Geoderma 148 (2008) 51–54

Contents lists available at ScienceDirect

Geoderma

journal homepage: www.elsevier.com/locate/geoderma

The impact of perennial cormorant colonies on soil phosphorus status

Henrik Breuning-Madsen [a], Camilla Bloch Ehlers [a], Ole K. Borggaard [b,*]

[a] Department of Geography and Geology, University of Copenhagen, Øster Voldgade 10, DK-1350 Copenhagen K, Denmark
[b] Department of Natural Sciences, University of Copenhagen, Thorvaldsensvej 40, DK-1871 Frederiksberg C, Denmark

ARTICLE INFO

Article history:
Received 17 January 2008
Received in revised form 20 August 2008
Accepted 9 September 2008
Available online 2 October 2008

Keywords:
Available P
Phosphate saturation
Phosphate adsorption capacity
P leaching indicators
Eutrophication

ABSTRACT

During the last decades, the population of cormorants in Northern Europe has grown rapidly due to protection. Their impact on vegetation has been recognized, as many trees containing cormorant colonies have collapsed, but their influence on the soil phosphorus (P) status and related ecological impacts have not been studied in details.
In this study, total and plant available P (P_{Total}, P_{Olsen}) together with phosphate adsorption capacity and saturation (PAC, P_{Sat}) were measured in the soil at a reference area (control) and below two cormorant sub-colonies that differed in age and bird dropping density (indicated by number of used nests). One colony with totally 831 nests was 24 years old ($Cormorant_{24}$), while the age of the other colony with totally 181 nests was 12 years ($Cormorant_{12}$). Analyses of soil samples collected in four layers down to 80 cm showed strong decreases in P_{Total} and P_{Olsen} in the order: $Cormorant_{24} >> Cormorant_{12} >>$ control and severe leaching of P into the subsoil below 80 cm at $Cormorant_{24}$ but not at $Cormorant_{12}$. Accordingly, in all four $Cormorant_{24}$ soil layers and in the upper three $Cormorant_{12}$ layers, P_{Sat} exceeded 0.25, which is considered the limit between retaining and leaking soils; $P_{Sat} = P_{Ox}/PAC$ and $PAC = 0.5 \times (Al_{Ox} + Fe_{Ox})$, i.e. half the sum of oxalate-extractable aluminium and iron. The importance of P_{Olsen} and P_{Sat} as indicators for P leaching was demonstrated as well as the strong impact that cormorants can have on the soil P status. This, in turn, will not only affect the ecosystem balance below the colonies but probably also threaten the water quality in nearby open waters as cormorant colonies are normally located on small lake islands or close to shallow bays.

1. Introduction

One of the major transport agents of nutrients from the marine to the terrestrial environment is cormorants and other piscivorous birds that breed in the coastal zone. Their diets consist mainly of fish, and they excrete nutrient-rich guano high in N and P. The excrements are mainly dropped in narrow nesting areas, and thereby the soils are heavily enriched by nutrients. This process is well known all over the world from penguin rookeries in the Antarctic (Speir and Cowling, 1984), over arid and semi-arid areas (Anderson and Polis, 1999; Wait et al., 2005) to humid temperate areas (Hogg and Morton, 1983; Mun, 1997; Ligeza and Smal, 2003; Hobara et al., 2005).

In Denmark, cormorants typically live at shallow water bodies such as lakes, bays and fjords and breed in colonies on land, most commonly in trees close to the shoreline. The number of cormorants has been kept at a low level until the 1970s where the species was protected by law, and consequently the population has increased dramatically from about 300 nests in 1971 to about 42,000 nests today (Bregnballe et al., 2003). The increase in the number of cormorants has led to a growing interest in how the species influences its environment, especially vegetation and soil. The high load of nutrients is expected to increase the leaching of nitrate and base cations from the soils, while phosphate is less prone to leaching because of strong fixation to mainly the aluminium and iron oxides in the soil (Borggaard et al., 2004). However, the heavy input of P to the nesting area of cormorants raises the question whether the heavy load of P has saturated the soil to an extent that the equilibrium phosphate concentration in the soil solution exceeds what can be accepted by open waters without eutrophication (Van der Zee et al., 1988; Daniel et al., 1998; Siemens et al., 2004). If so, not only nutrient cycling and the terrestrial ecosystem stability will be affected, but the water quality may also be threatened in nearby bays, lakes and fjords, where P is often a limited factor for creating algae blooms because of high N:P ratio (Smith, 1983; Ligeza and Smal, 2003; Hobara et al., 2005). Unfortunately, precise knowledge about the influence of cormorants on soil phosphate saturation and leaching is lacking.

Thus, in this paper the impact of the continental sub-species of the great cormorant *Phalacrocorax carbo sinensis* on the soil P status is investigated in a comparative study including a 24-year-old nesting place with many nests and a high density of bird droppings, a 12-year-old nesting place with fewer nests and a lower density of bird droppings and a nearby control area with no nests and consequently almost no bird droppings. The soil P status includes total and plant available phosphorus but most emphasis will be on phosphate

* Corresponding author. Tel.: +45 35332419.
E-mail address: okb@life.ku.dk (O.K. Borggaard).

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doi:10.1016/j.geoderma.2008.09.002

adsorption capacity and saturation of various soil layers in relation to P leaching in soil.

2. Materials and methods

2.1. Study area

The investigation was carried out at Vorsø, which is located in Horsens Fjord in Eastern Jutland, Denmark (55°52′ N, 10°00′ E). The area is about 60ha and includes two small forests hosting cormorant colonies. The mean annual precipitation is about 820 mm (Frich et al., 1997), and the mean monthly temperature is between 0.3 °C in January and 16.2 °C in July (Laursen et al., 1999). During summertime, from May to August, evapotranspiration exceeds precipitation, while from October to April the opposite situation exists resulting in leaching with about 400 mm. The parent material is calcareous sandy loamy Weichselian till deposited about 18,000 years ago (Houmark-Nielsen, 1987); since then, the calcium carbonate has been leached from the uppermost ~ 1m of the soil. The topography is rather flat, with the highest point being 4m above sea level. A few poorly drained depressions exist in the landscape.

Before 1928, most of the island was farmed, but in 1928 it became a natural reserve. Biologists have studied and registered the development in flora and fauna, and these studies included a registration of how many cormorant nests were used and where they were located (Halberg, 1996). Until 1970s when the cormorants in Denmark were totally protected by a conservation act (Bregnballe and Gregersen, 1995), the number of birds on Vorsø was kept at a low level by shooting. The protection led to a dramatic increase in the number of cormorants in the country as well as on Vorsø, where the number of nests increased from about 250 in 1970 to about 5000 in 1991 (Bregnballe and Gregersen, 1995).

Three study sites were chosen including Cormorant$_{24}$, Cormorant$_{12}$ and a control. Cormorant$_{24}$ is located below a big oak tree (*Quercus robur*) that has hosted cormorant nests for 24 years, and Cormorant$_{12}$ is located in a small ash (*Fraxinus*) forest that have hosted cormorant nests for 12 years. The control site is located in a forest without cormorant nests for at least 100 years. According to Gregersen (unpublished results), the total number of used nests registered until 2004 is 830 at the Cormorant$_{24}$ site and 181 at the Cormorant$_{12}$ site. The number of nests at the two cormorant sites can be used as a relatively measure of the impact at the two cormorant sites. This means that the amount of P added to the soil below the trees due to bird dropping is more than four times higher at Cormorant$_{24}$ compared to Cormorant$_{12}$, as the number of nests at Cormorant$_{24}$ was 830 and 181 at Cormorant$_{12}$.

2.2. Soil sampling and analyses

At each of the three sites, soil samples were collected from five small excavated pits to the depth of 40 cm and subsequently by boring. The samples were taken at 4 fixed depths, i.e. A1: 0–5 cm, A2: 5–15 cm, A3: 15–50 cm and B: 50–80 cm. Composite samples at each site and depth were obtained by pooling equal amounts of soil from the five subsamples. In addition, three samples were taken in each of the main horizons with 100- cm^3 steel cylinders and used for bulk density determination after over-night drying at 105 °C and weighing.

The soil samples were air-dried and sieved (2 mm sieve). All analyses were made on the less than 2-mm fraction as triplicate determinations except for duplicate texture analysis, which was determined by the combined sieving and hydrometer method (Day, 1965). Soil pH was determined by a combination electrode in a suspension of soil and distilled water at a soil:water ratio of 1:2.5 (Thomas, 1996). Total carbon was determined by dry combustion at 1250 °C in oxygen (ELTRA, 1995). Total P (P_{Total}) was determined by extracting a soil sample heated to 550 °C for 1h with 6M H_2SO_4 for 1h and available P (P_{Olsen}) was determined by the bicarbonate method (Olsen and Sommers, 1982). Oxalate-extractable aluminium (Al_{Ox}), iron (Fe_{Ox}) and phosphate (P_{Ox}) were determined by extraction with 0.2M ammonium oxalate for 2h at pH 3 in the dark (Schwertmann, 1964). The concentrations of Al and Fe in the extract were quantified by atomic absorption spectrometry and the phosphate concentration was determined by the molybdenum-blue method (Murphy and Riley, 1962) after at least 200 times dilution as suggested by Siemens et al. (2004). Coefficients of variation (CVs) of the chemical analyses were less than 6% except for P_{Ox} of control samples, where CVs were 5–10% because of very small concentrations.

3. Results and discussion

3.1. Soil characteristics

At all three sites, the soils have a 35–50 cm thick A horizon that is dark brown (7.5 YR 3/3 to 7.5YR 3/2, moist). This horizon is underlaid by a brown (10YR 4/3, moist) subsoil with reddish brown mottles. The uppermost 5 cm of Cormorant$_{24}$ is strongly influenced by the bird droppings and fallen nest material and form an almost peaty, structureless soil layer. Apart from this layer, the soils at the three sites appear similar and they are rather well-drained, although perched water table might develop during wintertime in the subsoil. This causes the formation of pseudogley, which can be recognized as mottling in the subsoil. According to Soil Survey Staff (2006), the soils are Dystrudepts.

The soil samples at the three sites have similar texture (Table 1), almost all falling into loamy sand according to Soil Survey Staff (2006). The bulk density is low in the topsoil, especially at Cormorant$_{24}$. In the three A horizons, the bulk density stays at a moderate level, but increases significantly at all three sites in the Bw horizon, to 1700 kg/m^3. The total carbon content in the three uppermost soil layers (A horizons) is rather high compared to the carbon content in Danish plough layers that have an average carbon content slightly below 2.0% (Madsen and Platou, 1983; Krogh et al., 2003). Cormorant$_{24}$ has significantly higher carbon content at all depths than the other two sites, which have almost the same carbon percentages.

At the control site, the pH in the soil is rather close to the normal pH profiles for forest areas in Eastern Jutland (Madsen and Munk, 1987). The soil is leached in the topsoil to a pH about 5.0, but in the subsoil the pH is increasing and is close to neutral at the depth of 70–80 cm. The topsoil has a little higher pH than the soil horizon below, probably due to the "ion pumping effect" of the plant cover that extracts nutrients from the entire soil profile and delivers it back as a

Table 1
Bulk density, texture, organic carbon content and pH of various soil layers at the three sites (Cormorant$_{24}$, Cormorant$_{12}$ and control)

Horizon/ depth (cm)	Bulk density (kg m^{-3})	Clay< 2 μm (%)	Silt 2–50 μm (%)	Sand 50–2000 μm (%)	Organic carbon (%)	pH_{H_2O}
Cormorant$_{24}$						
A1 (0–5)	400	–	–	–	10.0	4.4
A2 (5–15)	1200	10	27	63	4.9	3.8
A3 (15–50)	1200	10	27	63	2.8	3.6
Bw (50–80)	1700	7	20	73	0.7	4.6
Cormorant$_{12}$						
A1 (0–5)	1000	7	22	71	3.7	4.6
A2 (5–15)	1100	7	20	73	2.7	3.9
A3 (15–50)	1300	8	20	72	2.3	4.4
Bw (50–80)	1700	7	22	71	0.2	6.8
Control						
A1 (0–5)	900	–	–	–	3.9	5.1
A2 (5–15)	1000	9	40	51	3.0	4.9
A3 (15–50)	1300	10	34	56	2.4	4.9
Bw (50–80)	1700	7	15	78	0.4	6.5