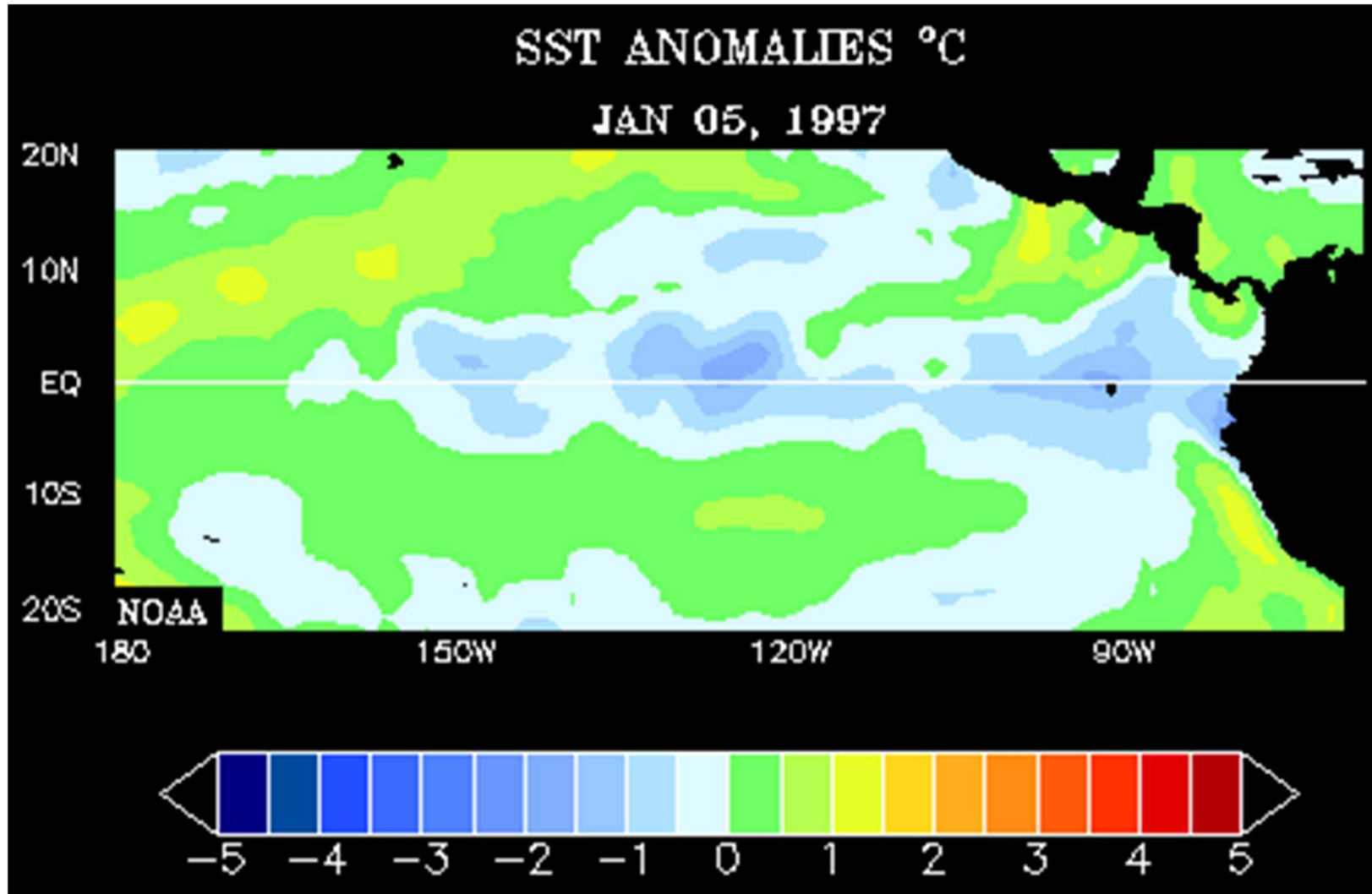


(b) El Niño conditions



(c) La Niña conditions

El niño 1997-1998



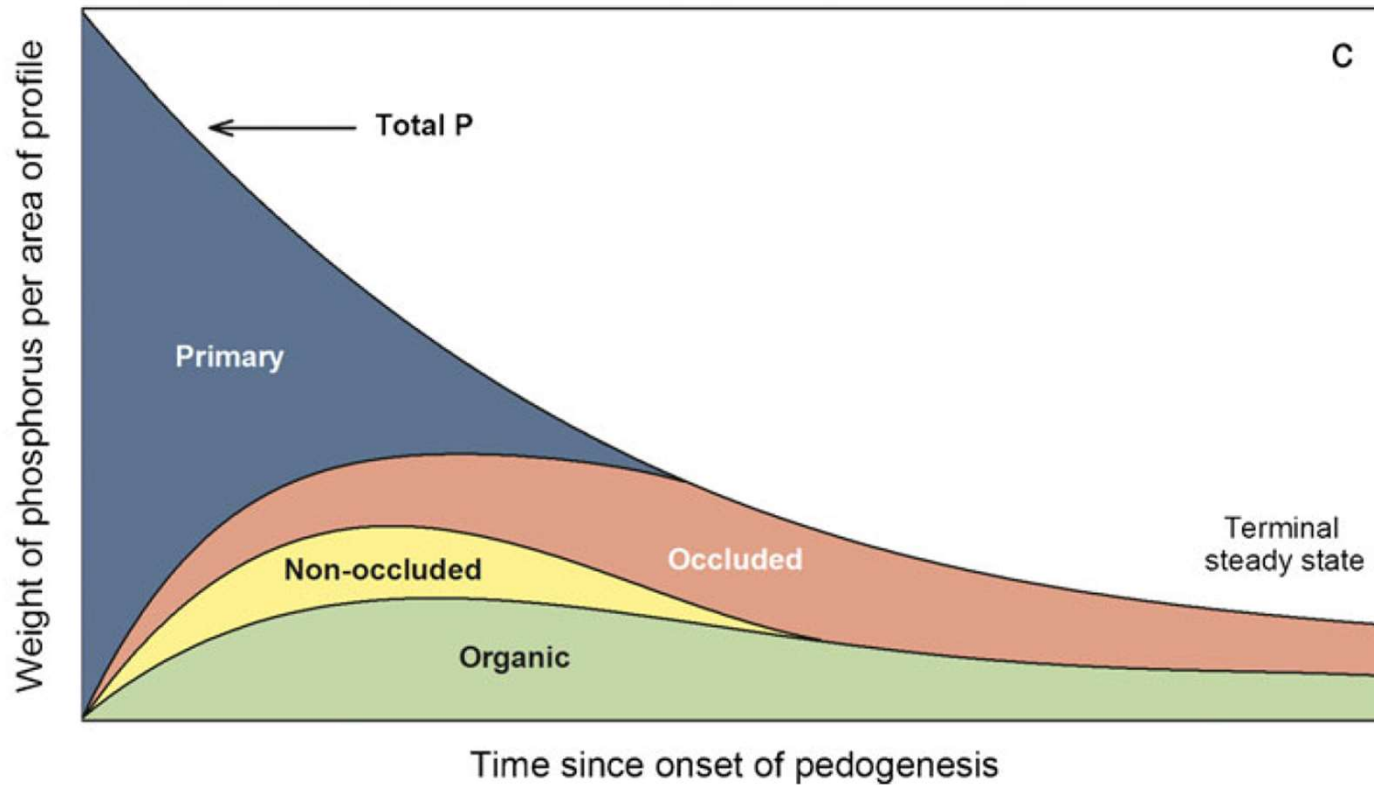
¿Queda claro porqué la surgencia de aguas oceánicas profundas aporta P?

La dinámica E.N.S.O.
no es toda la historia...

Vamos a aprovechar
para para introducir
otros procesos
biogeoquímicos
relevantes.

¿Cómo les parece que llega el P al suelo?

¿Que pasará a media que pasa el tiempo?



A medida que el **suelo** se desarrolla, el P total disminuye y, simultáneamente, cambia de forma: pasa de mineral primario (heredado de la roca) a formas orgánicas y a formas inorgánicas secundarias asociadas a óxidos de Fe y Al.

Ejes

- **Eje Y — "Weight of phosphorus per area of profile":** cantidad (masa) de P por unidad de área del perfil, es decir el *stock* de P del suelo (no la concentración).
- **Eje X — "Time since onset of pedogenesis":** tiempo desde que se inició la formación del suelo (edad del suelo; puede abarcar de miles a millones de años).

Conceptos graficados

1.P total (Total P). Suma de todas las formas de P del perfil. Es máximo en suelos jóvenes (todo heredado de la roca madre) y **decae de forma continua** durante la pedogénesis, porque el P se pierde por lixiviación/escorrentía más rápido de lo que la meteorización de la roca lo repone.

2.P mineral primario (Primary). P contenido en los minerales primarios de la roca madre, principalmente **apatita** (fosfato de calcio). Es la fuente original de todo el P del suelo; se meteoriza y **disminuye hasta agotarse** en suelos viejos. (*Operacional: P inorgánico extraíble en H_2SO_4 0,5 M sin ignición previa.*)

3.P no ocluido (Non-occluded). P inorgánico **secundario** adsorbido sobre las superficies de minerales secundarios (óxidos/hidróxidos de Fe y Al) y como precipitados; fracción relativamente lábil/disponible. Se forma a expensas de la apatita: **aumenta primero y luego decae** (patrón similar al del P orgánico).

4.P ocluido (Occluded). P inorgánico secundario **físicamente encapsulado** ("ocluído") dentro de los óxidos/hidróxidos metálicos, **inaccesible** para plantas y microorganismos. **Se acumula** con el tiempo y se vuelve la forma inorgánica dominante en suelos viejos. (*Operacional: P inorgánico insoluble en H_2SO_4 0,5 M después de ignición.*)

5.P orgánico (Organic). P incorporado a la **materia orgánica del suelo** por la actividad biológica. Se acumula rápido en las etapas tempranas (mientras sube la productividad), se mantiene alto un tiempo y luego **declina** a medida que el sistema pierde P. (*Operacional: diferencia entre el P extraído en H_2SO_4 0,5 M de muestras calcinadas vs. sin calcinar.*)

6.Estado estacionario terminal (Terminal steady state). Etapa final, en suelos muy viejos y fuertemente meteorizados, donde las **salidas de P se equilibran con las entradas atmosféricas** (polvo, lluvia). El P total es bajo y queda repartido casi exclusivamente entre **P orgánico y P ocluido**, en cantidades similares; la apatita y el P no ocluido prácticamente desaparecieron. Es el punto de **máxima limitación por P**, asociado a la *retrogresión* del ecosistema.

Turner, B.L. & Condon, L.M. (2013). *Pedogenesis, nutrient dynamics, and ecosystem development: the legacy of T.W. Walker and J.K. Syers. Plant and Soil* 367:1-10

Changes in phosphorus availability during pedogenesis

plant species and functional diversity

Hans Lambers
School of Biological Sciences
The University of Western Australia

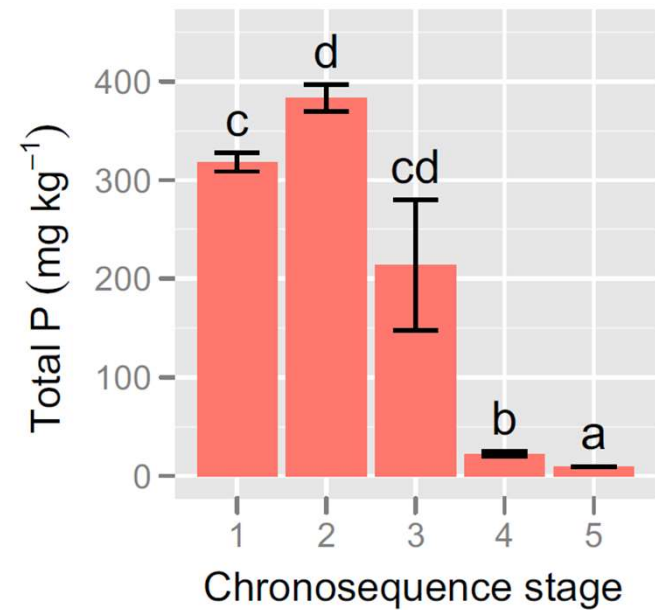
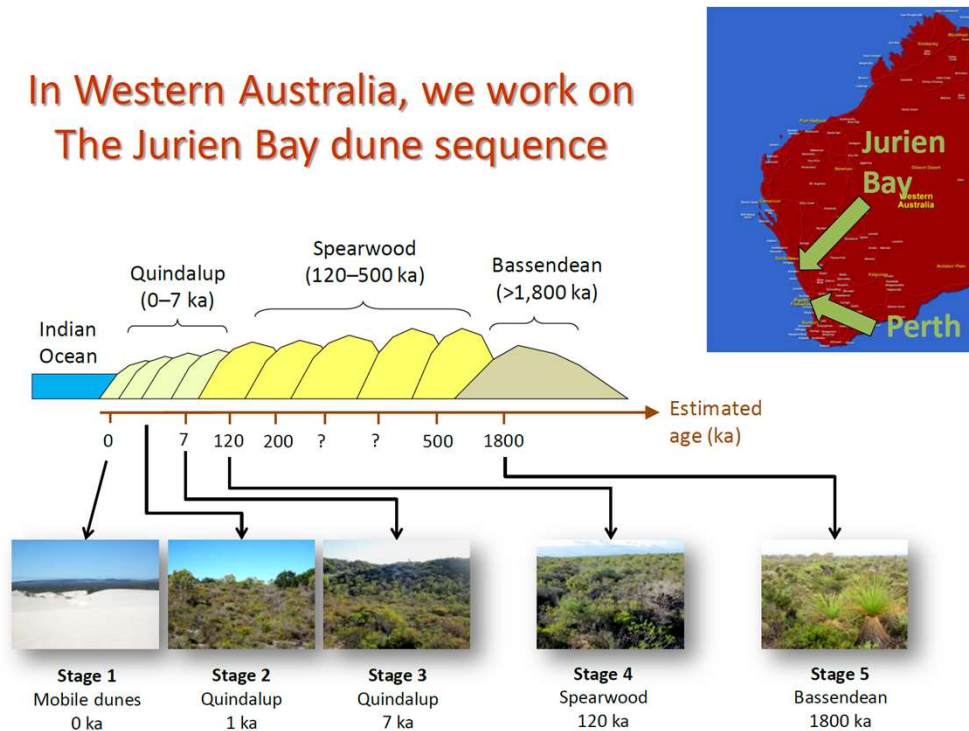
10th to 19th February 2019
Phosphorus Biochemistry Cycle and Plant Mineral Nutrition in Agroecosystems
CIURE-Maldonado | Udelar

Invited Professor: Dr. Hans Lambers
Emeritus Professor, School of Biological Sciences, University of Western Australia
Professor in charge: Dr. Guillermo Escamezola (CIURE-Udelar)
Assistant Professor (In-charge): Mag. Diego Michelini (PhD-Udelar)
Asst. Prof. Concepción Calvo (CIURE-Udelar)
Lic. Lucía Cabrera (CIURE-Udelar)

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Diego Michelini | dmichelini@ciure.com.uy

Postgraduate Programs: PEDECIBA-Biology & Agricultural Sciences

In Western Australia, we work on The Jurien Bay dune sequence



Laliberté, E., Turner, B.L., Costes, T., Pearse, S.J., Wyrwoll, K.-H., Zemunik, G., Lambers, H., 2012. Experimental assessment of nutrient limitation along a 2-million-year dune chronosequence in the south-western Australia biodiversity hotspot. *Journal of Ecology* 100, 631–642.

REJUVENECIMIENTO DEL SUELO

La actividad tectónica expone roca fresca y libera nutrientes, renovando los suelos y sosteniendo la vida.

ERUPCIONES VOLCÁNICAS

Las erupciones liberan cenizas y fragmentos de roca ricos en minerales (fosfatos), que al meteorizarse enriquecen el suelo.

TERREMOTOS

Los sismos fracturan y elevan la corteza, exponiendo roca fresca a la superficie y aumentando la meteorización.

DESPLAZAMIENTOS DE TIERRA

Los deslizamientos remueven materiales del subsuelo y exponen roca fresca, mezclándola con el suelo.

TSUNAMIS

Los tsunamis erosionan, transportan sedimentos y depositan nuevos materiales minerales sobre la tierra, enriqueciendo los suelos costeros.

LEVANTAMIENTO TECTÓNICO

El ascenso de la corteza expone roca madre fresca y rica en minerales.

Roca fresca expuesta

Depósito de sedimentos ricos en minerales

METEORIZACIÓN

El agua, el CO₂ y los microorganismos descomponen la roca, liberando nutrientes.

ROCA PROFUNDA

Roca rica en minerales (ej. apatita: fosfatos)

EXPOSICIÓN DE ROCA FRESCA

La tectónica expone roca madre sin meteorizar, rica en minerales esenciales.

FORMACIÓN DE SUELO

Se forman suelos nuevos, fértiles y ricos en nutrientes.

SUELO REJUVENECIDO

Suelos más fértiles que sostienen la vegetación y los ecosistemas.

CICLO DE REJUVENECIMIENTO DEL SUELO

1. Actividad tectónica (sismos, volcanes, tsunamis, deslizamientos)

2. Exposición de roca fresca

3. Meteorización física y química

4. Formación de suelo nuevo

5. Suelo fértil y ecosistemas saludables

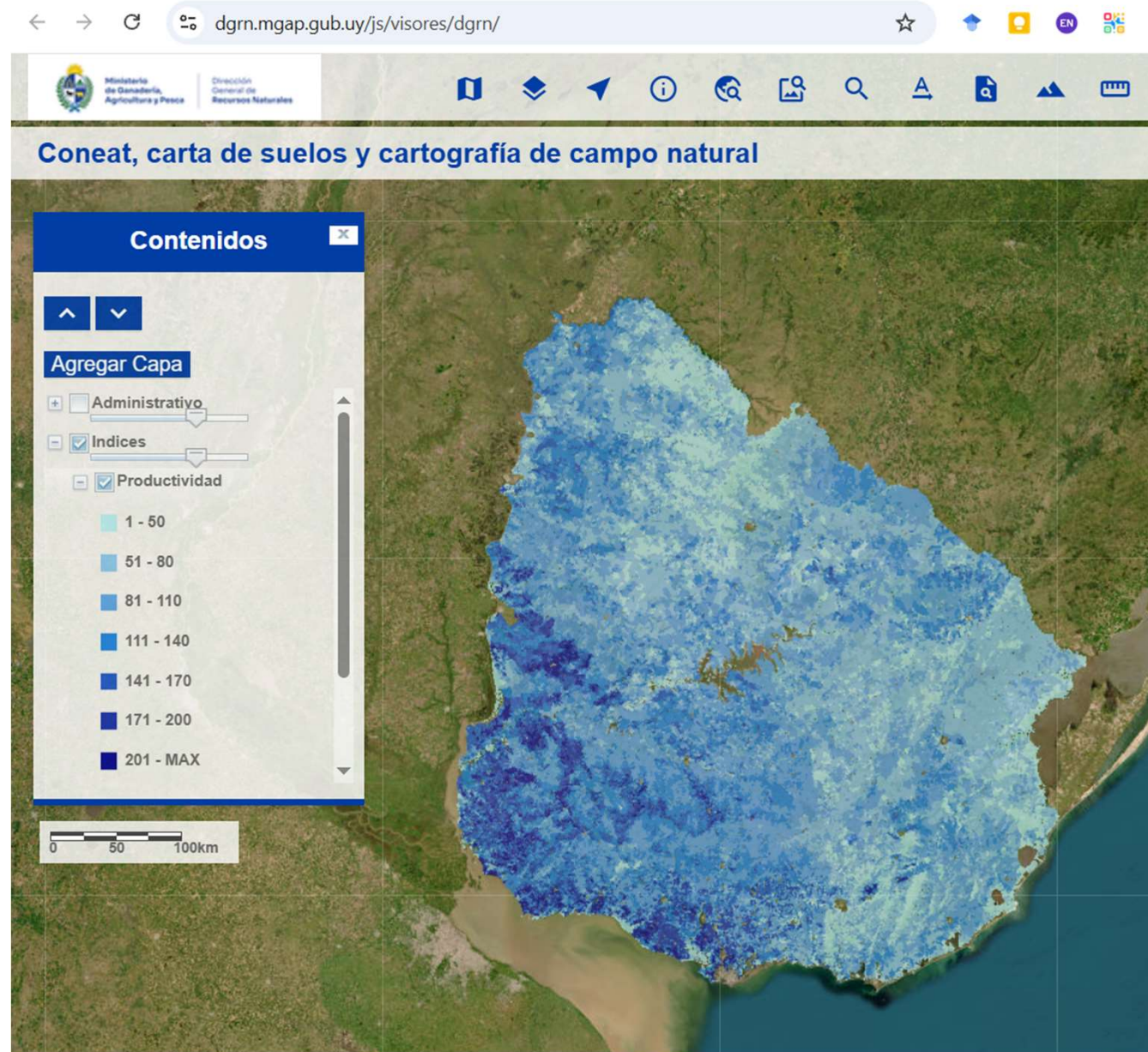
6. Tiempo geológico (millones de años)

7. Nuevo levantamiento tectónico reinicia el ciclo

PROCESOS CLAVE

- Procesos tectónicos (rápidos)
- Procesos de meteorización (medios)
- Formación de suelo y ecosistemas (lentos)

¿y en UY?



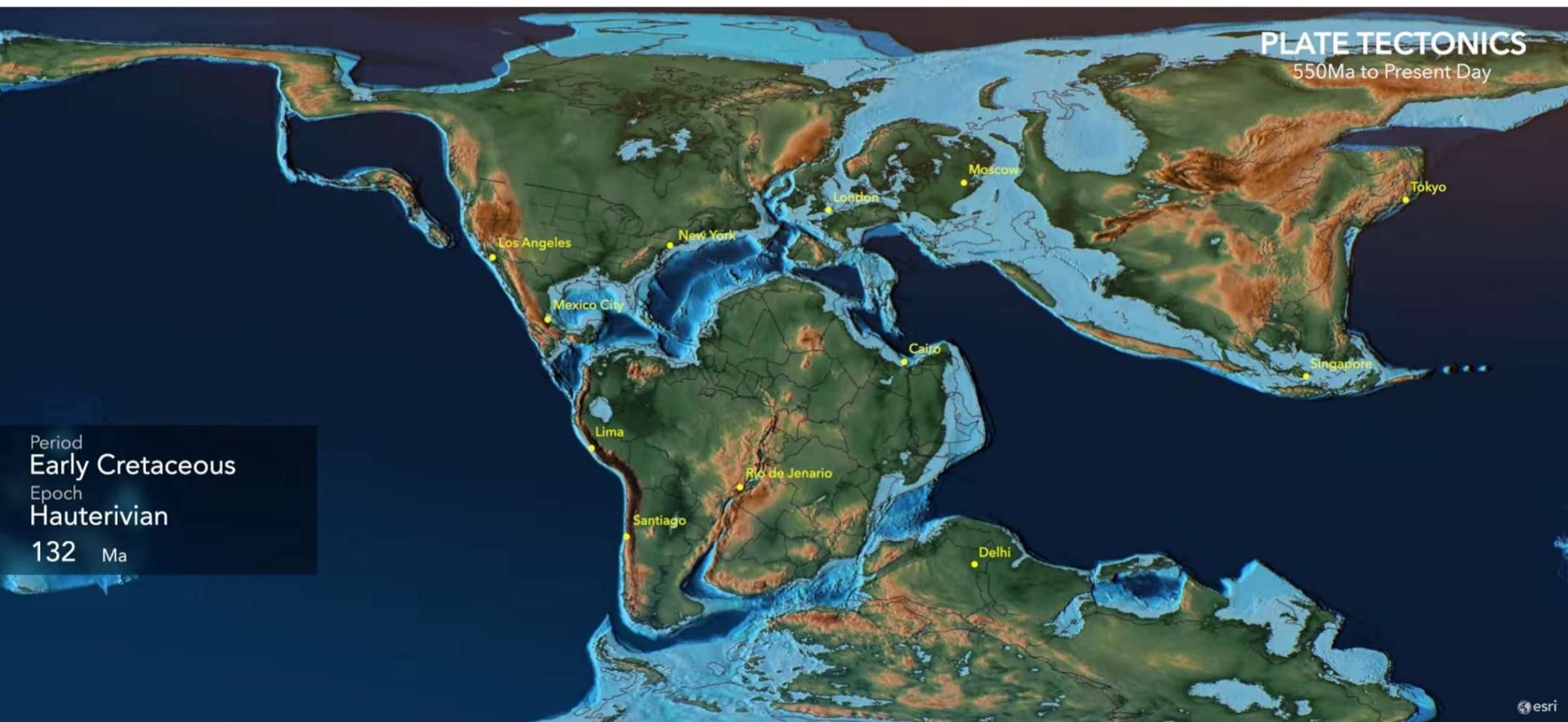
¿suelos viejos o jóvenes? ¿ricos o pobres?

El magmatismo más joven datado en Uruguay ~130 millones de años.

Desde entonces está volcánicamente inactivo, asentado en una posición intraplaca y tectónicamente estable.



Sierra de las Ánimas (Maldonado)



RESEARCH LETTER
10.1002/2015GL063040

Key Points
 • About 28 Tg of Saharan dust is deposited into the Amazon yearly
 • African dust plays an important role in preventing phosphorus depletion
 • Analytically well constrained by model simulation (uncertainty is clarified)

Supporting Information
 • Tables S1 and S2
 • Figures S1–S4
 • Text S1
 • Text S2
 • Text S3
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The fertilizing role of African dust in the Amazon rainforest: A first multiyear assessment based on data from Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observations

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¹Earth System Science Interdisciplinary Center, University of Maryland, College Park, Maryland, USA, ²Earth Sciences Division, NASA Goddard Space Flight Center, Greenbelt, Maryland, USA, ³Tuamotu Center for Earth Science and Technology, University of Maryland, Baltimore County, Baltimore, Maryland, USA, ⁴Cooperative Institute for Marine and Atmospheric Studies, Rosenstam School of Marine and Atmospheric Science, University of Miami, Miami, Florida, USA, ⁵Patrick Leahy Research Center, Hampton, Virginia, USA, ⁶Universities Space Research Association, Columbia, Maryland, USA, ⁷Department of Physics, University of Maryland, Baltimore County, Baltimore, Maryland, USA, ⁸Atmospheric Science and Global Change Division, Pacific Northwest National Laboratory, Richland, Washington, USA

Abstract The productivity of the Amazon rainforest is constrained by the availability of nutrients, in particular phosphorus (P). Deposition of long-range transported African dust is recognized as a potentially important but poorly quantified source of phosphorus. This study provides a first multiyear satellite-based estimate of dust deposition into the Amazon Basin using three-dimensional (3-D) aerosol measurements over 2007–2013 from the Cloud-Aerosol Lidar with Orthogonal Polarization (CALIOP). The 7-year average of dust deposition into the Amazon Basin is estimated to be 28 (8–48) Tg a⁻¹ or 29 (8–58 kg ha⁻¹ a⁻¹). The dust deposition shows significant interannual variation that is negatively correlated with the prior-year rainfall in the Sahel. The CALIOP-based multiyear mean estimate of dust deposition matched better with estimates from in situ measurements and model simulations than a previous satellite-based estimate does. The closer agreement benefits from a more realistic geographic definition of the Amazon Basin and inclusion of meridional dust transport calculation in addition to the 3-D nature of CALIOP aerosol measurements. The reported dust could provide about 0.022 (0.006–0.037) Tg of phosphorus per year, equivalent to 23 (7–39) g P ha⁻¹ a⁻¹ to fertilize the Amazon rainforest. This out-of-basin phosphorus input is comparable to the hydrological loss of phosphorus from the basin, suggesting an important role of African dust in preventing phosphorus depletion on timescales of decades to centuries.

1. Introduction

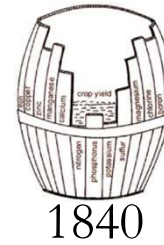
The Amazon rainforest represents about half of the planet's remaining rainforests and is an important ecosystem that plays a crucial role in regulating the Earth's climate. Relatively small changes in the forest cover and productivity could have important implications for the carbon cycle, atmospheric circulation, the hydrology cycle, and climate from regional to global scales (Dunbar et al., 1990; Ingersoll et al., 2008; Balch et al., 2008). Phosphorus (P) is the principal fertility factor influencing tree growth across the Amazon Basin (Vitousek, 1984; Meentemeyer et al., 2011). However, 90% of soils in the Amazon Basin are P deficient (Donner et al., 1992). It has been suggested that long-term productivity of the Amazon rainforest depends heavily on the atmospheric deposition of dust that may come from a distant ecosystem such as the Saharan desert (Dunin et al., 2008). Although the presence of African dust in the Amazon Basin has long been observed (Prospero et al., 1992; Taltel et al., 1995; Formenti et al., 2001; Scheffé et al., 2008; Atsumann et al., 2009; Ben-Ami et al., 2010; Bazzari et al., 2011, 2012), the dust deposition and associated P input are not yet well quantified. Recently, advanced satellite observations with routine sampling and large spatial and temporal coverage have become ideal for quantifying the intercontinental transport and deposition of aerosol (Kaufman et al., 2005; Yu et al., 2008, 2012a, 2013). Substantial discrepancies still exist between measurements and models (e.g., Sweep et al., 1992; Kaufman et al., 2005; Bazzari et al., 2010; Riley et al., 2012). Factors contributing to the large discrepancies in the dust deposition are not fully understood or at least not adequately accounted for. There are several possible reasons for the large range of discrepancy between

Transporte eólico (intercontinental)



Volvamos a los 1800s... post von Humboldt...

1802
von Humboldt



738

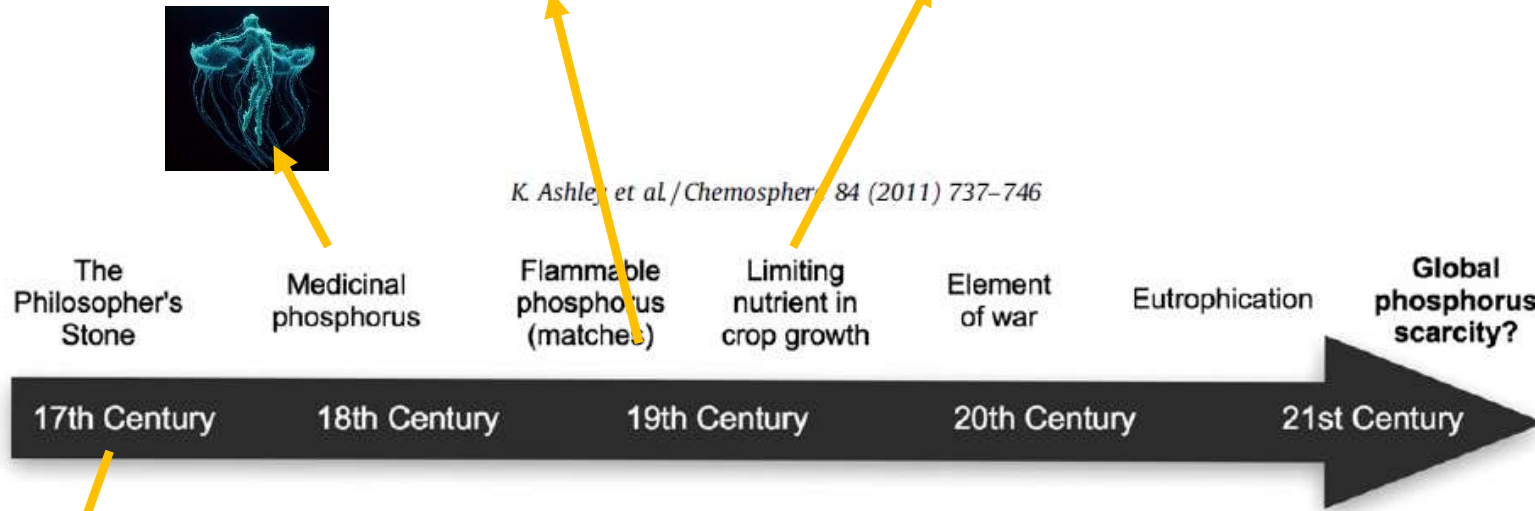
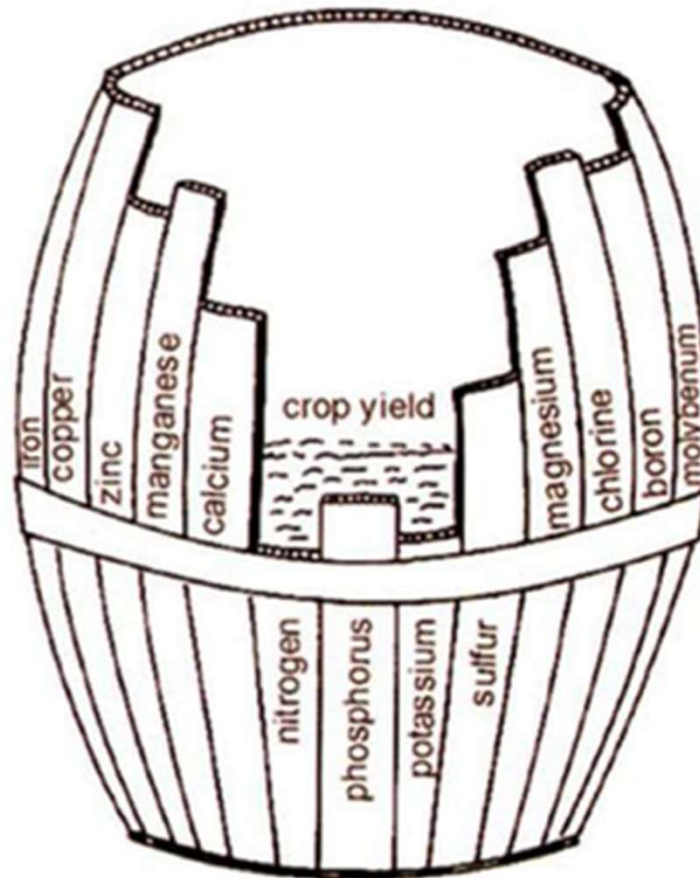


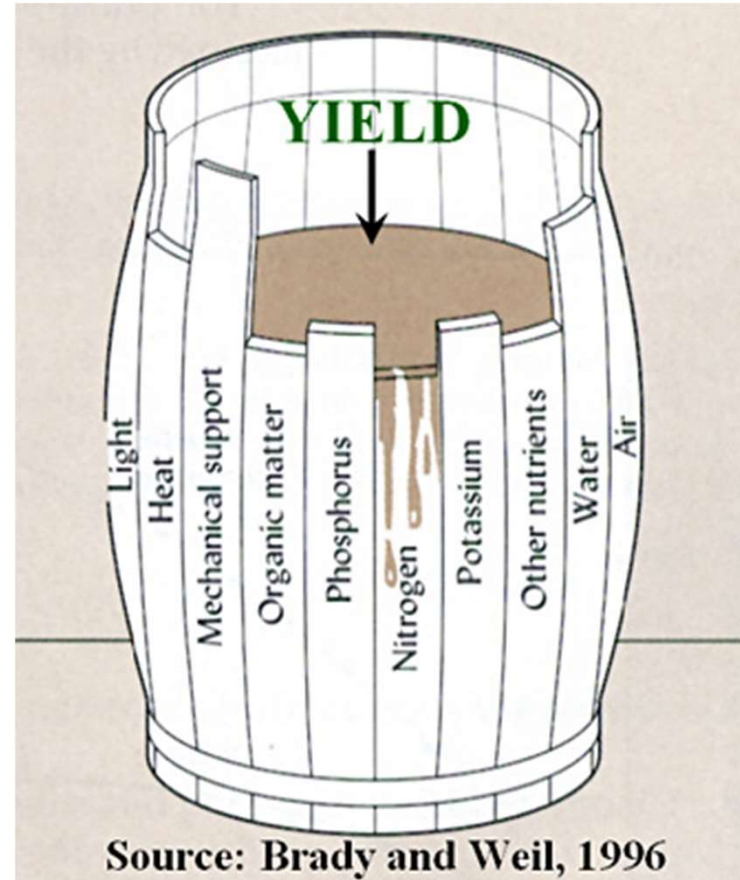
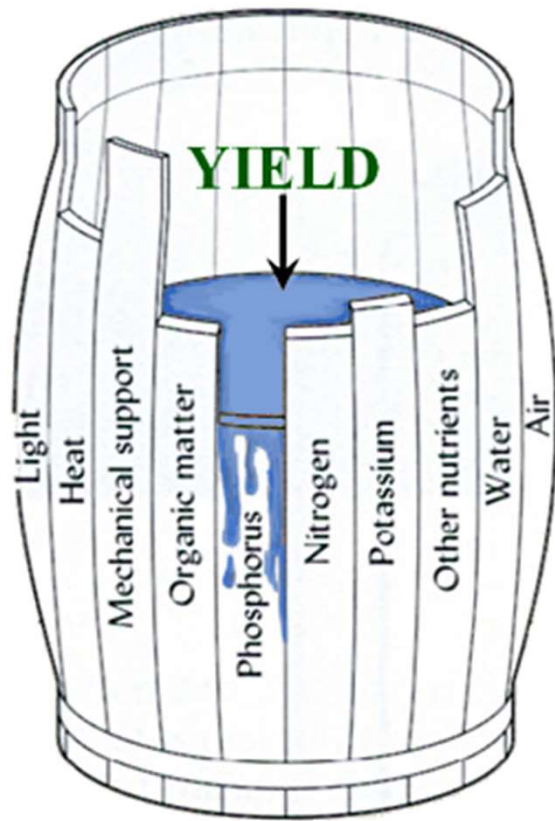
Fig. 1. The evolution of phosphorus use and abuse: from the Philosopher's Stone to use in war, food production, and more recently implicated in water pollution. A new emerging discourse of the 21st century may be global phosphorus scarcity. Source: Cordell (2010).



Ley del mínimo de Liebig



¿Cuál es la escala con la que se mide la altura de las tablas?



Relación demanda/disponibilidad

nutrientes

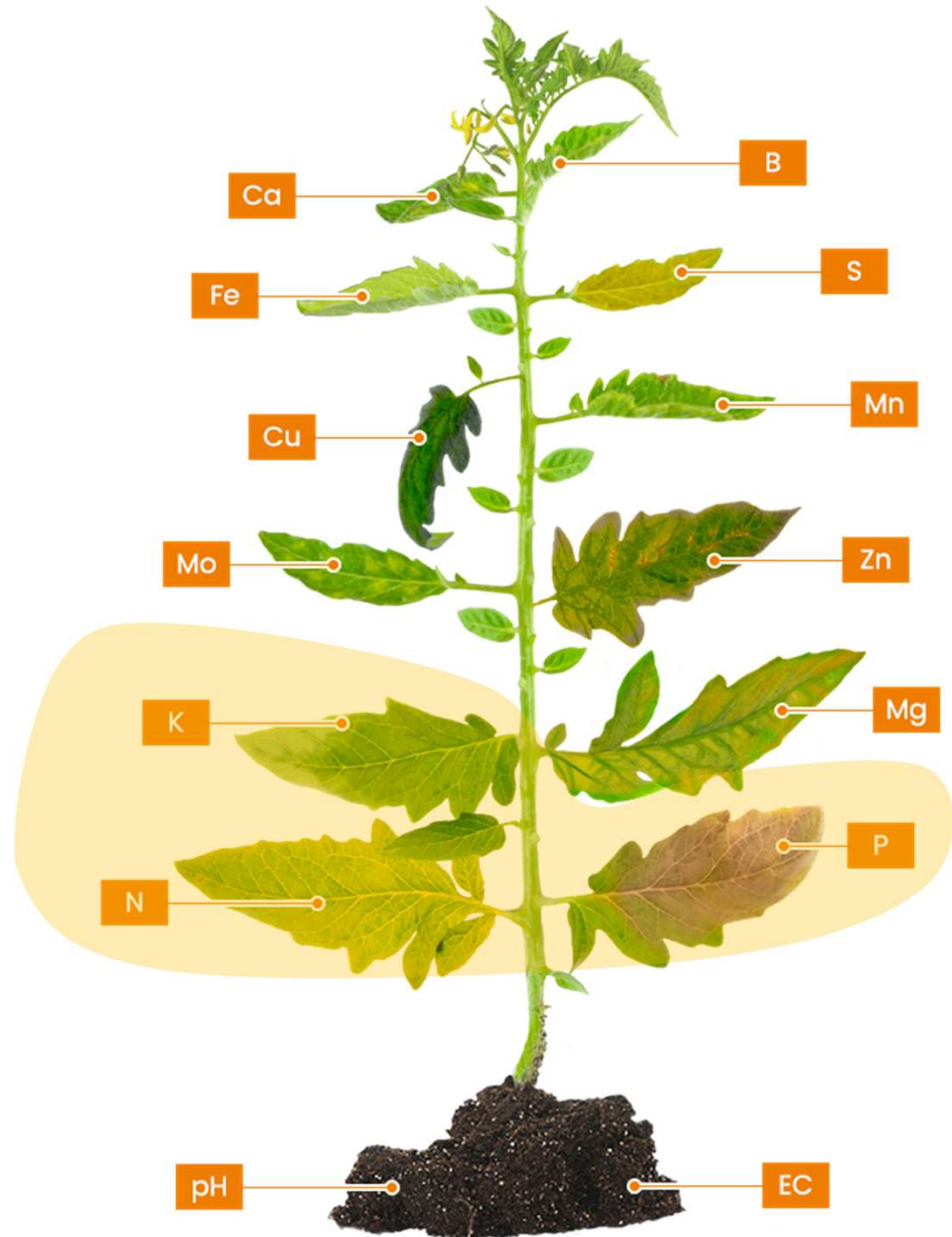
TABLE 36.1

Mineral Elements Required by Plants

ELEMENT	ABSORBED FORM	MAJOR FUNCTIONS
MACRONUTRIENTS		
Nitrogen (N)	NO_3^- and NH_4^+	In proteins, nucleic acids, etc.
Phosphorus (P)	H_2PO_4^- and HPO_4^{2-}	In nucleic acids, ATP, phospholipids, etc.
Potassium (K)	K^+	Enzyme activation; water balance; ion balance; stomatal opening
Sulfur (S)	SO_4^{2-}	In proteins and coenzymes
Calcium (Ca)	Ca^{2+}	Affects the cytoskeleton, membranes, and many enzymes; second messenger
Magnesium (Mg)	Mg^{2+}	In chlorophyll; required by many enzymes; stabilizes ribosomes
MICRONUTRIENTS		
Iron (Fe)	Fe^{2+} and Fe^{3+}	In active site of many redox enzymes and electron carriers; chlorophyll synthesis
Chlorine (Cl)	Cl^-	Photosynthesis; ion balance
Manganese (Mn)	Mn^{2+}	Activation of many enzymes
Boron (B)	$\text{B}(\text{OH})_3$	Possibly carbohydrate transport (poorly understood)
Zinc (Zn)	Zn^{2+}	Enzyme activation; auxin synthesis
Copper (Cu)	Cu^{2+}	In active site of many redox enzymes and electron carriers
Nickel (Ni)	Ni^{2+}	Activation of one enzyme
Molybdenum (Mo)	MoO_4^{2-}	Nitrate reduction

LIFE 8e, Table 36.1

LIFE: THE SCIENCE OF BIOLOGY, Eighth Edition © 2007 Sinauer Associates, Inc. and W. H. Freeman & Co.





La fiebre del guano

The Peruvian seabird guano
will normally test out to
10% NITROGEN
10% PHOSPHORUS and
2% POTTASIUM.

**SOLUBLE PACIFIC
GUANO**

CORN

POTATOES

TOBACCO

GRASS

ROOT

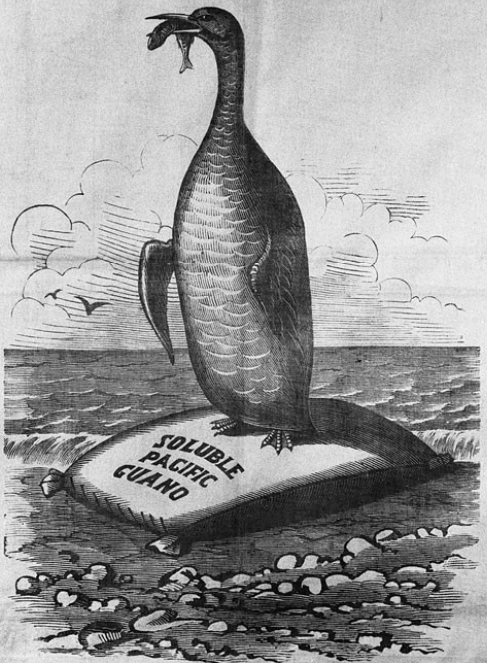
AND

GRAIN CROPS

Of all kinds

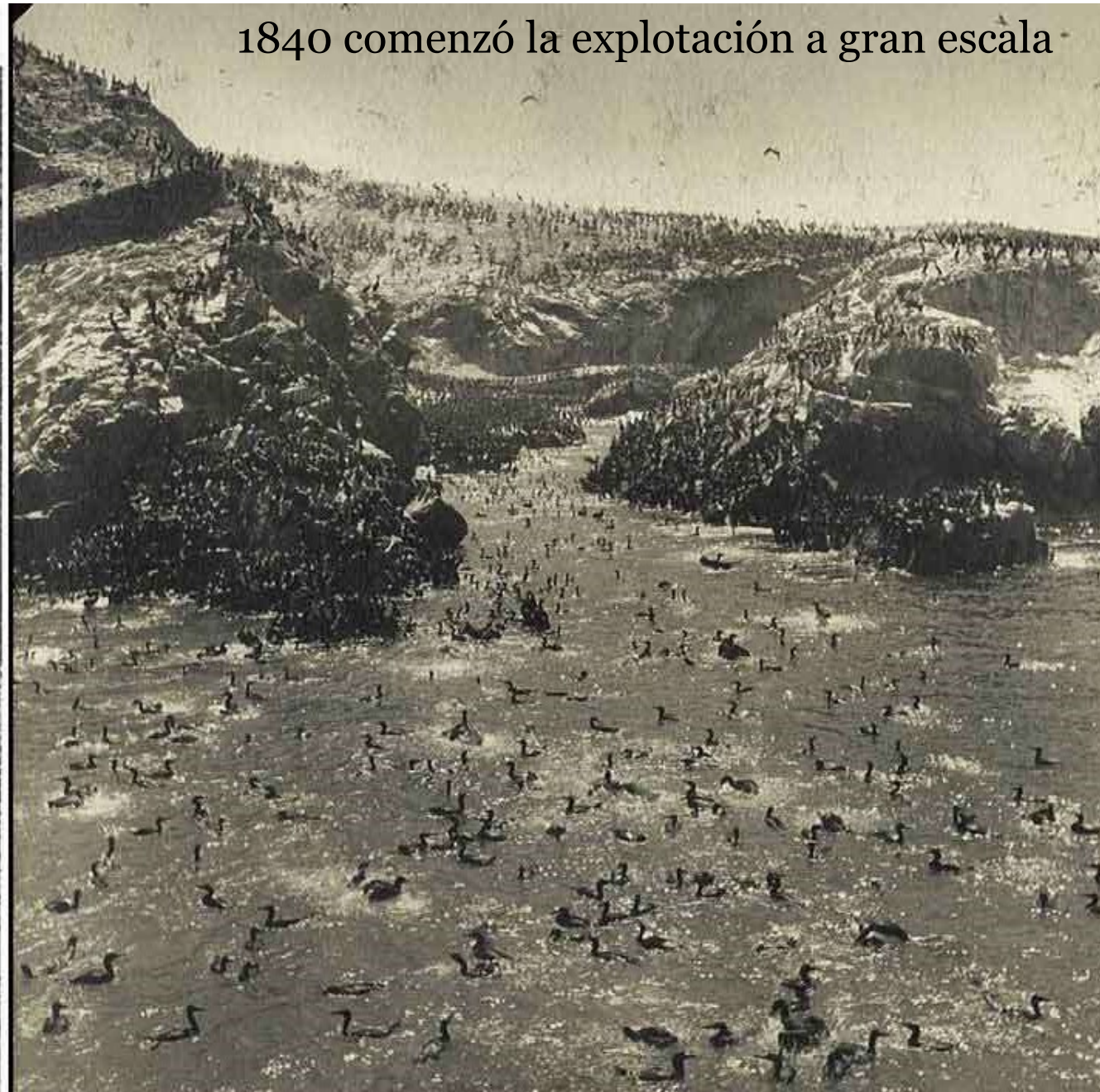
**GARDEN
VEGETABLES**

&c., &c.

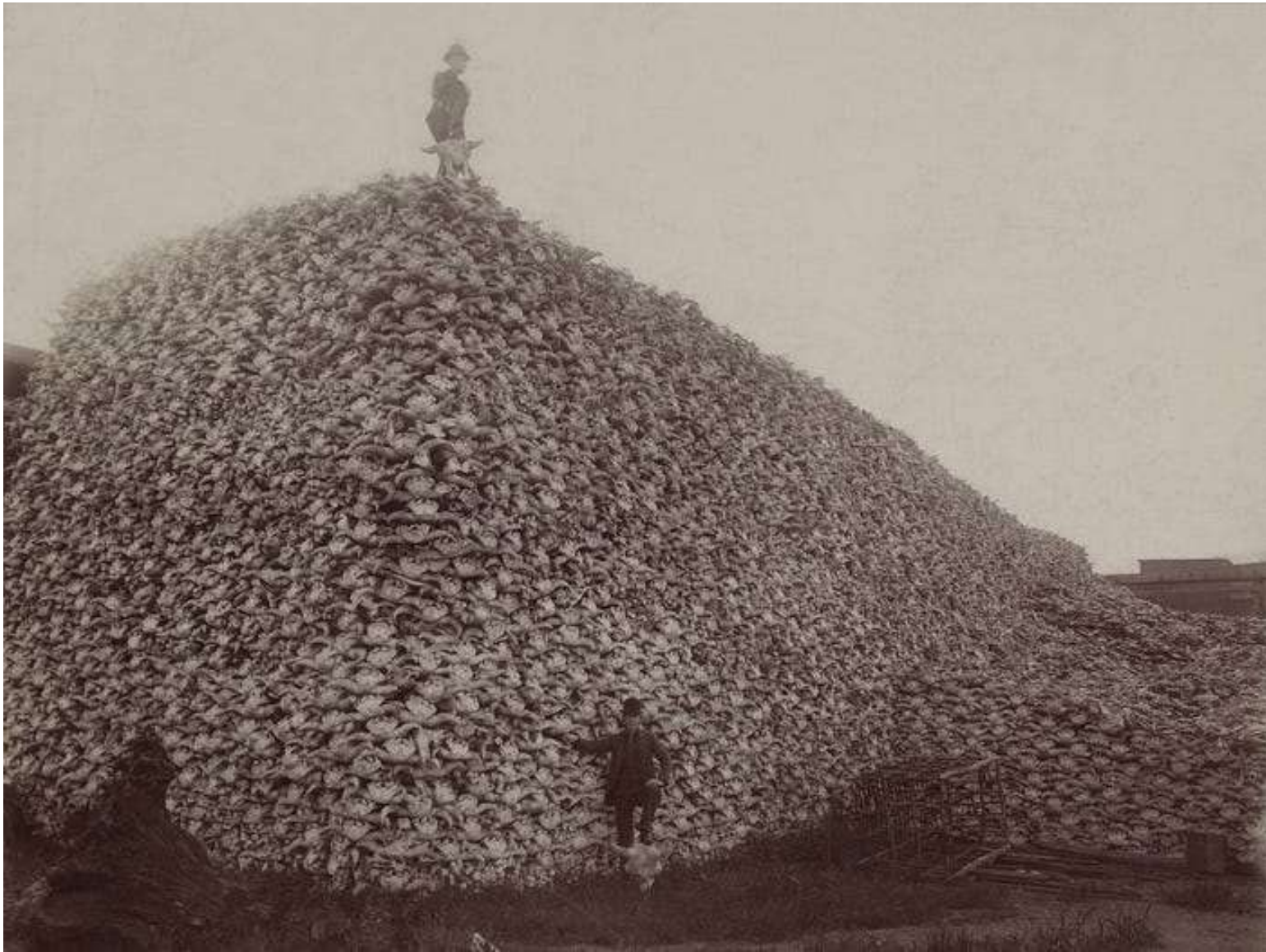


**ITS USE SECURES TO THE FARMER A
LARGE AND REMUNERATIVE CROP,**
And has been found to pay better than any other investment.

FOR PARTICULARS CALL ON



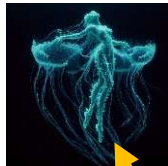




Large pile of bison skulls that will be ground into fertilizer in the US around 1870.

Ashley, K., Cordell, D., Mavinic, D., 2011. A brief history of phosphorus: From the philosopher's stone to nutrient recovery and reuse. *Chemosphere* 84, 737-746.

1802
von Humboldt



738

K. Ashley et al / Chemosphere 84 (2011) 737-746

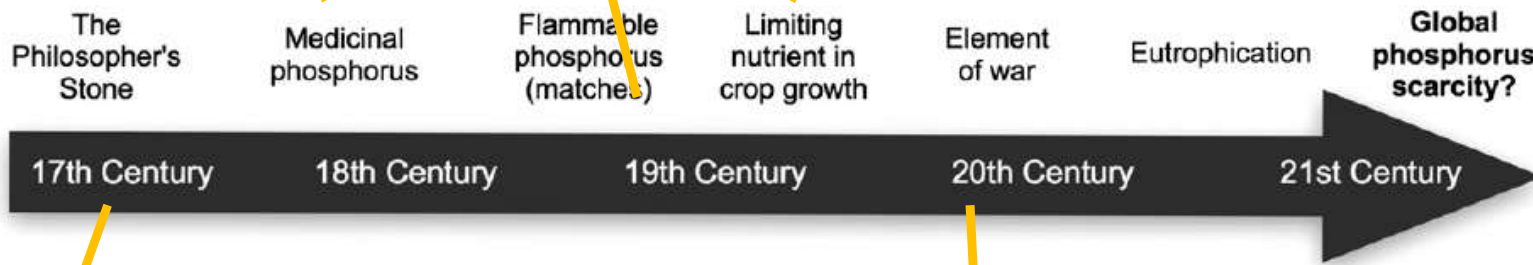


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1938



FRANKLIN D. ROOSEVELT

32nd President of the United States: 1933 - 1945

Message to Congress on
Phosphates for Soil Fertility.

May 20, 1938

The American Presidency Project

ABOUT

SEARCH

UC SANTA BARBARA



May 20, 1938

FRANKLIN D. ROOSEVELT

32nd President of the United States: 1933 - 1945

Message to Congress on Phosphates for Soil Fertility.



FRANKLIN D. ROOSEVELT

XXXII President of the United States: 1933-1945

64 - Message to Congress on Phosphates for Soil Fertility.
May 20, 1938

“El contenido de fósforo de nuestra tierra, tras generaciones de cultivo, ha disminuido considerablemente. Necesita reponerse. Por lo tanto, la necesidad de un uso más amplio de los fosfatos y la conservación de nuestros suministros de fosfatos para las generaciones futuras es un asunto de gran preocupación pública. No podemos dar a nuestra agricultura una base permanente a menos que le prestemos atención.”

“No puedo dejar de enfatizar la importancia del fósforo no sólo para la agricultura y la conservación del suelo sino también para la salud física y la seguridad económica de la gente de la nación. Muchos de nuestros tipos de suelo son deficientes en fósforo, lo que provoca bajos rendimientos y mala calidad de los cultivos y pastos.”



FRANKLIN D. ROOSEVELT

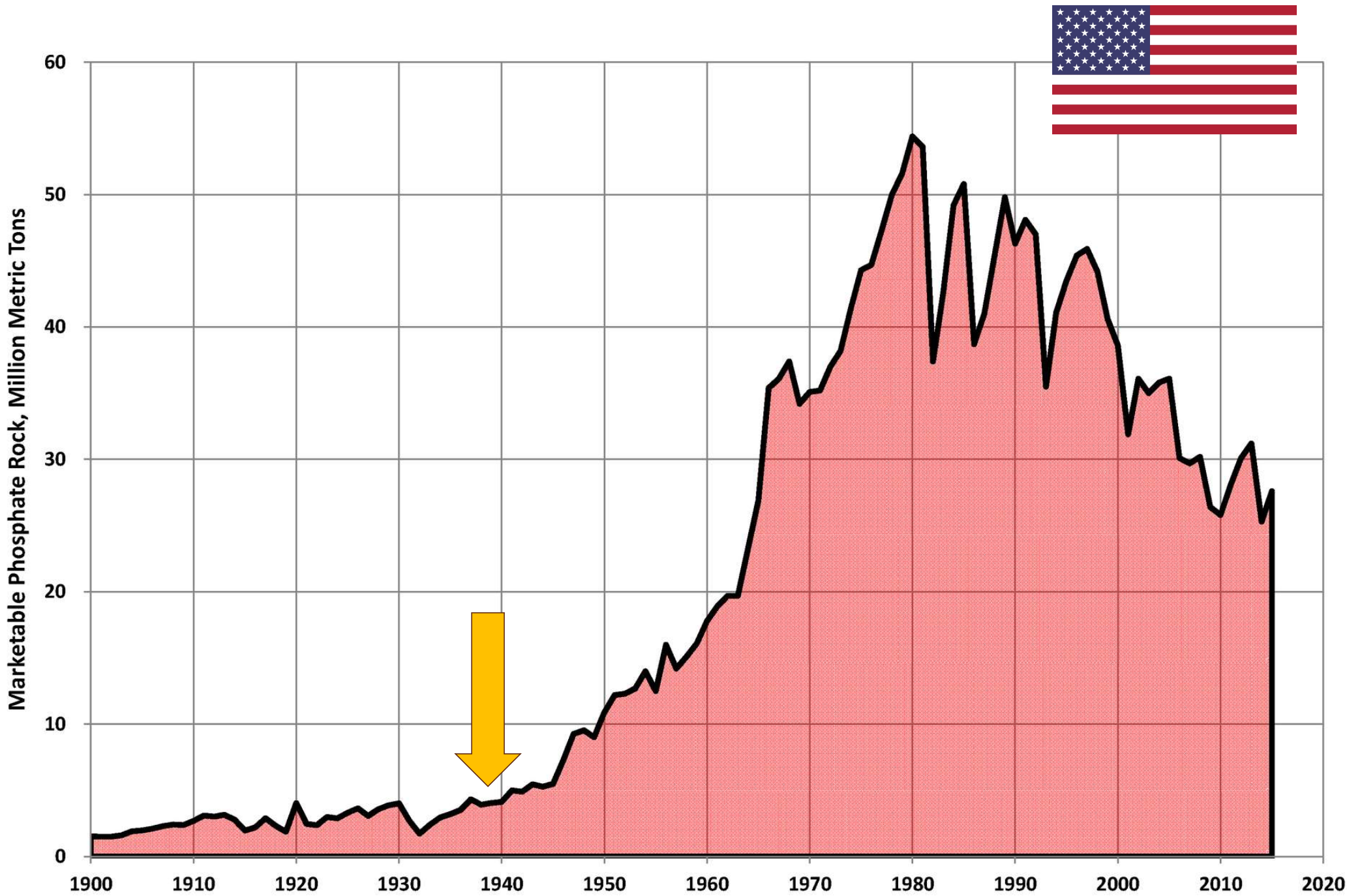
XXXII President of the United States: 1933-1945

64 - Message to Congress on Phosphates for Soil Fertility.
May 20, 1938

“Estimaciones recientes indican que la eliminación de fósforo de los suelos de los Estados Unidos mediante la cosecha, el pastoreo, la erosión y la lixiviación supera con creces la adición de fósforo al suelo mediante fertilizantes, estiércol animal, lluvia, riego y semillas.

Parece que incluso con un control completo de la erosión, lo que obviamente es imposible, no se mantendrá un alto nivel de productividad a menos que el fósforo regrese al suelo a un ritmo mayor que el que se hace actualmente. Los aumentos mediante la adición de fósforo al suelo deben realizarse en gran medida, si no en su totalidad, en forma de fertilizantes derivados principalmente de la roca fosfórica.

Por lo tanto, la cuestión del suministro continuo y suficiente de roca fosfórica atañe directamente al bienestar nacional.”



(US Geological Survey)

Global Fertilizer Trade Map 2025

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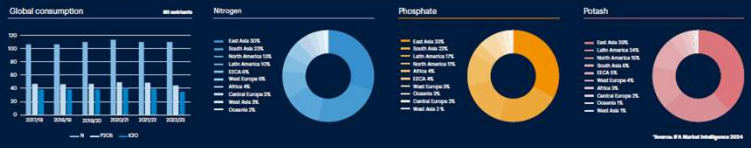
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Fertilizer Consumption By Region 2022/23



Conversion factors

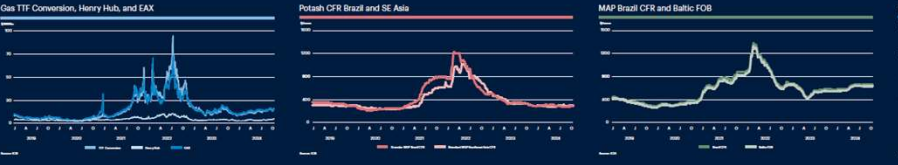
Ammonia (t)	Ammonia (t) (shaded by)	0.93
Urea (t)	Urea (t) (shaded by)	0.98
Phosphate (t)	Phosphate Rock (t)	0.38
MAP (t)	MAP (t)	0.93
DAP (t)	DAP (t)	0.93
Potash (t)	Potash (t) or K2O (t)	0.88

Key

- Green: Demand
- Blue: Supply
- Red: Net Demand
- Yellow: Net Supply

The width of the arrows indicates the relative size of flows from the current position of origin and destination on the global trade map.

Get all coverage for trade flows to 2025 (2020) season provided between 1st July 2024 and 31st July 2024.



Global Fertilizer Trade Map 2025

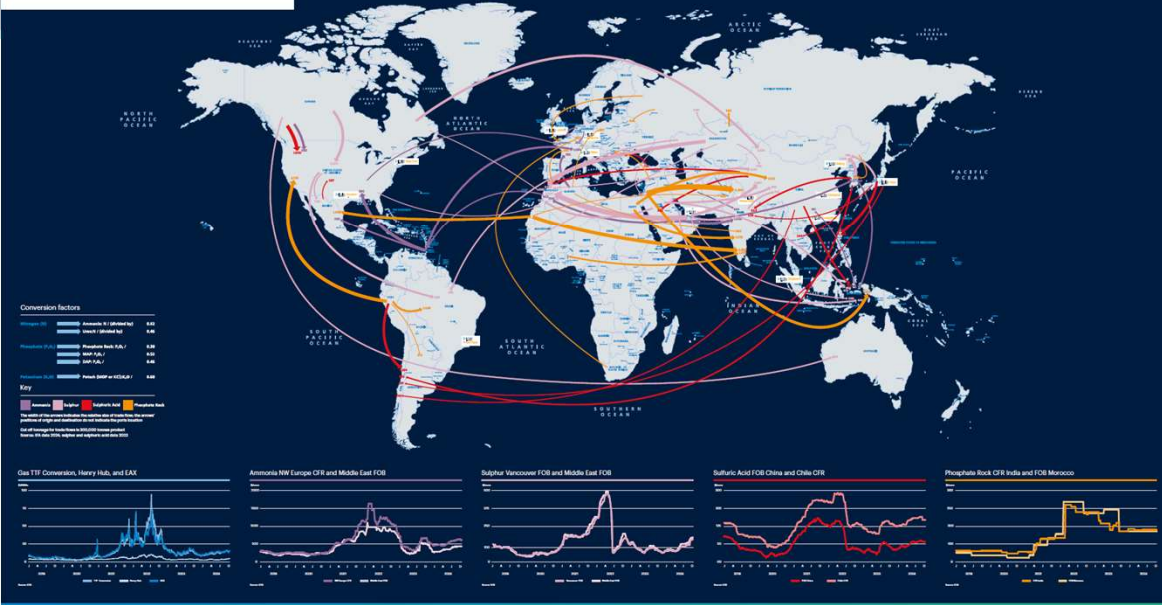
FERTILIZER FEEDSTOCKS

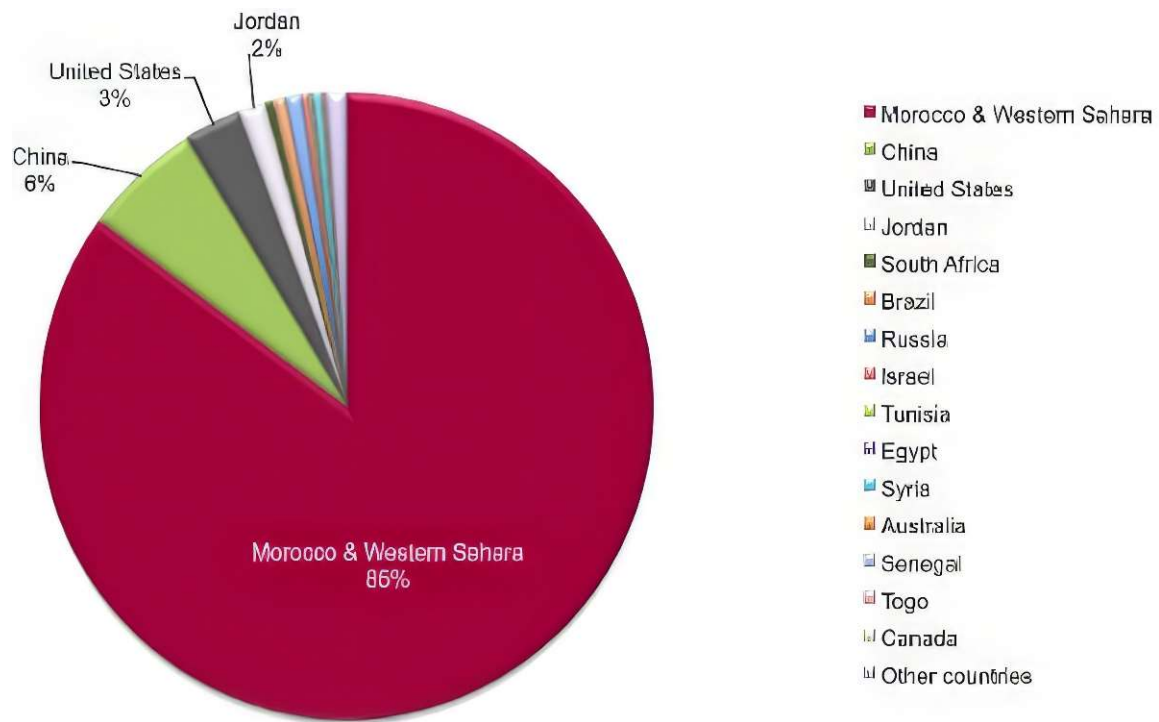
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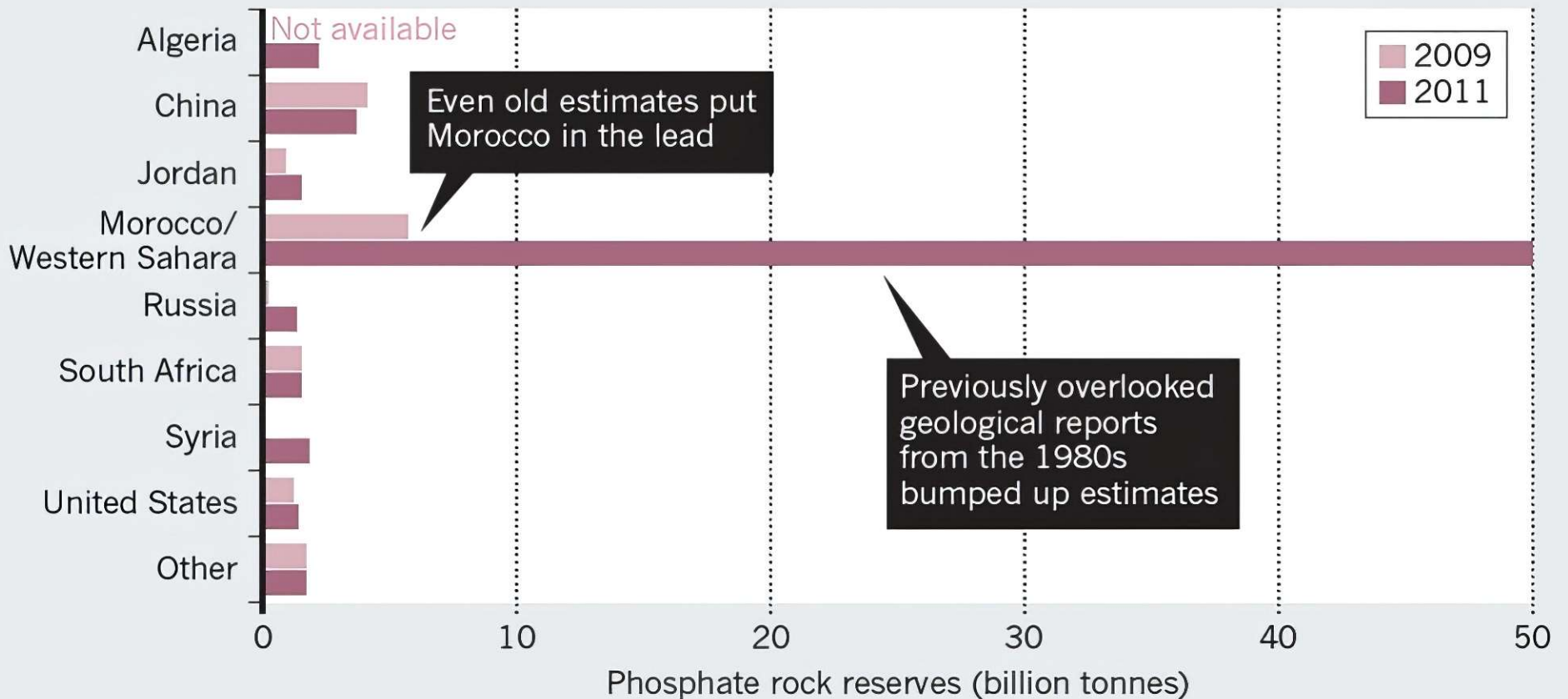




Cordell, D., White, S., 2011. Peak Phosphorus: Clarifying the Key Issues of a Vigorous Debate about Long-Term Phosphorus Security. Sustainability 3, 2027.

GLOBAL IMBALANCE

Morocco holds the vast majority of global supplies of phosphorus; but these estimates can change disturbingly quickly.



How is phosphate formed?



Phosphate is a sedimentary rock formed millions of years ago by the accumulation of organic matter on the ocean floor. Phosphate reserves are found in Africa, North America, Kazakhstan, the Middle East and Oceania but the world's largest deposits are located in Morocco, which is also one of the global leaders in phosphate extraction.



<https://maps.app.goo.gl/SR5PZeaHwo7ZP7h86>

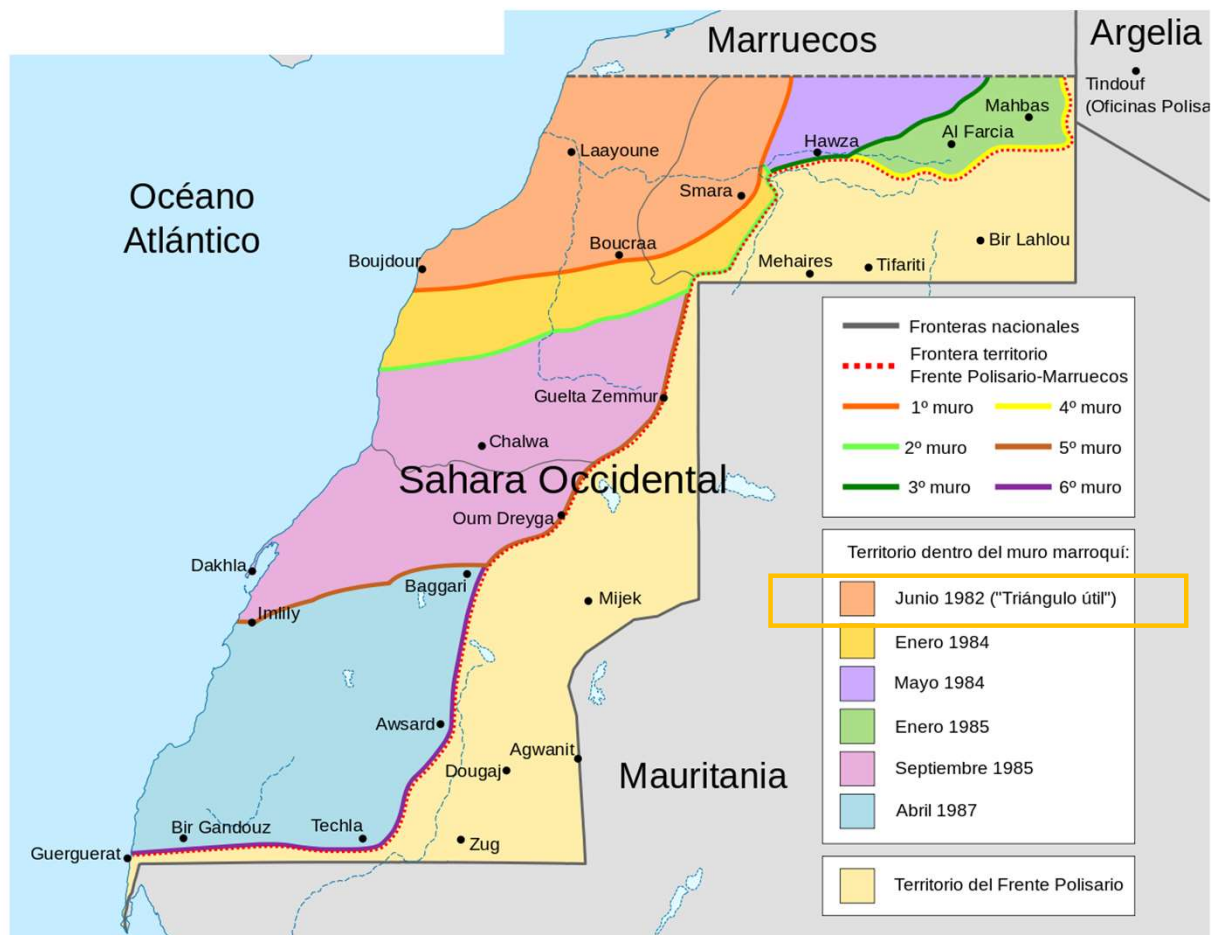
Bu Craa (West Sahara)



Estatus político del Sahara Occidental

Artículo [Discusión](#)

El **estatus político del Sahara Occidental** y la cuestión de su **soberanía** son objetos de controversia. Es uno de los diecisiete integrantes de la **lista de territorios no autónomos de las Naciones Unidas** bajo supervisión de su **Comité Especial de Descolonización**, y aunque para la **ONU** la potencia administradora sigue siendo **España**, lo cierto es que al retirarse del territorio en 1976 este país renunció a la **administración del Sahara Occidental** y a toda responsabilidad internacional sobre el territorio. Su soberanía es reclamada actualmente por el **Reino de Marruecos** y la **República Árabe Saharaui Democrática**, que se disputan el control de la totalidad del territorio.



1802
von Humboldt



Revolución verde
1960

738

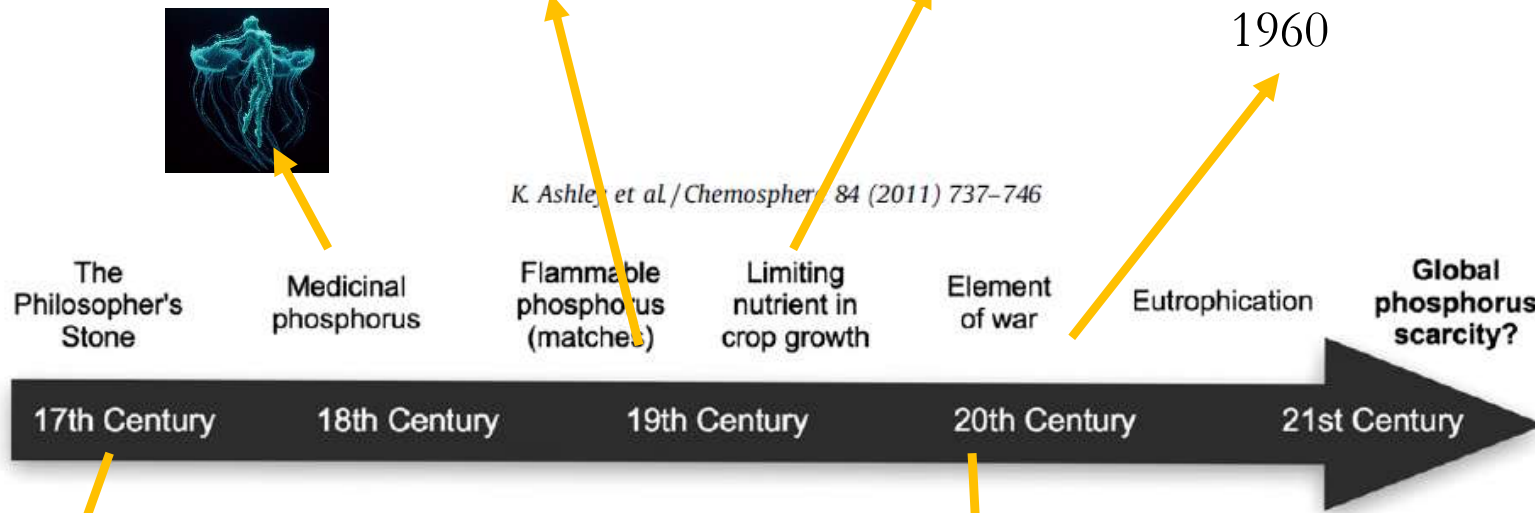


Fig. 1. The evolution of phosphorus use and abuse: from the Philosopher's Stone to use in war, food production, and more recently implicated in water pollution. A new emerging discourse of the 21st century may be global phosphorus scarcity. Source: Cordell (2010).



1938



FRANKLIN D. ROOSEVELT


32nd President of the United States: 1933 - 1945

Message to Congress on
Phosphates for Soil Fertility.

May 20, 1938

Revolución verde

Es la denominación usada internacionalmente para describir el importante incremento de la productividad agrícola y, por tanto, de alimentos entre 1960 y 1980 en Estados Unidos y extendida después por numerosos países.



Norman Borlaug, fue un agrónomo, genetista, fitopatólogo, humanista estadounidense, considerado por muchos el padre de la agricultura moderna y de la **revolución verde**. Ha sido llamado "el hombre que salvó mil millones de vidas".

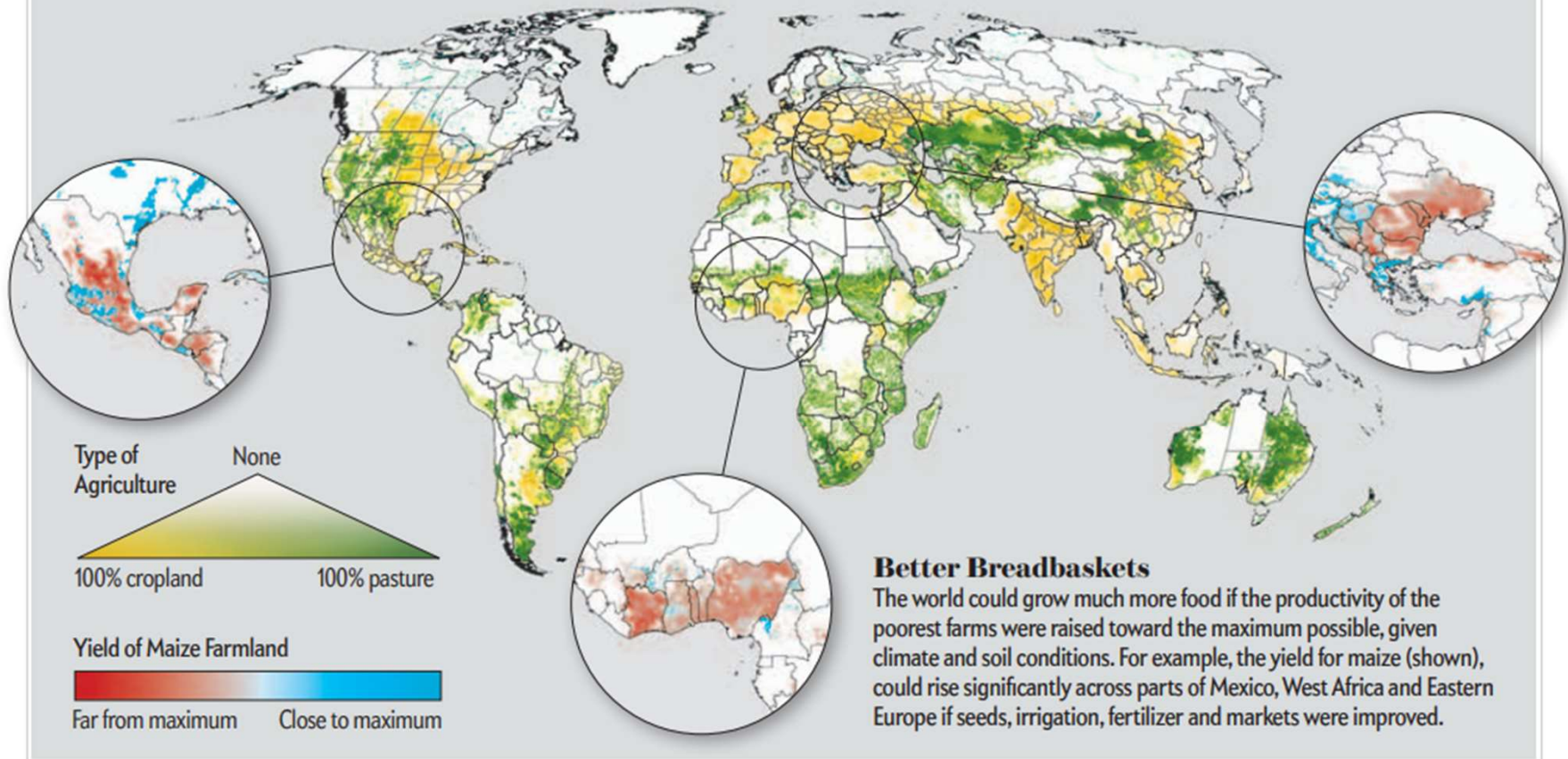
Revolución verde

Consistió en la adopción de una serie de prácticas y tecnologías siembra de variedades de cereal más resistentes a los climas extremos y a las plagas nuevos métodos de cultivo (incluyendo la mecanización) uso de fertilizantes, plaguicidas y riego.

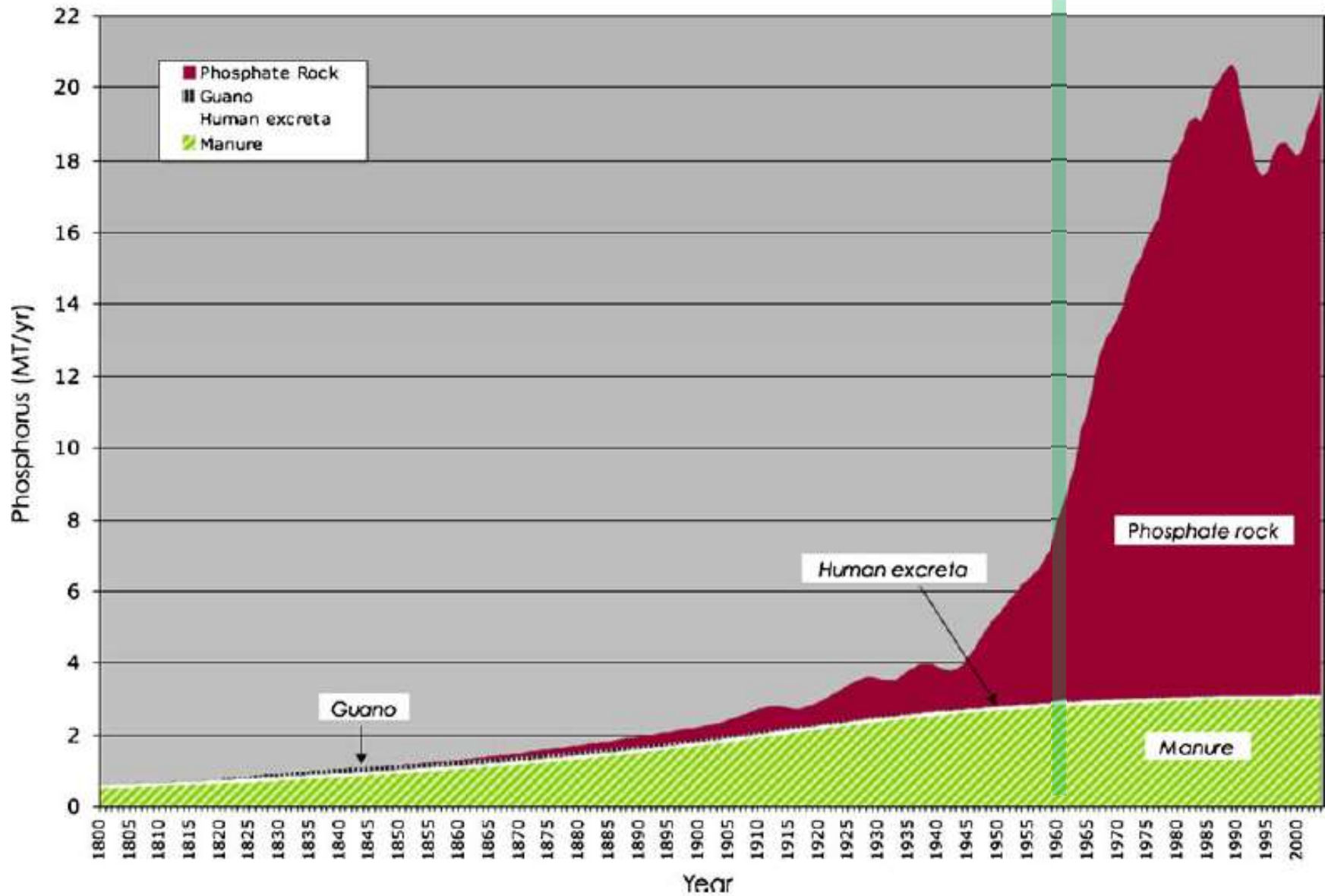


Farming Hits the Wall, But Not the Ceiling

Humankind now farms 38 percent of the earth's ice-free land. Crops cover one-third of that area; pastures and ranges for livestock cover the rest. Little room exists for expansion because most of the remaining land is deserts, mountains, tundra or urban. Still, farms in many existing areas could be more productive (insets).



Historical global sources of phosphorus fertilizers (1800-2000)



Cordell, D., J. O. Drangert and S. White (2009). "The story of phosphorus: Global food security and food for thought." *Global Environmental Change* 19: 292-305.

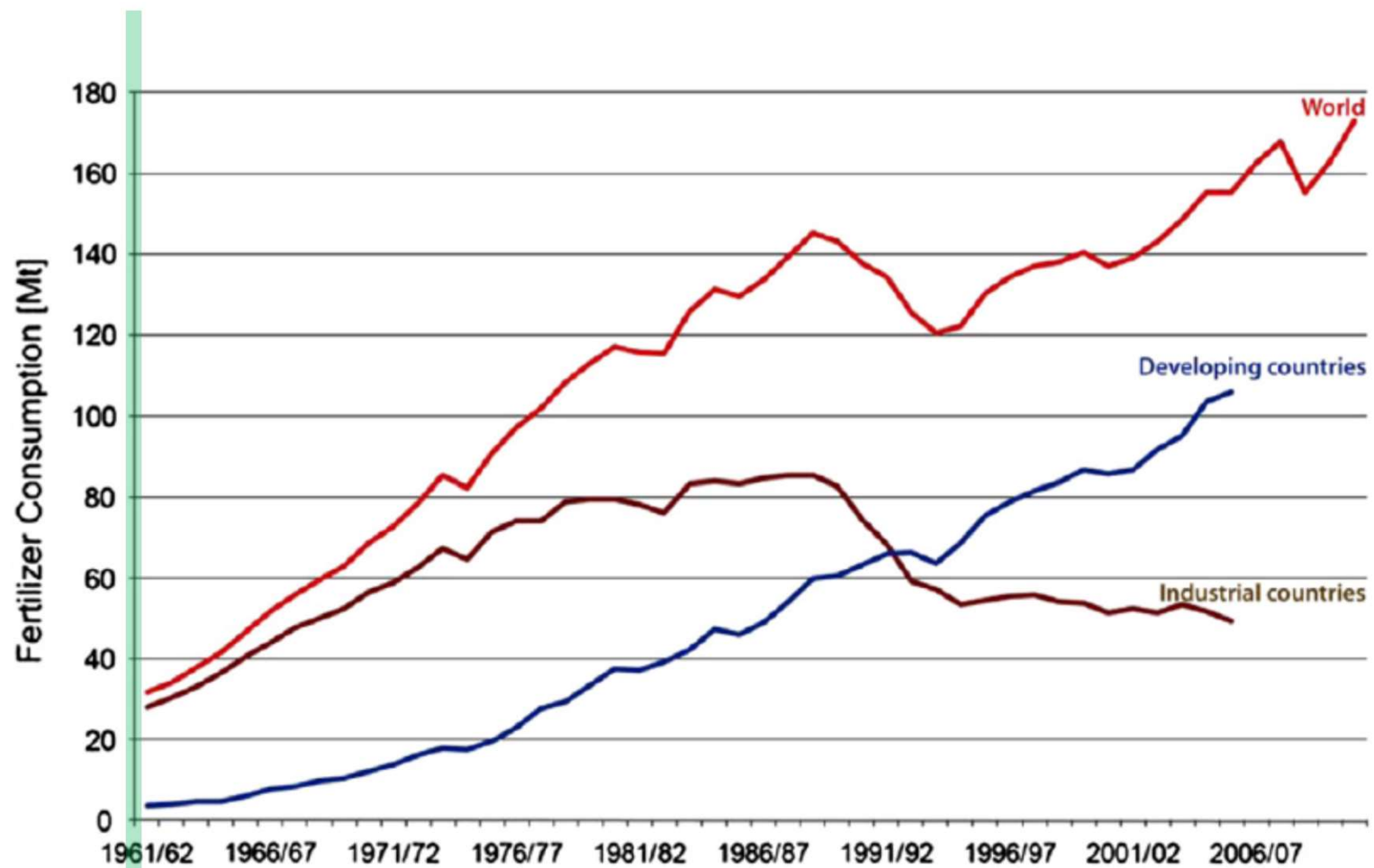
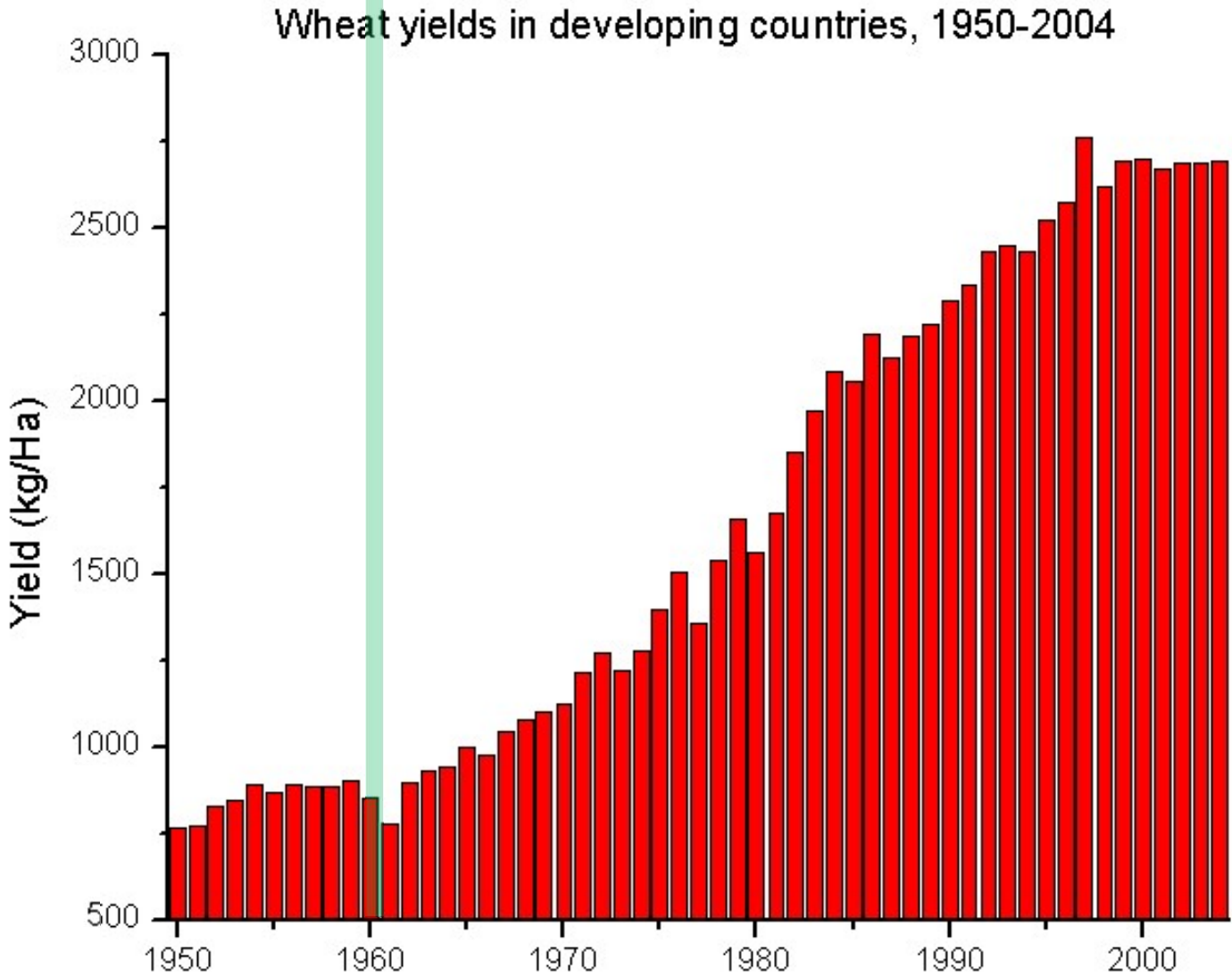


Fig. 1. Trends of fertilizer consumption in the world, developing countries and industrial countries (Röhling, 2010).

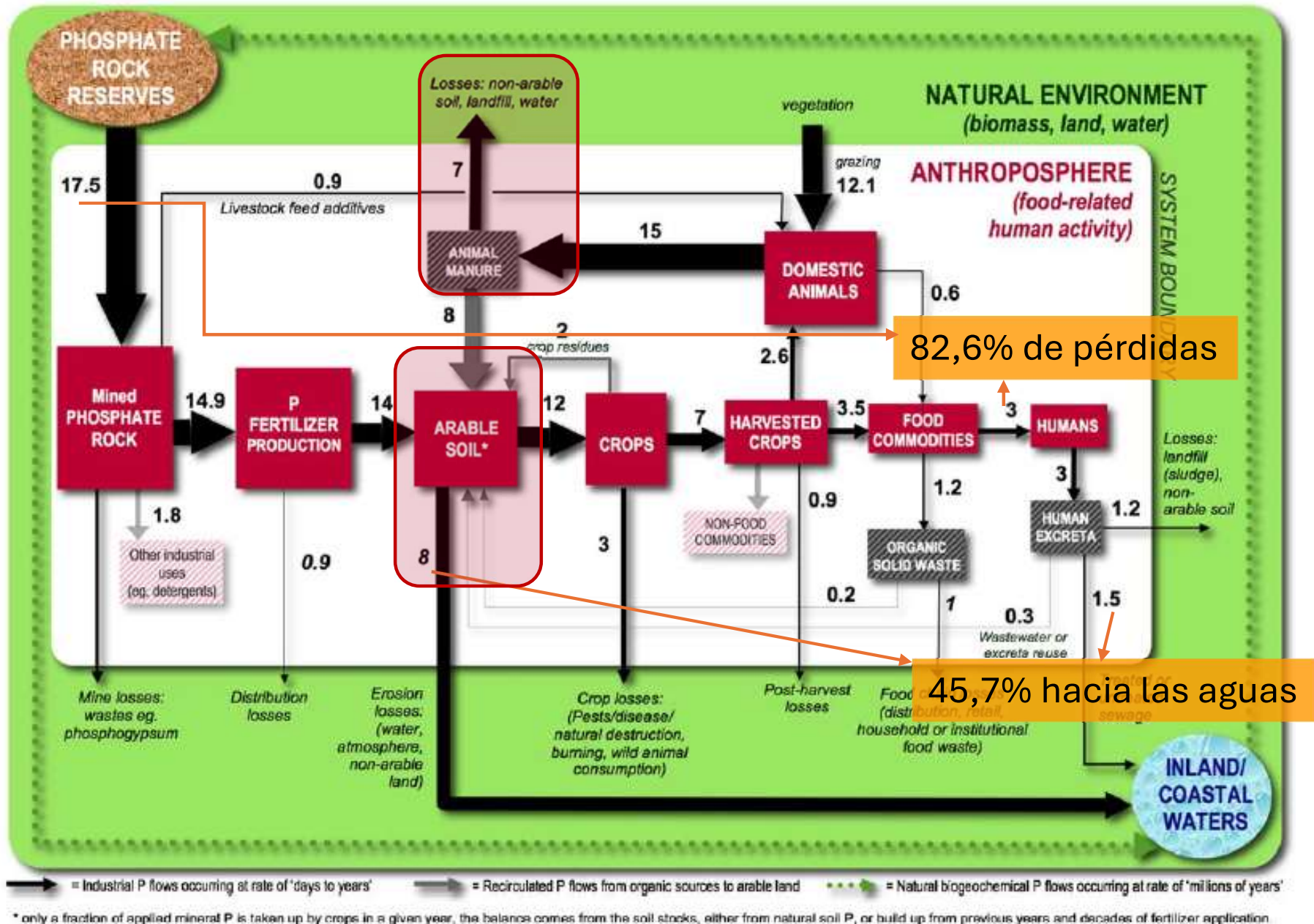
Revolución verde



Source: FAO



1 teragramo = 10^{12} g



P



F. LOEBIG/REUTERS/ISTOCK/ISTOCK

Phosphate is mined to produce fertilizers for crops, but phosphorus leaching into water supplies is an environmental hazard.

A broken biogeochemical cycle

Excess phosphorus is polluting our environment while, ironically, mineable resources of this essential nutrient are limited. **James Elser** and **Elena Bennett** argue that recycling programmes are urgently needed.

To meet our demands for energy, humankind has moved masses of carbon from deep underground into the atmosphere, wreaking havoc with the climate. To meet our demand for food, we have moved large amounts of nitrogen from the atmosphere to fields, rivers and forests, devastating ecosystems. To grow our crops we have interfered with Earth's reserves of a third element — phosphorus — which receives much less press and for which we face the unique problem of having both too much and too little.

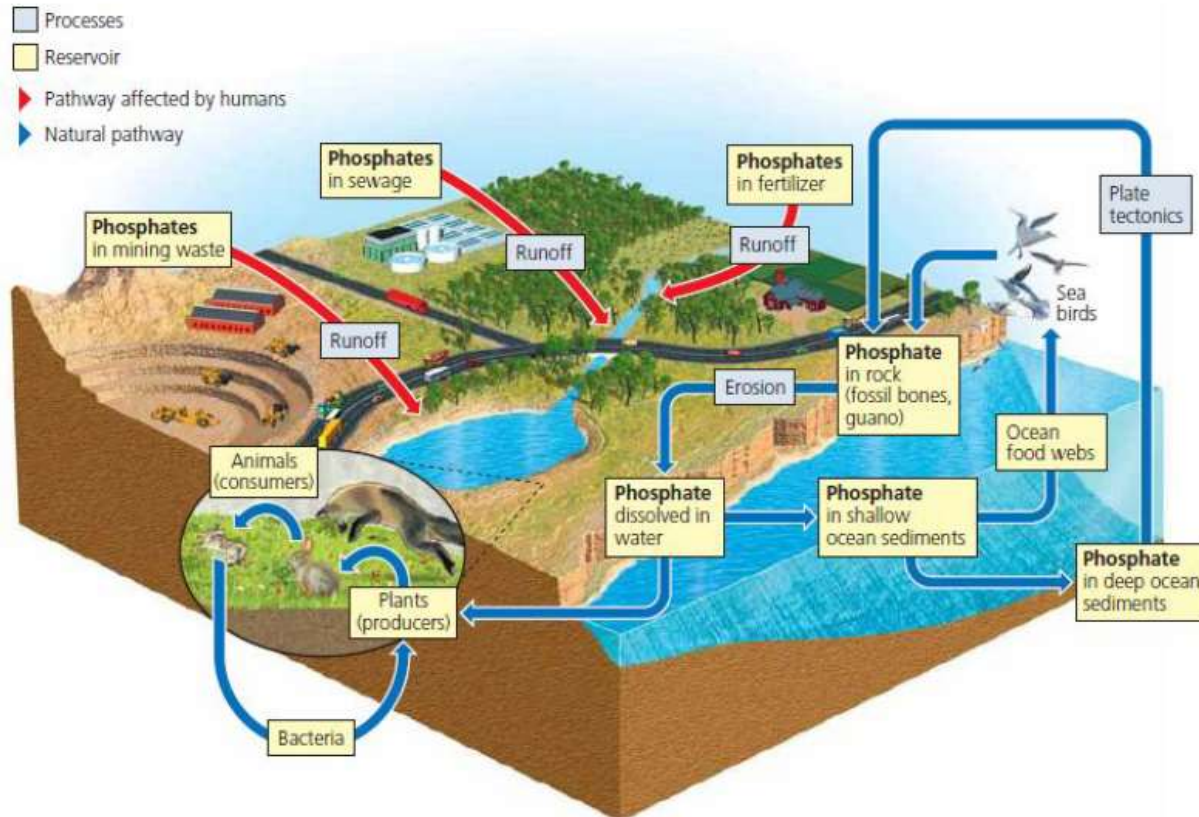
Since the middle of the twentieth century,

humanity has quadrupled the environmental flow of phosphorus¹, an essential element for all forms of life. We dig up geological phosphate reserves to produce fertilizers to feed the Green Revolution, creating a largely one-way flow of phosphorus from rocks to farms to lakes and oceans, and dramatically impairing freshwater and coastal marine ecosystems. Globally, oxygen-depleted marine coastal 'dead zones' caused by nutrient-stimulated algal blooms continue to expand. The Gulf of Mexico's dead zone, averaging more than 17,000 square kilometres in recent years, was forecast to

reach record dimensions this year before a tropical storm stirred the waters.

At the same time, concern is growing about how long we can count on cheap supplies of phosphorus for fertilizer: easily mineable deposits of phosphate rock are limited. Unlike nitrogen, phosphorus cannot be pulled from the air and, unlike the carbon in our energy system, there is no known replacement. In 2009, Dana Cordell of the University of Technology in Sydney, Australia, and her colleagues published a 'peak phosphorus' forecast² that predicted maximum production around 2030 — an

Ciclo del Fósforo en el ecosistema



Ciclo del P: no tiene componente atmosférico



Imagen generada por IA

WELCOME TO THE ANTHROPOCENE



GREAT ACCELERATION

Human activity, predominantly the global economic system, is now the prime driver of change in the Earth System — the sum of our planet's interacting physical, chemical, biological and human processes. This is the conclusion made visible in a set of 24 global indicators, or a "planetary dashboard", charting the "Great Acceleration" in human activity from the start of the industrial revolution in 1750 to 2010, and the subsequent changes in the Earth System — e.g. greenhouse gas levels, ocean acidification, deforestation and biodiversity deterioration. The post-1950 acceleration of the human imprint on the Earth System, particularly the 12 graphs that show changes in Earth System structure and functioning, have played a central role in the discussion around the formalisation of the Anthropocene as the next epoch in Earth history.

Source: [Anthropocene Review, 2015](#)

SOCIO-ECONOMIC TRENDS



EARTH SYSTEM TRENDS





The human age

Momentum is building to establish a new geological epoch that recognizes humanity's impact on the planet. But there is fierce debate behind the scenes.

BY RICHARD MONASTERSKY

Almost all the dinosaurs have vanished from the National Museum of Natural History in Washington DC. The fossil hall is now mostly empty and painted in deep shadows as palaeobiologist Scott Wing wanders through the cavernous room.

Wing is part of a team carrying out a radical, US\$45-million redesign of the exhibition space, which is part of the Smithsonian Institution. And when it opens again in 2019, the hall will do more than revisit Earth's distant past. Alongside the typical displays of *Tyrannosaurus rex* and *Triceratops*, there will be a new section that forces visitors to consider the species that is currently dominating the planet.

"We want to help people imagine their role in the world, which is maybe more important than many of them realize," says Wing.

This provocative exhibit will focus on the Anthropocene — the slice of Earth's history during which people have become a major geological force. Through mining activities alone, humans move more sediment than all the world's rivers combined. *Homo sapiens* has also warmed the planet, raised sea levels, eroded the ozone layer and acidified the oceans.

Given the magnitude of these changes, many researchers propose that the Anthropocene represents a new division of geological time. The concept has gained traction, especially in the past few years — and not just among geoscientists. The word has been invoked by archaeologists, historians and even gender-studies researchers; several museums

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ARE WE THERE YET?...



THANK GOODNESS FOR ALL THE ELECTRONIC GADGETS THAT KEEP THEM OCCUPIED ON THESE LONG TRIPS!

YOU ARE NOW LEAVING THE HOLOCENE

NEXT SERVICES

POPE 17.1.15





Subcommission on Quaternary Stratigraphy

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- Charts
- News
- Definitions
- Stratigraphic Guide
- Major divisions
- Regional divisions
- Members
- Working Groups
- Meetings
- Annual reports

You are in: [Home](#) » [Working Groups](#)

WORKING GROUP ON THE 'ANTHROPOCENE'



A surreal landscape featuring a large, dark, spherical object floating in the sky above a green valley with a village. The scene is set against a backdrop of mountains and a cloudy sky. The sphere has a textured, rocky appearance and is positioned in the upper left quadrant of the frame. The valley below is lush and green, with a small village of houses and a church visible in the distance. The overall atmosphere is one of mystery and potential danger.

Eutrofización

- Proceso natural
- En la teoría clásica, se le entendía como el envejecimiento de sistemas acuáticos
- Aumento de la carga de nutrientes
- Acumulativa
- Fertilización
- Aumento de la productividad

An aerial photograph of a traditional watermill in a lush green landscape. The mill is a two-story white building with a brown tiled roof, situated on a narrow stone bridge over a small stream. A large wooden waterwheel is attached to the side of the mill, partially submerged in the water. The surrounding area is a vast, flat green field, likely a meadow or pasture, with a few scattered trees and a fence line in the distance. The sky is blue with scattered white clouds.

Eutrofización antrópica

Eutrofización cultural

- Proceso artificial
- Acelerado



Lago Rodó
(Montevideo)



Lago Rodó
(Montevideo)



Lago Cachón
(Montevideo)



Lagomar
(canelones)




Laguna del Potrero
(Maldonado)




Laguna Blanca
(Maldonado)



Laguna del Diario
(Maldonado)



Laguna del Sauce
(Maldonado) 2008



Laguna del Sauce
(Maldonado) 2008



Laguna del Sauce
(Maldonado) 2013



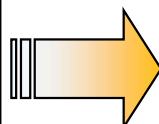
Laguna del Sauce, 2015

Laguna del Sauce, 2015

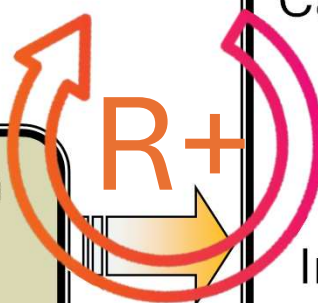


Eutrofización

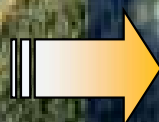
Aumento de la disponibilidad de nutrientes



Aumento de la productividad primaria



Cambio de la estructura y funcionamiento del ecosistema.
Pérdida de SSEE.
Interferencias múltiples



Floraciones o *blooms* de organismos fotosintetizadores

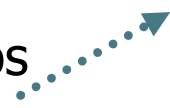
Descomposición
generación de malos olores

Anoxia o hipoxia

Muerte masiva de peces

Interferencias con potabilización

Riesgos sanitarios (Cianotoxinas)



Handling the phosphorus paradox in agriculture and natural ecosystems: Scarcity, necessity, and burden of P

Peter Leinweber, Ulrich Bathmann, Uwe Buczko, Caroline Douhaire,
Bettina Eichler-Löbermann, Emmanuel Frossard, Felix Ekardt,
Helen Jarvie, Inga Krämer, Christian Kabbe, Bernd Lennartz,
Per-Erik Mellander, Günther Nausch, Hisao Ohtake,
Jens Tränckner

La Paradoja del P, simultaneidad de:

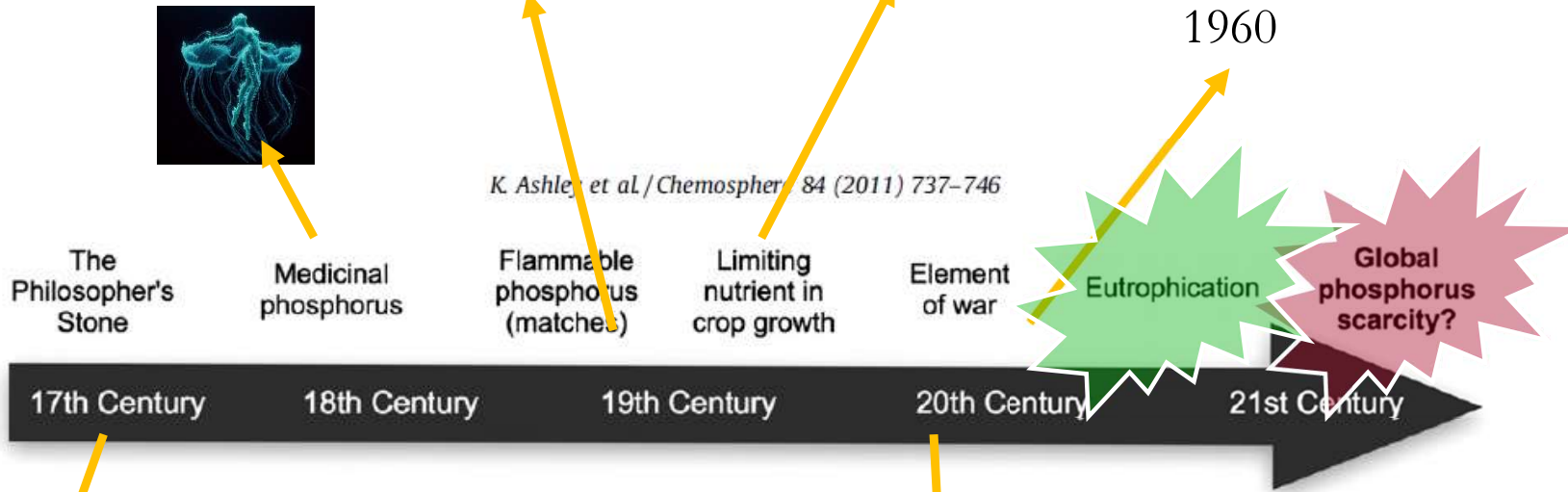
- escasez global para la producción agrícola
- sobreabundancia simultánea que perjudica la calidad del agua

1802
von Humboldt



Revolución verde
1960

738



K. Ashley et al / Chemosphere 84 (2011) 737-746

Fig. 1. The evolution of phosphorus use and abuse: from the Philosopher's Stone to use in war, food production, and more recently implicated in water pollution. A new emerging discourse of the 21st century may be global phosphorus scarcity. Source: Cordell (2010).



1938



FRANKLIN D. ROOSEVELT

32nd President of the United States: 1933 - 1945

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May 20, 1938

Table 2. Examples of human intervention in the global biogeochemical cycles of carbon, nitrogen, phosphorus, sulfur, water, and sediments. Data are for the mid-1900s.

Element	Flux	Magnitude of flux (millions of metric tons per year)		% change due to human activities
		Natural	Anthropogenic	
C	Terrestrial respiration and decay CO ₂	61,000		
	Fossil fuel and land use CO ₂		8,000	+13
N	Natural biological fixation	130		
	Fixation owing to rice cultivation, combustion of fossil fuels, and production of fertilizer		140	+108
P	Chemical weathering	3		
	Mining		12	+400
S	Natural emissions to atmosphere at Earth's surface	80		
	Fossil fuel and biomass burning emissions		90	+113
O and H (as H ₂ O)	Precipitation over land	111 × 10 ¹²		
	Global water usage		18 × 10 ¹²	+16
Sediments	Long-term preindustrial river suspended load	1 × 10 ¹⁰		
	Modern river suspended load		2 × 10 ¹⁰	+200

Falkowski, P., Scholes, R.J., Boyle, E., Canadell, J., Canfield, D., Elser, J., Gruber, N., Hibbard, K., Högberg, P., Linder, S., Mackenzie, F.T., Moore III, B., Pedersen, T., Rosenthal, Y., Seitzinger, S., Smetacek, V., Steffen, W., 2000. The Global Carbon Cycle: A Test of Our Knowledge of Earth as a System. *Science* 290, 291-296.

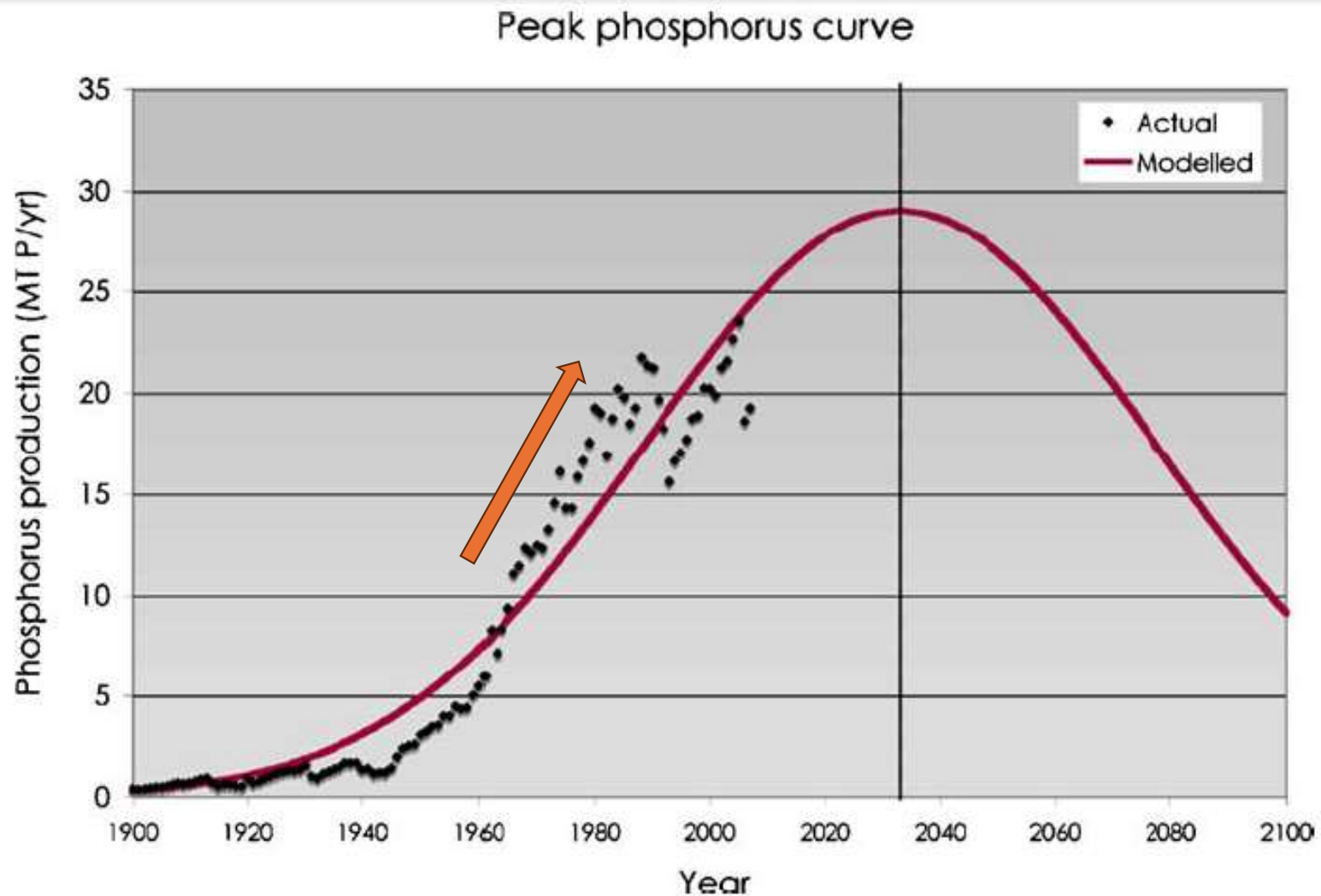


Fig. 4. Indicative peak phosphorus curve, illustrating that, in a similar way to oil, global phosphorus reserves are also likely to peak after which production will be significantly reduced (Jasinski, 2006; European Fertilizer Manufacturers Association, 2000).

Cordell, D., J. O. Drangert and S. White (2009). "The story of phosphorus: Global food security and food for thought." *Global Environmental Change* 19: 292-305.

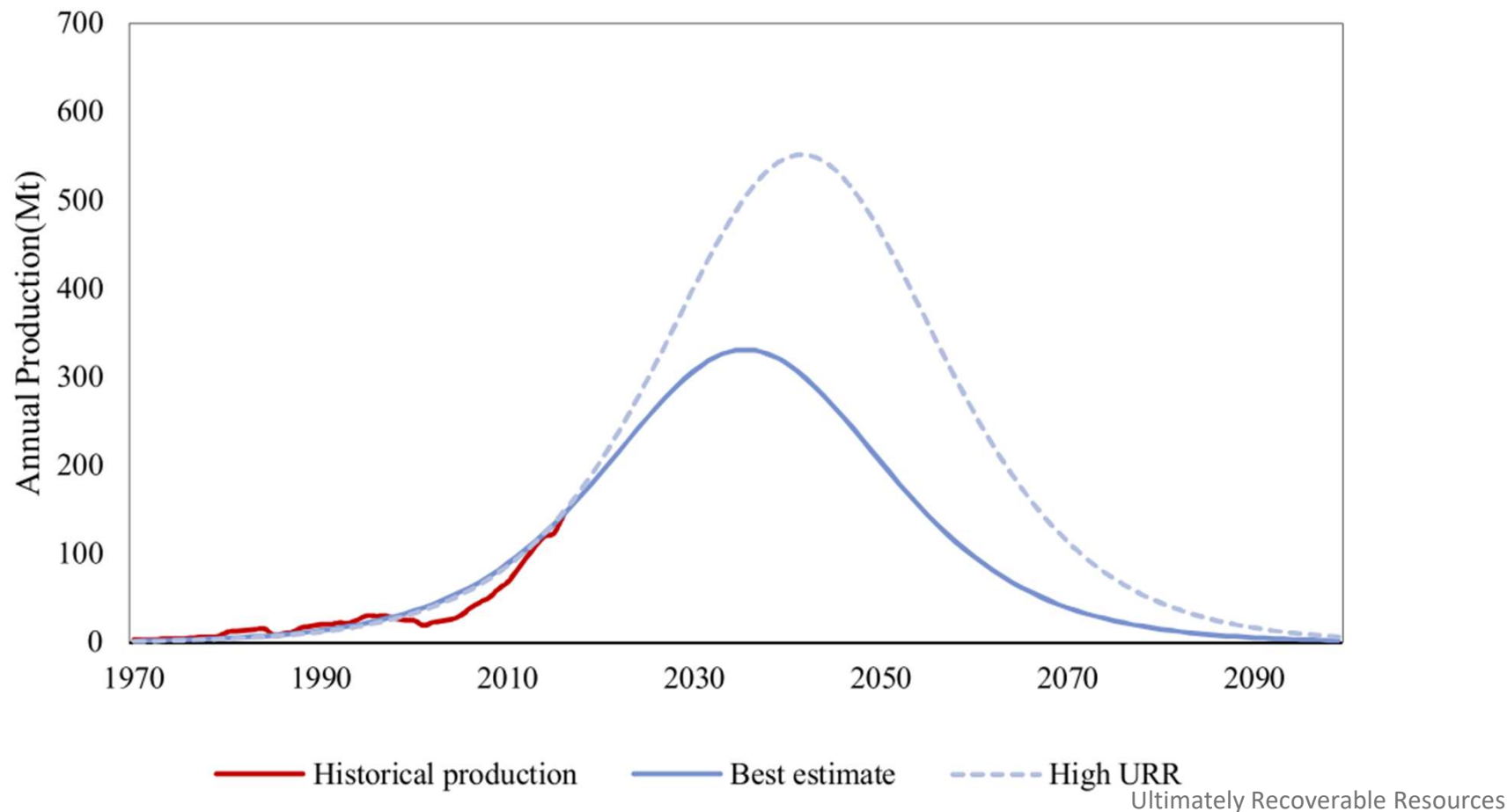
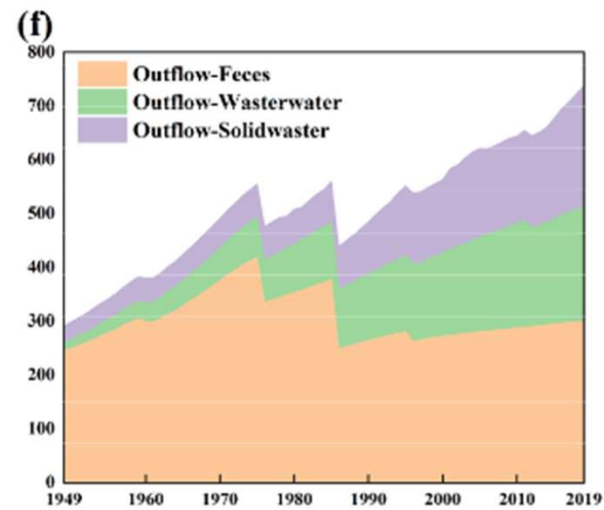
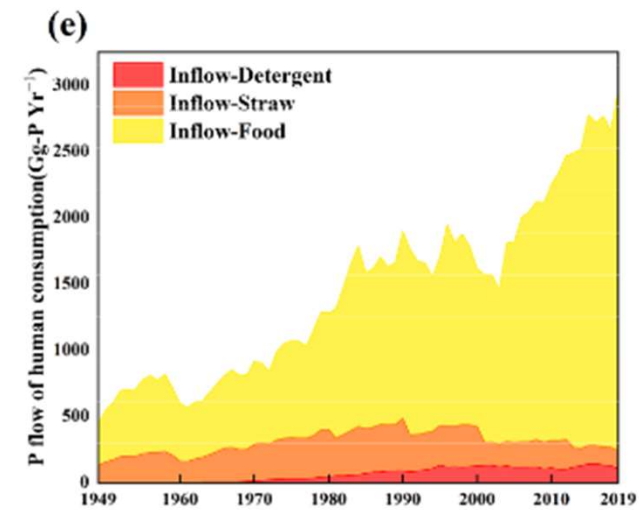
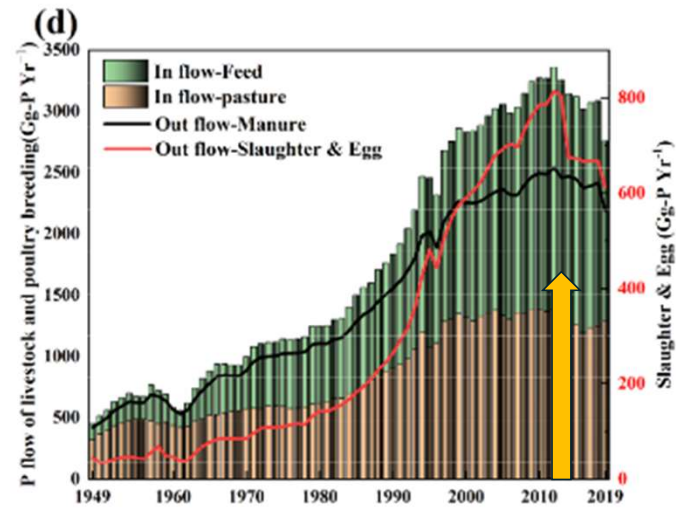
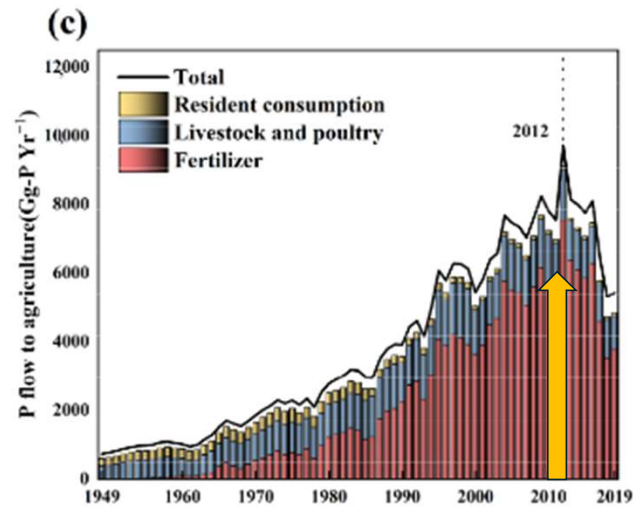
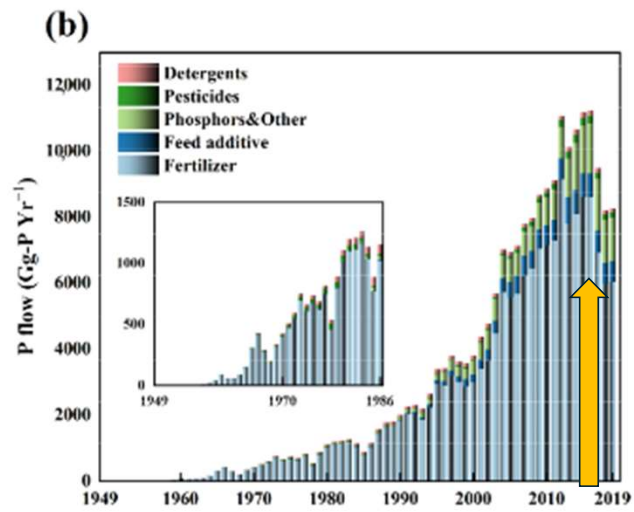
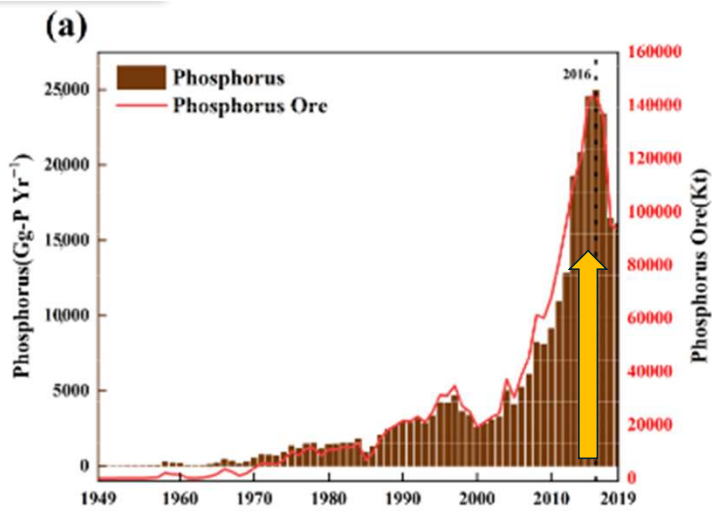


Fig. 4. PR production estimates for China.

Phosphate Rock



The results show that China's phosphate mining has reached its historical highest point and moved towards the green and healthy use of P resources. Since 1990, the P resource efficiency index system has revealed an overall increment in PUE in agricultural planting and product processing modules, PURP in agricultural planting and livestock and poultry breeding modules, PRR of straw, and PRR of human activities as a whole. Nevertheless, the PUE in aquaculture and livestock breeding modules have either decreased or remained relatively stable, suggesting that there is still room for further optimization in these areas. At the same time, the rational application of phosphorus fertilizers needs to fully consider the impact of past phosphorus legacy on the soil, which can effectively improve the effectiveness of phosphorus fertilizers, thereby reducing environmental impact [39].

PUE: P utilization efficiency

PRR: P recycling rate

PURP: proportion of recycled P use



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Available online at www.sciencedirect.com

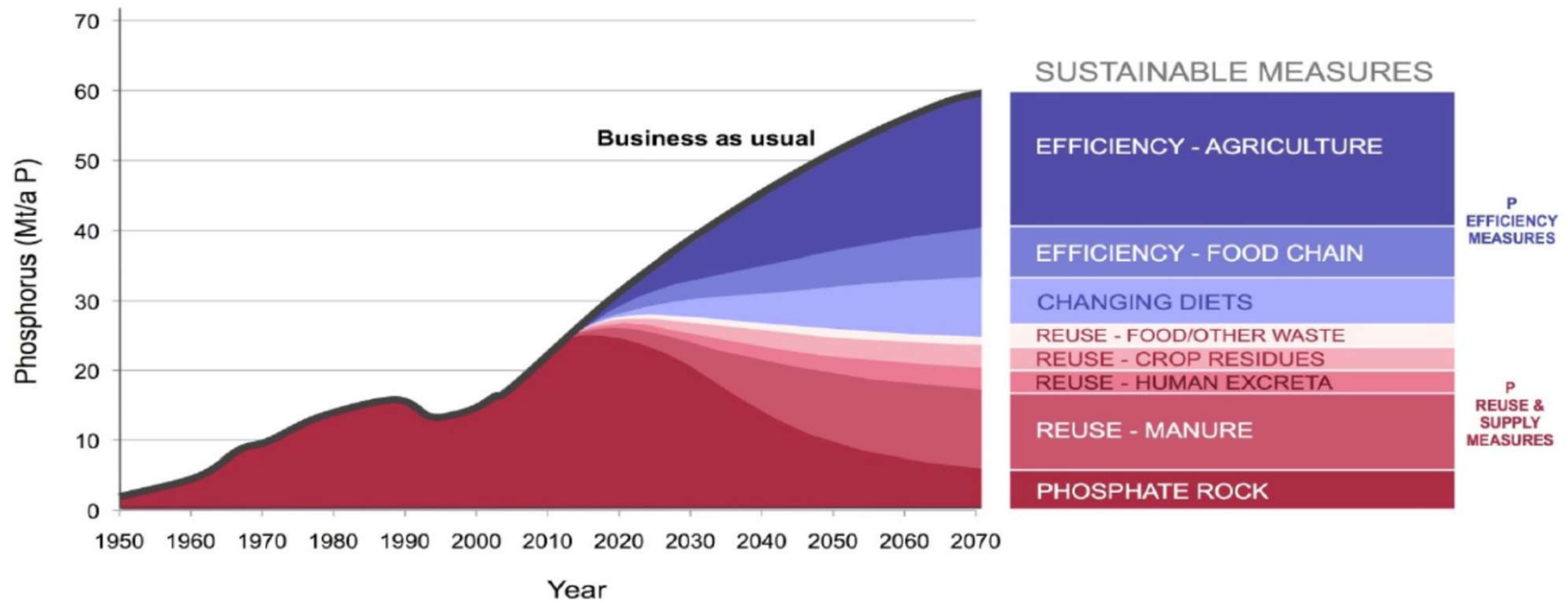
SciVerse ScienceDirect

Phosphorus: a limiting nutrient for humanity?

James J Elser

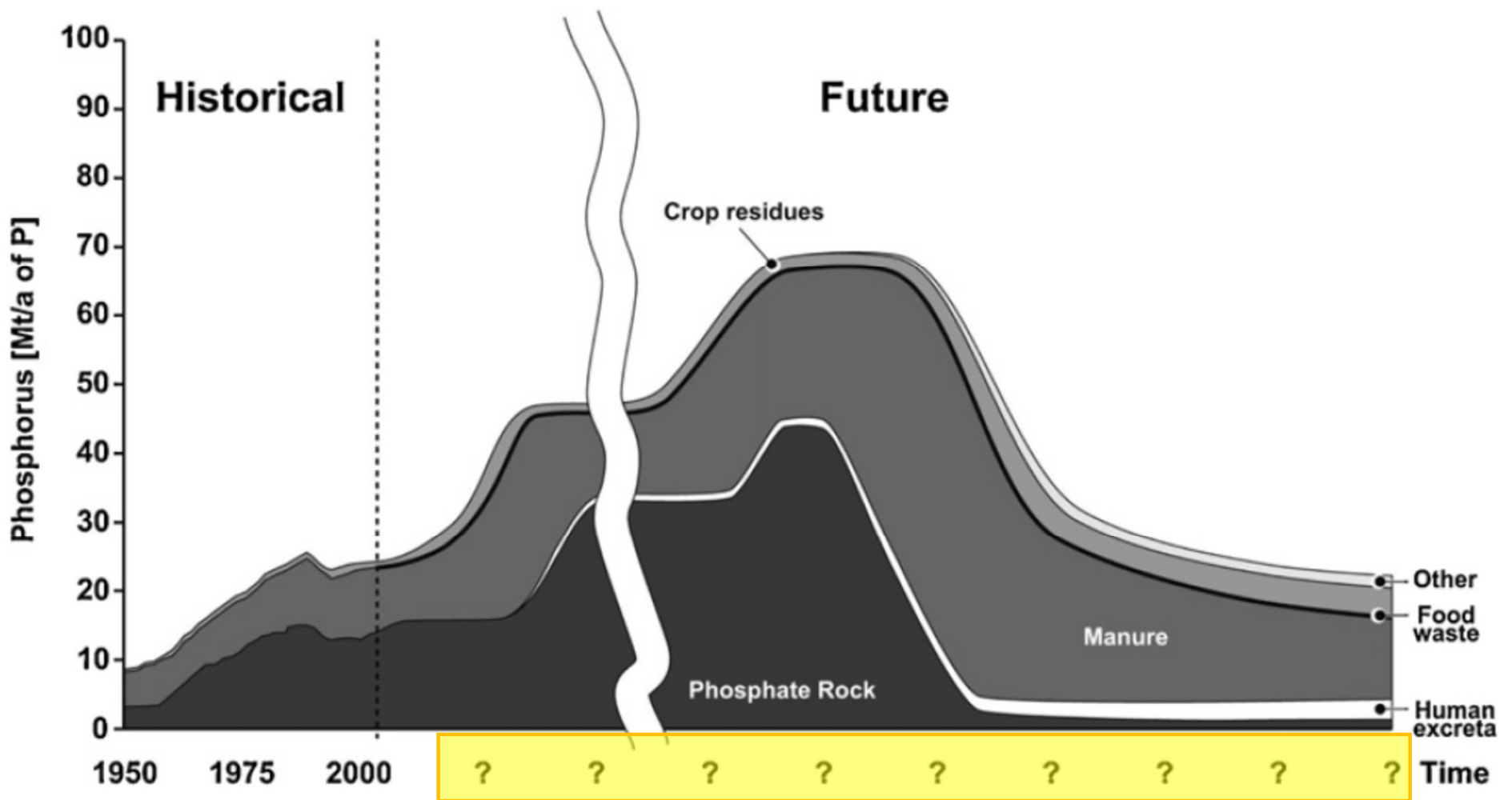
Elser, J. J. (2012). Phosphorus: a limiting nutrient for humanity?
Current Opinion in Biotechnology, 23(6), 833-838.
[doi:https://doi.org/10.1016/j.copbio.2012.03.001](https://doi.org/10.1016/j.copbio.2012.03.001)



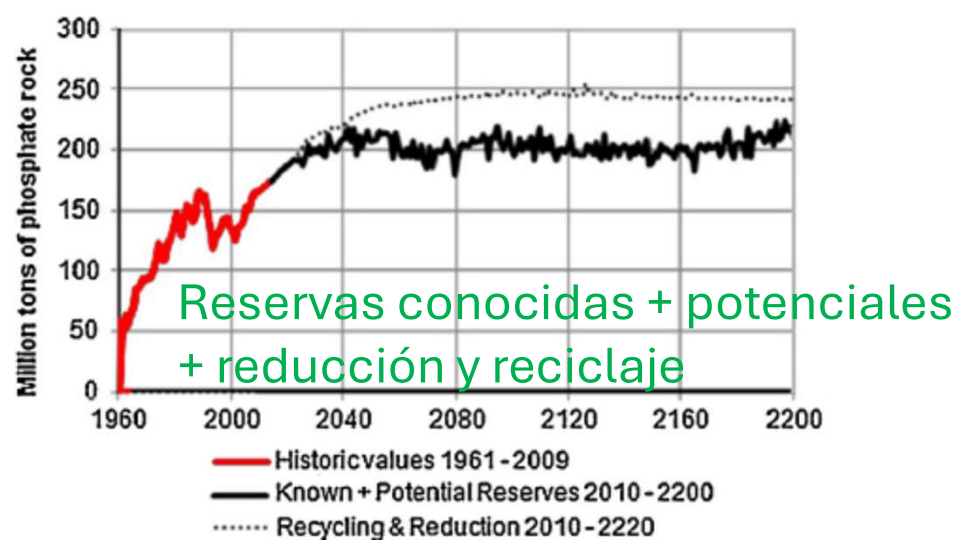
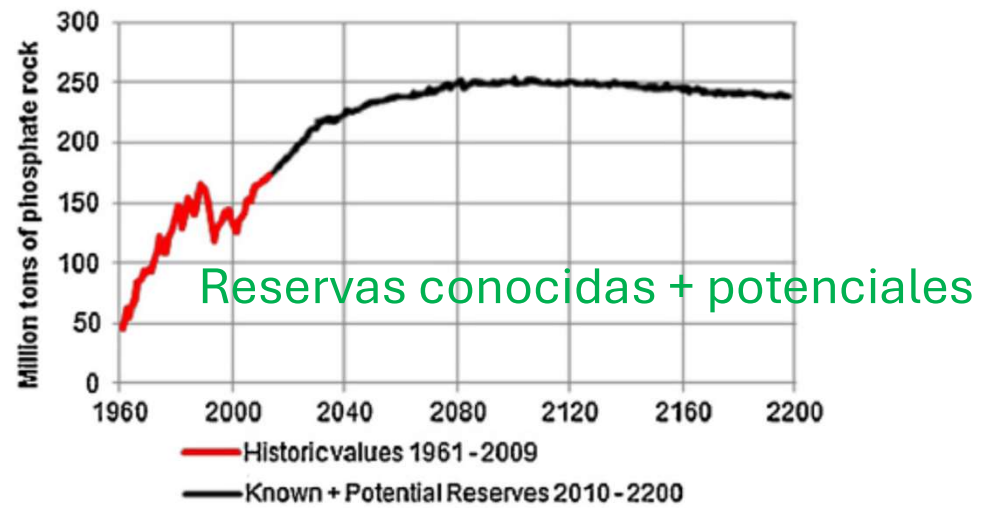
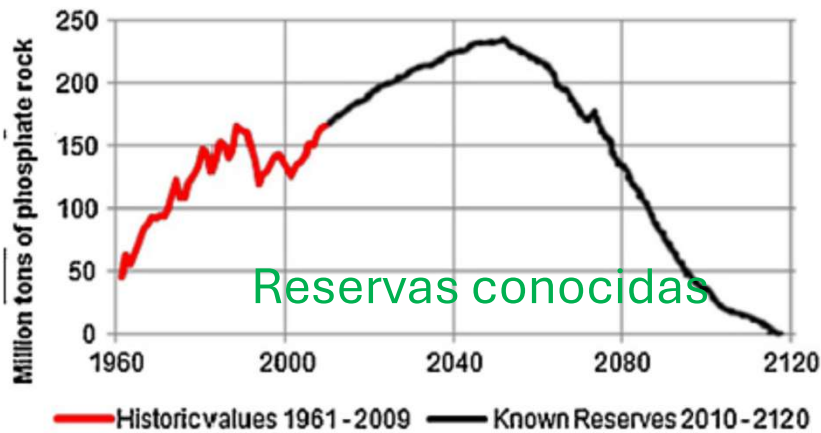


Un escenario preferido para satisfacer la demanda mundial de fósforo a largo plazo:

- Azul: medidas integradas de gestión de la demanda (eficiencia)
- Rojo: medidas del lado de la oferta (reutilización)



Scholz, R.W., Wellmer, F.-W., 2013. Approaching a dynamic view on the availability of mineral resources: What we may learn from the case of phosphorus? *Global Environmental Change* 23, 11-27.



Elevada incertidumbre de la magnitud de las reservas globales de P.

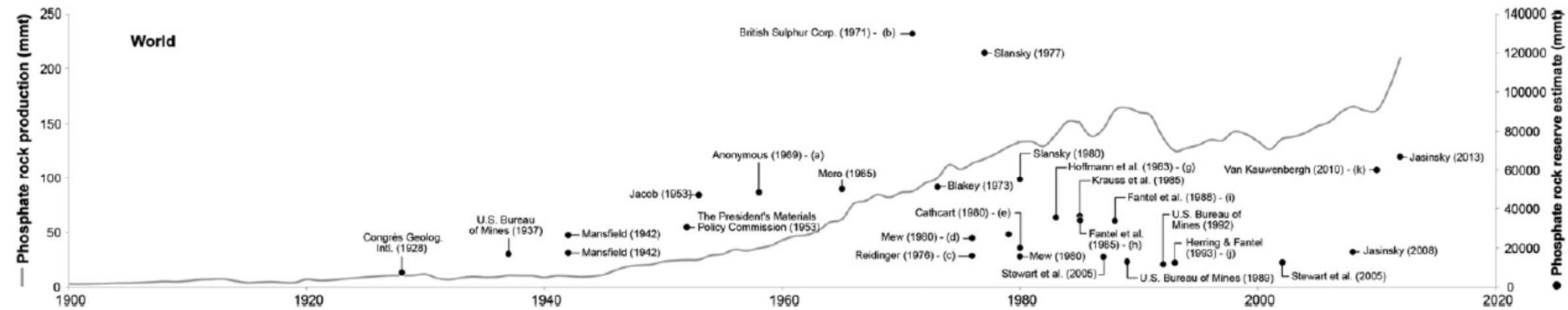


Fig. 1. Historic phosphate rock reserve estimates and production data for the world (1900–2012).

Ulrich, A.E., Frossard, E., 2014. On the history of a reoccurring concept: Phosphorus scarcity. *Science of the Total Environment* 490, 694-707.

Evaluación de futuros escenarios

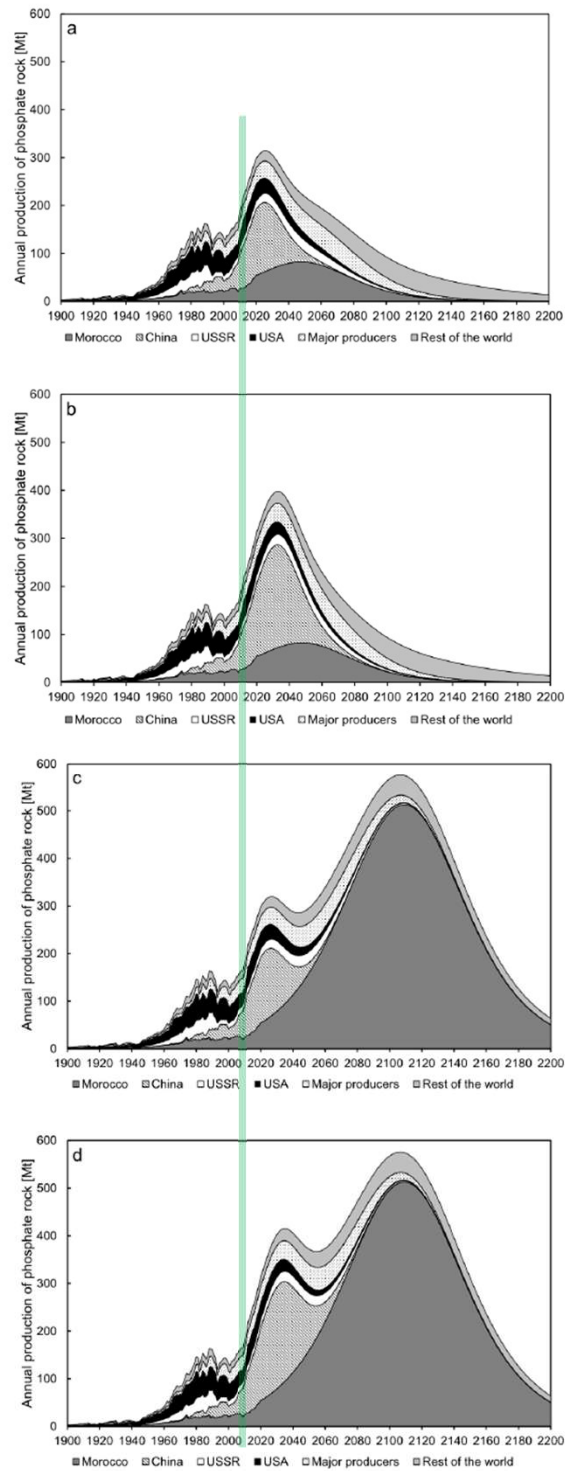


Figure 4. Resulting production from disaggregated model using logistic curves. a) Case 1 with low URR estimate for China and Morocco. b) Case 2, low URR estimate for Morocco, high for China. c) Case 3: High URR estimate for Morocco, low for China. d) Case 4: High URR estimate for China and Morocco.

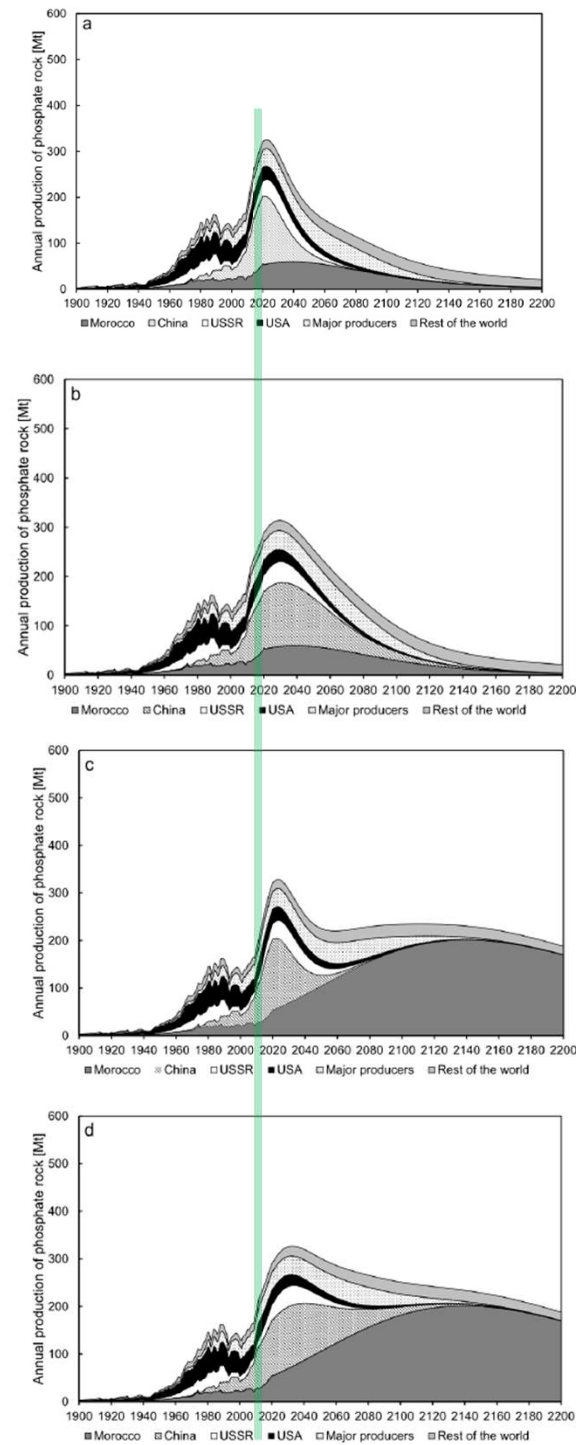
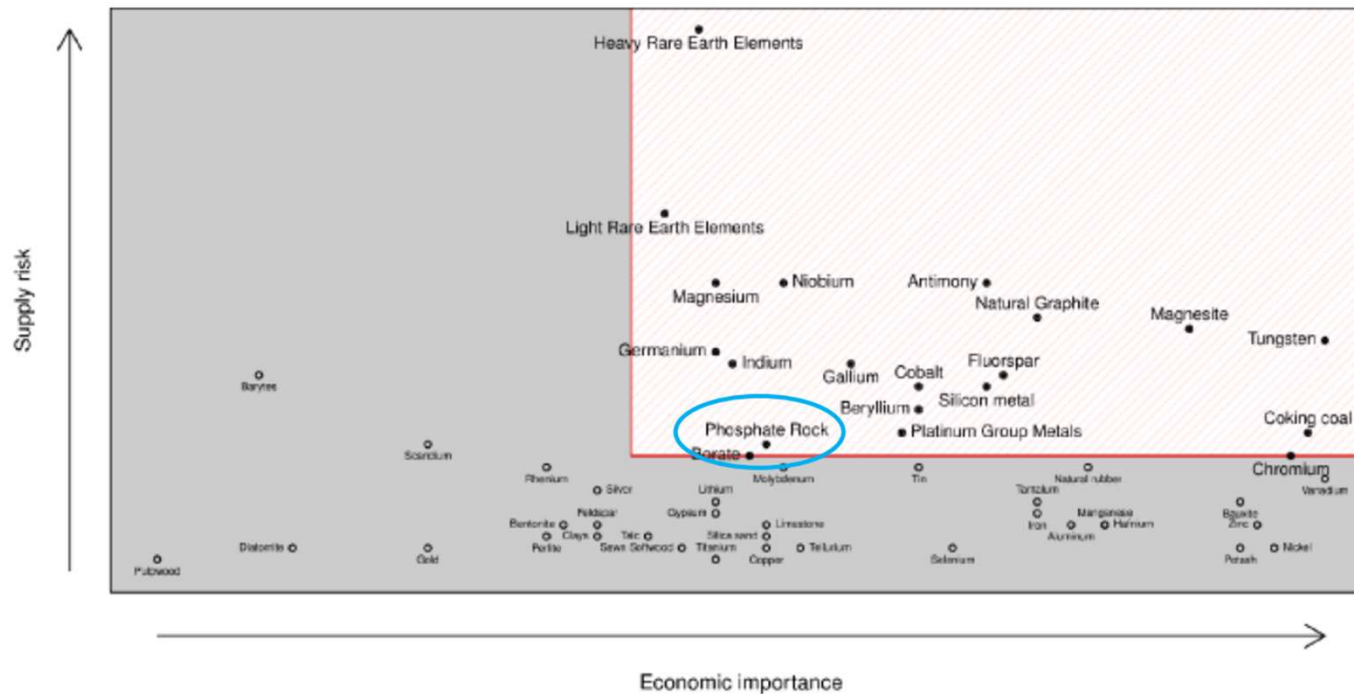


Figure 5. Resulting production from disaggregated model using Gompertz curves. a) Case 1 with low URR estimate for China and Morocco. b) Case 2, low URR estimate for Morocco, high for China. c) Case 3: High URR estimate for Morocco, low for China. d) Case 4: High URR estimate for China and Morocco.

Simple curve fitting modelling



Desde 2014 La roca fosfórica está en la lista de Materias Primas Críticas de la UE:



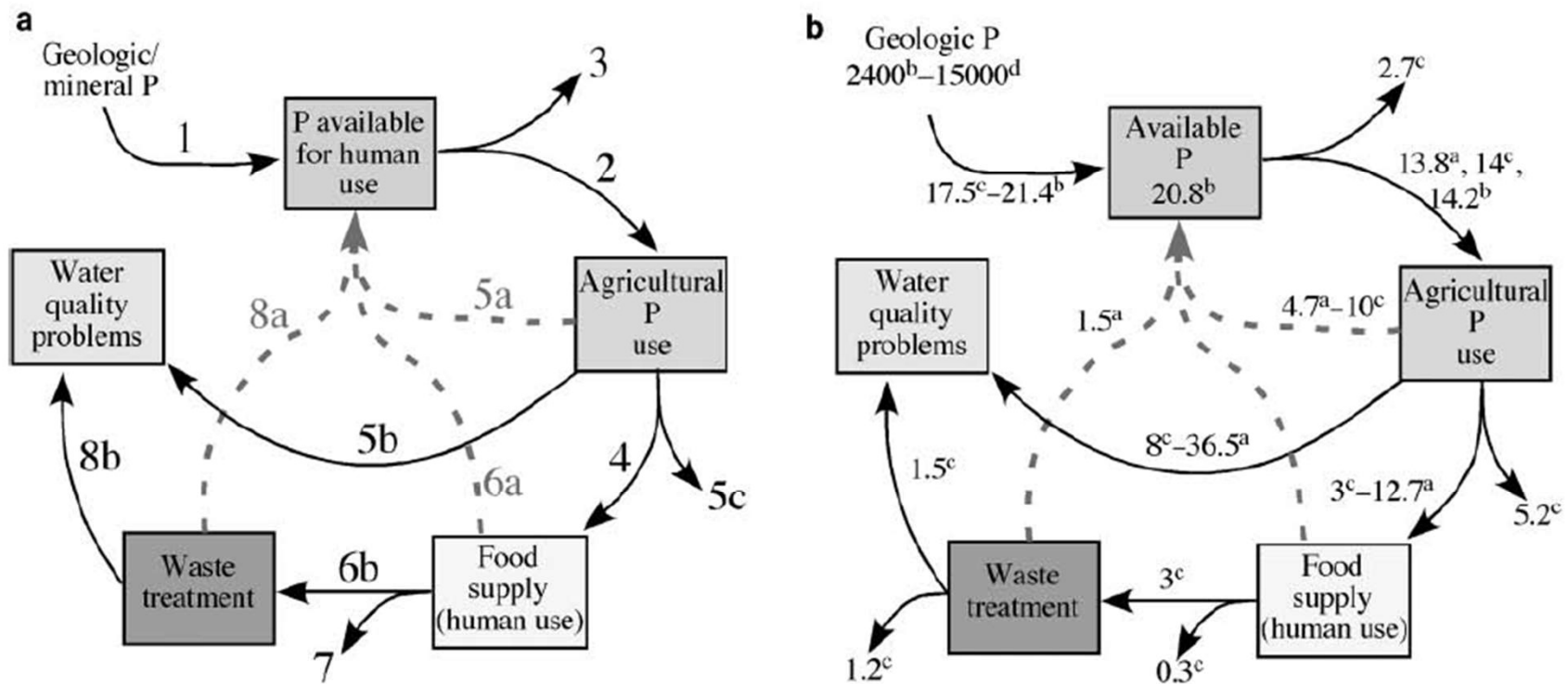


Figure 1. A conceptualization of the human phosphorus (P) cycle. (a) Solid arrows represent key P flows and dashed red arrows represent flows that close the human P cycle through sustainable solutions: (1) P mining and refining, (2) agricultural P use and efficiency, (3) nonagricultural P uses, (4) P in food, (5a) P recycled to agricultural production at the farm, (5b) P lost from farm fields, (5c) P lost in food processing and transportation inefficiencies, (6a) P in composted food waste, (6b) P in human excreta, (7) P in food waste lost to landfills, (8a) P from sewage treatment that is recycled to agricultural production, and (8b) P discharged from ineffectively treated sewage. (b) Estimates of P flows (arrows, in millions of metric tons [MMT] P per year) and P stocks (boxes, in MMT P). Superscripts correspond to the data sources: a, Liu and colleagues (2008); b, Villalba and colleagues (2008); c, Cordell and colleagues (2009); and d, Gilbert (2009). Note the large variability (and uncertainty) in many of the P flow estimates. Geologic supply is based on readily available mineral P reserves. Recycled agricultural P (dashed red arrow 5a) includes the reapplication of crop residues (2 to 2.2) and animal wastes (2.5 to 8) to fields. Agricultural P losses to water bodies (arrow 5b) include estimates of runoff and erosion.

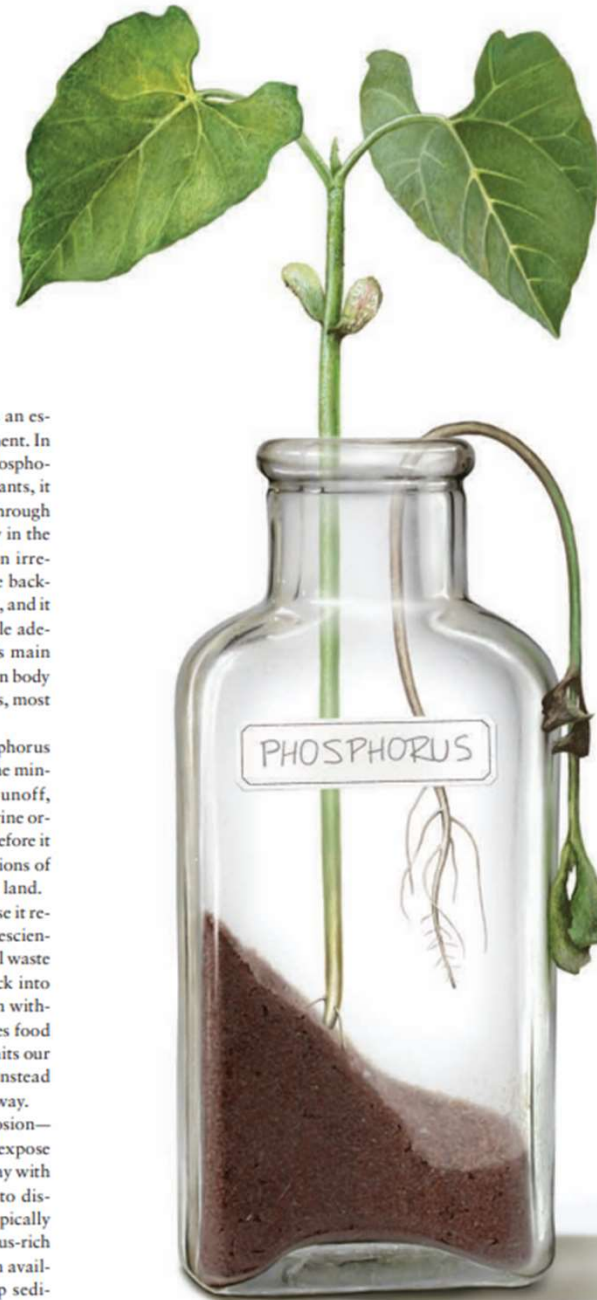
Crisis

Our planet is also a spaceship: it has an essentially fixed total amount of each element. In the natural cycle, weathering releases phosphorus from rocks into soil. Taken up by plants, it enters the food chain and makes its way through every living being. Phosphorus—usually in the form of the phosphate ion PO_4^{3-} —is an irreplaceable ingredient of life. It forms the backbone of DNA and of cellular membranes, and it is the crucial component in the molecule adenosine triphosphate, or ATP—the cell's main form of energy storage. An average human body contains about 650 grams of phosphorus, most of it in our bones.

Land ecosystems use and reuse phosphorus in local cycles an average of 46 times. The mineral then, through weathering and runoff, makes its way into the ocean, where marine organisms may recycle it some 800 times before it passes into sediments. Over tens of millions of years tectonic uplift may return it to dry land.

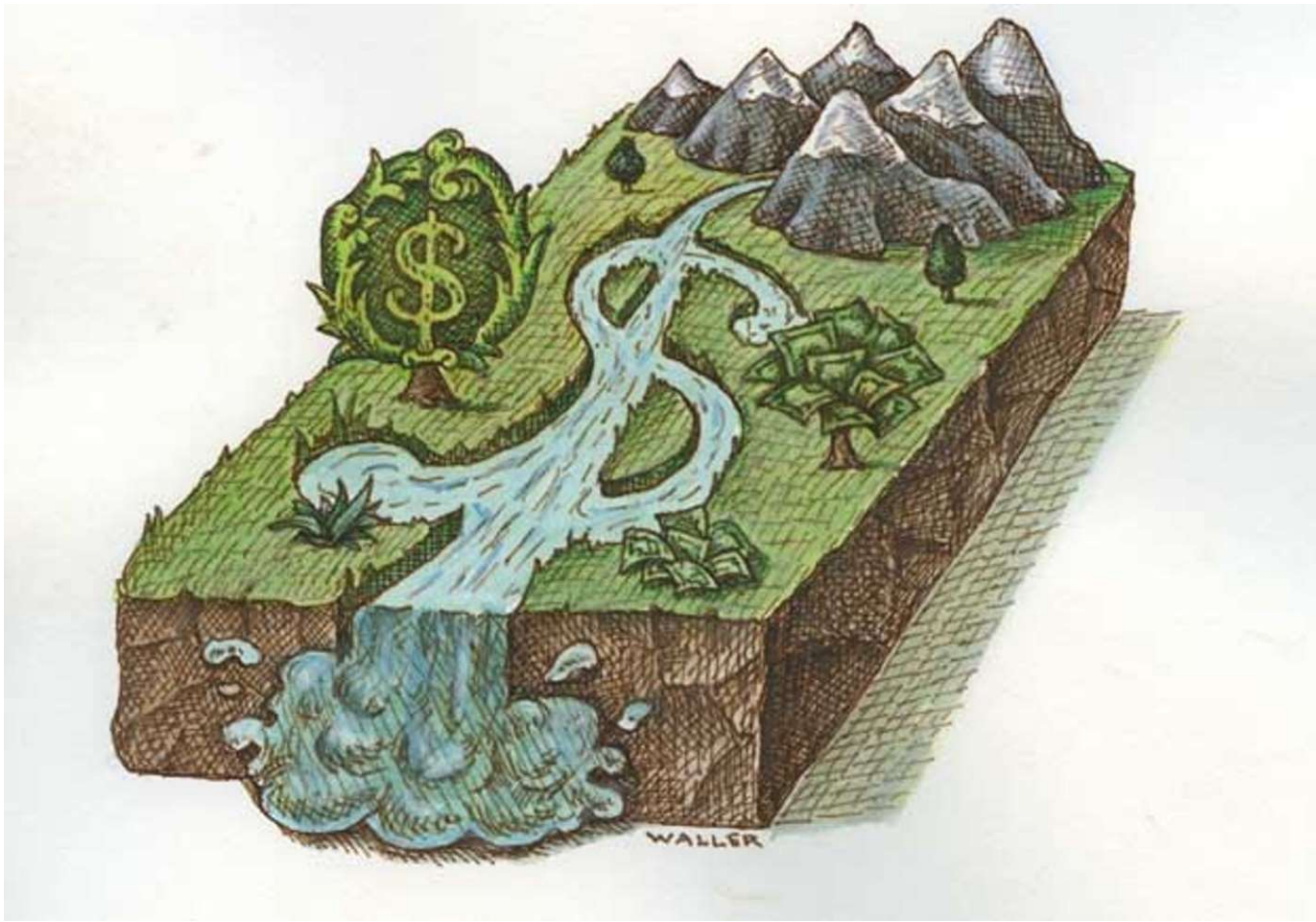
Harvesting breaks up the cycle because it removes phosphorus from the land. In prescientific agriculture, when human and animal waste served as fertilizers, nutrients went back into the soil at roughly the rate they had been withdrawn. But our modern society separates food production and consumption, which limits our ability to return nutrients to the land. Instead we use them once and then flush them away.

Agriculture also accelerates land erosion—because plowing and tilling disturb and expose the soil—so more phosphorus drains away with runoff. And flood control contributes to disrupting the natural phosphorus cycle. Typically river floods would redistribute phosphorus-rich sediment to lower lands where it is again available for ecosystems. Instead dams trap sedi-



KEITH CHRISTIANSEN

¿Estamos bien o nos fuimos de rosca?



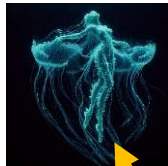
1802
von Humboldt



1960
Revolución verde

738

The
Philosopher's
Stone



Medicinal
phosphorus

K. Ashley et al / Chemosphere 84 (2011) 737-746

Flammable
phosphorus
(matches)

Limiting
nutrient in
crop growth

Element
of war

Eutrophication

Global
phosphorus
scarcity?

(?)

17th Century

18th Century

19th Century

20th Century

21st Century

Fig. 1. The evolution of phosphorus use and abuse: from the Philosopher's Stone to use in war, food production, and more recently implicated in water pollution. A new emerging discourse of the 21st century may be global phosphorus scarcity. Source: Cordell (2010).



1938



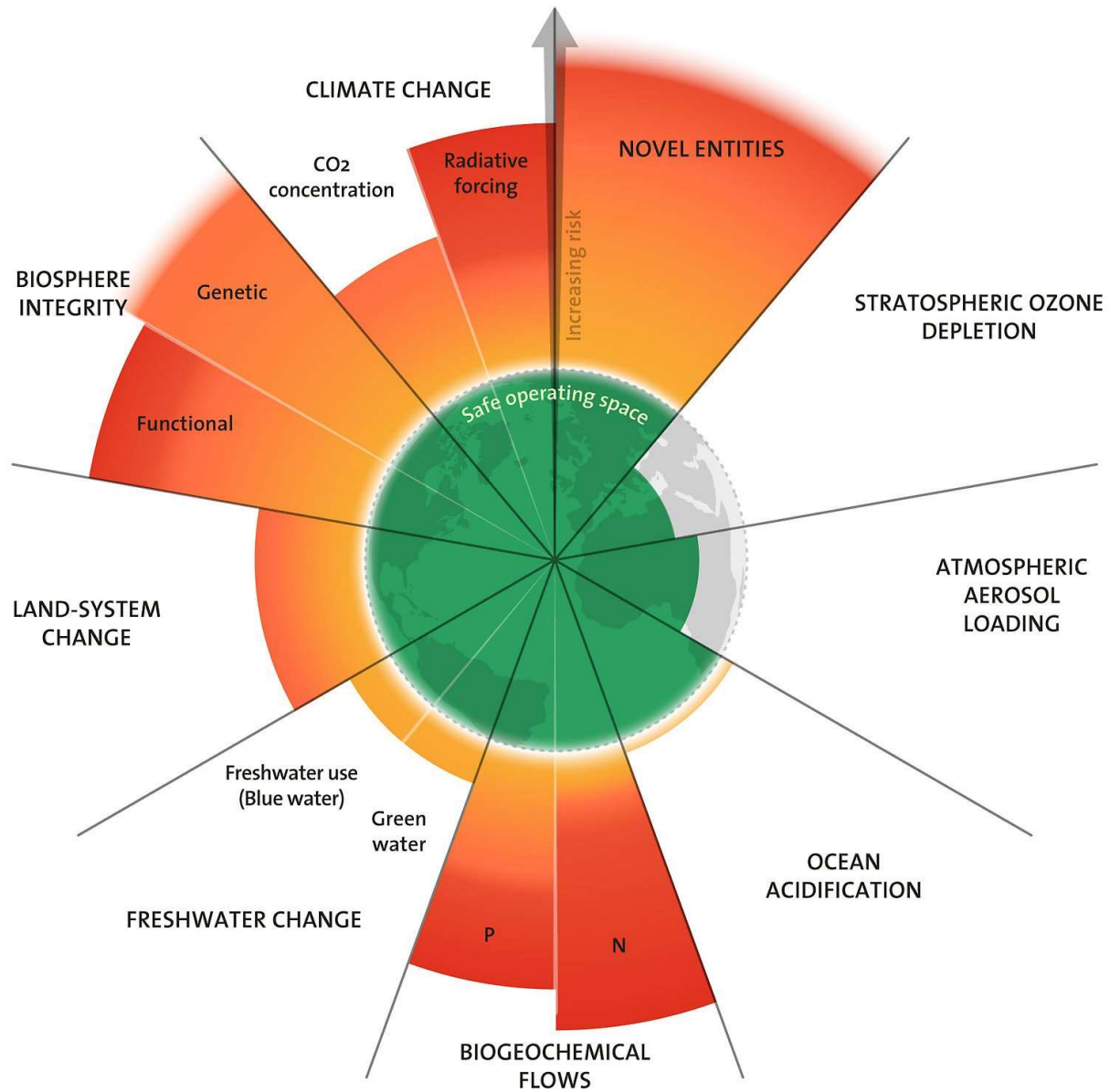
FRANKLIN D. ROOSEVELT

32nd President of the United States: 1933 - 1945

Message to Congress on
Phosphates for Soil Fertility.

May 20, 1938

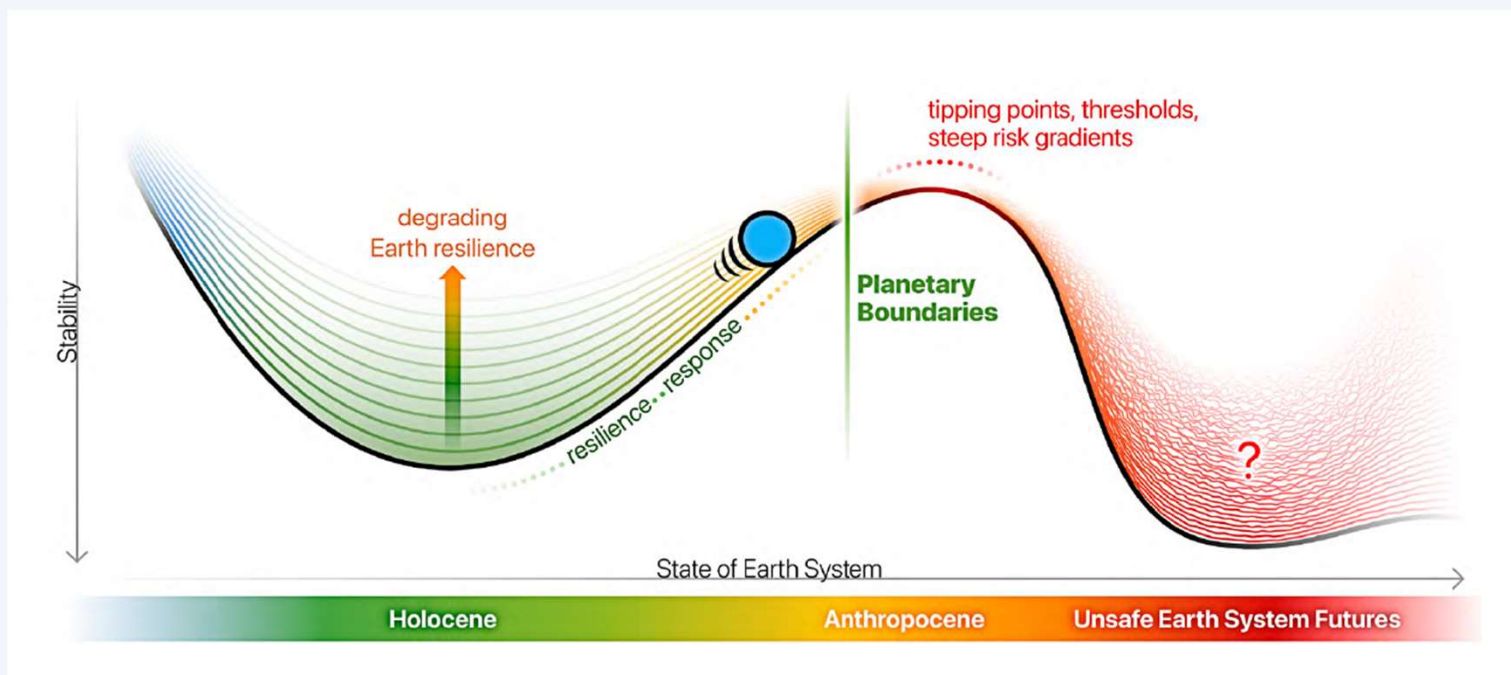
Los límites planetarios



Los límites planetarios

Earth Resilience

Earth resilience is the capacity of the biogeophysical Earth system to absorb human pressures (anthropogenic greenhouse gas emissions, degradation of biosphere integrity, land use changes, etc.) such that the system remains in (or returns to) a Holocene-like state. Only this state can provide the essential structures and functions that are the foundation for sustainable development of human societies. Staying within a habitable Holocene-like state will require active stewardship to revitalize and strengthen Earth's resilience.



Los límites planetarios

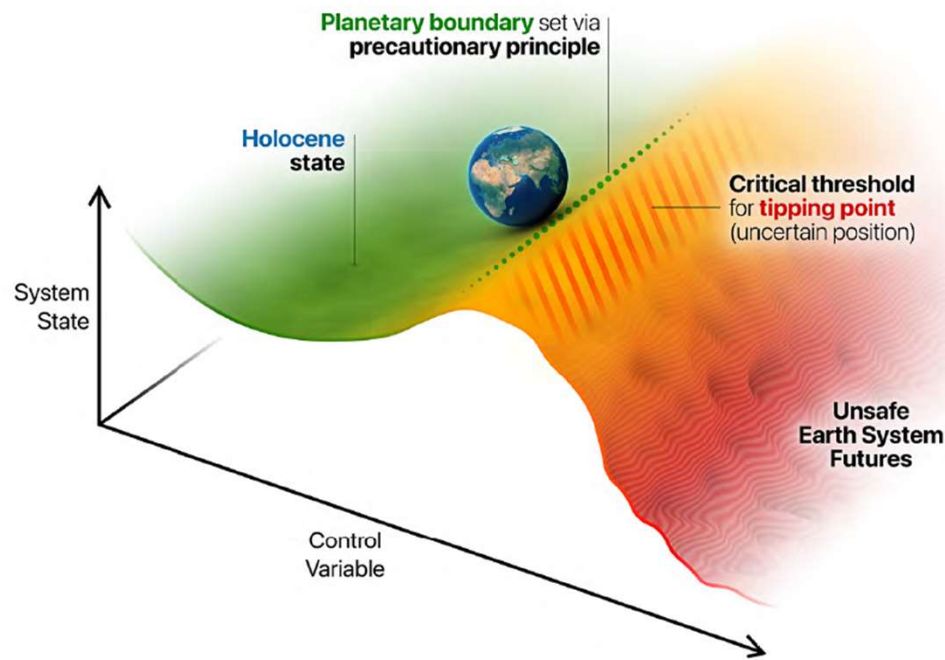
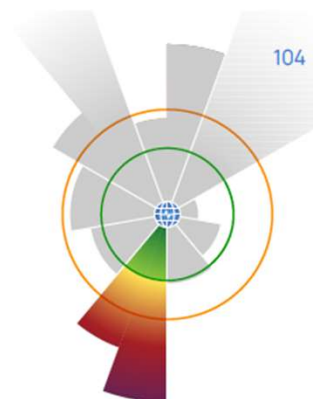


FIGURE 7 - Stylized stability landscape of the Earth system. Tipping points and Planetary Boundaries are interconnected – both address Earth system stability, but they serve distinct roles. Beyond a *tipping point*, a system fundamentally changes due to a shift in feedback dynamics: When stabilizing feedbacks are dominated by destabilizing ones, they drive the system to a qualitatively different state, often abruptly and/or irreversibly. Where quantifiable, the *Planetary Boundaries* are set in a safe distance away from risks of crossing tipping points.



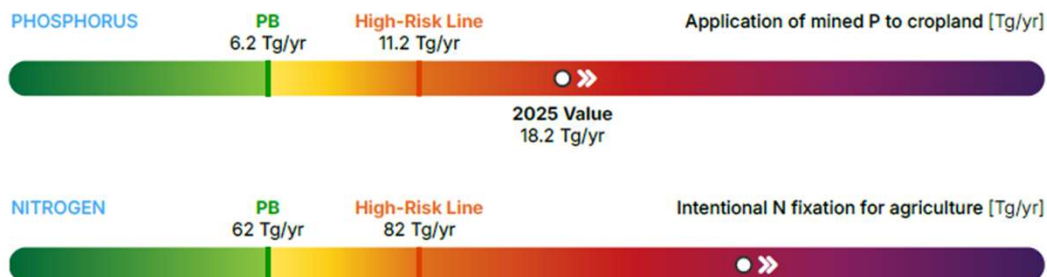
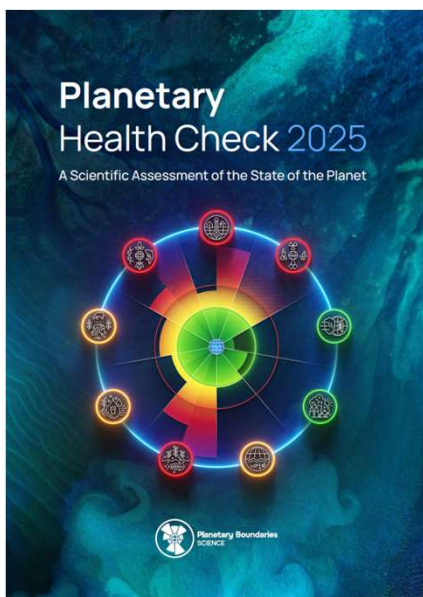
4.5 Modification of Biogeochemical Flows



Main Takeaways

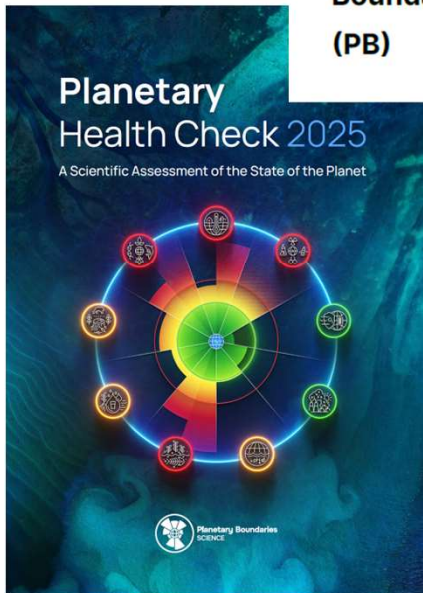
In the 20th century, the invention of industrial nitrogen fixation made it possible to convert molecular nitrogen from the atmosphere into reactive forms, such as those used in inorganic fertilisers. Combined with the mining of phosphate rock, this led to a drastic increase in fertilizer application on agricultural land.³³⁶ Because only a part of the fertilizer is actually taken up by crops, large quantities of both nutrients remain in the environment.^{337,338}

Nitrogen is released into the air and stored in groundwater and surface waters. Phosphorus accumulates in soils and is released into surface waters via soil erosion and surface runoff. Excess nutrients can have negative effects on biodiversity and the resilience of ecosystems on land, in freshwater and in the ocean, which are adapted to specific nutrient levels. Currently, losses of both nutrients to the environment are disrupting ecosystems beyond the safe level.



#1 Phosphorus (P) Flows

Definition	The phosphorus boundary consists of a regional component, aiming to prevent eutrophication of freshwater systems, and a global component, aiming to prevent large-scale ocean anoxia. The regional boundary uses the application of mined phosphorus to erodible soils as an indicator of phosphorus flow into freshwater systems, while the global boundary is based on riverine transport of phosphorus to the ocean.
Unit	Teragrams of Phosphorus per Year (Tg of P year ⁻¹). 1 teragram equals 1 million metric tons.
Historical Range	Before human intervention, phosphorus flows were low (~2.5 Tg P year ⁻¹ from land to freshwater and ~1.3 Tg P year ⁻¹ of export to the ocean). ³⁴⁰ Human activities have increased flows from land to freshwater systems through a global application of mined phosphorus to cropland of around 18.2 Tg P year ⁻¹ (regional, aggregated) and have increased phosphorus flows to the ocean to around 4.4 Tg P year ⁻¹ (global), largely due to fertilizer use. ^{340,341}
Planetary Boundary (PB)	The regional boundary is set to an application of 6.2 Tg P per year, ³ while the global boundary is established at a flow of 11 Tg P per year, which is roughly ten times the natural flow rate. ³⁴² Here, we focus on the regional boundary, as it is more limiting than the ocean boundary.



Planetary Health Check 2025

A Scientific Assessment of the State of the Planet

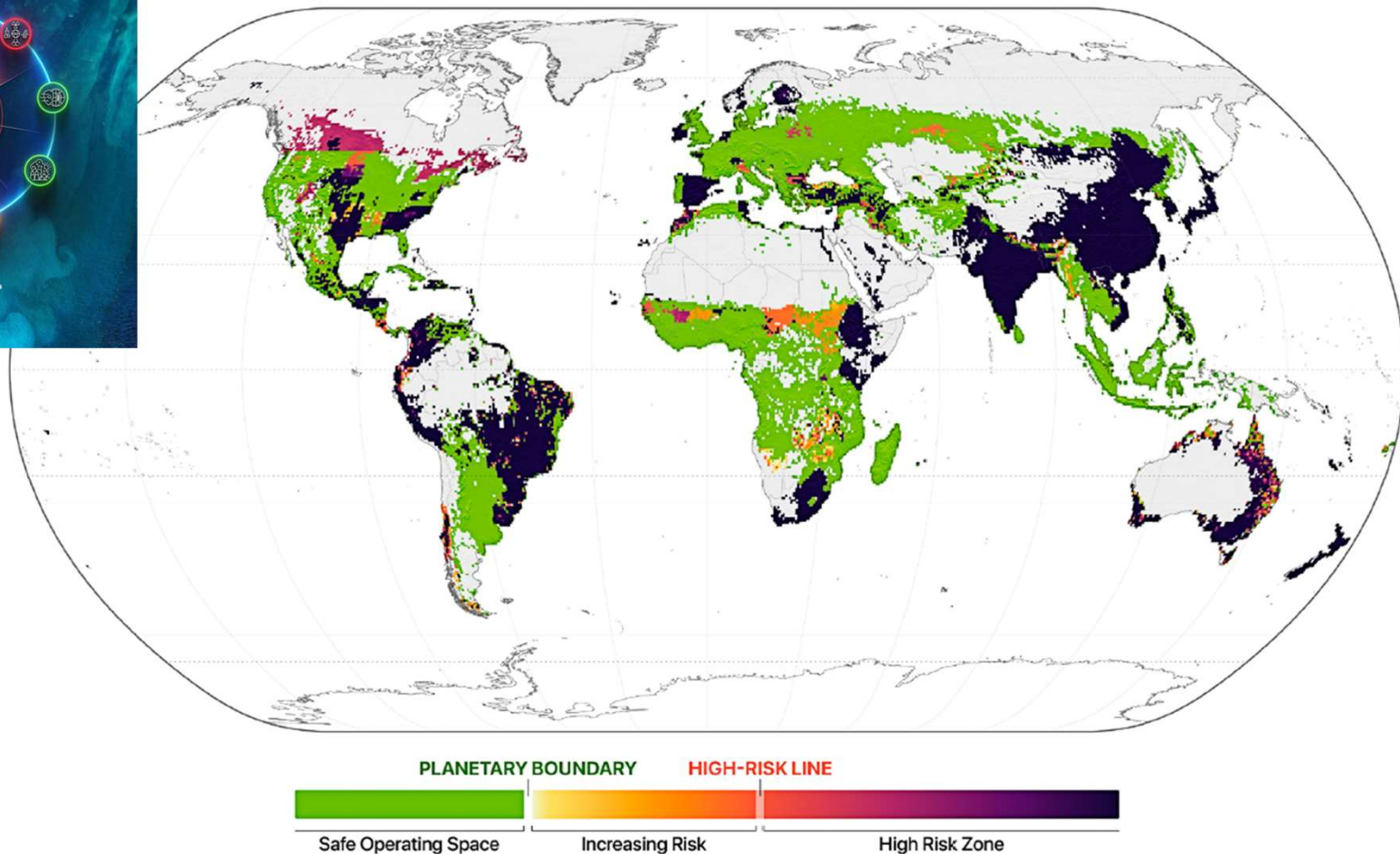


FIGURE 34 - Global risk map for the transgression of the Modification of Biogeochemical Flows boundary – Phosphorus cycle.

The regional boundary status is calculated based on agricultural phosphorus surplus in the year 2020. This graphic aligns with the suggestion for a control variable definition that is more closely related to phosphorus losses to the environment (phosphorus surplus instead of input).¹⁰³ The regional boundaries were preliminarily derived from the global boundaries, assuming a uniform rate of fertilizer surplus on cropland. Regional pollution limits may deviate significantly from these boundaries.³ Based on data from model runs with IMAGE-GNM, using the methodology of van Vuuren et al. (2025).¹⁰³

Key takeaway: The transgression of the phosphorus cycle boundary is particularly notable in parts of South America and Asia, where phosphorus use has exceeded safe ecological limits, indicating potential environmental threats.



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'Great news': EU hails discovery of massive phosphate rock deposit in Norway

By Frédéric Simon | Euractiv.com ⌚ Est. 7min

📅 29 jun 2023 (updated: 📅 26 ene 2024)

Content-Type: News



The Norwegian deposit is estimated to be worth 70 billion tonnes at least, which is just under the 71 billion tonnes of proven world reserves as evaluated by the US Geological Survey in 2021. [Photo credit: Laszlo Kupi]

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8 Julio 2023



Phosphate

Phosphate fertilisers could provide the natural answer to global food security.

CROP YIELD BOOST

The use of phosphate fertilisers in the past 50 years has boosted crop yields and helped feed millions, if not billions, of people. Fertilisers are typically comprised of three major water-soluble macronutrients such as phosphate, potash and nitrogen.

BURGEONING MARKET

It's predicted the global phosphate fertiliser market will reach \$207 billion by 2026 (Global Market Insights), registering a 5.1% CAGR therein. The world's increasing population (and, therefore, increasing meat consumption), limited availability of land and drive for food diversity have been key drivers of demand. Asia is currently the largest market, due to large farming communities in China and India. Awareness programmes in emerging economies in Latin America, Africa and Asia-Pacific are encouraging greater use in these areas.

SECURITY AND SUSTAINABILITY

The European Union once again named phosphate rock as a 'Critical Raw Material' in 2020. Its security is emerging as a vital global sustainability challenge. Supply strategies to ensure farmers have sufficient access to phosphates to feed the world are therefore becoming increasingly urgent.

KEY POINTS

- CRITICAL RAW MATERIAL (EU: 2020)
- KEY INGREDIENT FOR GLOBAL FOOD SECURITY
- BOOSTS CROP YIELDS
- MARKET PREDICTED TO REACH \$207 BILLION BY 2026
- ASIA IS LARGEST MARKET; EMERGING ECONOMIES SHOWING INTEREST

communications materials


MATTERS ARISING



<https://doi.org/10.1038/s43246-022-00236-4>

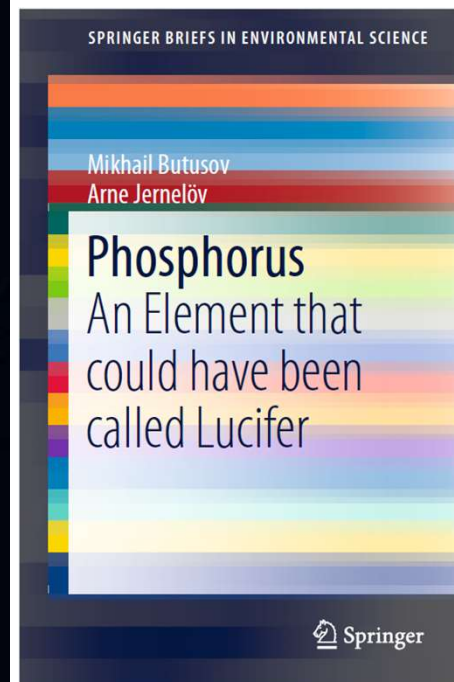
OPEN

Concerns about global phosphorus demand for lithium-iron-phosphate batteries in the light electric vehicle sector

Bryan M. Spears^{1,2✉}, Will J. Brownlie^{1,2}, Dana Cordell³, Ludwig Hermann⁴ ⁴ & José M. Mogollón⁵ ⁵

ARISING FROM Xu et al. *Communications Materials* <https://doi.org/10.1038/s43246-020-00095-x> (2020)





P en la Biósfera



“DEMAND & SUPPLY” (2017)

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