Phosphorus Biogeochemistry of the Everglades: Implications to Restoration


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Phosphorus Cycling Processes

Topic Outline

- Introduction
- Forms of phosphorus
- Abiotic processes
- Biotic processes
- Ecosystem phosphorus memory
- Implications to restoration
Phosphorus Gradients

Phosphorus Limited Wetlands

C:N:P Ratios [High]
Low Organic Matter Accumulation
Slow turnover rates
Longer residence time
High nutrient use efficiency

Phosphorus Enriched Wetlands

C:N:P Ratios [Low]
High Organic Matter Accumulation
High turnover rates
Shorter residence time
Low nutrient efficiency
Phosphorus Gradients

High

Low
Phosphorus Gradients – WCA-2a

Total Phosphorus (mg kg\(^{-1}\))

Depth (cm)

[E] = Eutrophic Site I (1.9km)
[T] = Transition/eutrohphic Site II (3.5 km)
[O] = Oligotrophic Site (8.3km)
Phosphorus Cycle

Runoff, Atmospheric Deposition

Litterfall

Plant biomass P

Peat accretion

Outflow

DIP

POP

DOP

DIP

DOP

DIP

POP

DOP

[Fe, Al or Ca-bound P]

Adsorbed IP

Periphyton P

Outflow

AEROBIC

ANAEROBIC
Inorganic Phosphorus-
Organic Soils

\[ Y = 0.01X^{1.54} \]
\[ R^2 = 0.897; \ n=390 \]
Soil Cores - WCAs

S. Newman, SFWMD)
Organic Wetland Soils – Drainage Effects

Peat Depth < 10 cm
Total P = 836 mg P/kg

Peat Depth > 30 cm
Total P = 411 mg P/kg

**Diagram:**
- KCl-Pi (available)
- Fe- and Al-bound P
- Alkali extractable organic P
- Ca- and Mg-bound P
- Residual P

8/19/2008
WBL
Organic Wetland Soils – Fire Effects

Pre Surface Burn

Labile P
Fe- & Al-bound P
Ca- & Mg-bound P
Organic P

Post Surface Burn

Pre Peat Burn

Post Peat Burn

Smith et al., 2001
Inorganic Phosphorus Retention

**Solid phase**

- **P\textsubscript{adsorbed}**
- **P\textsubscript{solution}**

**Porewater**

- **P\textsubscript{w}**
- **P\textsubscript{solution}**

**Soil**

- **P\textsubscript{ad}**
- **P\textsubscript{s}**
- **P\textsubscript{ret}**

**Water**

**EPC\textsubscript{0}** = Equilibrium P concentration at which point adsorption equals desorption

**slope = KD**

**S\textsubscript{max}**

**So**

**Adsorption**

**Desorption**

Phosphorus in Soil Porewater

EPC\textsubscript{0} = Equilibrium P concentration at which point adsorption equals desorption
Inorganic Phosphorus Retention-WCA-2A

\[ EPC_0 = \text{Equilibrium P concentration at which point adsorption equals desorption} \]
Phosphorus Loading – Biotic Processes

**WATER**

- Plants

**SOIL**

- Detritus
- Labile Detritus
- Microbial Biomass
- Nutrient (N, C, P)

**PLANTS**

- Nutrient (N, C, P)

**MICROBIAL BIOMASS**

- Nutrient (N, C, P)

**ROOTS**

- Nutrient (N, C, P)
Short-term P partitioning: $^{32}\text{P}$ 18 days

- Floc: 35%
- Soil: 27%
- Metaphyton: 12%
- Water: 10%
- *Utricularia* spp.: 7%
- Consumer: 3%
- Macrophyte dead: 3%
- Epiphyton dead: 3%
- Roots: 1%
- Other macrophytes: 1%
- Epiphyton live: <1%

(Noe et al. Freshwater Biology 2003)
Organic Phosphorus

Detrital Matter
- Phytin
- Phospholipids
- Nucleic acids
- Sugar phosphates

Plants
Animals
Microbes

Humus

Inorganic Phosphate
Organic Phosphorus – WCA-2A

$^{31}$P NMR spectroscopy

Enriched (*Typha*)

Unenriched (*Cladium*)

Monoesters

DNA

Floc

Soil

Turner et al., 2006
Organic Phosphorus – Isolated Wetlands - Okeechobee Basin

Cheesman et al., 2008
**Alkaline Phosphatase Activity**

*Everglades- WCA-2A*

- **p-nitrophenol**
- **(mg g\(^{-1}\) hr\(^{-1}\))**

- *Litter*
- *0-10 cm*
- *10-30 cm*

*Wright and Reddy, 2001*
Phosphatase Activity

Periphyton APA along the WCA 2a Nutrient Gradient

July 1996 [Newman, S]
Biotic and Abiotic Interactions

Epiphytic

Benthic

Soluble P

Floating

Water

Soil

Ca-P

Ca-P

Soluble P

Soluble P

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Diagram showing interactions between epiphytic and benthic organisms, soluble P, floating Ca-P, and soil Ca-P.
32P Partitioning- Periphyton

- Abiotic
- Biotic
- Water

1 hr
- 74%
- 22%
- 5%

12 hr
- 88%
- 10%
- 2%

Water DRP: 5 ug l⁻¹
Light: 10 W m⁻²
(Scinto and Reddy, Aquatic Botany, 2003)
Periphyton-Phosphorus-CaCO$_3$ Interactions

Solution P  CaCO$_3$

(Scinto and Reddy, Aquatic Botany, 2003)
Phosphorus and Calcium Accumulation-WCA-2a

![Graph showing the relationship between Phosphorus and Calcium accumulation. The correlation coefficient, $R^2$, is 0.969.](image)
Sulfur-Calcium -Phosphorus Interactions under Aerobic Soil Conditions

Floodwater

Aerobic soil

Ca + P

H+ + SO4^{2-} \rightarrow H_2S + O_2

Anaerobic soil

Ca - P

SO4^{2-} \rightarrow H_2S
Sulfur-Iron -Phosphorus Interactions under Anaerobic Soil Conditions

Inputs

Soil

Water

FeS

FePO$_4$

[Strengite]

Fe$_2$(PO$_4$)$_3$

[Strengite]

Fe$_3$(PO$_4$)$_2$

[Vivianite]

SO$_4^{2-}$

H$_2$S

Fe$^{2+}$ + PO$_4^{3-}$

FeRB

FePO$_4$

Fe(OH)$_2$-PO$_4$

Fe$_3$(PO$_4$)$_2$

[Vivianite]
Phosphorus Memory in the Everglades

- Legacy phosphorus in various ecosystem components (uplands, wetlands, and aquatic systems)
  - Transient pools
  - Stable pools
- Capacity for showing effects as a result of past practices
- Length of time over which phosphorus release extends before returning to a stable condition
Legacy Phosphorus
Phosphorus Accretion-WCA-2A

![Graph showing phosphorus accretion rate vs. distance from inflow in g m⁻² y⁻¹. The graph depicts a downward trend as distance increases.]
Phosphorus Memory

- External Load Reduction
- Internal Memory
- Background Level
- Lag time for Recovery

Water Column Phosphorus vs. Time - Years
Phosphorus Memory - Everglades - WCA-2A

Fisher and Reddy, 2001

![Graph showing P flux (mg P m$^{-2}$ day$^{-1}$) against distance from inflow (km). The graph shows a declining trend in P flux as the distance from inflow increases.]
Ecological Significance

Detritus Production

Biomass Production

Release of Plant Available N

Microbial Biomass

Legacy Phosphorus

White, 1999
Research Needs

- Identification of inorganic and organic P compounds
- Stability of legacy P under range of hydrologic/redox conditions
- Multiple roles of microbial and plant mediated processes on P retention and release
- Develop methods to reduce P memory effects to enhance the recovery
- Linkage between P biogeochemistry and other elemental cycles
- Forecast models based on mechanistic understanding of biogeochemical processes