# Chapter 2
# Changing Paradigms in the History of Tropical Peatland Research

**Hans Joosten**

**Abstract** The history of peatland research in Southeast Asia can be understood as a story of changing paradigms. Whereas already in 1778 the idea had been proposed that coal originates from peatlands and that during the Carboniferous a tropical climate had prevailed, peatland science maintained that in the tropics decomposition would proceed too rapidly to allow peat formation. The many reports of the contrary never reached nor convinced the mainstream scientific world. Only in 1909 with a publication of coal geologist Henri Potonié the existence of real peatlands was widely accepted. Potonié simultaneously underscored that tropical peatlands could only be groundwater fed. In 1933 Betje Polak convincingly argued that many Southeast Asian peatlands are in fact ombrogenous bogs, not geogenous fens.

Instrumental in these scientific revolutions was the long-term devotion and the 'un-disciplinary' background of both Potonié and Polak. The decades that passed between the emergence of evidence and its wide acceptance support the observation that new scientific truths do not triumph by conviction, but because their opponents eventually die. As the peatlands in Southeast Asia are currently dying faster than their researchers, a new sustainability paradigm is urgently needed.

**Keywords** Peat • Bog • Tropics • History • Paradigm

## 2.1 Introduction

> "Guicciardini says, that it is not known whether Asia, Africa, or America, contain any mosses, as no search has been made. Degner and Dr. Anderson deny that there are any in these regions. . . . The former argues upon this as a fact: "If, "says he, "forests are converted into moss, the greatest part of Moscovy, Tartary, America, and other woody uncultivated regions would have, ere now, undergone this change, which is not the case."

H. Joosten (✉)
Institute of Botany and Landscape Ecology, Greifswald Mire Centre,
Ernst-Moritz-Arndt-University Greifswald, Greifswald, Germany
e-mail: joosten@uni-greifswald.de



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> "To this I reply, . . . , That in woody regions, moss is of little value; it is never in request as a fuel, as the abundance of wood supplies its place. No efforts are made to search for it as a soil or a manure. The former can be produced in abundance; the latter is less requisite. Mosses, therefore, may exist in these regions, though no notice be taken of them." (Rennie (1807): Essays on the natural history and origin of peat moss)

Scientific progress can be understood as a sequence of 'paradigms' (Kuhn 1962/1996). A paradigm represents the matrix of generalizations, beliefs, values, and examplars that are shared by mainstream scientists. Paradigms are not only 'disciplinary' in the sense that they unify a scientific discipline, they also 'discipline' by self-confirmation and education and by – consciously and unconsciously – suppressing views that do not fit in the prevailing paradigm. A paradigm may be replaced, when sufficient challenging observations/considerations have accumulated and in a 'scientific revolution' (Kuhn 1996) a new paradigm with wider explanatory power is established.

Also the history of peatland research in Southeast Asia is such a story of changing paradigms. In this paper I describe the people, ideas and events that accomplished the two main scientific revolutions: the mere acknowledgement of the existence of peat in the tropics and the recognition of ombrogenous peatlands.

Especially Dutch scientists were instrumental in both revolutions. The Netherlands combines the oldest major economic and scientific peatland tradition (De Zeeuw 1978, cf. Schoockius 1658, the worldwide first scientific book on peat and peatlands) with its past as colonialist of the prime tropical peatland country Indonesia. Most countries in Europe where peatland science did originate have no tropical colonist tradition, the United Kingdom and The Netherlands being the exception. Whereas English publications were widely read, the Dutch (and German) language of many relevant reports and publications impeded diffusion of the 'revolutionary' ideas they contained. And where translations into English were indeed made, severe mistakes confirmed rather than challenged the prevailing paradigm. In this paper I therefore present new English translations of various original Dutch and German language texts that demonstrate historical development and illustrate topicality.

## 2.2 The Age of Denial (1778–1909)

In 1778 the German theologian and speculative geologist Franz von Beroldingen (1740–1798) propounded the theory that coal "largely originates from the Plant Kingdom, and that it is originally nothing else than . . . at times topsoil, at times trees, but most commonly peatlands that have been flooded and covered by earth, that through the works of Nature eventually have transformed into coal." This theory gloriously spread in spite of his second preposition that – as had been deduced from fossils in coal – during the Carboniferous period a tropical climate had prevailed over the entire globe. Mainstream science, however, maintained that autochthonous peat deposits were not found in tropical countries. In order to escape from this contradiction some geologists assumed that coal did not derive from peatlands at all, while others sought a solution by supposing that coal formation could only take place in a cool climate (Wichmann 1910a, b).

The maxim that peatlands do not exist in tropical countries was supported by the most influential scientists of that time. The leading Dutch geologist and soil scientist Winand Staring stated in his 1856 benchmark book on the soils of The Netherlands explicitly "that in the tropics peat formation is impossible, because the plants decompose too rapidly"(Staring 1856), a statement that was not challenged in publications of the same rank, in spite of many reports supporting the opposite.

Already Anderson (1794) had declared: "I have seen genuine peat that was found on the island of Summatra; which is a proof that it is not confined to cold regions only". Peatlands from Djambi (Sumatra) had been described by Groote in 1820 (Wichmann 1909). Pijnappel (1860) had reported on Von Gaffron, who – while exploring Central Kalimantan for coal and gold – had noted extensive swamp forest fires that for months had raged the Kotaringin area over almost 700,000 ha during the drought of 1846. Schwaner (1852–1854) had pointed out the presence of large peatlands in the southern and eastern part of Borneo, whereas Michielsen had presented peat from the Sumatran village of Siak to the 1864 meeting of the Koninklijke Natuurkundige Vereeniging (Dutch Royal Scientific Society) (Bernelot Moens 1865). Various early reports exist on the occurrence of peats on Java. Bernelot Moens (1865) noticed in his description of peat from near Djoegelangan village: "The presence of a peat deposit at this location would … conflict with the general accepted view that between the Tropics no peat soils can be formed, except on high places in the mountains, e.g. on the high plains of the volcanos on Java, because in the lower, warmer regions, the change of plant materials into humic soil occurs so rapidly, that no time is available for peat formation". Bernelot Moens explained tropical peat formation by the fact that "whereas the turn-over in a tropical country is faster, the all the more powerful plant growth also guarantees a proportional production." Vlaanderen (1865) presented the chemical profile of peat (loss-on-ignition 25.9 %) occurring south of Djenoe (Central Java), whereas Edeling (1867) described gas eruptions from a peatland in the Ambarawa basin associated with earth quakes. And shortly after Koorders in 1895 (see below) had published his detailed observations on pristine peat swamps in East-Sumatra, Van Bijlert (1897) presented a detailed analysis of the peatland soils (called "pajas") in that area used for tobacco cultivation: "Closer to the sea the paja soil is so loose and rich in water that the main canals can be made with dredge machines. Big pieces of peat float up, as do pieces of wood stems. The latter, initially hard as stone, fall within a very short time apart to an extremely fine, grey-black powder under the influence of heat and desiccation."

Van Bijlert (1897) also warned for the risks of fire and the inevitable subsidence of drained peat soils: "Has the soil become somewhat accessible by drainage, a start is made to cut the trees and to remove the lower vegetation. The burning of the dried trees should progress carefully and not in too large piles, because in such case the peat layer may also be burned. If a drained paja accidently catches fire, the peat layer burns away to the water level or to the incombustible subsoil. The deep paja soils ... are without exceptions located low, and can thus only be made suitable for cultivation by a very well-developed and well-maintained drainage system. Like all peat soils the peat volume decreases very much and the surface thus approaches the drainage level. In case the land has over long time ... remained constantly rather dry, this subsidence is doubtlessly of importance. ... In general the land will continuously subside as a result of drainage. ... The black or dark coloured soil is very strongly heatened by the sun, the peatified plant remains that have originated from water plants, fall apart to an extremely fine substance and are being decomposed very rapidly because of the effect of the easily penetrating air and the large heat in combination with humidity. ... Returning to the same land in a next year, one finds the land laying deeper than before".

In spite of these early and detailed reports, the seminal peatland bible of Früh and Schröter (1904) included a special chapter "On the absence of typical peatlands in subtropical and tropical climates". The chapter concluded, after a thorough discussion of the literature (which excluded most above mentioned papers) and own observations:

1. "As far as hitherto existing studies range, no substantial proper autochthonous peat exists in the lowlands of the tropics, but at most peaty soils, raw humus and shallow fibrous sods.
2. Peat formation in the tropics only starts in higher regions with the climate of the temperate and cold zones.
3. The allegedly encountered peat deposits in the alluvia of the large tropical rivers are predominantly allochthonous formations."

Until 1909 the paradigm persisted that in the tropics no peat can be formed, because in the warm climate decomposition would proceed too rapidly and intensively. The many reports of the contrary never reached nor convinced the mainstream scientific world.

## 2.3 The Coal Man and the Focus on Fens (1909)

> "The commitments that govern normal science specify not only what sorts of entities the universe does contain, but also, by implication, those that it does not." (Kuhn 1996: The structure of scientific revolutions, p. 7.)

Whereas the ample observations over decades should have challenged the paradigm of a peat-free tropics, the scientific revolution only came with the publication of a paper with the fascinating title "Die Tropen-Sumpfflachmoor-Natur der Moore des produktiven Carbons" (The tropical swamp fen character of the peatlands of the productive Carboniferous; Potonié 1909). This booklet linked the concept of tropical peat to the globally important industrial energy carrier 'coal'. Its author Henry Potonié (1857–1913), a botanist by training and Professor of Palaeobotany and Coal Geology at the Royal Mining Academy and University of Berlin, was at that time preparing a magnus opus on combustible deposits of recent biotic origin (Potonié 1906; 1908–1915). Because of his strong interest in the genesis of coal (Potonié 1905, 1907a), Potonié was well aware of the hypothesis of von Beroldingen (1788). He had over years requested tropical investigators to search for peat deposits and had on scientific meetings interrogated travellers on the presence of "real peatlands" (i.e. with a peat soil) in the tropics (Potonié 1907b). Finally on a meeting of the Botanical Society of the Province of Brandenburg in 1907 Potonié met Sijfert Hendrik Koorders. Koorders was a Dutch forester and botanist born in Bandung and based at Buitenzorg (Bogor), who happened to be on health grounds on a sojourn in Europe. The meeting of the Society on June 14, 1907 took place in the newly built Royal Botanical Museum in Dahlem (Berlin), where Koorders was just finishing his long-term research on parasitic fungi of the rubber tree *Ficus elastica* (Koorders 1907). At the meeting a presentation on the geography and flora of Siam lead to a discussion on tropical peat bogs, in which – evidently – Potonié and Koorders participated.

Koorders (1863–1919) had in 1891 as a young botanist participated in the IJzerman expedition that with over 250 persons had crossed an 800 $km^2$ large peatland at the northern bank of the Kampar River in East-Sumatra. In the expedition report Koorders describes how the group had struggled for 3 days through a swamp consisting of 30 m high trees with overground roots emerging from a soft, very acid, brown peat soil. At the two nights they had to bivouac in the 12 km wide swamp, Koorders had pushed a more than 6 m long pole in the soil without reaching the mineral substrate (Potonié 1907b).

The report of the expedition (IJzerman et al. 1895) had only been published in Dutch and had consequently failed to attract international attention. Potonié immediately recognized the importance of Koorders' observations. He invited Koorders to share his insights on the nature of the peatland and they co-authored a paper that still in the same year appeared in the Naturwissenschaftliches Wochenzeitschrift (20 October 1907), a popular weekly science magazine of which Potonié was one of two editors, and in the influential Oesterreichisches Moorzeitschrift (15 November 1907; Potonié 1907b). The paper held the first scientific illustrations of a tropical peatland (Figs. 2.1 and 2.2) and a detailed botanical characterization of the peat swamp forest. It described the numerous pneumatophores ("that severely complicate progressing") that hitherto were only known from mangroves, the mighty stilt roots and buttresses that may reach up to 3–4 m up the trunk, and the horizontal aerial roots that grow like brooms out of the stems. For a second peat swamp near Pangkalan-Dulei (4 day's marches northeast of the Kampar swamp forest), Koorders described a peatland with

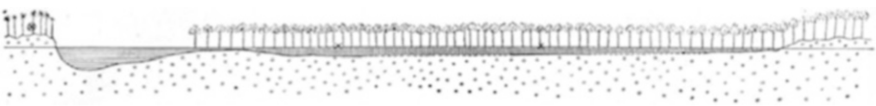

**Fig. 2.1** (Original caption in translation) High forest-flat mire close to the equator, in the hot plane of Inner Sumatra in the Dutch East-Indies. Original drawn by Koorders (Potonié 1907b). Horizontal stripes: water, grid: peaty soil, X: bivouac

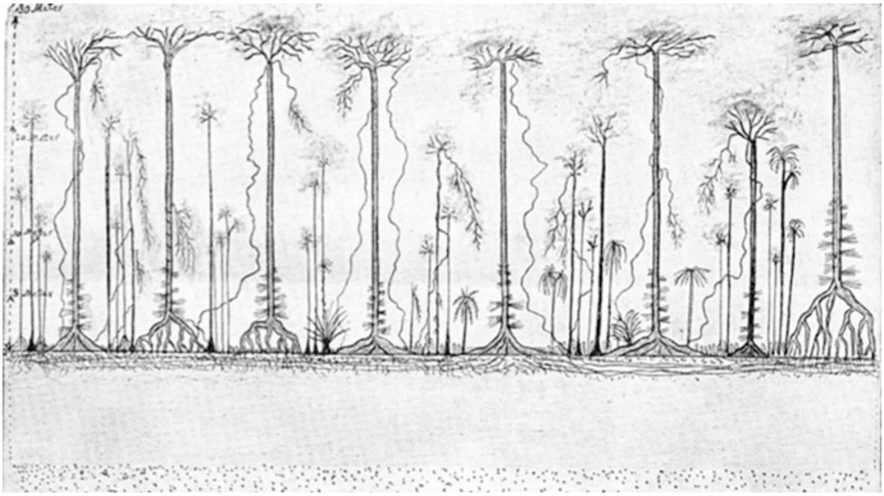

**Fig. 2.2** (Original caption in translation): Part of Fig. 2.1 somewhat magnified to characterize the vegetation types of the peatland close to the bivouac of 20/21 March 1891. Original drawn by Koorders (Potonié 1907b)

a less dense forest cover with the trees – with low branched and twisted branches and dense crowns – only reaching heights of 5–12 m. Also the number of tree species was very low and no trees with large buttresses, high stilt roots or aerial roots were found.

To ascertain the presence of a real tropical peatland, Potonié and Koorders organized that controleur J.G. Larive – with huge efforts– in 1908 collected soil samples for analysis from the same spot of the Kampar peatland, where Koorders had pressed his pole into.

Meanwhile, independent from these developments but in support of the observations of Koorders, Wichmann (1909, 1910a, b) summarized most of the available literature in a detailed overview of the peatlands of Java, Sumatra (incl. the island of Bengkalis), Kalimantan, and New Guinea, using the presence of blackwaters as an important indicator. He especially described large extents of peatlands along the northeast coast of Sumatra. For the southwestern and southern parts of New Guinea, Wichmann cited the reports on the presence of peatlands of van Nouhuys and of Heldring who near Merauke had determined a peatland extent of 2240 km$^2$ (Wichmann 1909).

Whereas his German (1909) and Dutch (1910a) language papers had used the expression for ‘peatlands’ in general (German: ‘Moore’, Dutch: ‘veenen’), his English language publication (Wichmann 1910b) restricted the subject to ‘fens’, i.e. minerotrophic/geogenous peatlands, both in the title (“The fens of the Indian Archipelago”) and in the text. It is unclear whether this was done intentionally to adhere to the prevailing paradigm (cf. Potonié 1909) or whether it was a translation mistake of the etymologically similar Dutch word ‘veen’ into the English 'fen' which accidently supported that paradigm in international literature. Anyhow, Wichmann (1910b) concluded "The following brief survey may afford proof of the wide-spread distribution of fens in the Indian Archipelago, and, in spite of the very incomplete data, we may deduce from it that fens there occupy more than a million hectares." The fen peats he described from Java had ash contents of 27 %, 26 %, 36 and 49 %, respectively, so these must indeed have been derived from geogenous peatlands. Furthermore he interpreted the existence of most 'fens' in Sumatra as caused by the fact "that in consequence of the deposit of sludge etc. the river beds are constantly raised, so that the banks are also higher than the surrounding country. In the lowest portions of the depressions thus formed between the rivers, lakes and swamps were formed which gave rise to peat formation", which also would support a geogenous nature of the peatlands. In contrast, he also reported on fen formation in New Guinea, with peat with an ash content of only 4.58 %.

With the acknowledgement of the presence of peatlands in the tropics, immediately a new paradigm was vested, as had already been announced by Adolph Mayer in his 1901 textbook on soil science: "The truth is indeed that swamp mire soils (fen peatlands, laag veen in Dutch) are no rarity in the tropics, but that only the proper bogs thereat are absent."

"That is also my opinion", Potonié (1907b) added approvingly . . .

## 2.4 The Single Woman and the Emergence of Bogs (1933)

> ". . . a new theory, however special its range of application, is seldom or never just an increment to what is already known. Its assimilation requires the reconstruction of prior theory and the re-evaluation of prior fact, an intrinsically revolutionary process that is seldom completed by a single man and never overnight." (Kuhn 1996: The structure of scientific revolutions, p. 7.)

It was not so that the presence of ombrogenous bogs had remained completely unnoticed. Already Molengraaff had in 1892 observed raised bogs in the Madi mountains in Babas Hantu. In the Dutch publication of this expedition (Molengraaff 1900) he had described how the entire Madi high plateau was covered by "een echt tropisch hoogveen", i.e. a real tropical raised bog. The 1902 English edition, in contrast, did not differentiate explicitly between (ombrotrophic) bogs and (minerotrophic) fens, but translated the Dutch word "hooge veenen" (raised bogs) wrongly with "fens": "As we neared the bottom of the valley the patches of peat became more connected, and I soon realized that the whole of the valley, and probably the whole of the Madi plateau, was covered with marshy forest, standing in a thick layer of peat, originating from the half decayed remains of all kinds of trees, shrubs and mosses, a true tropical peatbog. In contrast to the fens of moderate zones, originating principally from a limited variety of shrubs and mosses, the tropical fens are principally composed of the remains of various trees" (Molengraaff 1902).

It was Dr Elisabeth Polak, Betje Polak as she was casually called, who finally in 1933 clearly pointed out the ombrogenous character of most Indonesian peatlands.

Betje Polak (1901–1980) had obtained her doctor's degree (with the highest honours) in 1929 (Polak 1929) and, with the appearance of her thesis, at once had made a name as a pre-eminent peat specialist. Her study was concerned with the nature of the peat deposits in the western Netherlands. At that time opinions widely diverged on their character and origin. In The Netherlands peatlands were traditionally differentiated in 'hoogveen' ('high peatland', located above sea level, solely fed by rain or fresh river water, where peat extraction could be practiced by digging after drainage) and 'laagveen' ('low peatland', below sea level, often flooded by the sea or by brackish rivers, with peat extraction taking place under undrained conditions by dredging, De Sitter 1796). As the extensive peat deposits in the western Netherlands were clearly lying below sea level and the peat was being dredged, the peatlands were in common parlance called 'laagveen' and most scientists assumed a subaquatic origin of this low-lying peat. A competitive theory questioned this interpretation by pointing at the botanical composition that was similar to peat deposited above the regional groundwater level ('hoogveen'). It was the detailed stratigraphical and palaeoecological study of Polak, which demonstrated that the succession of the low-lying peat had progressed from eutrophic fen peat via forest peat to older and younger *Sphagnum* peat, identical to the succession of the raised bogs on the higher Pleistocene sand soils of The Netherlands.

After the defence of her thesis Polak decided to leave The Netherlands, which suffered a severe economic crisis. With an award of the 'Buitenzorg Fund' she sailed in 1930 for the Netherlands Indies, the present Indonesia, to become temporarily attached to the Botanical Garden at Buitenzorg (Bogor), when its director went on holiday. After his return, she was in July 1931 appointed as a technician in the department of Physiological Chemistry at the Medical University in Batavia (Jakarta), a position probably created to enable her to continue her peat studies (Havinga and Muller 1981).

During these few years, Polak devoted immense energy to the study of tropical peatlands. The labels on the herbarium plants she collected show that in 1930 she visited West- and Central-Java, Northwest-, East- (e.g. Bengkalis) and South- (e.g. Palembang) Sumatra, and West-Borneo (e.g. Pontianak and Kapuas Lakes) (http://www.nationaalherbarium.nl/FMCollectors/p/PolakB.htm). These expeditions, which were out of tune with her somewhat un-athletic disposition, slow way of movement and lack of orientation ability (Havinga and Muller 1981), demonstrated her considerable initiative and courage. As a woman on her own, she travelled upriver accompanied with a native crew and penetrated – aided by local forest officers – the vast peat swamps on foot or by means of a 'peat-sled' (Havinga and Muller 1981).

On the 31st of March 1932 she resigned and returned to The Netherlands for private reasons. There she finished and published – next to some smaller papers on the subject (Polak 1933a, b) – her classical paper 'Ueber Torf und

Moor in Niederländisch Indien' (On peat and peatland in the Netherlands Indies, Polak 1933c) in which she concluded the ombrogenous character of the peat swamp forests. Her arguments for arriving at this conclusion included the following:

> "... the question can be asked with which already known peatland types the forested peatlands of Sumatra and Borneo can be compared. All researchers who described these formations have followed the viewpoint of Potonié and have asserted their 'Flachmoornatur' (fen character). Such mighty wood layers, such luxurious forest development, not hampered by external influences, do not exist in the temperate zones. Much more than with 'Tiefmoor' (Polak uses here a not existing German word/concept to cover the Dutch term 'laagveen' = fen, HJ), which always results from the terrestrialization of mineral rich open waters and whose peat is thus mainly composed of herbs, and whose surface lies deeper than or equal to the surroundings, a comparison with 'Hochmoor' (raised bog) suits. First the lens shape: the raised bog derives its name from the fact that its surface curves over the area like a small cupola. This is equally so for the Netherlands-Indian forested peatlands and for the European raised bogs. Secondly the high acidity typical for raised bogs. A third shared feature of the raised bog of the temperate zone and the forested peatland of the tropics is the oligotrophic character of the peatland water. Such formations are called 'ombrotrophic' mire formations by Von Post (1926) and they form thus an oligotrophic substrate for the vegetation. In Western-Europe the climax vegetation of such formations is a Sphagnetum, and one gets the impression, as if authors who described tropical peat deposits always had the Sphagnetum mire in mind. Widely spread is therefore the idea that raised bogs in the tropics only occur in mountains above 1200 m altitude, because it is there that *Sphagnum* is found, whereas in the lowlands only fens occur. (Schimper 1908; Potonié 1909; Von Faber 1927; Von Bülow 1929)
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> However, even in the temperate zone the climax stage of an oligotrophic peatland does not necessarily have to be a Sphagnetum. This only applies to areas with an explicit oceanic climate such as the coastal area of North-western Europe; in more continental regions the raised bogs have a vegetation of Ericaceae and coniferous trees. Actually it should be self-evident that the oligotrophic peatland vegetation of the tropics should be uttermost different from that of Europe and one does not need to wonder that in these areas with the most luxurious plant cover we find the raised bog covered with a dense pristine forest and the peat consisting of the remnants of this forest. A feature of this wood peat is its poverty in inorganic constituents. The peat of Bila-estate had a loss-on-ignition of 1.35 %. In the 'Jaarboek voor Nijverheid en Handel' (1922) it is mentioned that the peat of the large forested peatlands chemically resembles the oligotrophic peat of Europe and that the small local peat formations more resemble the eutrophic peat. (cf. White 1924)
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> Von Bülow (1929) regards raised bog formation in the tropics and the subtropics as utterly impossible. "In the realm of the Mediterranean, semi-arid or subtropical climate, no oligotrophic peatland formation has hitherto been observed. Self-evidently in the tropics even less." However, he fails to recognize, that equatorial regions with an oceanic climate have large quantities of precipitation, which is evenly distributed over the year. In the forest high air humidity prevails: desiccation of the soil and consequent oxidation of the organic constituents is not occurring. The relatively rapid decomposition is compensated by a very intensive production of plant remains. The soil water has a high acidity, is rich in dissolved humic acids, and has conserving properties.
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> Von Bülow claims for the temperate zone that "Proper raised bogs are bound to the vicinity of the coast and the consequent smoothed climate", but the same conditions apply to the oceanic areas of the tropics. Also here the dominance of production over decay of plant remains is so large that similarly to Europe extensive regional peat accumulating conditions originate that are controlled by climate and the vicinity of the sea."

Another important issue she discusses is the zonation of vegetation types over the peat dome:

> "Is the peat swamp forest the climax vegetation, or is this eventually replaced by brushwood or a swamp with grasses and Cyperaceae? Observation of European raised bogs instigates various possibilities. The shape of the European raised bog and similarly of the tropical forested peatlands is a large biconvex lens that on one side is sunk in the ground and on the other side domes as a cupola over the land. The marginal rise in height is rapid, in the centre, however, the peatland is flat. Often the centre of European raised bogs has an open water area, one of more lakes, secondarily originated as a remnant of the precipitation that was not absorbed by peat and vegetation, or as a relic of the former lake that was the origin of the peatland. The same could apply for tropical forested peatlands. Although no systematic observations are available, one claims in the region of Bengkalis, that the centre of the forest consists of brushwood alternating with smaller and larger pools (footnote 1: Prof. Dr. R. Kolkwitz informed me in an oral communication that he had seen from the airplane large open areas in the swamp forests). . . . However, whatever may be, it is a fact that according to the results of the "Boschwesen" (forestry service, HJ) and also consistent with own observations the vegetation is zonally constituted."

Indeed some foresters of the Boschwesen were meanwhile measuring the depth of the peatlands and had noted the lens character of the peatland surface (Luytjes 1923; Boon 1935, 1936; Sewandono 1938), whereas Boon (1935) had made a systematic levelling of the surface (Van Doorn 1959).

"On the basis of own observations and in accordance with the literature" Polak (1933c) subdivided the peatlands in:

1. "regionally distributed ombrogenous coastal peatlands in the plains of Sumatra, Borneo, and probably New Guinea,
2. topogenous peatlands:
   (a) in the plains of Java and Sumatra
   (b) in the mountains of Java, Celebes, and Burus (Moluccas)."

Inspired by her preparatory work, peatland research in the Netherlands Indies continued vigorously. Schophuys (1936) described and mapped some 2000 $km^2$ of forested peatlands in the Barito catchment in Southeastern Kalimantan and confirmed their ombrogenous character. Boon (1936) described plans for the exploitation of forests in Bengkalis, Sewandono (1937) made an inventory of the peat swamp forests in the Panglon area on Sumatra's east coast, whereas Van der Veen (1938a, b) described peat soils under coffee plantations.

In 1939 Polak returned to Java (which almost certainly saved her life as almost her entire – Jewish – family was murdered by the Nazis in the following years) and found temporary employment as a soil scientist at the Institute for Soil Science at the General Agricultural Research Station in Bogor. There she had to change her focus to agricultural aspects (cf. Hardon and Polak 1941), but continued her study trips. In September 1939 she investigated Rawa Lakbok, a major fen area in West Java, in October Southeast Borneo in the vicinity of Martapoera and Bandjermasin, in 1940 again various areas in West-Java and Central Sumatra (incl. the 'Riouw Archipelago') and West-Borneo (http://www.nationaalherbarium.nl/FMCollectors/p/PolakB.htm). In 1941 she published in the journal Landbouw ('Agriculture') a review on peatland research in the Netherlands Indies with an extensive reference list, including many unpublished reports.

In the first year of the Japanese occupation (1942–1945) Polak managed to finish a manuscript about Rawa Lakbok based on field visits made in 1939 and 1941. The paper was on Japanese command translated into English and – without her approval – published when Polak was already interned in a concentration camp (Polak 1943). Her physical and mental health suffered severely in the camp and after the liberation she was granted recuperation leave (Havinga and Muller 1981). She stayed 3 months in the USA in the laboratory of the well-known peat specialist (and 1952 Nobel Prize receiver) Salman Waksman and in the Department of Agriculture in Florida, where she got further acquainted with (sub)tropical peatland agricultural research. Back in The Netherlands she prepared a review study on the suitability of Indonesian peat soils for agriculture (Polak 1948a).

In January 1948 Polak returned to Indonesia and got a permanent position as a soil scientist. From then on she engaged in research on the fertilization of peat soils with special attention to trace elements (Polak 1948b, 1950b; Havinga and Muller 1981). With respect to the more fundamental research, her attention moved to less acid peat deposits that were more suitable for cultivation than the coastal ombrogenous peats. In search of such deposits Polak travelled in 1949 to the upper reaches of the Kapuas river in Borneo, but almost no peat was found (Polak 1950a). On Java she continued to investigate Rawa Lakbok and published in 1949 a new version of the English 1943 paper (Polak 1949), with which she had been extremely dissatisfied. Her palaeobotanical investigations demonstrated the geogenous origin and eu/mesotrophic character of the Rawa Lakbok peatland. Furthermore the 1949 paper illustrated her ambition to improve the livelihoods of the local people in the poverty trap the peatlands constituted: "The population has given her uttermost forces to open up and meliorated the swamp as well as was possible with the available means. Because of the complex and unfavourable economic conditions, but certainly not in the least because of the difficulties experienced by the burden of excess water, the population has become deprived. In 1939 and 1941 many had to sell the self-reclaimed fields; others ended deep in debt. Signs of malnutrition and poverty were also clearly visible in the pre-war years (Photo 6 Poor Lakbok colonists). With effective technical improvements, however, the work that has been started with simple means but much effort can be continued and completed. Thereby the pioneers and immigrants of the Lakbok, which have migrated from the poorest regions to there to build up a livelihood, can get the reward they deserve for their hard labour and entrepreneurship."

In May 1952 Polak was promoted principal scientific officer at the Institute for Soil Science and on August 1st, 1952, appointed Professor of Botany and Genetics at the Medical Faculty of the University of Jakarta.

Her 1952 publication "Veen en veenontginning in Indonesia" (Peat/peatland and peatland reclamation in Indonesia, Polak 1952) reflected her widened activities. In this paper she presented a first detailed map of the distribution of peatlands in Indonesia and estimated their total area on "roughly" 163,498.65 $km^2$. This number became the basis of all areal estimates of Indonesian peatlands, although nobody dared to repeat the exact figure in its incredible detail. Andriesse (1974) and Shell International (1982) thus came up with an area of 165,000 $km^2$, whereas Schneider (1980), Bord na Mona (1985), and Andriesse (1988) used the figure of 170,000 $km^2$. It lasted until 1981 until the Indonesian Soil Research Institute came up with an alternative figure of 270,230 $km^2$. This figure would also have resulted if Polak had applied the later definition of histosols (over 30 % organic matter in a cumulative layer of 40 cm or more) instead of the one she had used (more than 65 % of organic matter in the first 1 m or 0.5 m if under cultivation) (Driessen and Soepraptohardjo 1974, cf. Anonim 1969).

In June 1954 Polak went back to The Netherlands on long leave, but at the end of this period, in 1955, she decided not to return, because the prospects in Indonesia were too uncertain (Havinga and Muller 1981). She joined the Department of Regional Soil Science of the Agricultural University in Wageningen where she retired in 1966.

Her last public performance was in 1975 in Groningen, the city where peatland science had started more than 300 years before (Schoockius 1658). In reflecting her own research over the past half century, she used the Symposium on the Quaternary of Southeast Asia to warn against the enormous agricultural, pedological and ecological risks involved in the exploitation of the peatlands of Southeast Asia (Polak 1975):

> "In our time, exploitation and conservation of nature are opposed to each other. Exploitation of the extensive peat forests is difficult and expensive and cannot be very profitable. It should be recommended to leave the regional peat forests in their natural state or use them for timber-growing with the application of proper silvicultural techniques. These practices may not involve measures interfering with the natural environment."

In 1980 she died after a long illness. Shortly after the final stage of peatland destruction in Southeast Asia set in . . . (Dommain et al. 2015).

## 2.5 Final Remarks

> "Any new interpretation of nature, whether a discovery or a theory, emerges first in the mind of one or a few individuals. It is they who first learn to see science and the world differently, and their ability to make the transition is facilitated by two circumstances that are not common to most other members of their profession. Invariably their attention has been intensely concentrated upon the crisis-provoking problems; usually, in addition, they are men so young or so new to the crisis-ridden field that practice has committed them less deeply than most of their contemporaries to the world view and rules determined by the old paradigm." (Kuhn 1996: The structure of scientific revolutions, p. 144)

The story above confirms that the research history of tropical peatlands can be seen as scientific revolutions exchanging one paradigm for the other. It illustrates how prevailing 'truths' managed to survive over decades in spite of clear evidence to the contrary. Instrumental in the paradigm shifts was the long-term devotion of the key players to questions that would eventually undermine the prevailing paradigm: Potonié searching for the origin of coal, Polak addressing the fundamental differences between geogenous fens and ombrogenous bogs.

Typical is also the 'un-disciplinary' background of the major players: Potonié as a coal geologist, Polak as a young female palaeobotanist, both looking for and seeing things that contemporary soils scientists and botanists did not dare or failed to see.

Finally the long time span between the observation of the first contrary proof and the replacement of the established paradigm has to be noted. The decades that passed between the emergence of evidence and its acceptance in mainstream science supports the observation of Max Planck (1949) that "a new scientific truth does not triumph by convincing its opponents and making them see the light, but rather because its opponents eventually die, and a new generation grows up that is familiar with it."

Peatlands in Southeast Asia are currently dying faster than their researchers. Fascinating and hitherto little understood aspects of their ecology, like their sophisticated self-organisation and self-regulation (Dommain et al. 2010), can no longer be studied in their full expression, as peatlands are sacrificed to unsustainable drainage-based agriculture and forestry faster than science can follow (Dommain et al. 2015). Potonié would have needed these insights to understand the long-term stability of coal formation. Polak (1933c) touched upon them in her description of peat swamp vegetation zonation (cf. Anderson 1983; Bruenig 1990; Shepherd et al. 1997; Yamada 1997).

Throughout her life Betje Polak, the heroic pioneer of Indonesian peatland research, prepared the paradigm to come: how to reconcile the short-time demands of people with the long-term interests of society. It is urgent time that this sustainability paradigm is established.

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