The biogeochemistry of ornithogenic soils from a penguin rookery in Antarctica

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Introduction

In the polar desert of Antarctica's McMurdo Dry Valleys, temperatures and precipitation are very low. The low availability of water and nutrients places constraints on the soil microbial community which in turn limits the biogeochemical processes of carbon (C), nitrogen (N) and phosphorus (P) cycling. Future climate change may greatly disrupt the current state of a nutrient and water limited environment. In the harsh habitat, ornithogenic (bird-influenced) soils from penguin rookeries are nutrient rich, and can serve as an outgroup for soils of continental Antarctica. Although many studies have been conducted on climate change and penguin colonies, few studies have examined the penguins effects on the soil biology which loop their excreted nutrients back into the soil. To investigate the responses of ornithogenic soil biogeochemical processes to nutrient and water pulses, we analyzed microbial respiration, nutrient content of the soil and bacterial biovolume from ornithogenic soils taken from a gradient of low, medium, high, and no penguin activity.

Questions:

- What immediate effects do penguins have on soil nutrient cycling?
- One of the predicted outcomes of climate change is an increase in nutrient availability. What are possible effects of climate change on this outgroup of fertilized soils? How will they respond to fertilization?

Methods

- Site: Cape Royds, an Adélie penguin rookery on Ross Island, Antarctica (Figure 1)
- Location: Soils were collected over a gradient of high, medium, low, and no penguin activity (Figure 2). In the lab, 50 g of soil and rock from each location were put into 9 replicate incubation jars.
- Fertilizer: 3 replicate jars from each location were treated with the following:
  - Added N (as aqueous NH_4NO_3) or P (as aqueous Na_2HPO_4)
  - Controls received only water
  - Later, N and P were reapplied with the addition of C (as sucrose)
- Incubation: Jars were covered, then placed at 4°C with 24 h of constant light
- CO_2 flux measured over a period of 55 days (a measure of biotic activity)
- Bacterial biovolume was measured using epifluorescent microscopy.
- At the beginning and end of the incubation, we measured the following soil properties:
  - Gravimetric soil water content
  - Extractable phosphate, nitrate, and ammonium
  - Total and organic carbon and nitrogen
- Data were analyzed using a two –way ANOVA of site*treatment with, time as a covariant for CO_2 flux

Figure 2. Sampling locations at Cape Royds. The pond edge is an area of High activity, with penguins entering and leaving the water. The trafficked area between the pond and the nesting sites is of Medium activity. The area just below the rocks is of Low activity, because penguins avoid the large rocks and walk around. The area outside the rookery on the other side of the pond receives No activity.

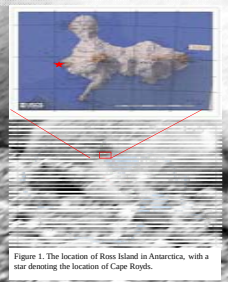
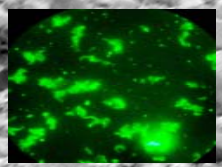


Figure 1. The location of Ross Island in Antarctica, with a star denoting the location of Cape Royds.



Results and Discussion:

CO_2 Flux:

- A significant site effect (P< 0.001), where low and no activity sites have visibly lower fluxes, which is an indication of lower biotic activity.
- A significant site*treatment interaction (P=0.006):
  - Under medium and high penguin activity, addition of water with treatment resulted in an immediate increase in activity.
  - N and P alone yielded no noticeable response. However, addition of C with N and P stimulates activity, but sites respond differently.
- Therefore the soils are carbon and water limited.

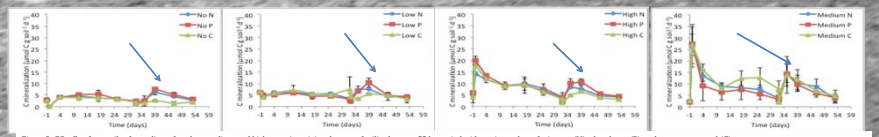
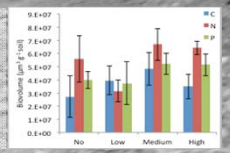


Figure 3. CO_2 flux from soils of a gradient of no, low, medium, and high penguin activity, that were fertilized over a 55day period with nutrient pulses of nitrogen (N), phosphorus (P), and water as a control (C) . Arrow denotes addition of C with N and P.

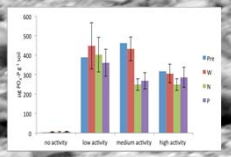
Microbial Biovolume

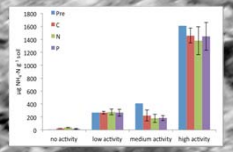
- A significant site effect (P= 0.006), such that low and medium activity sites are different.
- Treatment effect (P= 0.005), such that nitrogen is higher than the control.

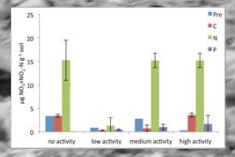


Soil Chemistry:

- Penguin activity significantly influenced both PO_4 and NH_4 (P< 0.001) .
- The medium level of penguin activity utilized P when also given C (P= 0.015), whereas other locations still had same amounts of N and P as untreated soils.
- With the addition of nitrogen, we saw a buildup nitrate (P< 0.001), which suggests that the soil community is adapted to the ammonium deposited by penguins.







Conclusion:

- There was minimal measurable variation in activity with the addition of N and P. Therefore, nutrient fertilization alone will likely not influence these ornithogenic soils.
- C addition stimulated greater microbial respiration with the greatest stimulation under medium and high penguin activity.
- Microbial biovolume was stimulated by N, but CO_2 flux was not. biovolume and activity are not responding the same.
- Therefore, if climate change is accompanied by pulses of nutrients and eventually C (via increased primary productivity), the way the soil will respond will therefore depend upon the level of penguin activity. This can be further complicated if climate change also alters penguin populations.
- Future work: Soil CN analyses are forthcoming to determine the impact on organic matter decomposition.

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