Life tourbières du Jura

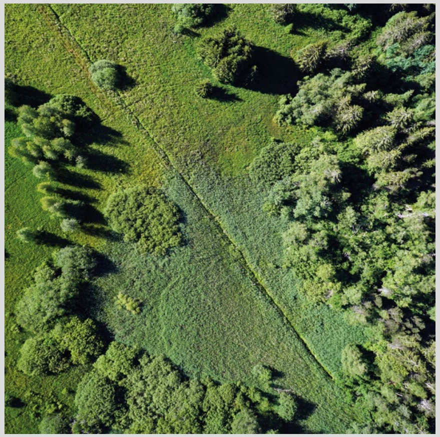
Life Réhabilitation fonctionnelle des tourbières du massif jurassien franc-comtois

LIFE13 NAT/FR/762 - 2014 / 2021

Collection of experiences

Functional restoration of peatlands in the Jura massif





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From left to right :
The Life team in the field (© Clémence Curlier)
Cutting of a steel sheet pile fencing, Frasne (Doubs) (© Magali Crouvezier)
Drainage ditch, Rousses peatland (Jura) (© Corvus monitoring)
Calluna vulgaris (© Clémence Curlier)
Lac des Mortes, Bellefontaine-Chapelle des Bois (Jura-Doubs) (© Clémence Curlier)


et aux couleurs de l'eau
Life
NATURA 2000

Summary

The Jura Peatlands Life programme, an essential step towards restoring France's peatlands

The «Functional rehabilitation of the Jura mountains peatlands in Franche-Comté» Life programme, which began in 2014, is the most remarkable peatland restoration operation ever undertaken in France. Firstly, by the scale of the areas restored and the budgets involved, but above all – and this is the essential point – due to the extraordinary network of skills mobilised and the considerable amount of new technical knowledge and valuable practical experience that this programme has produced. The results achieved on the different sites are already being used as the working basis for the implementation of ongoing projects and constitute a precious body of data for the construction of future programmes.

The time for peatland restoration has come. The role of peatlands in long-term climate regulation has, of course, long been recognised. By fixing the carbon dioxide present in the atmosphere (approximately 0.2 to 0.5 tonnes of carbon per hectare per year) in plant tissues (peat), they help to slowly cool the climate. However, in reality, this has virtually no effect on the climate in the short term, as peatlands also release methane, a powerful greenhouse gas with an atmospheric lifetime of over twenty years. As the planet is dramatically warming, what is really at stake in the restoration of peatlands lies elsewhere: in the urgent preservation of the stocks of peat already accumulated. The destruction of peatlands by extraction or simple drainage leads to the release of phenomenal quantities of CO2 into the atmosphere. In France, emissions are between 10 and 20 tonnes per hectare per year depending on the degree of damage to the peatland, reaching 30 tonnes per hectare per year in the worst affected areas. Studies that have been conducted, mainly in Europe and Canada, show that careful restoration work can drastically and, above all, very quickly cut these emissions.

The idea is not, of course, to forget about the other issues involved in peatland restoration. The remarkable biodiversity of these environments and their role in the wetland continuum must remain priorities. However, the role peatlands can play in regulating climate change and achieving carbon neutrality by 2050 places new responsibilities on the managers of natural environments. It is now urgent, therefore, in line with the report submitted to the French Prime Minister by Jérôme Bignon and Frédérique Tuffnell in 2019, to implement an unprecedented programme of restoration and rehabilitation of all of France's peatlands. A project which will include the most damaged environments and even the main cultivated peat bogs, which are actually the sites that emit the most carbon.

As the first page turns on the Jura Peatlands Life programme, an inventory of France's peatlands, providing as much data as possible on their locations, peat depths and degree of damage has become more necessary than ever and is due to be conducted in the near future. This will help to identify the sites to be restored as a priority and, more widely, allow an ambitious programme of restoration to be established. The accumulated experience from the successful experiments conducted in the Jura mountains will no doubt serve as a model for future restoration work. Many thanks to all those who have worked so hard to achieve this success..

Daniel Gilbert
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Part 1

Introduction

The Jura Peatlands Life approach

Functionality and/or biodiversity?

Thanks to the distinctive nature of both their flora and their fauna, the Jura peatlands are among the most intensely studied environments of the first and second Jura plateaus.

The vegetation, the flora and the fauna were in fact the subject of many publications in the 20th century, including monographs, biotype studies and mapping exercises.

This approach to the visible aspects of the environment naturally led to early management measures aimed at preserving the existing situation (habitats and rare and threatened species), but without any targeted research on the causes of the deterioration of the environment through a functional approach.

Fringed pink
Dianthus superbus

Although this biodiversity remains a major issue, water is the fundamental element in the existence of a peatland. Its elimination, whether natural (due to evapotranspiration, climate change, etc.) or induced (by drainage, pumping, etc.), inevitably leads to its deterioration, with the disappearance of habitats and the species that live in them.

The hydrological aspect has therefore gradually been added to the previous investigations, becoming an inescapable part of the picture, to arrive at a better «hydro-ecological» understanding of these systems. This then provides managers with the scientific and technical means to intervene effectively, in terms of mitigating or adapting to climate change.

Work aimed at restoring the hydrological functioning of these peatlands has therefore emerged. On this subject, the progress made by the Swiss, our close neighbours, has been decisive.

Approach

This Life project dedicated to the «functional rehabilitation of the Jura mountains peatlands» has therefore deliberately concentrated on a programme of concrete actions intended to restore – where it was still possible – hydrological conditions favourable to the correct functioning of each of the sites. This is the only way of guaranteeing that the characteristic habitats of these environments, which are directly reliant on water saturation, can be maintained, as well as the species dependent upon them. Any work undertaken must enable these peatlands to re-establish a functional balance, guaranteeing a degree of resilience sufficient to cope with the consequences of global warming and atmospheric nitrogen deposition.

Designing a rehabilitation programme requires, first of all, an appreciation of its relevance through an evaluation of the expertise already accumulated on the status of the environment (species, habitats, etc.). There is also a need to establish what needs to be understood in terms of its hydrological functioning, the reasons why it is malfunctioning, the potential for regenerating the sites and then, based on that knowledge, what actions it is possible to take (*cf.* p. 13: How the functionality studies guided the works).

Once the actions have been implemented and the work has been carried out as planned, the next step is to ensure that the objectives sought have in fact been achieved or, more modestly, to measure the extent to which they have been achieved by means of medium and long-term monitoring and reporting on the progression of several factors:

1/ Evolution of water retention capacity by measuring the level of the water table (monitoring by piezometer);

2/ Improvement of the quality of the water courses that have been «worked on» by monitoring several indicators (temperature, water quality, etc.)

3/ Biological evaluation of the conservation status of populations of targeted species or habitats: floristic (including bryological) monitoring, phytosociological monitoring (transects, mapping) and faunistic monitoring (monitoring of invertebrates: Odonata, butterflies, etc.);

4/ Analysis and testing of the relevance of using the «Syrph the Net» method (providing biodiversity indicators) in the Jura peatlands.

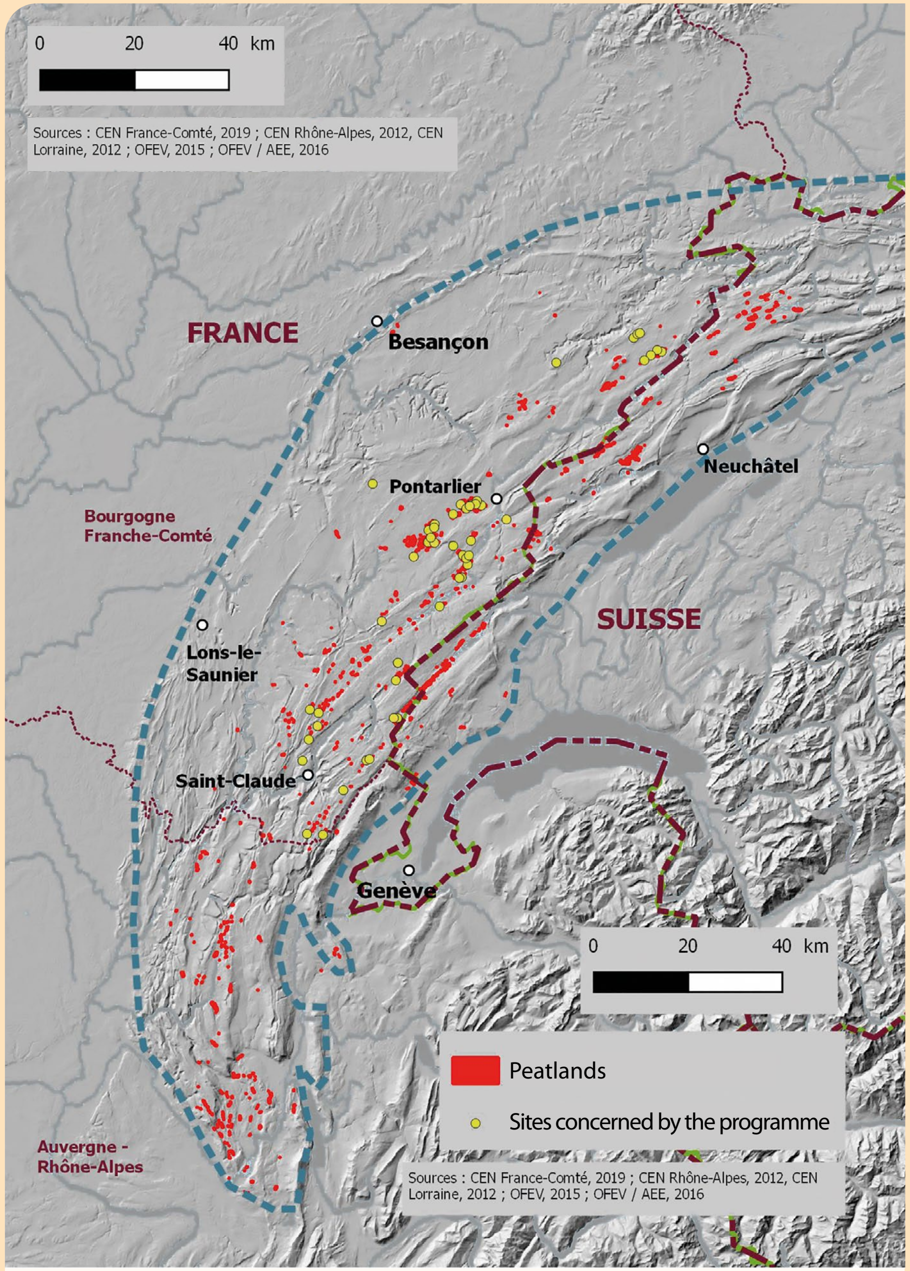
For greater efficacy, and in view of the resources which are available but not guaranteed over the long term, it was necessary to choose a set of representative sites to be able to collect sufficient, usable data to monitor each of the factors mentioned (rather than each of the sites) depending on the work being carried out.

This is why not all the sites where work has been carried out have been monitored under the Life scheme. The continuation or setting up of inventories, analyses or research work linked to other programmes (conservation plans, Natura 2000, research subjects, etc.) will be needed to complete the scheme over the long term.

This report is intended, above all, to be a useful, practical document highlighting the various difficulties encountered, some expected and some unexpected and, where relevant, the pitfalls to be avoided.

Thus, after a brief presentation of the Jura peatlands, followed by some information on the different approaches that can be taken and the tools available (including geological, geomorphological, topographical, phytosociological, and historical approaches), 12 selected sites (*cf.* p. 21: 12 Life works) are presented to illustrate the steps taken, the malfunctions identified, the actions undertaken and the outcomes expected, along with the type of monitoring set up. The aim of these information sheets, as with those devoted to the technical means (*cf.* p. 83: Focus on techniques), is to share an experience, its expectations and its doubts, thereby facilitating the continuation of this type of programme on other sites.

Restoration work on the Frambourg peat bog, which is part of the "Valleys of the Drugeon and Haut-Doubs" Natura 2000 site, at La Cluse-et-Mijoux (Doubs)



1 *Location of the Jura peatlands (in red)*
The yellow dots show the sites concerned by the Life programme.

Preamble

«Peatlands» plus «Jura» is at first sight not an obvious association to make. And yet, these limestone and therefore karst mountains contain several hundred peat sites, a large part of which are acidic with sphagnum mosses.

A peat mountain?

In spite of the predominance of karst permeability, the Jura mountains are home to a relatively high number of peat bogs 1. This paradox can be explained by a combination of several favourable factors:

- a relief formed by large folds that have created vast flat areas between the ridges;
- a geological substratum partially consisting of marls, which are impervious and therefore slow the infiltration of water;
- a recent glacial past, the geomorphological impacts (moraines, overdeepening, etc.) and hydrogeological impacts (more modestly-sized aquifers with interstitial permeability and slow percolation, as opposed to the fracture permeability of karst) of which have created, in places, conditions favourable to the slowing of flows and even the stagnation of water;
- a mountain-modified oceanic climate, characterised by high precipitation spread relatively evenly throughout the year;
- and of course an "intermediate" altitude limiting evapotranspiration, but allowing sufficient vegetation productivity to induce sometimes substantial build-ups of peat.

To date, about 530 peat bogs have been identified across the Jura Arc (320 of which are in Franche-Comté), mainly situated at altitudes over 800 metres and representing a total area of almost 5,500 ha. Their average size is therefore 10.5 hectares, with the largest reaching over 100 ha (and up to 220 ha for the Forbonnet peat bog at Frasne).

Limnogenous peatland complex in the Orb Valley (Jura)

Wooded peatland typical of the north of Haut-Doubs (Doubs)

Diversity of the Jura peatlands

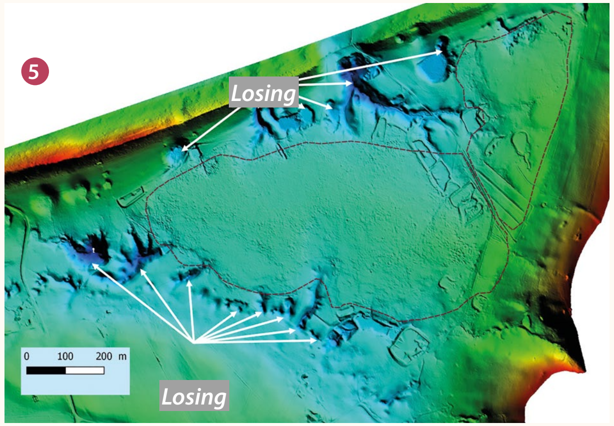
There are two main functional types of peatland in the Jura mountains, often dovetailed together 2 3 :

► Fens, which are alkaline to neutral, oligotrophic to mesotrophic, and closely linked to the local limestone context. They occur in places where the water table rises to the surface and/or where there are concentrations of depressions and they develop in diverse locations: in valley bottoms, on the edges of lakes, on slight slopes, etc 4.

► Peat bogs, which are acidophilic and oligotrophic, are necessarily the result of ombrotrophic peat development in the fens and can therefore be found in similar topographical situations.

The peat bogs' (shown in red) high dependency on water means that in the Jura they tend to shy away from the forests which usually occupy the most permeable limestone substrata. As a result, they are most often found in highly agricultural areas. Le Grandvaux (Jura) sector, at an altitude of about 900 m

These two types, peat bogs and fens, are often overlapping on the same site, leading to some startling contrasts in vegetation. In addition to this already diverse situation, there are also transition mires, water compartments, acidic fens (which can develop locally around certain raised bogs) as well as surrounding peat grasslands. This juxtaposition of environments, combined with karst drainage, constitutes one of the originalities of the Jura peatlands 5, the only real equivalents of which are found in certain mountain regions of Central Europe (Beskids, Tatras, etc.) or in Russia.



La Grande Seigne, Passonfontaine (Doubs): the peat deposit (dotted line) is literally ringed by a network of almost 30 karst losing streams along the line of contact between marls and limestones

This rich variety allows the development of diverse flora and fauna, although certain species are now seriously threatened. Nine of these species are listed in Annex II of the Habitats Directive:

- flora: the marsh saxifrage (*Saxifraga hirculus*), fen orchid (*Liparis loeselii*) 6 and glossy sickle moss (*Hamatocaulis vernicosus*) 7 ;

Glossy sickle moss
Hamatocaulis vernicosus

Fen orchid
Liparis loeselii

Round-mouthed whorl
Vertigo genesii

• fauna: the marsh fritillary (*Euphydryas aurinia*), the violet copper (*Lycaena helle*), the dusky dark blue (*Phengaris nausithous*), the large white-faced darter (*Leucorrhinia pectoralis*), Geyer's whorl snail (*Vertigo geyeri*) and the round-mouthed whorl snail (*Vertigo genesii*) 8. Also present: certain species listed in the Birds Directive, such as the spotted crake (*Porzana porzana*).

Natural monuments severely impacted

The Jura peatlands have long been exploited by humans, in particular as grazing land, as human occupation of the mountains has ebbed and flowed.

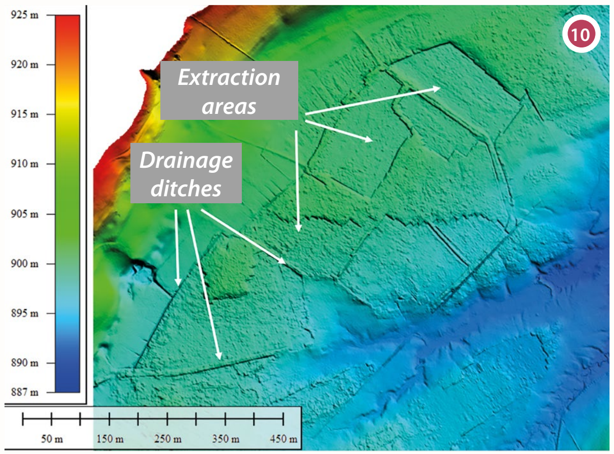
The greatest impact has unquestionably been rudimentary peat extraction 9 for use as fuel, which only very few peat bogs in the mountains appear to have escaped.

Extracting peat at La Pesse (Jura)

This extraction mainly took place between the 17th century and the early 20th century, to make up for the depletion of wood resources. Although locally this practice led to a diversification and regeneration of some peaty environments, often the consequence was serious and lasting damage to the sites due to the drying out that it causes.

Later on, in the second half of the 20th century, a second large-scale «attack» on the peatlands took place. Now using mechanisation, it consisted of attempts to convert these spaces, previously considered as useless, into agricultural land or forest.

And so drainage, straightening of water courses, plantations, etc. once again disrupted the functioning of the peatlands 10. In addition to these most common factors of degradation, there were also many others: fertilisation of the watershed, water withdrawal, pollution, backfilling, the creation of lakes, etc.



Drainage and peat extraction have been the most common disruptions
DTM of the Belles Seignes peat bog (Le Russey sector, Doubs)

Over the last few decades, «global» factors have also come into play, namely climate change and atmospheric nitrogen deposition.

Together all of these disturbances have severely impacted the Jura peatlands. It has thus been estimated that 30% of the peatland areas of the Franche-Comté Jura have been completely destroyed (*Moncorgé and Gisbert, 2016*). The extent of inactivated areas, that is to say areas that are no longer accumulating peat is unknown, but is likely to be considerable 11.

The functional disruptions most often take the form of a reduction in, or even the disappearance of peat-forming species and a predominance of downy birch, spruce or moor grass.

It was in light of this situation, with a future outlook that seemed even worse, that it was decided to launch a programme of intervention centred on the functional rehabilitation of the sites.

How the functionality studies guided the works

This stage, which is indispensable to any peatland revitalisation project has already been the subject of a number of publications. The idea here, therefore, is not to describe the methodology.

The aim of this document is to illustrate, through the different sites studied as part of the Jura Peatlands Life programme, the advantages of the different combined approaches and the different methods used.

The aim of the Life programme was to plan peatland "revitalisation" projects in locations deemed to be disturbed. It was therefore necessary to ask the right questions in the right order in order to increase understanding of how the sites studied functioned.

As far as possible, it was necessary to approach the peatland ecosystems as a whole, that is to say in their three dimensions (diachrony, structure and transfer) in order to:

- reposition the peatlands in context of their overall landscape (all components);
- attempt to characterise the peat accumulation processes;
- better understand how they function;
- identify the nature and intensity of the disturbances;
- assess the potential for regeneration: the idea was not to return to an impossible "natural" status, but to attempt, wherever possible, to restart a momentum favourable to the conservation of the peatland and its ecosystem services (water, biodiversity, carbon, etc.) or to abandon them if this was not possible;
- propose reactivation projects consistent with the functioning, potential and goals for the sites.

The difficulty of this functional approach lies in the multidisciplinarity of the various involved (biology, geology, pedology, hydrology, history, etc.), which cannot always be concentrated within the competence of a single managing body. We attempted to change our usual space-time framework so that, in short, we could fit together the different pieces of the jigsaw to give overall coherence to the functional synthesis.

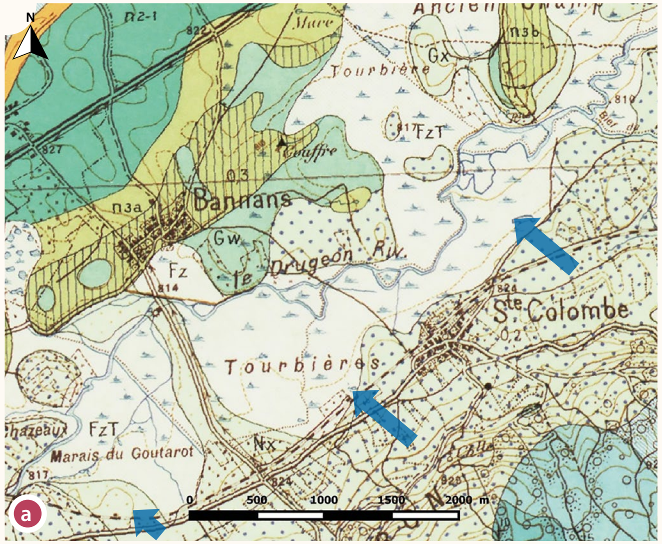
This is compounded by a further original feature of the Jura peatlands, namely mineralised, fairly calcareous water sources. Even in the pseudo-climactic context of an acidic ombrotrophic peat bog, water bodies of different physico-chemical types overlap and are dovetailed together. This makes it all the more indispensable to have a precise understanding of how the sites function.

Depending on the known or, at least, the anticipated complexity of the approach, as well as on the time, funding and skills available, the analysis was more or less thorough. The minimum across-the-board approach applied as the basis for all our Life programme peatland revitalisation projects was the analysis of the digital terrain model (DTM) in conjunction with the vegetation and the thickness of the peat. Revitalising disturbed mountain peatlands amounts to managing an ecosystem where the topography is of the utmost importance and where the vegetation is an indication of what is happening on the surface, hence the use of this common denominator, the DTM/peat thickness and structure combination, throughout the Life programme.

Overall approach:
the peat bog in its geographical and geomorphological contexte

Beyond the classic lacustrine infilling, which is widespread in the southern part of the massif, more complex origins can be observed, which necessarily imply that the works be adapted to the specific context.

A first, a macroscopic consideration of the location of the peatland in its wider environment is indispensable. This initial approach already provides an insight into certain hypotheses regarding the water sources, geomorphology, geology and topography of the terrain on a relatively large scale.



Geological map of the Drugeon basin (Doubs)

EXAMPLE: the Gouterot and Champs Guidevaux peat bogs (Bannans, Doubs)

A reading of the geological map of this part of the Drugeon basin coupled with the field visits showed that these bogs lie at the foot of the slope of the Le Laveron fractured limestone massif, on a thick layer of morainal sediments. These bogs are sloping, facing the Drugeon basin on the north-west which drains the valley at the bottom of the syncline a.

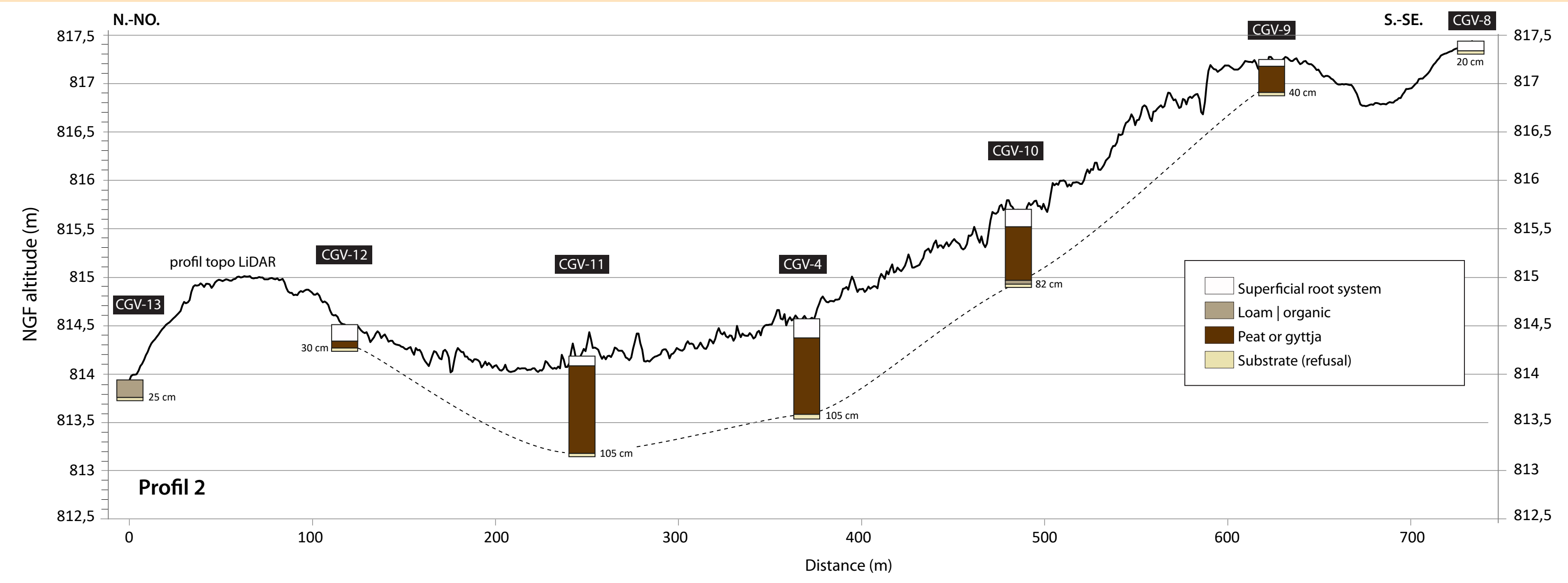
The use of this information provided some initial hypotheses about the formation of these peat bogs:

- formation due to surface water from the watershed coming from the south-east, in a slowed flow context, to be confirmed;
- possibility of water coming from a transfer aquifer in the sediment, to be confirmed.

This starting point opened the way to further investigations on the depths and type of peat. The underground mineral b profile clearly shows a fairly steep slope on the fluvio-glacial deposits, but this is entirely blocked in the west by a morainal sill, which has obstructed and slowed the flow of water, even backing it up. From a historical point of view, the peat bog has been comprehensively exploited for heating fuel, and so a substantial layer, albeit of undetermined thickness, is missing.

At this stage, the different elements of information gathered suggest that the formation of the peat system benefited from favourable conditions due to:

- a source of water from a karst mountain massif that receives plenty of precipitation;
- a source and transfer of water through the thick compartment of morainal sediment;
- water retention facilitated by a trough morphology



b

East-west topographical profile of the Champs Guidevaux peat bog and peat thickness in the north-west part.

Phytosociological diagnosis

The vegetation on all the Natura 2000 sites studied in the Life programme had already been mapped, with varying degrees of detail. This allowed the localisation of:

- the characteristic environments: fens, bogs, transition mires;
- the regeneration pools formed by old extraction pits in general;
- the finer details specific to a fen or bog that characterise the vegetation, such as supplying water to a spring or diffuse minerotrophic percolation.

EXAMPLE 1: the Porfondrez peat bog (Bannans, Doubs)

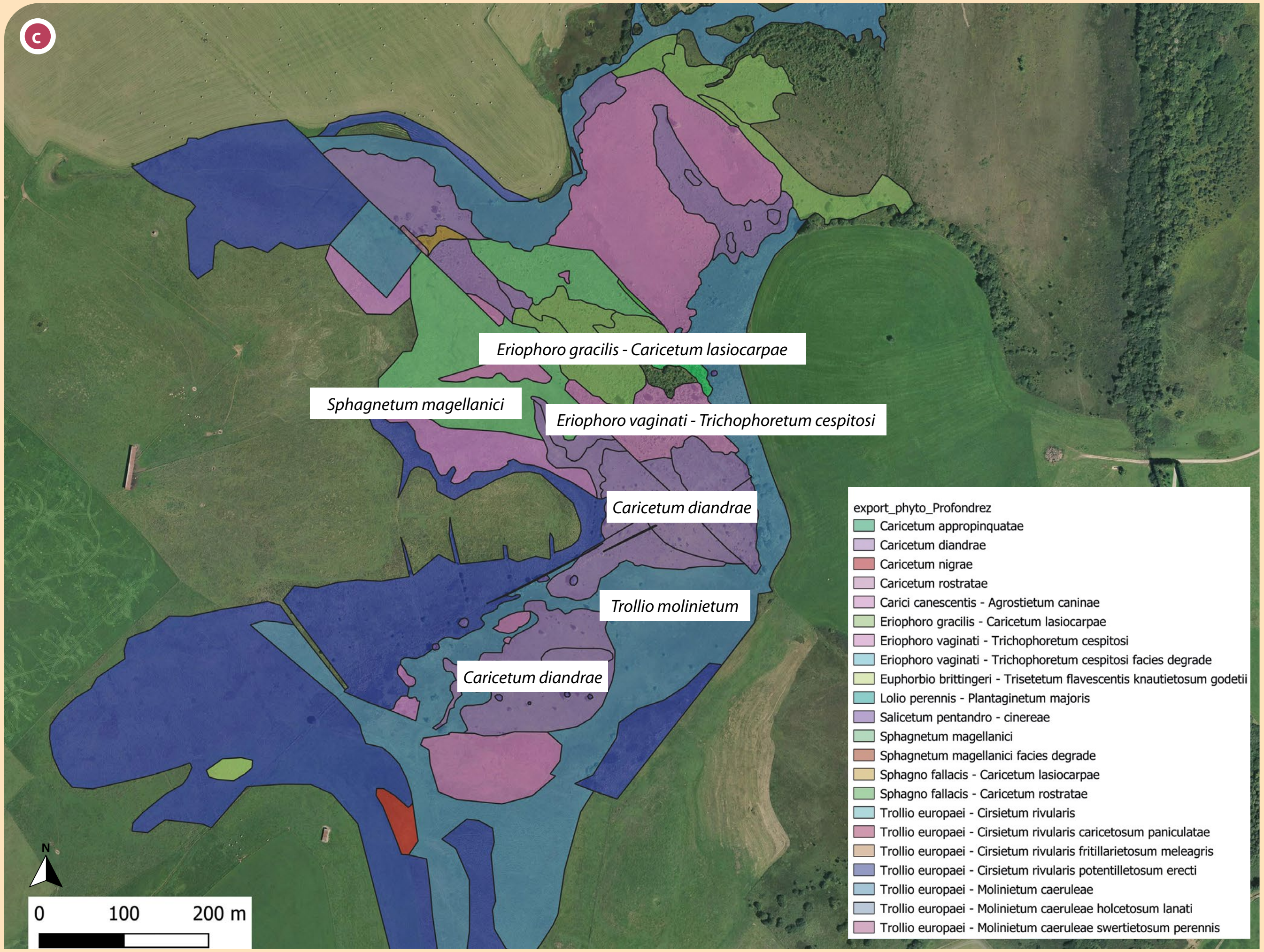
This vast bog, which has been profoundly modified by peat extraction and successive drainage works, presents highly organised facies of vegetation (c) which served to guide further piezometric and physico-chemical investigations.

The bog is enclosed between hummocks of moraine. Areas of transition mire (shown in blue) are clearly detached from more eutrophic, drier zones, which consist of areas of purple moor grass and megaphorbs, more in contact with agricultural zones and their trophic inputs. Further to the north there is an expanse of damaged bog.

This mapping-based approach has brought to light some quite marked contrasts, reflecting the varied hydrological and trophic situations.

It is not possible to explain this phytosociological distribution in simple terms, but it was possible to begin to imagine different hydrological and piezometrical hypotheses, which were subsequently verified:

- characterisation of the water supply from the transition mire (surface runoff due to the topography, quantity, quality, variability): water supply from the ground water by Artesian flow;
- which hydrological supply to and the piezometric function of Trollio-Molinetum in contact with *Caricetum diandrae*.



Phytosociological mapping of the Porfondrez bog (Doubs) (CBNFC, 2010)

EXAMPLE 2: the "Sur les Seignes" peatland (Frambouhans, Doubs)

The vegetation of this peatland is typical of the north of the Haut-Doubs: a peat bog that is totally wooded, with mountain pines in the centre and a spruce stand on its periphery. The southern part is, nonetheless, an exception, as a result in particular of peat extraction (mechanical cutting between the 1960s and the 1980s).

The peat was extracted in rectangular strips, from the edges towards the centre of the peatland (thereby allowing the evacuation of the water) to different depths as the extraction progressed. The thickness of the peat remaining in the bottom of these strips ranged from zero (the underlying clays having been reached) to almost 2 metres d:

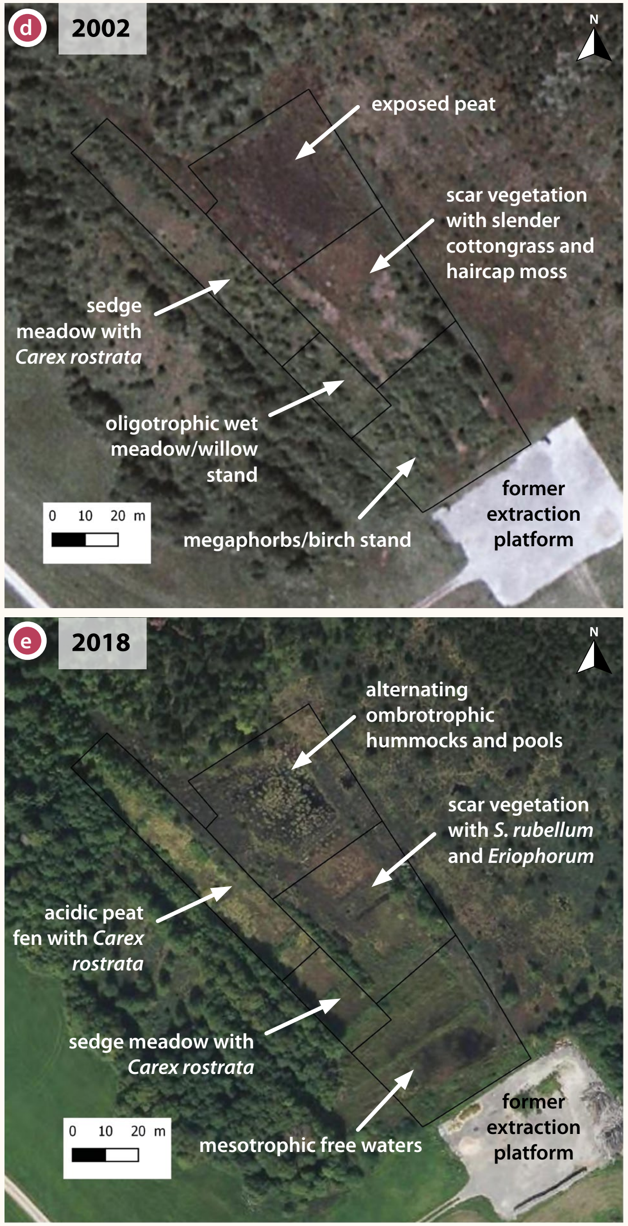
- the parts with the thickest layer of peat then presented areas of exposed peat which were in the course of being colonised by sparse acidophilic, oligotrophic vegetation consisting of slender cottongrass and haircap moss;

- the parts with the thinnest layers featured a gradient of vegetation ranging, from upstream to downstream, from oligo-mesotrophilic and acidicline communities (mainly sedge meadows with Carex rostrata) to mesotrophilic neutrophilic communities (wet meadow/megaphorbs/birch stand).

This reading of the vegetation rapidly provided a picture of how it would likely develop if the water level were raised e:

- in the thicker parts: orientation towards active peat bog communities dominated by red sphagnum mosses;

- in the thinner parts: upstream development towards an acid peat fen with *Carex rostrata* and green sphagnum mosses (change from *Caricetum rostratae* to *Sphagno-Caricetum rostratae*) and downstream a choice to move towards mesotrophilic aquatic communities.



Situation of the "Sur les Seignes" peat bog (Frambouhans, Doubs) before and after the works. Bottom photo: the yellowish colour of the strip on the west side shows the development of sphagnum mosses from the recurvum group

Approach to surface topography and link to hydrology

The "theoretical surface water flows" approach was a systematic preliminary step in the Life programme, facilitated by the use of the digital terrain model (DTM) derived from large-scale LiDAR scanning (LiDAR = Light Detection And Ranging).

▶ **The digital terrain model (DTM)** was invaluable in:

- the previously exploited zones which have become covered by woodland;

- in the zones where the pits are visually hidden by the trees or by the recolonisation of the surface by vegetation, but visible in the microtopographical survey carried out by LiDAR. The drainage action persists by underflow;

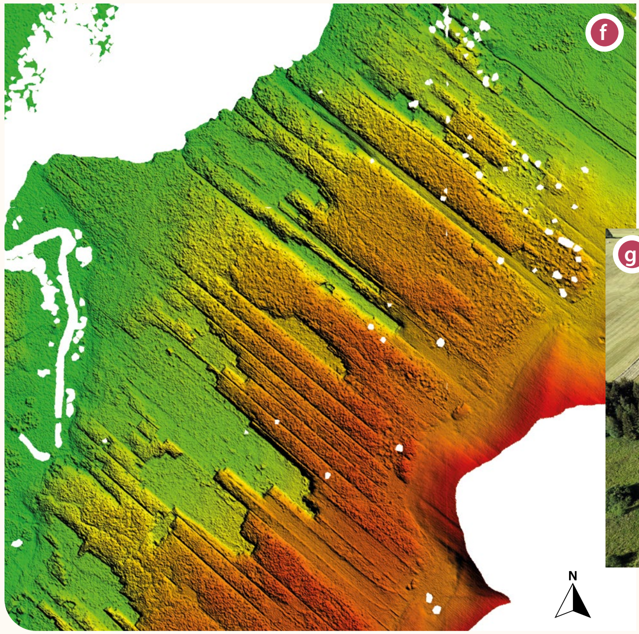
- in the areas of the bog where the water courses have been recalibrated, where it helps to locate the former meanders masked by the vegetation.

▶ **Digital processing of the topography data in the DTM** established the contours of the sites, traced out the theoretical watersheds and allowed potential surface flows to be identified.

Using topographical analysis software, it was possible to model the potential surface water flows, taking account of the topography. The theoretical surface water flows are outlined and can be used to detect hydrological disturbances of the peatland (often rectilinear): inputs/outputs, diversions, etc. This model was compared with the terrain, in an active period in the hydrological cycle, namely in a mountain zone during the snowmelt period (or at the end of a wet winter), when the vegetation is less concealing, flattened out and there is substantial runoff.

EXAMPLE 1: the Les Rousses peatland (Jura)

The woodland coverage made the topography and water flows difficult to see, especially over such a large area of peatland. The pattern of surface water flows , as revealed by the DTM (f), was often barely perceptible on the ground, and all the more so for being covered by spruces and mountain pines (g).



Certain particularly narrow pits had been covered by surface vegetation (g), although they retained their draining effect by a phenomenon of underflow.

Footprint of a ditch hidden by bilberry bushes, which became visible again when its water supply was restored. Before the obliteration work, the depression was always dry and heavily masked by the vegetation (right-hand photo).

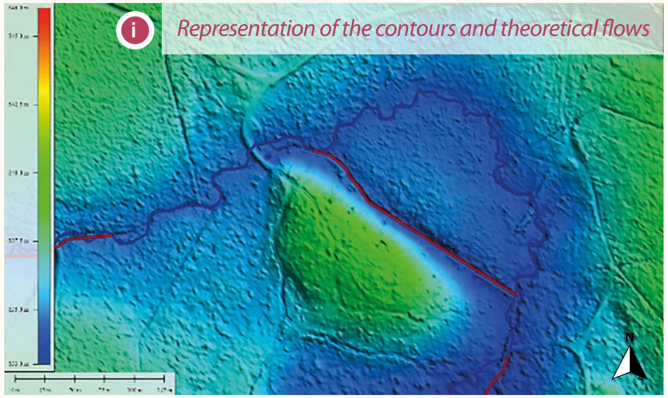
Heath plants, which densely cover the ground, often mask these slight depressions. Without the help of the DTM, given the scale of the drainage network, a single approach to the terrain would have been extremely complicated and of limited effectiveness. The DTM also enabled the necessary linear dimensions of the works to be calculated quickly.

In the peat bog, the ditches can be clearly seen on the DTM, whereas they are virtually invisible on the ground, especially in the pine woods.

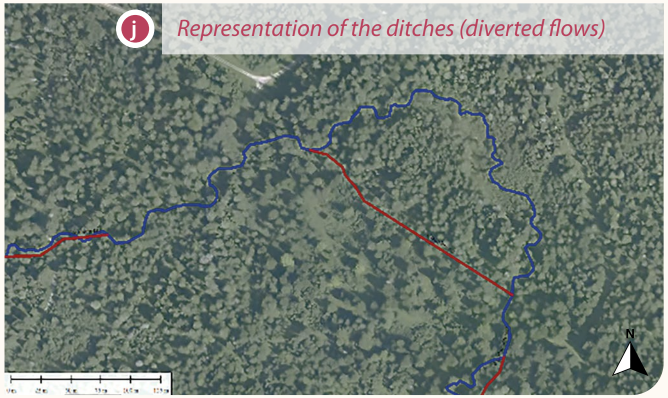
EXAMPLE 2: the Champs des Auges stream (Frasne, Doubs)

The Champs des Auges stream had undergone straightening work to improve forestry production, via drainage. The forest had become much denser and the old stream bed was no longer visible.

Analysis of the DTM made it possible to precisely identify the old meanders in a particularly dense area covered by trees (i) (j) (*cf.* L'Azuré magazine, No. 24, p. 6).



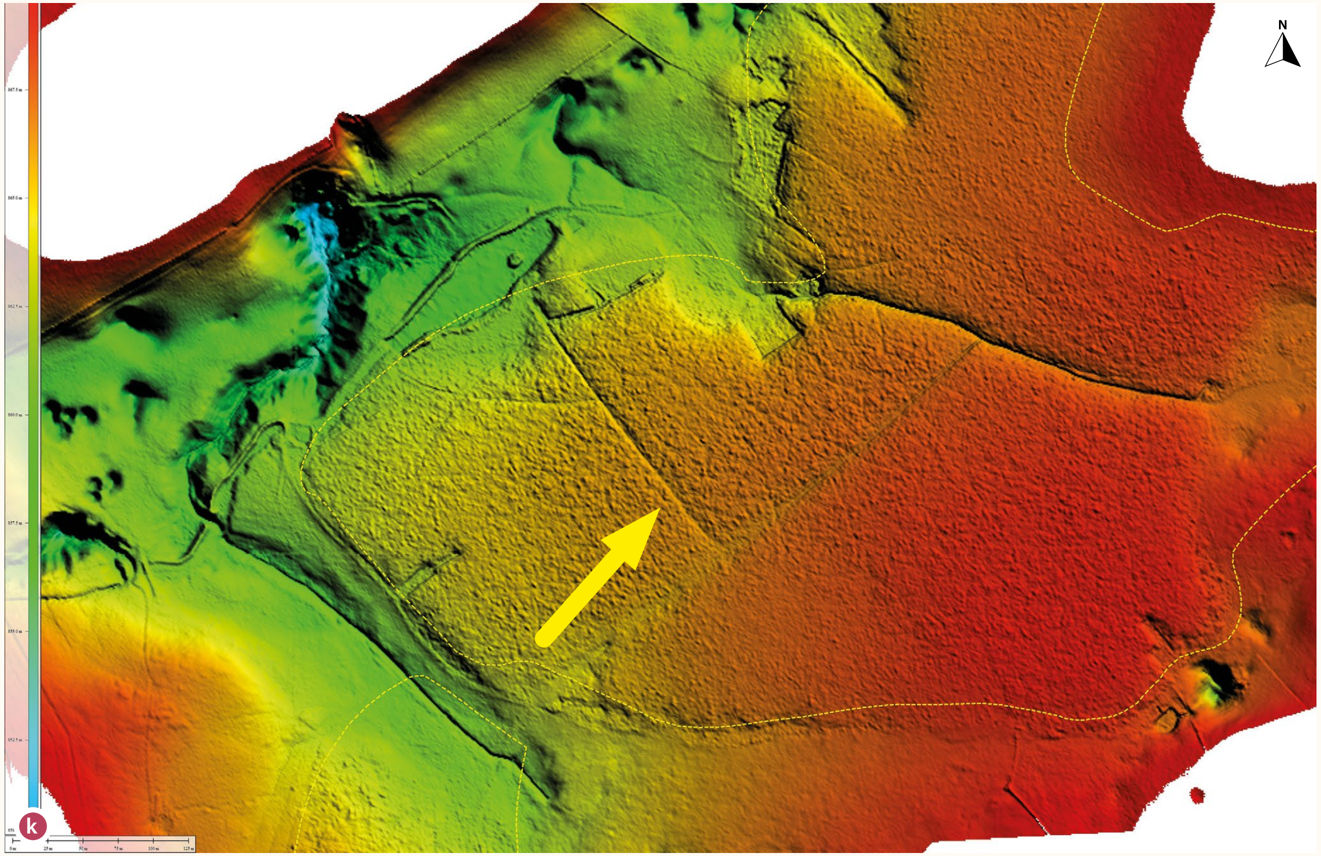
Representation of the contours and theoretical flows



Representation of the ditches (diverted flows)

EXAMPLE 3: the Cerneux-Gourinots peat bog (Fournet-Blancheroche, Doubs)

Here, once again, the mountain pine woods and the vegetation cover on the surface made it difficult to see the two complementary drains that exist in addition to the main ditch. The start of the drain shown by the yellow arrow k is, furthermore, so well concealed by the vegetation that it does not even appear on the DTM. It was by observing its extension on the DTM that its presence could be identified. Likewise, the direction of flow of the main ditch was particularly difficult to identify on the ground.



DTM of the Cerneux-Gourinots peat bog (Doubs) The contours of the deposit are shown by the yellow dotted line

Quantity and quality of water

By eliminating the upper layers of the bog's peat, peat extraction led to the emergence on the surface of more mineralised waters during high water periods. However, active drainage limits the effects of this inflow on the vegetation.

The result is vegetation that is mainly ombrophilic on the surface, in a mosaic alongside patches of more minerophilic vegetation.

To get a better understanding of the hydro-ecological functioning of the habitat complexes resulting from the regeneration of the exploited peatland, the diagnostic studies gave rise, in some cases, to in-depth hydrological investigations.

EXAMPLE 1: the Grande Seigne peat bog (Granges-Narboz et Houtaud, Doubs)

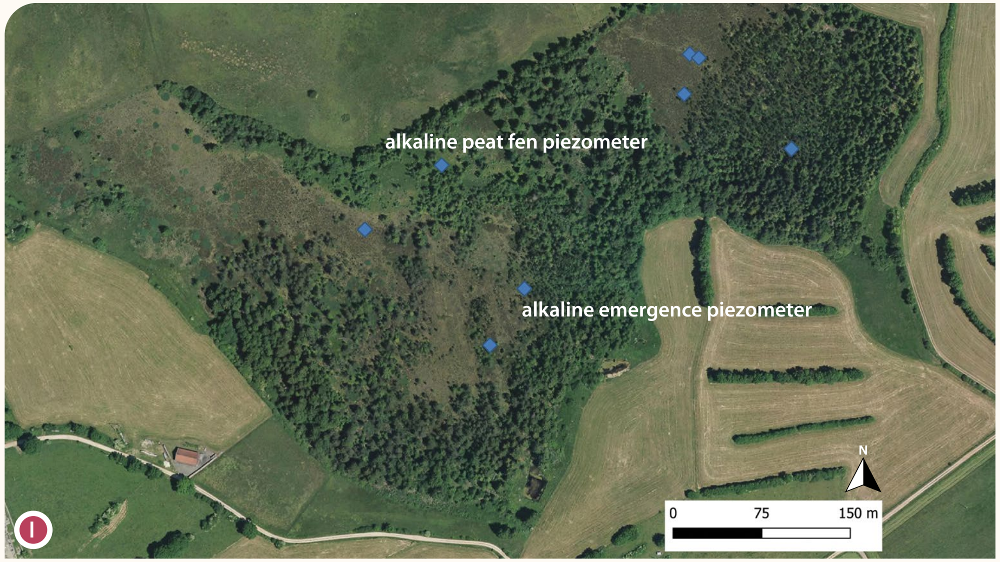
cf p. 33: La Grande Seigne peatland, 3D model

The Grande Seigne peat bog was significantly exploited, which created a "stepped" topography descending from the edge into the centre. A mosaic of habitats has regenerated in the disturbed context, where a large central ditch drains the runoff from the peatland. Temperature, pH and electrical conductivity measurements at different depths have revealed inflows of mineralised water from the bottom and the slopes of the bog, which drain westwards via the large central ditch.

This has allowed hypotheses to be generated from the model of the initial formation of the peat bog and its functioning after the extraction of peat. The restoration potential was therefore worked out, based in particular on these hydrological transfers.

EXAMPLE 2: the Seigne des Barbouillons peat bog (Mignovillard, Jura)

A first approach based on an analysis of the surface vegetation and coring samples allowed hypotheses to be formulated on the non-natural eutrophisation of part of the peatland complex, potentially generated by possible inputs of nutrients from the watershed. Physico-chemical analyses of the water taken from the piezometers during the different seasons l were therefore necessary to test this hypothesis and



Seigne des Barbouillons peat bog (Mignovillard, Jura)

Le Forbonnet peat bog: coring points (Frasne, Doubs)

Analysis	Unit	Minimum value	Maximum value
pH		6,4	7,2
Electrical conductivity at 25°C	µS/cm	170	316
Ammoniacal nitrogen by distillation	mgN/l	0,5	4,8
Total phosphorus	mg/l	0,09	1,7
Calcium	mg/l	41,8	105

m *A few physico-chemical measurements taken on the water from the piezometers situated in the alkaline peat fen and at the alkaline emergence in the Seigne des Barbouillons peat bog*

showed an upwelling of minerotophic lime water into the peatland complex (Goubet 2019), with high seasonal variability. These measurements were linked to the functioning of the watershed and possible hydraulic load transfers. Furthermore, the point in the peat fen is characterised by what amounts to real pollution with ammoniacal nitrogen m, given the concentration (4.8 mg N/l), indicating a direct link with manuring of peripheral agricultural land, via hydrological and/or atmospheric transfers.

This means that vigilance is required regarding the actions to be taken, which must limit the connections between the peatland and watershed as far as possible. Where these re-connections are necessary to the water supply of the peat system, they must be the subject of prior works to eliminate or limit the trophic inputs.

Paleo-environmental information

Other investigations, more extensive in terms of the resources and skills involved, can contribute towards a better understanding of the formation of the peat bog and its evolution, in particular where peatland complexes are large.

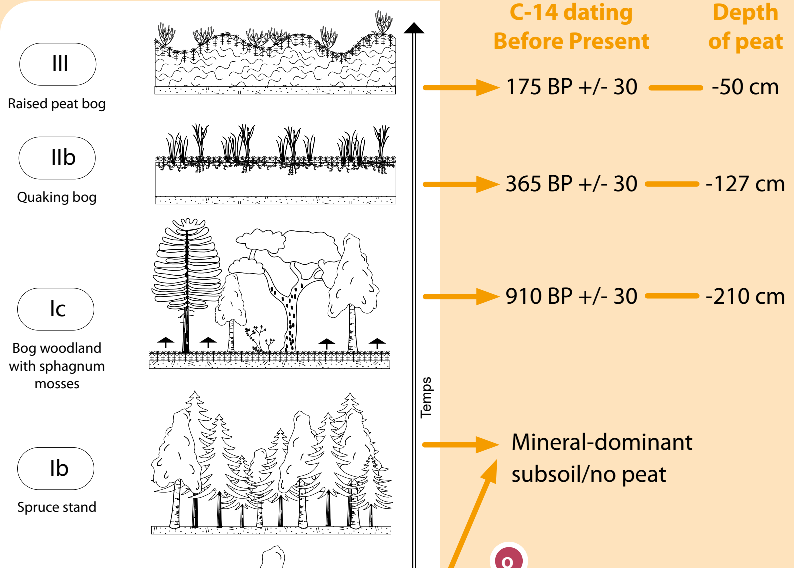
EXAMPLE: the Forbonnet peat bog (Frasne, Doubs)

cf p. 48: The Forbonnet peatland

The Forbonnet peatland at Frasne is very large, covering almost 300 ha, a large part of which is wooded peatland, with mountain pines or spruce, but also an active raised peat bog. With such a diversity of environments, it is clear that the infilling with peat did not take place in the same way and at the same speed everywhere, in what is a very specific geomorphological context with "micro-valleys", moraines and dolines.

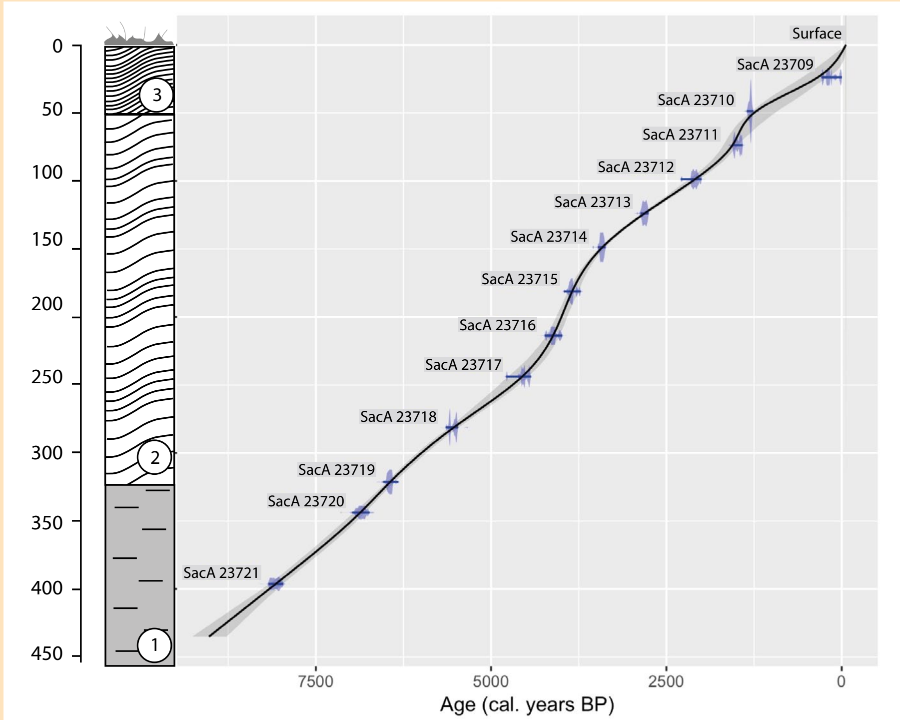
Two coring samples were taken 10 years apart, 300 metres from each other n: one in a drained, active peat bog in the process of afforestation, the other in the wooded peat bog covered by mountain pines.

The first was the subject of an analysis of the macro-botanical remains, with age dating of the five main phases identified in the peat core sample (o, next page).



o

Schematic representation of the history of the peatland complex at the point surveyed and C-14 dating of the different layers (Goubet, 2015)



p

Stratigraphy of the 2010 peat core (Gauthier et al., 2019)

key :

1: clay;
2: successive layers of sapric and fibric peat;
3: compact, fibrous peat

+ age-depth model, based on smooth interpolation of the radiocarbon 13 dates

This shows an extremely rapid accumulation of peat (2.5 m in only about a thousand years) and hydrological conditions that seem to have evolved very fast.

The second was the subject of a palynological analysis and full dating p. This shows a much slower accumulation of peat (3.3 m in 6,200 years). This led us to re-examine the peat formation model, which looks more like a complex of peat units that have coalesced over time, rather than a single body of peat.

Today, this work has led to geophysical prospecting to better characterise the composition and structure of the mineral subsoil, which has generated the water flows and influenced the formation of the peat in a heterogeneous way in space and time.

In conclusion :
from a functional approach to a restoration project

The functional diagnosis carried out must be as efficient as possible: certain key elements of the functioning are important and easily identifiable and measurable. They must allow the clear identification of dysfunctional element(s) of earlier and/or current peat formation, it order to be able to judge whether it is possible to act on it.

Certain large sites require more measurements and time, because a larger peat ecosystem often means a more complex one.

The different functional approaches were adapted to an objective of operationality, to allow for a maximum number of intervention sites, without overlooking the vegetation/peat/hydrology inter-relationships.

But once this step was completed, it was important to measure the restoration potential based on the issues specific to the site (heritage, carbon, low water restoration, etc.), its current functioning and its capacity for regeneration.

The construction of the peat bog revitalisation projects was calculated with a view to achieving the best possible cost effectiveness, taking into account the values previously defined.

Part 2

12 Life works

Map of 12 projects presented in this collection

Over 7 years, the Jura peatland Life program has made it possible to restore 52 peatlands, i.e. 10% of the Jura massif's peatlands and 16% of those of its Franche-Comté part.

In total, 300 ha of peatlands were directly impacted by the restoration actions implemented, on 34 municipalities and 16 Natura 2000 sites.

In this collection, it was not possible to present all the rehabilitated sites. The choice was therefore made to present 12 projects in the form of a data sheet, summarizing the different approaches initiated, issues identified, solutions found and expected results.

At the end of some sheets, a list of useful documents is offered in order to complete the reading. The icon 🌐 indicates that the reference is available on the internet while the icon ? specifies that the document is available on request.

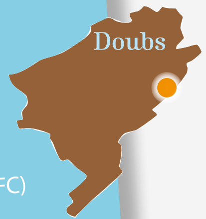
The actors involved on the sites

- Parc naturel régional du Haut-Jura
- Conservatoire d'espaces naturels de Franche-Comté
- Les amis de la Réserve naturelle du lac de Remoray
- Etablissement public d'aménagement et de gestion des eaux Haut-Doubs Haute-Loue
- Syndicat mixte Doubs Dessoubre

The Cerneux-Gourinots peat bog

Aerial view of the Cerneux-Gourinots peat bog

Fact sheet



Natura 2000 site: The Cerneux-Gourinots peat bog and surrounding wetlands, Les Seignes des Guinots, Le Verbois

Managing organisation: Conservatoire d'espaces naturels de Franche-Comté (CEN FC)

Period of works: 2017-2018

Municipalities concerned: Fournet-Blancheroche, Frambouhans & Les Écorces (Doubs)

Accessibility of the site: 80% private property, 20% associations (CEN FC and others)

Surface area of the peatland complex: approx. 60 ha

Altitude: 865 m

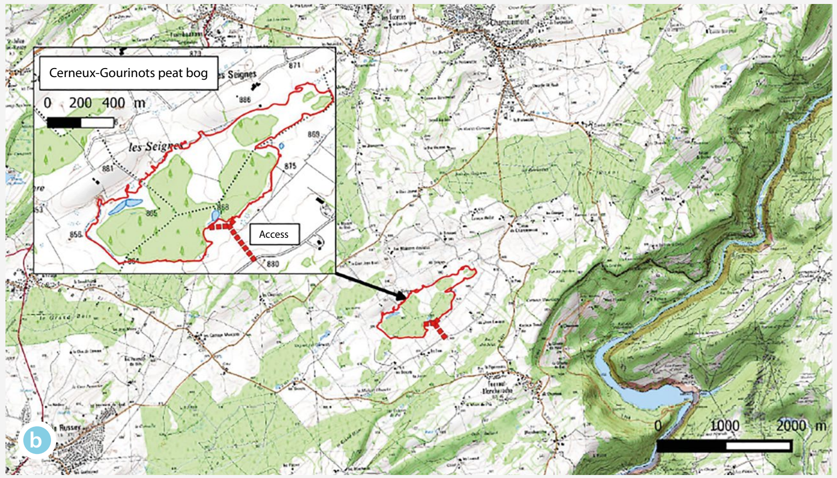
Usages:
- Previously, peat extraction (from 19th to 20th century)
- Grazing on the edge of the peat bog (AOP Comté)
- Hunting, foraging

Species of interest: Hudson Bay sedge (*Carex heleonastes*), Arctic bladderwort (*Utricularia stygia*), slender cottongrass (*Eriophorum gracile*), whinchat (*Saxicola rubreta*), large white-faced darter (*Leucorrhina pectoralis*), cranberry fritillary (*Boloria aquilonaris*), among others.

Whinchat
Saxicola rubreta

Background

The Cerneux-Gourinots peat bog (a), situated on the Le Russey limestone plateau, occupies the bottom of a structural depression formed by the Alpine compression (b). Contrary to the classic pattern of the peat bogs in the Jura mountains, the geomorphology of the Le Russey plateau was not influenced by the Würm or Riss glaciations, whose external frontal moraines are mapped just a few kilometres to the south (*Bichet V. & Campy M., 2016*). The genesis of this site is thus thought to be due to the presence of a small, poorly drained karst basin on an impervious substratum. Marls (Purbeckian/ Cretaceous) have produced hydromorphic conditions favourable to the formation of peat in this karst setting, as evidenced by the presence of the numerous dolines bordering this site.



Situation of the Cerneux-Gourinots peat bog

Today, it is an ombrotrophic peatland, almost entirely covered by mountain pine woodlands.

The spread of this habitat to the entire peat bog can be attributed to past human activities such as drainage or peat cutting carried out between the 17th and 19th centuries and which left scars on the peatland which are visible to this day. Old peat pits mark the periphery of the dome and there are numerous old drainage ditches dug to carry water to a mill c.

Diagnosis

IDENTIFICATION OF THE PROBLEMS

Hydrologically, the peat bog behaves like an isolated compartment, supplied almost exclusively by meteoric waters. The hydrological functioning of the upper layer (acrotelm) is disrupted by a network of drainage ditches or extraction pits which accelerate the flows and play a role in drying out the peat bog. The lack of water leads to the mineralisation of the peat, which as it subsides, increases the drainage phenomenon, and so the cycle continues. These sectors are occupied by spruce, which is a good marker of mineralised zones.

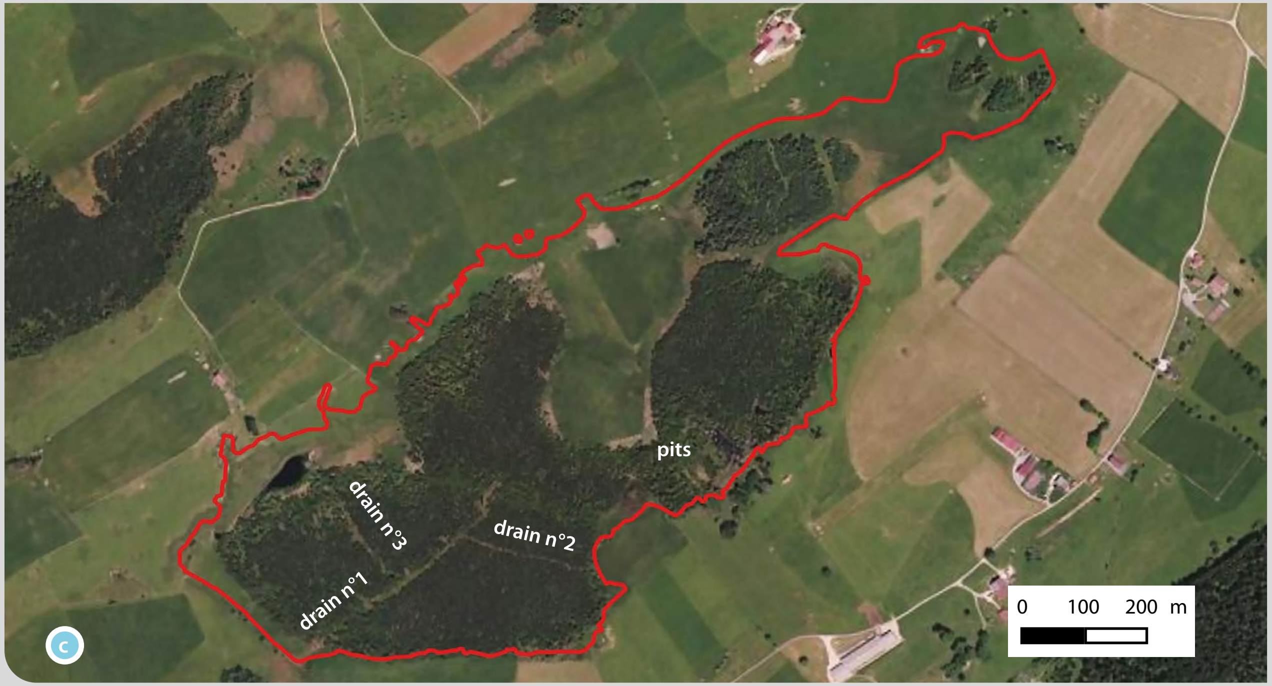
FUNCTIONAL ANALYSIS AND RESTORATION POTENTIAL

Based on the elements in the management plan (*Billant O., 2015*) and the acquisition of the data for a Digital Terrain Model (DTM) by LiDAR, several hydrological rehabilitation scenarios have been studied. Rapidly, the suspicions raised by the mapping of the vegetation were confirmed by the microtopographical survey of the site. The modelling of the water flows showed the disturbances caused by the drainage ditches, especially those perpendicular to the natural slope. A notable subsidence of the peat due to mineralisation, sometimes by more than a metre, accompanies the network of ditches that criss-cross the site.

Taking into account different aspects including land ownership and technical and financial issues, the choice was made to intervene on two sectors of the peat bog which were most severely affected:

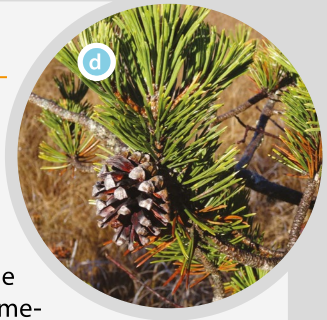
- to the west, a network of ditches (750 metres) rapidly evacuating the rainwater from the peat bog and diverting part of the overland flows;
- to the east, a series of peat pits of varying depths draining and diverting part of the flows towards a karst losing stream.

In light of these factors, the slowing and a restoration of the original flows in the direction of the general slope appeared to be a good compromise to limit the mineralisation of the peat bog, and even to restart a localised process of peatification.



Disruptions identified on the Cerneux-Gourinots peat bog

CHALLENGES OF THE SITE



Mountain pine
Pinus uncinata

▶ **Biodiversity:** the peatland has been considerably closed off by mountain pines d. Nevertheless, it remains a major biological reservoir for many peat bog plant species. This fragile equilibrium is threatened in the medium or long term by a phenomenon of mineralisation that is worsening as the site is drained.

▶ **Water supply:** as the topography has been substantially modified, it is necessary to slow the water flows to limit the influence of the drainage and its corollary, mineralisation.

CONSEQUENCES

The Cerneux-Gourinots peat bog has been seriously impacted by past activities. Although the site's evolution seems to have stabilised at the stage of the mountain pine forest, the insidious effects of the drainage ditches and peat pits remain and continue to contribute to the slow, but inexorable mineralisation of the site.

The work in figures

Périod: work began on 01/08/2017 (tree felling) and was completed on 24/01/2018. The old peat pits were protected from grazing animals in March 2019

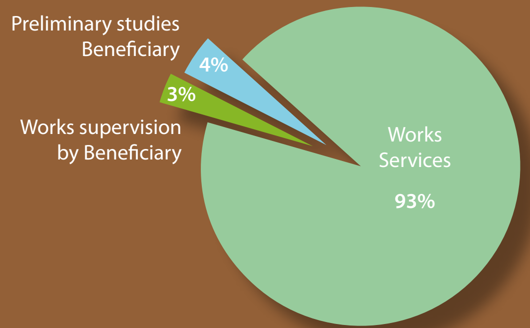
Length and surface areas:

- Neutralisation of 719 m of drainage ditches
- Closure of 1.2 ha of old peat pits
- Impact expected: 2 ha of rewetted ground in the medium to long terme

Providers: Jura Natura Services for the hydrology work & Lycée François Xavier for the protective fencing

Total cost of the Life action: €177,851 incl. VAT *

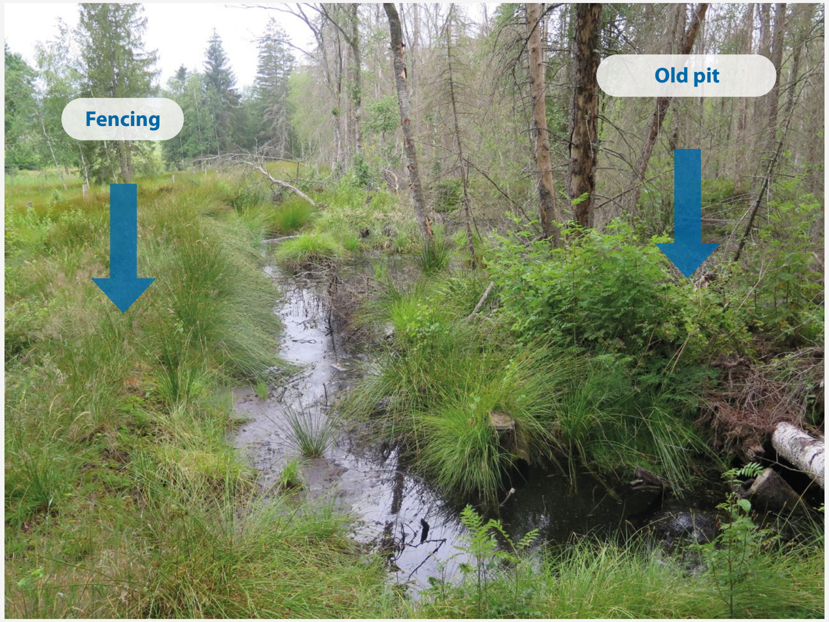
- Works (green): €169,920
- Preliminary actions (blue): €7,931



** the costs of actions carried out previously (outside the Life scope) on the site are not included*

Before - After

Raised water level in an old peat pit



Works

Works were carried out to neutralise the drainage network with the aim of raising the level of the water and redirecting it towards the natural slope (see next page).

To avoid too many back-and-forth trips by vehicles to bring in the materials necessary to build the wooden fences, it was decided to drop them in by helicopter. This avoided compacting the ground, at an equivalent environmental cost (in terms of carbon emissions).

REGULATORY FACTORS

► None – the «water» unit of the DDT 25 (local land use department) and the BEP (biodiversity, water, heritage) department of the DREAL FC (regional environment and planning department) were kept informed.

Results

Once the fences were in place, the water level rose in the old peat pits, to reach ground surface level.

The spruces, which previously found conditions favourable to their growth on the site, rapidly withered and the sphagnum mosses spread.

Contact

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03 81 53 97 81 - julien.langlade@cen-franchecomte.org

Online

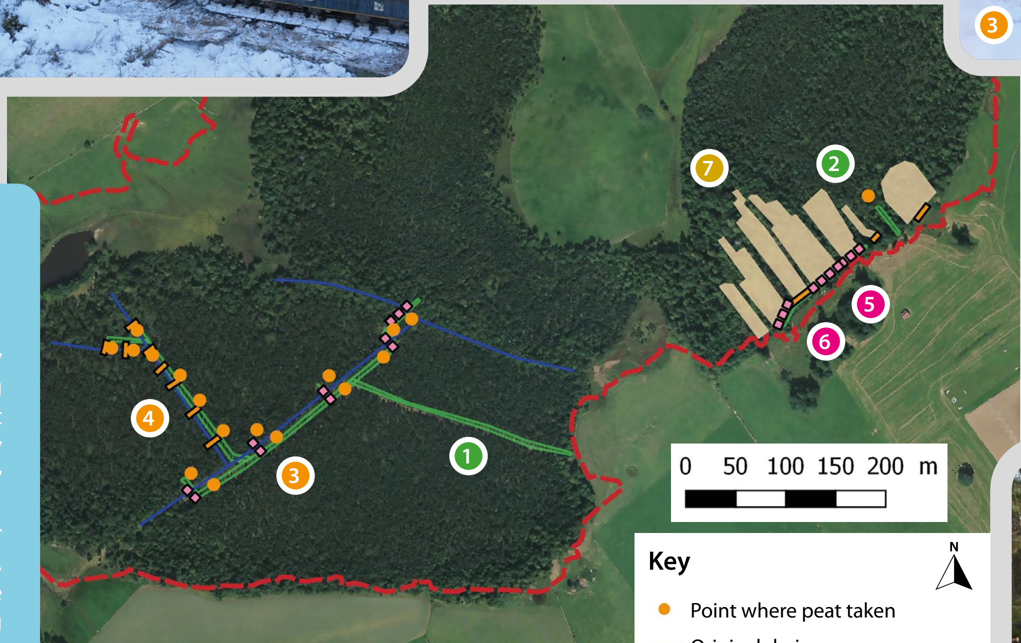
The functional restoration works

To allow access to the work areas and install the structures, **special trails** (1 and 2) were cleared through the peat bog pine woods (about 800 m long and 10 m wide).

Installation of three-ply fence panels

To **neutralise the water flows in the drainage ditches** in the western sector, dams were installed: five fences made of timber planks 3 (110 m in total) and eight fences made of wooden panels 4.

Installation of timber plank fencing



Plan showing the works carried out as part of the peat bog restoration at Le Crossat

The **old peat extraction pits were closed off to maintain a water level favourable** to the resumption of peatification in the eastern sector: installation of four timber plank fences 5 (80 m in total) and two wood panel fences 6.

Covering of the timber plank fencing with peat and then vegetation

Points requiring particular attention

- **Peat bund:** The peat cover has subsided considerably over a few square metres at one of the structures exposing the wood of the fencing underneath. The hypothesis put forward to explain this phenomenon is that the very hot, dry summers of 2018 and 2019 meant that the humidity required for the peat in the bund could not be maintained. It was repaired over a half-day's work by the contractor with the help of two students from Lycée François-Xavier, an agricultural high school in Besançon. The results were mixed, with the water levels behind the fencing being regularly low and not wetting the peat on the surface. However, chamaephytes such as blueberries and heathers seem to be recovering on the bund despite the dryness. This is an area to monitor in the future.
- **Securing the peat bog:** some horses from a farm nearby found their way into an unfenced area of the peat bog, and a mare got bogged down in a waterlogged hollow where peat had been removed, leading to the animal's death even though she was initially rescued. In addition to the farmer's loss, this incident also caused some slight damage in the approach to and on the site of the intervention. This area has now been fenced off and the waterlogged hole has been partially filled in with remnants from the trees which were felled when preparing the site.

Protective fencing 7 was installed around the old peat extraction pits.

Protection of the restored sectors: fencing

The Villeneuve-d'Amont peatland

Aerial view of the peatland from the north. In the foreground, the extraction pit colonised by downy birch

Fact sheet

Natura 2000 site: Valley of the Loue and Lison

Managing organisation: Conservatoire d'espaces naturels de Franche-Comté (CEN FC)

Year of works: 2018-2019

Municipality concerned: Villeneuve-d'Amont (Doubs)

Accessibility of the site: unregulated site, not equipped for visits

Surface area of the peatland complex: 24 ha

Altitude: 660 m

Usages:
- Forestry operations

Species of interest: Round-leaved sundew (*Drosera rotundifolia*), Marsh cranesbill (*Geranium palustre*) *Sphagnum compactum*, *Odontoschisma sphagni*, Marsh fritillary (*Euphydryas aurinia*), Northern emerald (*Somatochlora arctica*), among others.


Sphagnum compactum

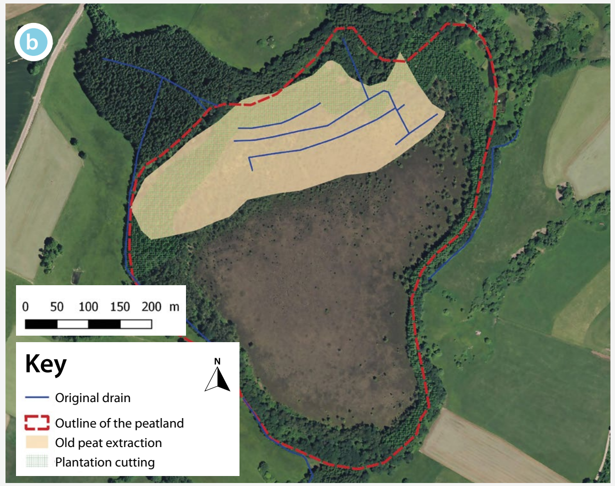
Background

The Villeneuve peatland (a) is a peat bog which, although at a modest altitude for the Jura (the lowest raised bog in the mountains) is highly typical. As well as a very marked dome shape, one of the most spectacular in Franche-Comté, it features all the characteristic zones with, in the centre, open communities of active peat bog and moor, surrounded by a peripheral wooded belt. The transition (topographical, hydrological, trophic and biologic) from the non-peaty surrounding environments (wet meadows, mesophilic meadows and spruce plantations) is very abrupt. The excess water is collected by a network of dolines situated around the immediate edge of the peat bog.

Diagnosis

IDENTIFICATION OF THE PROBLEMS

A large part of the peat bog was functioning correctly at the time of the diagnosis, although a certain number of disturbances were visible, more particularly in the northern part (b): a network of drainage ditches (850 m); a massive amount of peat extracted (c, next page - of the order of 60,000 m³), which had created a vast pit covering a quarter of the area of the peatland (6.8 ha); a plantation of spruce (5.0 ha).



Location of the damaged areas

CONSEQUENCES

These different types of disturbances have had several effects on the Villeneuve-d'Amont peatland:

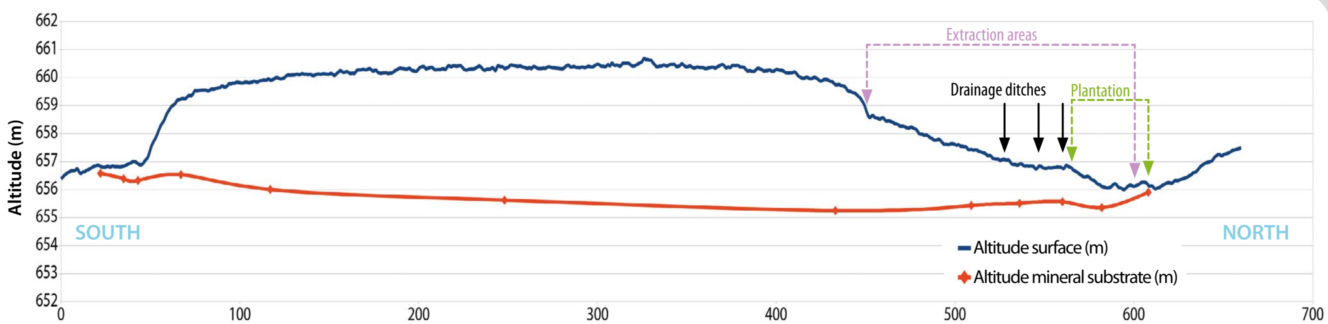
- peat extraction created a 2% slope in the pit;
- the spruce plantation caused an increase in evapotranspiration, an interception of the precipitation and significant shading:
- the drainage network intercepts the waters from the centre of the peat bog to rapidly evacuate them towards the outside.

The combination of these effects has mainly led to a pronounced drop in the water table, reflected in:

- under the spruce plantation (d): the absence of any peat-forming vegetation, most of the surface being reduced to a carpet of needles, with the first few tens of centimetres of peat being marked by substantial mineralisation;
- in the rest of the extraction pit (e): an increased presence of downy birch and purple moor grass, considerably more pronounced close to the ditches.

View of the plantation before the works

Progression of the birch and purple moor grass within the drained part of the extraction zone (the spruce plantation can be seen in the background)



(c) *Topographical transect of the surface and sub-surface*

Works

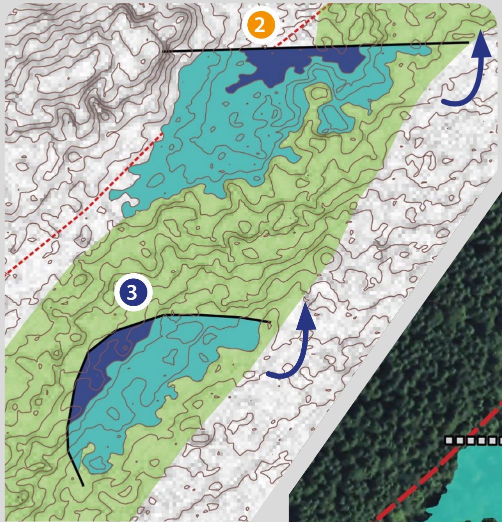
In order to raise the water table, locally restart the process of peat formation and reconstitute the habitats most typical of peaty environments, three types of actions were chosen:

- cutting down spruce trees;
- neutralisation of drainage ditches, by partially or totally plugging them;
- localised rewetting of the extraction zone, by constructing four steel piling dams.

This third operation required considerably more thought that the others. The configuration of the peat cutting zone (large area, relatively steep slope, absence of bunds remaining from the extraction), on the one hand would not allow the water table to be raised over the entire zone and, on the other, posed problems for the lateral anchoring of the structures.

It was therefore decided to raise the water table in localised areas, by created four dams with lateral overspills.

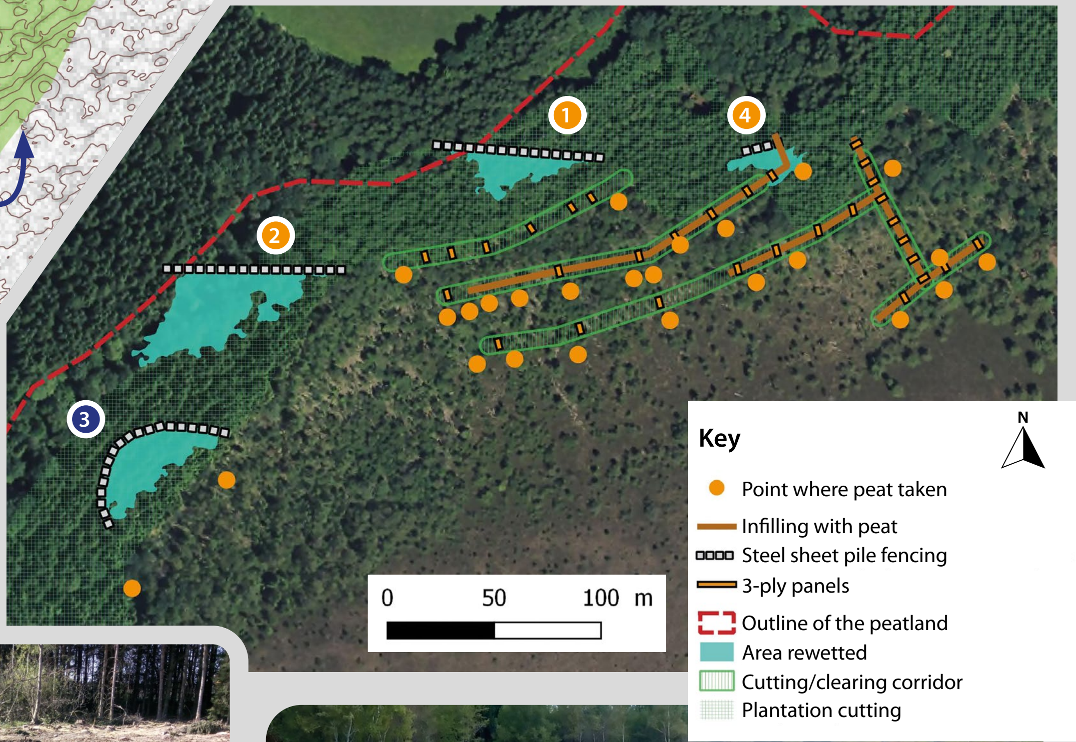
Their precise positioning was decided based on the detailed topographical survey of the zone, in that they were placed where it was possible to position both ends of each dam at the highest points (the rest of the width therefore being lower down than the ends). As for the choice of steel piles, this was driven by the need to create curved structures (see dam no. 3, next page) that would last a long time and, in this particular case, cost less than timber plank dams.



Contour interval: 10 cm

Blue arrows: lateral overspill

The existence of small thalwegs made it possible to design **straight dams** for structures 1, 2 and 4. On the other hand, the absence of this type of configuration in the sector where the dam 3 was to be built made it necessary to design a **curved structure** to obtain the desired retention effect.



Dam no. 1 formed (except the ends), before covering with straw

Dam no. 3 during construction

The work in figures

Periods: from July 2018 to August 2019

Length and surface area:

- Cutting of the plantation: 4.95 ha (2,220 m^3 of timber removed)
- Neutralisation of drainage ditches: 850 metres in length
- Structures to raise the water table: 4 steel piling dams with a total length of 277 m
- Rewetting of approximately 4.2 ha of peatland

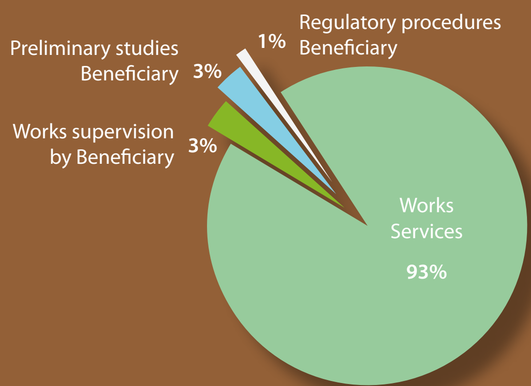
Project owner and main contractor:

- Cutting of the plantation: municipality (owner) and ONF (main contractor)
- Other works: Conservatoire d'espaces naturels de Franche-Comté

Contractors: SARL Franchini for the forestry works, FCE/Rusthul TP consortium for the drainage ditch neutralisation works and ONF for the clearance of the drainage ditch footprint

Total cost of the Life action: €164,759 incl. VAT *

- Works (green): €159,452
- Preliminary actions (blue + grey): €5,307



Expected outcomes

The zones where the water level has been raised closest to the surface should be colonised by peat bog vegetation or, on the outer edges of the peatland, by transitional marsh vegetation. As for the peripheral zones where the water table is not raised, they should see a natural development of birch and spruce populations on the peat like those occupying the non-artificialised margins of the peat bog. Finally, the sector where the drainage ditches have been neutralised should see a decline in the momentum of the colonisation by downy birch and purple moor grass.

MONITORING SET UP

▶ Vegetation monitoring: 2 transects (RhoMéO protocol, 17 plots). To be repeated five years after the works.

▶ Hydrological monitoring: on one of the two vegetation transects, installation of four piezometers equipped with automatic recording sensors in the intervention zone. To be continued for about three years after the works.

▶ Hoverfly monitoring (analysis of the pre-/post-works population; first campaign in 2015). To be repeated five years after the works.

Points requiring particular attention

▶ **Archaeological remains:** according to a document dating from beginning of the 20th century, the Villeneuve peatland contains Neolithic archaeological remains (very rare in the Jura peatlands), but these had never been found in spite of several surveys. Hence the excitement among the archaeological community when a piece of wood resembling a stake was found in the peat extracted to cover the structures. After a visit from the Regional Archaeology Department, dendrochronological examination and carbon dating, it was concluded that this piece of wood was not placed here by human hand, but rather had probably grown naturally on the site, at the beginning of the peat accumulation.

▶ **Detection of drainage ditches:** a large proportion of the length of the ditches was clogged up on the surface, giving the impression that they were inactive. But most of these portions were in fact still active underneath, due to an ongoing "conduit" (sometimes more than 40 cm in diameter) at a certain depth. These parts therefore had to be surveyed in their entirety to see which ones would have to be neutralised and which ones could be left as they were.

▶ **Topographical adjustment:** impoundment no. 1 had to be extended to the west to allow a gentle discharge in that direction, thereby diverting the flows which, at high water, were undermining the structure.

▶ **Clearing of woodland around the structures:** the clearing which had been conducted around the dams was found to be inadequate for certain structures f, in particular on the occasion of a tornado that caused a substantial windfall onto the peat bog, just one month after completion of the works. Other experiences in the LIFE programme have shown that any tree within the potential footprint of a structure should be eliminated whenever possible, as repairs after the works are always more complex.

Result of inadequate tree clearance around dam no. 2 - fortunately no damage was caused to the dam

Before - After

Aerial view of the Villeneuve-d'Amont peatland

Useful documents

? MONCORGÉ, S. 2017. *Tourbière de Villeneuve-d'Amont (25) - Plan de gestion 2017-2026.* Conservatoire d'espaces naturels de Franche-Comté ; Union européenne ; Agence de l'eau Rhône-Méditerranée-Corse ; Conseil régional de Bourgogne-Franche-Comté ; Conseil départemental du Doubs. 59 p. + annexes.

Contact

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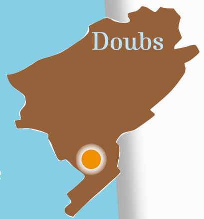
03 81 50 51 29 - sylvain.moncorge@cen-franchecomte.org

La Grande Seigne peatland

Aerial view of the Grande Seigne peat bog

Fact sheet



Natura 2000 site: Drugeon Basin

Ramsar site: Peatlands and Lakes of the Jura Mountains

Prefectoral order on the protection of the Drugeon basin biotope

Project owner: EPAGE Haut-Doubs Haute-Loue

Period of works: 2018-2019

Municipalities concerned: Granges- Narboz and Houtaud (Doubs)

Accessibility of the site: site not regulated for access, but for certain uses, not developed for visitors

Area of the peatland complex: approx. 200 ha

Altitude: 815 m

Usages :
- Hunting
- The peatland is geographically an extension of the groundwater supplying the Pontarlier region with potable water.

Species of interest: String sedge (*Carex chordorrhiza*), Hudson Bay sedge (*Carex heleonastes*), round-leaved sundew (*Drosera rotundifolia*), fen orchid (*Liparis loeselii*), large white-faced darter (*Leucorrhinia pectoralis*), large heath (*Coenonympha tullia*), violet copper (*Lycaena helle*), moorland clouded yellow (*Colias palaneo*), marsh fritillary (*Euphydrias aurinia*), common snipe (*Gallinago gallinago*), Northern lapwing (*Vanellus vanellus*), among others.


Common snipe
Gallinago gallinago

Background

The vast Grande Seigne peatland complex a is made up of a mosaic of habitats related to past exploitation of the peat. This has heavily impacted the central part of the peat bog, lowering its topographical elevation, but it has also “refreshed” the layer of peat in the peat fen which is more minerotrophic in origin.

The peatland complex is enclosed between, on the one hand, the morainal Granges-Narboz hills to the south and east, which supply the peat bog with mineralised lime spring water which is low in oxygen, and on the other hand, the Arlier plain to the north, an old fluvial-lacustrine delta of glacial origin, the groundwater from which provides the potable water supply to the town of Pontarlier. The peat bog was most likely formed secondarily over a percolation fen, making it similar to a soli-ombrogenic hydrological type.

Historical publications prove that there was intense exploitation of the peat over at least two hundred years (*André and André, 2004*), which considerably modified the topography of the peatland, and therefore the circulation of the surface and percolation waters.

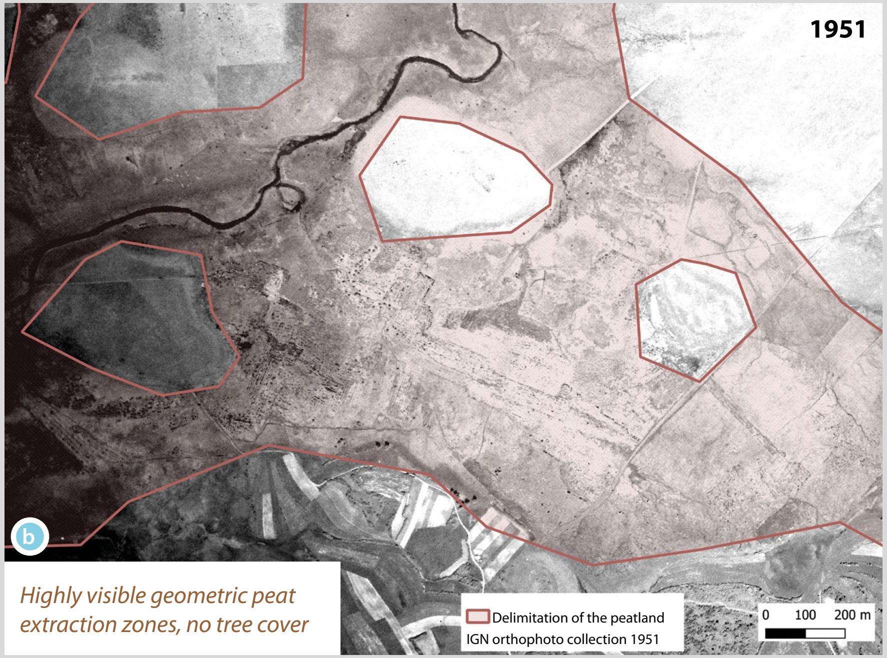
Diagnosis

IDENTIFICATION OF THE PROBLEMS

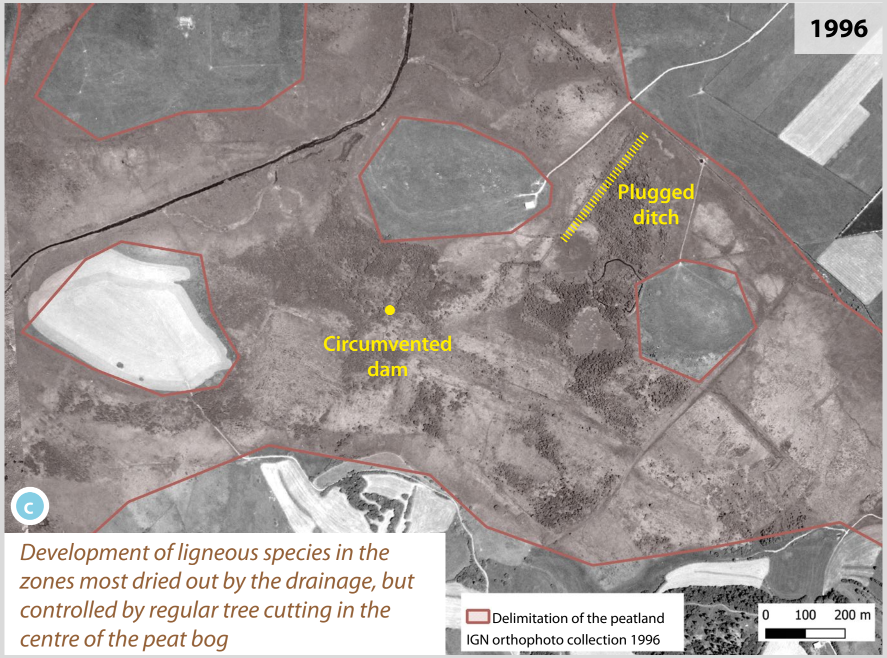
The Grande Seigne peatland was colonised by ligneous species (birch, alder buckthorn, willow) from the 1950s onwards (as can be seen in the aerial photographs b et c, next page).

Purple moor grass covers a growing area of the peatland and increases the mineralisation in the zones of intermittent saturation. The peatland’s habitats are deteriorating, jeopardising the presence of several animal and plant species.

Aerial view of La Grande Seigne



Highly visible geometric peat extraction zones, no tree cover



Development of ligneous species in the zones most dried out by the drainage, but controlled by regular tree cutting in the centre of the peat bog

The main central drainage ditch, also corresponding to the central extraction pit, was identified as the element disrupting the hydrological functioning of the site as early as 1995, during the "Restoration of the Drugeon Basin" Life programme.

► Cutting of ligneous species was started in 1996 ("Restoration of the Drugeon Basin" Life programme, the Natura 2000 contracts), and was repeated every four years, to stop the closing of the site which is prejudicial to open-country species (flora, butterflies, birds). However, in fact cutting back failed to control the suckers, revitalising them instead of weakening them.

► The downstream part of the central drainage ditch was blocked by two wooden dams in 1996: due to a lack of experience and the continued mineralisation of the peat, the dams, which were not long enough, were circumvented and the drainage continued c d.

► The drainage ditch carrying the waters off the peatland to the north was totally and successfully blocked by marl dams and infilling with peat in 2004 c e.

2018: one of the two dams circumvented, structure built in 1996

Infilling of the north outlet drain with marl and peat done in 2004

FUNCTIONAL ANALYSIS AND RESTORATION POTENTIAL

In 2015 LIN'eco, an ecological consultancy firm, was commissioned to carry out a diagnostic study of the functioning of the peat bog, to define its regeneration potential and propose measures. The study confirmed that peat extraction had dramatically altered the surface and percolation water flows within the peat body f. The digital terrain model, the piezometric data and the modelling of the percolation flows in the peat all confirmed the nature of the disturbances.

▶ The mineralised, low-oxygen spring waters that formed the peatland are drained by the peripheral and central ditches instead of spreading northwards through the peat. The consequences of this are:

- the residual peat, theoretically fen, becomes ombrotrophic: meteoric waters predominate over the deep mineralised groundwater over a large area of the peatland;
- the peatland becomes mineralised: purple moor grass develops in the over-drained areas;
- the central ditch continues its deterioration of the peat upstream, by a process of headward erosion.

▶ **Geomorphology:** The slope in the mineral subsoil is generally oriented south to north, with a slight obstructing sill in the north, which delimits the pseudo-trough. Before the exploitation of the central part of the peat bog, this slope must have encouraged a slowed transfer of spring water flows from the south to the north, by percolation. When the central ditch was dug, it intercepted this flow and diverted it westwards g.

CHALLENGES OF THE SITE

▶ **Biodiversity:** the peatland, although hydrologically disturbed, is a major biological reservoir (17 protected plant species and six animal species), due mainly to the fen and transition mire habitats in areas that still have a high enough, stable water table. The restoration potential for the habitats and species is therefore high.

▶ **Water supply:** the springs that formed the peatland are still active and can be remobilised to provide a slower, diffuse water supply to the peat. There is therefore real potential for rewetting.

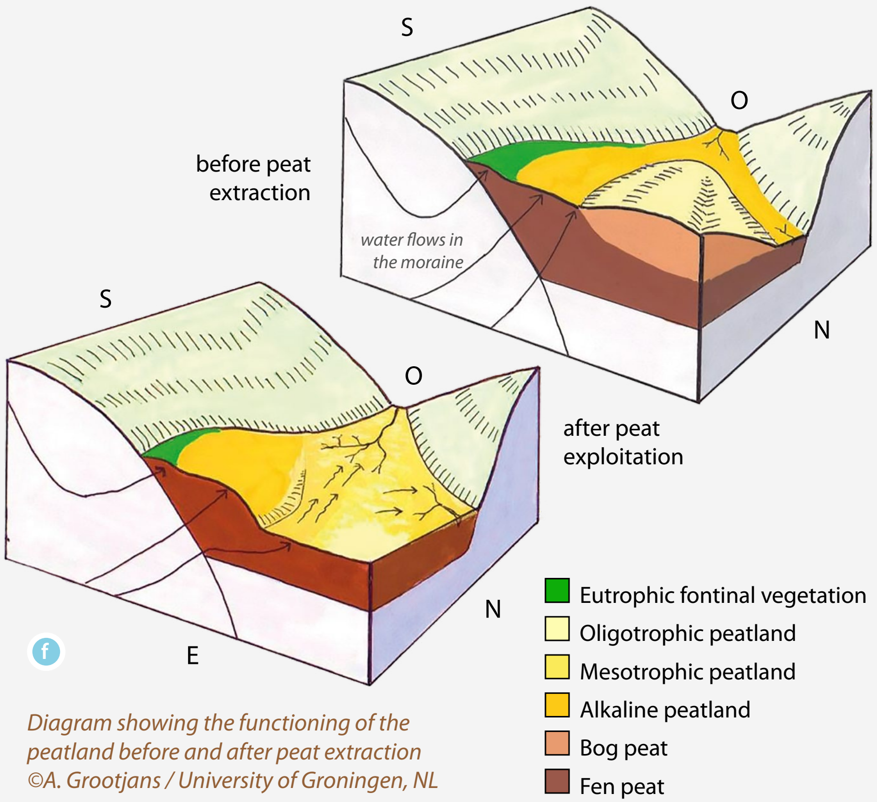
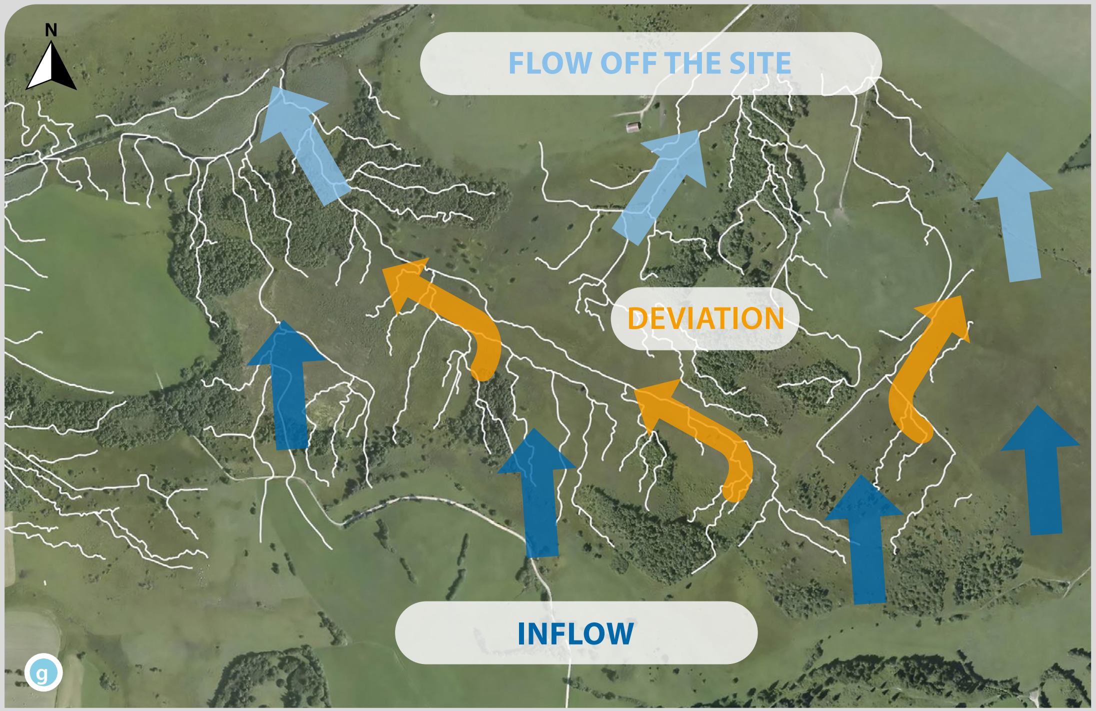


Diagram showing the functioning of the peatland before and after peat extraction ©A. Grootjans / University of Groningen, NL



Deviation of water flows following the extraction of the peat

CONSEQUENCES

The result is an extensive marshy, peaty complex, dried out by the deviation of the water flows generated by the excavation of the peat. The situation is evolving rapidly towards afforestation and an increase in central drainage due to headward erosion. The restoration potential is high thanks to the persistence of some very wet patches which are still functional and rich in biodiversity. The project therefore consisted of:

- eliminating the drainage effects and extending the areas of rewetting with water of mineral origin devoid of oxygen from favourable functional patches (i.e. whose functioning as wet zones has been restored). This water should be driven to the surface by the effect of the hydraulic gradient and the topography of the mineral substratum, to supply the north-east part of the site;
- remobilising the deep mineral water, which will have two beneficial effects: to supply the heritage species with minerals and smother tree roots due to the low oxygen content;
- stopping the headward erosion of the central ditch.

Works

The works were on a scale unprecedented in a French peatland and consisted of:

- redirecting the flowers of water drained from south to north on the upstream part (east): five simple timber plank fences (480 m of fencing in total);
- blocking and slowing the flows with overspill on the downstream part (west): five double submersible timber plank fences (306 m x 2 of fencing in total).

Installation of the worksite: given the considerable distance between the access to the site and the delivery points, the size of the peatland, its fragility and the numerous hazardous extraction pits, helicopter transport was preferred for reasons of cost effectiveness, lower impact on the site and a lower carbon cost (two full days' use of a helicopter compared to three weeks of overland deliveries using three vehicles, with no guarantee that they would get through).

REGULATORY FACTORS

▶ Procedure under the Law on Water and Aquatic Environments:
Sections 3.2.3.0 (creation of water bodies) and 3.3.1.0 (backfilling) of the Water Act impose a declaration procedure above certain thresholds, and these works exceeded the declaration (0.1 ha), but not the authorisation threshold (1 ha) for both sections.

▶ Evaluation of the impact of Natura 2000:
As the areas impacted led to an improvement in the conditions for maintaining species and habitats of Community interest in the medium term, although there was a short-term impact (worksite), no significant impact threshold was met.

▶ Protected species:
The areas concerned by the protected bird populations identified were assessed for short, medium and long-term impacts. In view of the ecological requirements and the expected outcomes of the works, none of these species were considered as threatened.

The work in figures

Periods: from September to November 2018 and July to September 2019

Length and surface area:

- Neutralisation of 420 m of drainage ditches
- Rewetting of 19 ha of old extraction pits

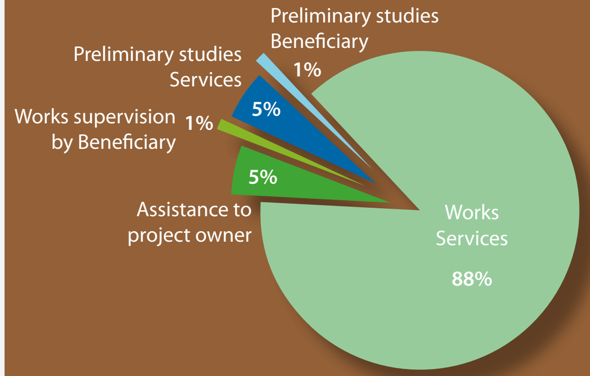
Equipment used:

- two wetland excavators with platforms, one mini-excavator with platform, one shredder, one dumper, two tracked wheelbarrows, one helicopter
- 250 t of timber planks
- 3,000 m^3 of peat moved (excavated material/backfill)

Contractors: LIN'eco for the technical study and support and Jura Natura Services for the work on site

Total cost of the Life action: €945,196 incl. VAT *

- Works (green): €887,877
- Preliminary actions (blue): €57,319

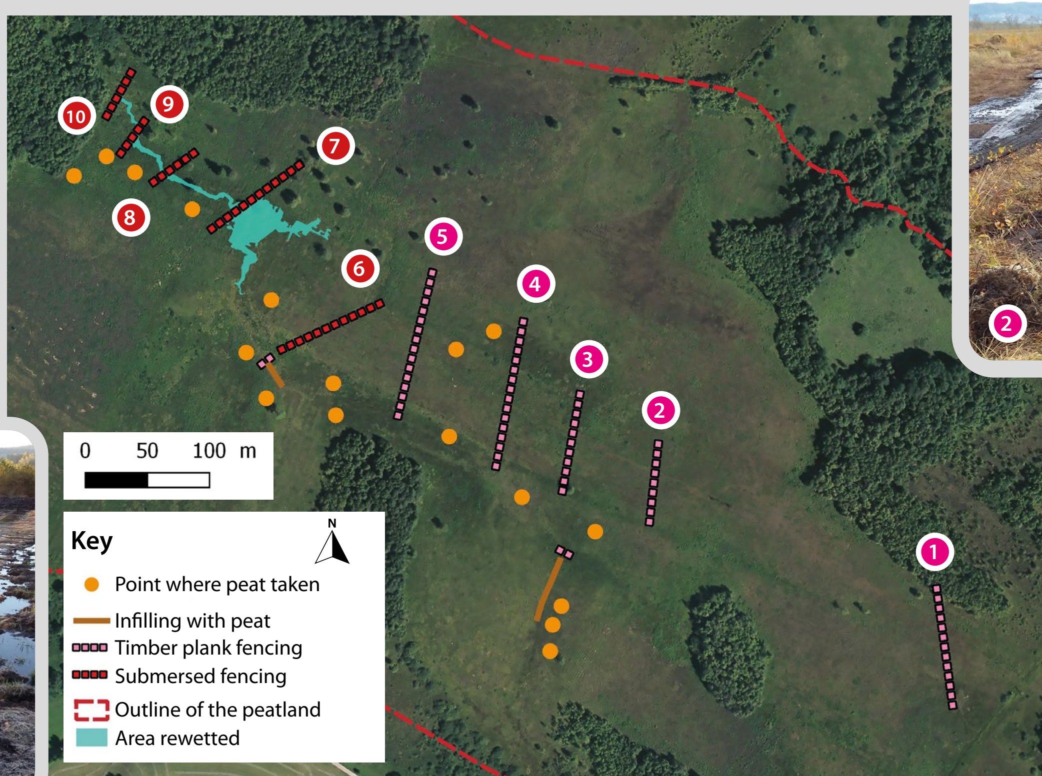


** the costs of actions carried out previously (outside the Life scope) on the site are not included*

The five downstream dykes (6 to 10) are **double wooden fences** from 40 to 90 m long, **technically adapted to be submerged** (peat + bentonite + coconut coir netting + double steel grilles to ensure equidispersion of the water flow = LIN'eco prototype).

The planks are anchored in the mineral subsoil, their length adapted to the depth of the peat, between 1.5 m to 3.1 m.

Double submerged wooden fencing



General view of the works

Covering a single wooden fencing dyke with peat. To avoid creating draining ruts in the ground, the excavator is working on plates

The five dykes in the upstream part (1 to 5) are **wooden fences** 63 to 125 m long, the purpose of which is to **keep and direct the water into the operational ditch** and take it over the old operational bank so that it can flow and spread northwards.

The planks are anchored in the mineral subsoil and their length is adapted to the depth of the peat, between 1.5 m to 3.75 m.

Points requiring particular attention

▶ **Topography:** to achieve the post-works goals in terms of the circulation of the surface waters, a detailed topographical survey was conducted to identify the areas where the passage of machinery/vehicles could be allowed or not. Routes were marked out on the site to help the drivers, as even machinery/vehicles specially designed for such sites leave tracks on the ground.

▶ **Risk of the presence of old shells:** the peatland is on the edge of an early 20th century artillery training ground. A risk assessment by the bomb disposal services allowed, firstly, the risk of explosion to be evaluated and minimised, and, secondly, the contractors' workers to be informed about security measures to follow if an explosive device was found or moved.

▶ **Drought:** the work was carried out in 2018 during an exceptionally harsh drought, which made the colonisation of the ridges of peat by vegetation somewhat hypothetical. The peat used to cover the structures split and cracked on the surface, but since the substantial thickness of the peat (40 cm) had been respected, none of the planks were exposed. Consideration is is being given as to whether to spread straw, but the lengths of these structures are considerable and access has become very difficult.

Onliane

The hydro-ecological restoration work

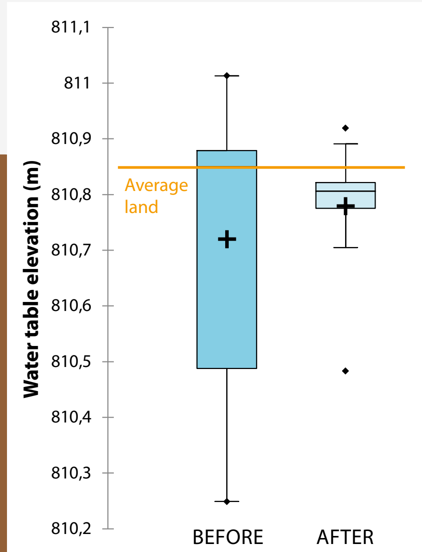
Results

The Grande Seigne peatland is a site that has attracted interest for many years, given both its size and the conservation issues concerning its fauna and flora. For these reasons and given the data that already existed, managers' opted for large-scale, long-term monitoring.

MONITORING SET UP

- Monitoring of the flora: 10 plots of vegetation (pre/post-works - 2016/2019)
- Specific monitoring of *Carex heleonastes* in the 10 monitoring squares by the National Botanical Conservatory of Franche-Comté - Regional Invertebrates Observatory (CBNFC-ORI): monitoring pre/post-works - 2015/2016/2020
- Piezometric monitoring: Five piezometers monitored (since 2017)
- Monitoring of *Liparis loeselii* by the CBNFC-ORI and the Botanical Society of Bourgogne-Franche-Comté: Life monitoring pre-works 2015/2016, Life monitoring post-works 2019-2020
- Monitoring of *Calamagrostis neglecta* in 2020;
- Hoverfly inventories: 2014
- Monitoring of Lepidoptera
- Monitoring of the common snipe: even years between 1996 and 2020. 2020 very disappointing and surprising with no singing birds, but proven presence of birds until at least mid-April. The bog was very wet and so comparatively favourable...

Water table elevations at the "GS_amero" station on the Grande-Seigne peatland: pre/post-works comparison



- **Pre-work study period:** 01/11/2017-1/11/2018
- **Post-work study period:** 24/12/2018-24/12/2019

The effect of the works is quite visible on the water table fluctuation, very limited after the works. The median elevation is slightly lower (a few centimetres), which can be explained by the fact that the subwatersheds were reduced at each dyke and the system is not yet fully loaded, due to the exceptional drought of 2018.

Before - After

The Grande Seigne peat bog before the works - December 2015

The Grande Seigne peat bog after the works - April 2020

Useful documents

BEDOLLA, A. 2013. *Hydrologie et potentiel de restauration de quelques marais français et suisses - Notes des visites de terrain d'experts réunis à l'occasion de la venue d'Ab Grootjans - 24-29 juin 2012*. WSL. 16p.

GROSVERNIER, P. 2014. *Tourbière de la Grande Seigne - Eléments d'analyse pour un diagnostic hydroécologique du site*. SMMAHD. 38p.

GROSVERNIER, P. ; CONTESSE, E. ; POTTIER, Y. ; MONTAVON, C. 2017. *Tourbière de la Grande Seigne - Définition des enjeux de conservation et des potentialités de restauration*. SMMAHD Life tourbières du Jura. 51p.

GROSVERNIER, P. & MONTAVON, C. 2018. *Tourbière de la Grande Seigne - Analyse hydrologique : circulation des eaux en provenance des collines morainiques avant et après travaux de revitalisation*. SMMAHD Life tourbières du Jura. 14p.

POTIER, Y. & GROSVERNIER, P. 2018. *Mesures de restauration hydrologiques en faveur de la tourbière de la Grande Seigne, Cahier des plans et schémas des principes d'exécution*. SMMAHD. 33 p.

Contact

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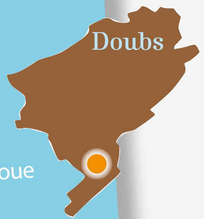
The Gouterot stream

Fact sheet



Natura 2000 site: Drugeon Basin

Ramsar site: Peatlands and Lakes of the Jura Mountains

Project owner: EPAGE Haut-Doubs Haute-Loue

Period of works: 2019-2020

Municipalities concerned: La Rivière-Drugeon and Bannans (Doubs)

Accessibility of the site: site subject to a prefectoral biotype protection order

Surface area of the peatland complex: approx. 200 ha

Altitude: 815 m

Usages:
- Hunting/fishing
- Potable water supply (syndicate of six municipalities, 47,300 m^3 a year)

Species of interest: Glossy sickle moss (*Hamatocaulis vernicosus*), great sundew (*Drosera longifolia*), Southern damselfly (*Coenagrion mercuriale*), Violet Copper (*Lycaena helle*), large heath (*Coenympha tullia*), marsh fritillary (*Euphydrias aurinia*), common snipe (*Gallinago gallinago*), Eurasian curlew (*Numenius arquata*), among others.

Southern damselfly
Coenagrion mercuriale

a *Aerial view of the Gouterot stream*

Background

Emerging at a locality named Vau les Aigues in the municipality of La Rivière-Drugeon, where the foot of the Laveron mountain meets the peatland area across which these waterways spread, the Gouterot (a) and its tributary, the Raie Saint-Nicolas, are limited to the south by the Laveron mountain and to the north by the Drugeon river into which they flow (b, next page).

Topographically, its watershed extends between 951 m and 812 m. Its source is at an altitude of about 815 m.

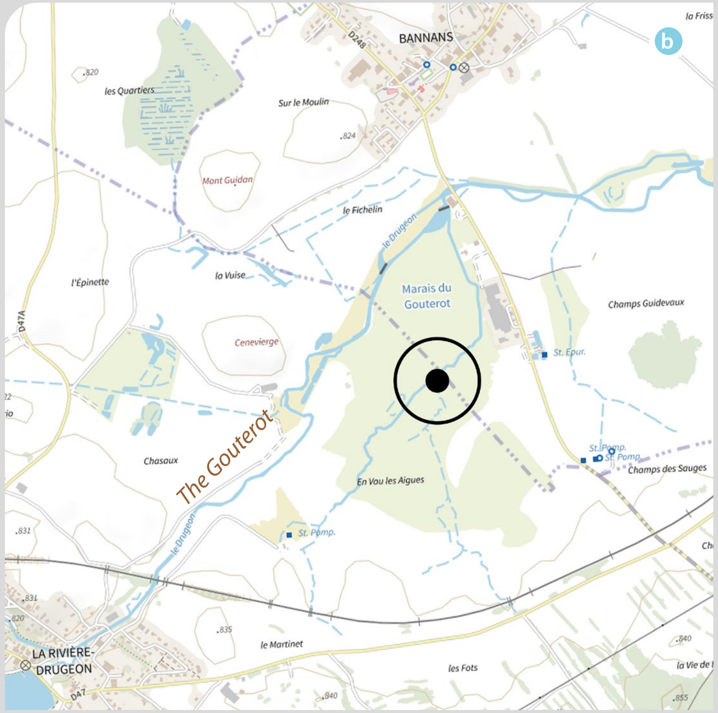
Geologically, it is made up of limestone, and the upstream part of the basin mainly consists of shallow, permeable soils, in which many infiltrations of water can be observed. The "apparent" hydrological watershed (subject to any resurgences that have not yet been observed) has therefore been estimated to cover 554 ha (*Téléos-suisse, 2014*).

Diagnosis

IDENTIFICATION OF THE PROBLEMS

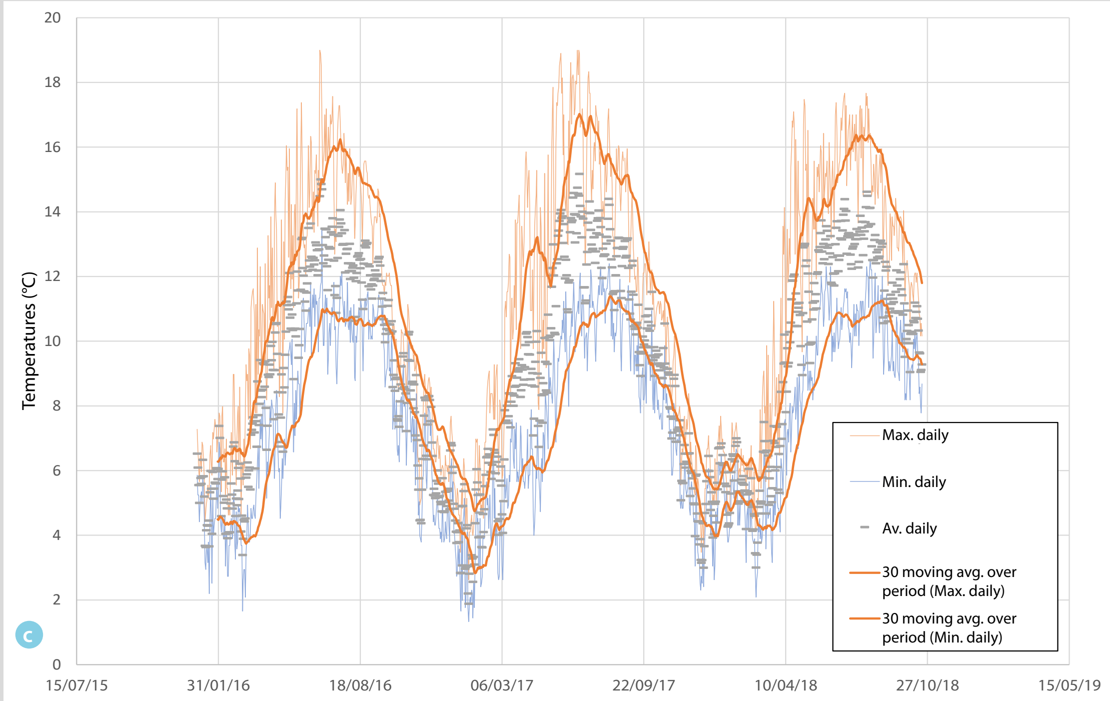
For some years now, the quality of the stream and its capacity to produce a balanced aquatic ecosystem seemed to be deteriorating, a phenomenon confirmed and specified by several diagnostic studies. While the Gouterot did not appear to be very disturbed from a morphological point of view, diachronic analyses revealed evidence of sediment removal and straightening, some of which dates from before 1950. It is highly likely this straightening began as long ago as the 18th century. Traces of work to remove sediment from the stream bed are visible on the aerial photos (*Téléos, 2014*), on both the Gouterot and the Raie Saint-Nicolas.

This damage was aggravated by the straightening of the Drugeon, which led to the lowering of the base level as well as the elevation of the associated water table.



Situation of the Gouterot

TNotable daily temperatures (min., max., mean) over three consecutive years before restoration c



The depletion of the groundwater and the spread of the runoff at low water have led to a reduction and the warming up of the summer flows (*Téléos, 2014*). This reduction in flows is accompanied by very substantial plant growth, silting up due to sedimentation, but also the progression of ligneous species into the peatland. It is these developments and the manifest erosion of the hydro-biological quality of the water course that led to the inclusion of the restoration of the Gouterot in the Jura Peatlands Life programme.

FUNCTIONAL ANALYSIS AND RESTORATION POTENTIAL

The diagnosis was mainly based on the analysis of the water course:

- analysis of the watershed;
- study of the macrobenthic communities (2001-2008):
  - analysis of the aquatic insects (Plecoptera, Ephemeroptera and Trichoptera orders),
  - biological indices (IBGN CB2);
- study of the fish population (1998-2008-2019);
- study of hydromorphological quality: Morphodynamic Attractiveness Index - IAM (2008);
- temperature monitoring (since 2001).

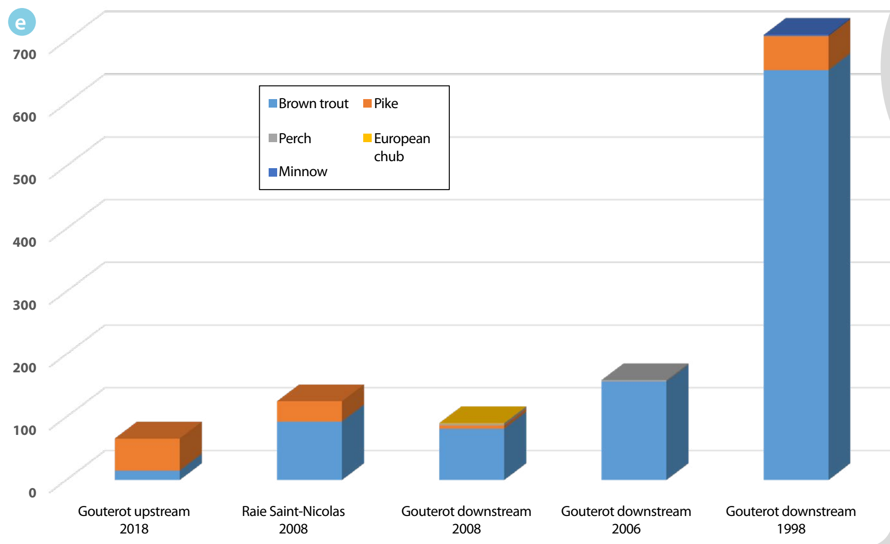
In addition, a series of piezometers was installed before starting the works to measure the impact in the short, medium and long term.

The hydrological functioning of the Gouterot peatland was heavily impacted by the straightening of the Drugeon in the 1960s. The groundwater level was lowered by an average of 1.15 m, which was only partly made up for by the restoration work done on the Drugeon in this sector in 1998 and 1999.

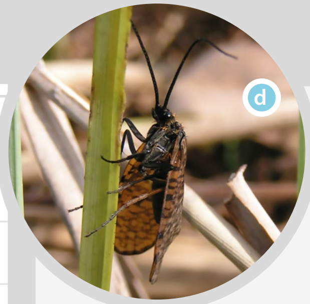
The hydromorphological quality of the water course and its capacity to sustain fish fauna only reaches 20 to 30% of the reference score for this type of water course, whereas its thermal regime remains cold c (maximum daily temperatures very rarely exceed 17°C), and the water quality remains fairly good.

It is, indeed, the poor quality of the habitat that explains the relatively low aquatic population:

- IBGN (standardised global biological index) between 11/20 and 13/20 (low taxonomic variety);



Comparison of the fish populations of the Gouterot and the Raie Saint-Nicolas from 1998 to 2008



Oligostomis reticulata

- fish biomass between 20 kg/ha and 60 kg/ha in 2019 for the Gouterot. The Raie Saint-Nicolas (a tributary of the Gouterot) manages to produce 101 kg/ha, which remains very modest (the values observed in 1998 do not necessarily reflect the real populations as the Gouterot was managed as a nursery stream, it was used for massive fry rearing of trout intended to be moved afterwards);

- although it has some heritage species (*Hagenella clathrata* and *Oligostomis reticulata* d, species typical of peaty environments), the sector's diversity of Ephemeroptera, Trichoptera and Plecoptera is diminished with only about twenty species recorded along the banks of the two water courses in 2008.

An examination of the evolution of the fish populations e also shows that there was a gradual deterioration between 2001 and 2008, which is thought to be related to:

- continued destructuring of habitats due to old sediment removal work in the streams;

- reduced flows (increased water withdrawals, introduction of conifers in the watershed, etc.) ;

- intense silting up with fine sediment of the stream course, which has a significantly and excessively high cross profile. This silting up seriously limits the sectors favourable to the reproduction of aquatic organisms (and fish in particular).

Although not perfect, the quality of the water in the Gouterot stream and Raie Saint-Nicolas remains relatively satisfactory. Temperatures never exceed those lethal to sensitive species such as the brown trout. The straightening of the main water course, the Drugeon, has had an intense impact on the associated groundwater and the wetland in the sector. This deterioration was partly reduced by the restoration work carried out on the Drugeon in the sector in 1999, although this was not optimal.

The hydro-ecological analyses carried out on the stream and its tributary showed that the deterioration continued. This deterioration can be linked to a reduction in hydromorphological quality caused by old straightening works and regular sediment removal. However, it was also linked to a drop in the low water flows, which could be due to several factors: increase in water withdrawals, introduction of conifers on the watershed (the area covered by mature spruce increased from 231.9 ha to 336.5 ha between 1951 and 2012 and could explain a reduction in low water flows of 10 to 20 l/s due to increased evapotranspiration and the interception of the summer rains – *Téléos 2014*), and reduction of exchanges with the associated groundwater, among other things.

CHALLENGES OF THE SITE

▶ **Biodiversity:** the Gouterot stream and its tributary, the Raie Saint-Nicolas, constitute an aquatic environment of the utmost importance close to the Drugeon. The temperatures of these water courses, which remain low, make them a true refuge for cold-water stenothermal species, in a context where the main water course does present fairly high temperatures.

▶ Although severely disrupted by consecutive sediment removal works, the Gouterot still has a high rate of flow, representing more than 50% of the low water flow of the straightened Drugeon. It is, therefore, essential to the entire sector that this water course supports the low water flows.

▶ **Potable water supply:** the site has been subjected to water withdrawals for the production of potable water. The preservation of the resource and a supply balanced with the groundwater play a crucial role for society.

Works

The aim of the restoration programme was:

- to eliminate the draining effect of the deepened straight courses and reinforce the connectivity between the low-flow channel and the high-flow channel by raising the bottom line;

- to diversify the aquatic habitats by returning the river to its old course to allow the restoration of a quality aquatic population (restoring the Gouterot and the Raie Saint-Nicolas, for example, would allow them to become environments favourable to the reproduction of these species once again).

REGULATORY FACTORS

- Authorisation under the Water Act.
- Natura 2000 impact notice.

The work in figures

Periods: from July 2019 to July 2020

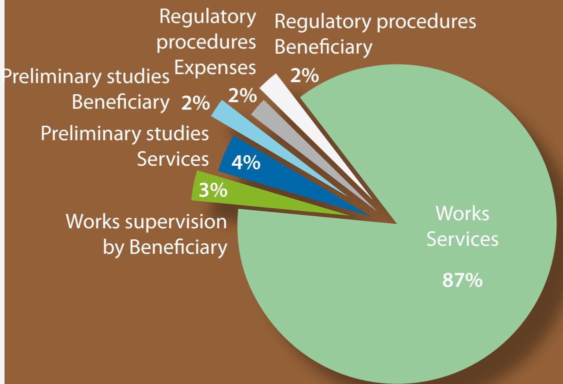
Length and surface area:

- Remeandering: 1,492 m
- Closing off the straight course and the peripheral ditches: 1,478 m
- Length replenished with material: 1,023 m
- 2,760 m^3 of material used for infilling and 600 m^3 for replenishment

Contractors: Téléos-Suisse for the preliminary study (non-LIFE) and Jura Natura Services for the work on site

Total cost of the Life actions: €251,374 incl. VAT *

- Works (green): €226,986
- Preliminary actions (blue + grey): €24,388

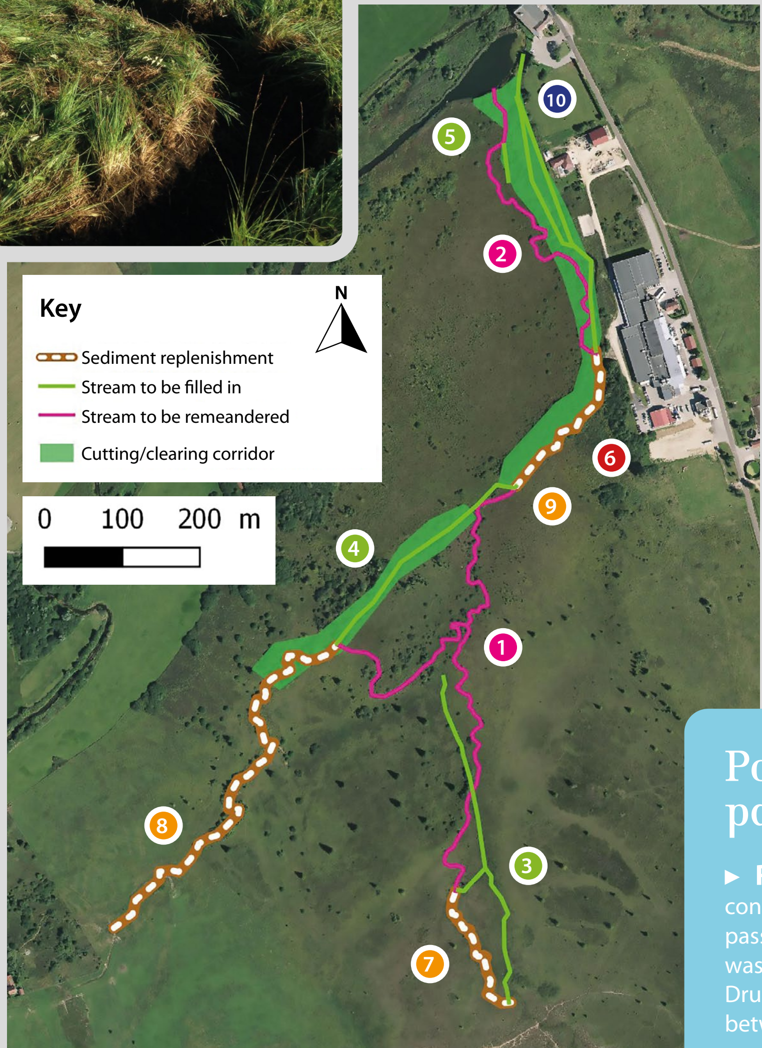


** the costs of actions carried out previously on the site (outside the Life scope) are not included*

New course of the Raie Saint-Nicolas before the water was restored

1 and 2 part of the works consisted **restoring the water to old meanders**.

3 to 5: the **straight course was completely filled in** , as were a whole series of old ditches that participated in draining the zone.



Map showing of the works carried out

The works also included the**alteration of an existing fish pass** on the Drugeon 6, near the Gouterot confluence.

7 to 9: on long stretches where the old meanders could not be identified or where the topography had been altered by the drainage so that it was impossible to remeander the water course, its **cross profile was modified by substantial replenishment with appropriate mineral material** (in particular the grain size was adapted to the spawning needs of the species present).

The **removal of a village fountain water supply connection** 10 and the creation of a closed circuit instead also allowed withdrawals of water from the wetland area to be reduced (the water used by these fountains was equivalent to the daily consumption of the town of Bannans).

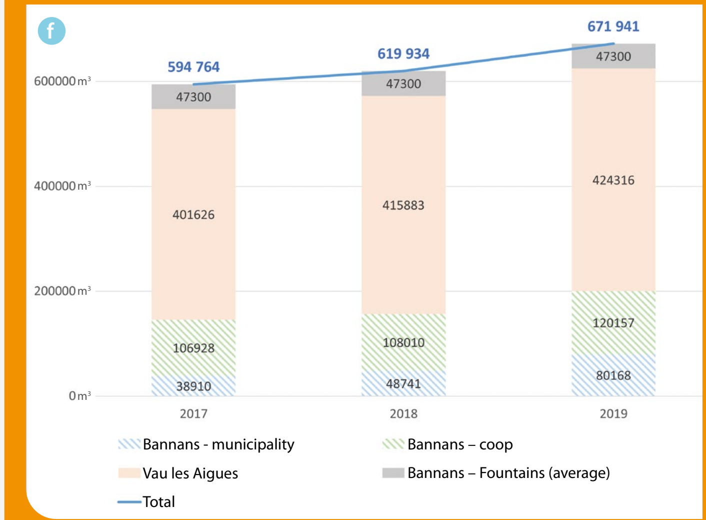
Points requiring particular attention

- **Restoration of a fish pass:** near the Gouterot confluence, an old mill weir had been equipped with a fish pass as part of the Drugeon restoration works in 1999. It was intended to facilitate the movement of trout from the Drugeon to the Gouterot. However, substantial differences between the design and what was actually constructed meant that it was not very effective. It was reconfigured as part of the Life programme.

The Gouterot peatland and potable water

Water is withdrawn at three main points in the immediate vicinity of the Gouterot peatland:

- the withdrawal for Bannans, which supplies the town, a neighbouring village and a food factory (not situated on the Gouterot watershed);
- the Vau les Aigues withdrawal station, situated at the source of the Gouterot, which supplies six municipalities;
- the withdrawal for the Bannans water fountains , which takes surface water directly from the stream.



Water withdrawals close to the works

The supply to the Bannans fountains is an ingenious system. It takes water from the stream by gravity to a distribution system situated in the centre of the village more than 570 m away, passing underneath the Drugeon river. It supplies five fountains in the village.

The total flow rates of the five fountains represent about 1.5 l/s. It is likely that the flow rate taken from stream is higher due to leaks in the pipes carrying the water to the village. This amounts to an annual consumption of about 47,300 m³, in other words, the same quantity as the village's annual consumption. This water joins a losing stream without going back through the surface environment.

The remeandering of the Gouterot stream carried out under the Life programme has rendered the fountain withdrawal system obsolete. To save water resources, the municipality has decided to create a closed circuit for the fountains.

Before - After

Restoration of the Raie Saint-Nicolas

Before: September 2012

After: November 2020

Results

The works are too recent to evaluate their impact. Nevertheless, it is interesting to note a very significant colonisation of the site by birds during the nesting period and in particular the northern lapwing, with 12 individuals fiercely defending the territory until the end of July 2020. Eurasian curlew and common snipe nests were also observed in 2020.

MONITORING SET UP

▶ Biological monitoring planned: macroinvertebrates and fish fauna with intervals of three years after the works and six years after the works. An inventory of the evolution in the species present will also need to be carried out to compare it to the data available in 2008.

▶ Monitoring of the groundwater

Useful documents

- NALDEO. 2017. *Conception d'un ouvrage de franchissement piscicole sur le Drugeon à Bannans*. SMMAHD. 35 p.
- DREAL FRANCHE-COMTÉ. 2013. *430002290, Zones humides de Vau Les Aigues à la Loitiere*. INPN SPN - MNHN Paris. 26p.
- BRICOTTE, V. & GOULMY, F. 2001. *Potentiel biocénotique de trois affluents du Drugeon, Gouterot, Bief Voulain & Bief Rouget*. Memoire DESS qualité des eaux et bassins versants, Université de Franche-Comté. 46p. + annexes.
- PIERRE, B. 2008. *Caractérisation écologique d'un petit cours d'eau de marais : le Gouterot*. Memoire M2 qtebv, Université de Franche-Comté. 52 p. + annexes.
- TELEOS-SUISSE. 2014. *Restauration du Gouterot, volume 1. Du diagnostic physique a la restauration*. SMMAHD. 11 p.
- TELEOS-SUISSE. 2014. *Restauration du Gouterot, volume 2. Expertise hydraulique*. SMMAHD. 75p.

Contact

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The Levresses peat bog

Fact sheet

Natura 2000 site: Drugeon Basin

Ramsar site: Peatlands and Lakes of the Jura Mountains

Regional nature reserve: the Frasne-Bouverans peatlands

Project owner: EPAGE Haut-Doubs Haute-Loue

Year of works: 2011 (excl. Life)

Municipalities concerned: Frasne (Doubs)

Accessibility of the site: site subject to an order classifying it as a regional nature reserve (access limited to the public paths) and a Prefectoral biotype protection order.

Area of the peatland complex: approx. 15 ha

Altitude: 835 m

Usages :
- Old, intense peat extraction (from 19th to 20th century)
- Grazing on the edges of the peatland
- Hunting

Species of interest: Hudson Bay sedge (*Carex heleonastes*), fen orchid (*Liparis loeselii*), great sundew (*Drosera longifolia*), large heath (*Coenonympha tullia*), Northern lapwing (*Vanellus vanellus*), among others

a

Aerial view of the Levresses peatland

Hudson Bay sedge
Carex heleonastes

Background

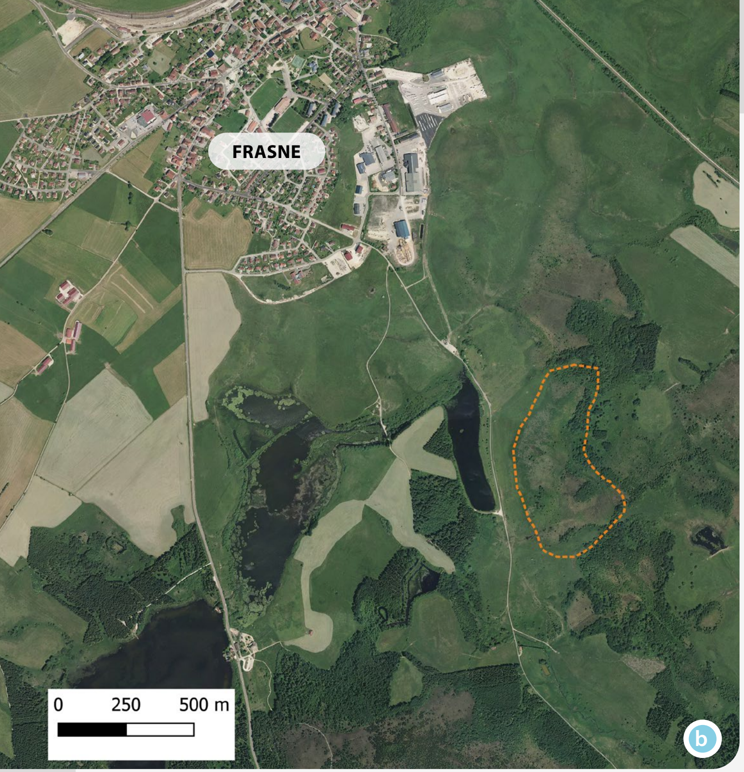
The Levresses peat bog (a), in the municipality of Frasne ((b), next page), is situated in a particular geomorphological context: the western ice margin of the Würm glaciation.

The area is therefore characterised by a somewhat chaotic relief consisting of morainal hummocks, which have formed basins and dams, all of which constitute obstacles to the flow of water. Furthermore, these moraines consist of a mixture of clays and more or less coarse gravel, relatively watertight, but not enough not to be penetrated by percolation waters. The Levresses bog has therefore formed in one of these depressions, partially closed in by a morainal sill to the south, the peat bog's natural outlet in periods of excess water.

Frasne's rich history of peat extraction shows that this site was the subject of intense exploitation, at least from the second half of the 17th century onwards.

Minutes of meetings of the Frasne town council mention figures of the order of 3,500 m³ of peat extracted in one year, 1894 (*Bôle L., 2009*), for a population of only about a thousand inhabitants.

The Levresses peat bog was undoubtedly exploited for about a hundred years according to the town council records, which suggests that the bog must have been completely transformed, since it must be missing something of the order of 300,000 m³ of peat. Peat extraction ended in 1903 when the deposit was exhausted, and moved instead to the Le Forbonnet peatland complex (*J. Guyonneau, 2004*).



Situation of the Levresses peat bog (Frasne, Doubs)

Diagnosis

IDENTIFICATION OF THE PROBLEMS

The study of the bog, initiated by a precise phytosociological diagnosis (*J. Guyonneau, 2004*) counted 305 species of plants, all of them products of neutral-alkaline secondary successions, following the extraction of the peat.

The phytoscociological analysis, completed by a comparative approach to Guinochet's phytosociological map (1955) shows on the Levresses peat bog:

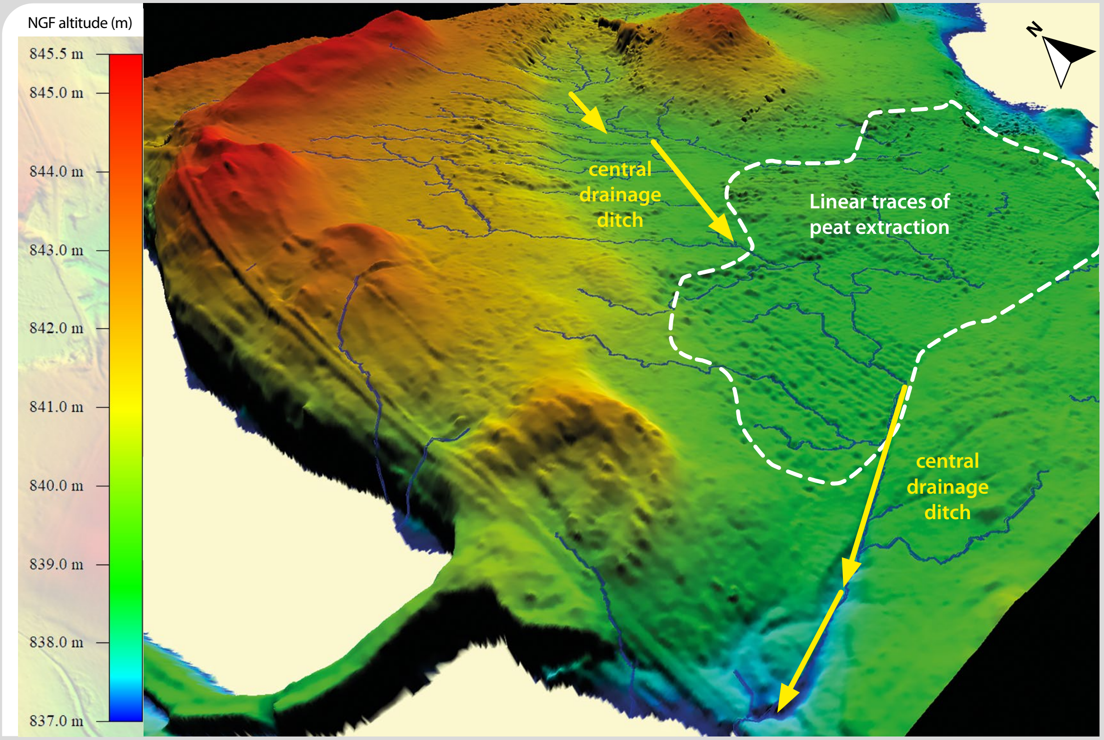
- a substantial invasion of ligneous species, in particular in the old peat extraction pits (downy birch, willow, alder buckthorn), a sign of hydrological disturbance;
- hypertrophy that can be linked to the mineralisation of the peat, whose water table elevation is too unstable for it to be maintained (development in particular of communities of *Molinia caerulea* and megaphorbs).

This high-heritage value range of plants, even though it corresponds to regeneration secondary successions, is deteriorating very fast.

FUNCTIONAL ANALYSIS AND RESTORATION POTENTIAL

At the beginning of the 2000s, our functional analyses were not very thorough as we did not yet have the DTM. However, they did include, as well as a detailed phytosociological analysis, a topographical, hydrological and piezometric diagnosis that was as precise as possible, and pedological surveys.

The Levresses peat bog is in a depression drained by a central ditch c. The peat that subsists is no more than 1.5 metres thick. The piezometric variations in 2004 could be as much as 75 cm in the most severely drained areas. The water in the peat is neutral to alkaline. The bog is in the bottom of a depression supplied by water from the watershed and, more hypothetically, from the groundwater in the morainal aquifers. The presence of a central ditch resulting from the past exploitation of the peatland drains the water off the bog. Only the flat areas away from the drainage ditch enjoy wetter conditions (transition mires).



c

3D view of the theoretical flows on the surface of the peatland, taken from the DTM (vertical exaggeration)

CHALLENGES OF THE SITE

▶ **Biodiversity:** the peatland, although hydrologically disturbed and increasingly closed off as a result of colonisation by ligneous species, remains a biological reservoir for all the fenland and transition mire plant species, but also a good number of species of Rhopalocera, Odonata and hoverflies.

▶ **Water supply:** as the topography has been totally modified, it is necessary to attempt to slow the flows of available water to limit the influence of the drainage, otherwise the mineralisation effect, which is also having the effect of lowering the level of the land, will continue.

CONSEQUENCES

The result is a marshy, peaty complex dried out by the drainage, modified topographically by the extraction of the peat, and now in a phase of scrub encroachment and mineralisation.

The situation is evolving rapidly towards afforestation with willow/birch/alder buckthorn and a collapse of the dried-out peat surface, which then further accelerates the evacuation of the water into the central channel d.

Enfrichement du site

On this site, there is strong potential for restoration due to the quality of the peat, an uncaptured water supply, and active morainal aquifers. The hydrological dysfunction is virtually exclusively due to the presence of the central drainage ditch (without taking into account the effects of climate change).

Works

The project therefore consisted of neutralising the central channel to spread the runoff waters over the largest possible area of the peatland (*Lin'eco, 2010*). Implemented in 2011, the actions taken were innovative for this type of work.

REGULATORY FACTORS

▶ Procedure under the Law on Water and Aquatic Environments:
No procedure required following the DIT (threshold not reached).

▶ Natura 2000 impact notice:
Since the areas impacted lead to an improvement in the conditions for maintaining species and habitats of Community interest in the medium term, although there was a short-term impact (worksite), no significant impact threshold was met.

▶ Protected species:
No protected species were directly impacted by the works themselves. However, the medium-term impact of the works was deemed positive for the protected species.

▶ Authorisation of the Nature Reserve:
The opinion of the CSRPN (regional natural heritage scientific committee) was required by the nature reserve's managing authority, the Regional authority, given that this worksite was not mentioned in the reserve management plan, which had lapsed.

The work in figures

Period: Two weeks, from 16 to 29 May 2011 due to an exceptionally dry start to the spring (otherwise this season is not recommended). This early intervention had the advantage of starting plant growth immediately and developing coverage of the structures by vegetation to protect against drying out.

Length and surface area:

- Neutralisation of 745 m of drainage ditches
- Impact expected: 1.5 ha of rewetted ground in the medium and long term

Equipment used:

- Technical equipment: One 8T excavator on a platform (80 g/cm^2), one small Kubota crawler dumper (80 g/cm^2), one Eurotrack reversible wheelbarrow (150 g/cm^2)
- Materials: 66 m^3 sawdust, 19 wooden panels (3-ply) and 13 m^3 timber (planks)

Contractors: LIN'eco for the technical support and Jura Natura Services for the hydrological work

Cost of the first experimental works before the Life programme (2011): €31,664 incl. VAT*
This cost corresponds to all the works and the technical assistance funded as part of a Natura 2000 contract.

To neutralise the ditch completely, **plugs consisting of wooden panels** were installed, then the steepest parts of the ditch were filled in with sawdust: 3 and 4.

Given the not very thick peat deposit and the high concentration of protected species, it was not possible to neutralise the ditch with peat cut on the site itself, hence the use of sawdust.

Four timber plank fences were built in the areas where the spreading of the water was to be optimised, in order to raise the water level: 1 and 2.

Plan of the work in the Levresses peat bog (2011)

Installation of timber fences

Upstream fence, covered with peat and straw

Step 1 in the ditch neutralisation: placing the wooden panels

Step 2 in the ditch neutralisation: filling the channel with sawdust

Step 3 in the ditch neutralisation: covering the sawdust with peat from the clearance of mineralised peat

Points requiring particular attention

▶ **Fencing:** The last fence downstream was trampled by cattle, and the ridge of peat had to be redone. Since then, it has collapsed again, probably because the area where it was repaired was not sufficiently stabilised (two different qualities of peat). The structure has an overspill feature that reduces the retention of water upstream. All our fences are now enclosed by wire fencing and wooden posts, to keep animals away, which is all the more necessary as the dry years have led them to venture into the bog in search of water.

Results

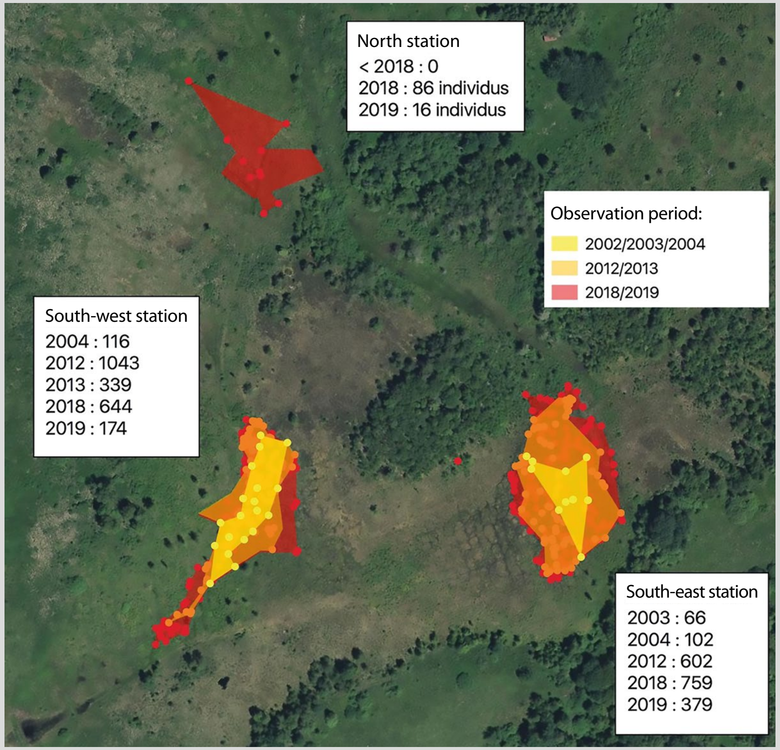
This peat bog benefits from ten years' monitoring after the works and has enriched our knowledge of the functioning of the post-works hydrological system.

MONITORING SET UP

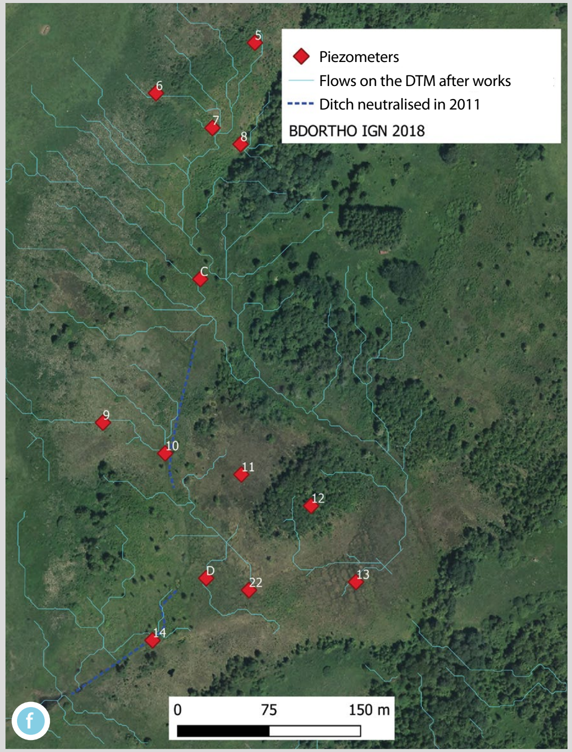
▶ **Monitoring of the flora:** 32 vegetation monitoring plots (pre/post-works) were set up to monitor any impact of the works. The surveys date from 2004 (pre-works), 2012 (one year after the works) and finally 2017 (six years after the works).

The Botanical Conservatory has concluded that there was a positive effect on vegetation in 2012. On the other hand, the effect had worn off by 2017, probably due to the recurrence of hot, dry episodes (2015 and 2017), which unfortunately continued in 2018, 2019 and 2020. The development of ligneous species has not stopped (birch, alder buckthorn, willow). However, the older birches, which had never been cut, are tending to die off.

Several hypotheses will need to verified in the future: the Levresses peat bog has relatively little residual peat and constitutes a small watershed with a small water reserve. The hot, dry episodes of the last few years do not allow stable, high water tables to be maintained. The ligneous species benefit from a minerotrophic water supply favourable to them with, in addition, water table fluctuations that are still pronounced on the edges of the peatland, which allows them to develop quickly. The wettest zones, the central transition mire zone where the water table is more stable, show much less scrub encroachment. Ageing of the trees is perhaps an option, since they also produce shade for the periods of intense evaporation that we have seen in the last few years. Cutting back these trees would only have the effect of revitalising their growth.



(e) *Monitoring the fen orchid on the Levresses bog*



Map showing the piezometer monitoring of the Levresses peat bog (and theoretical flows generated by the DTM after the works)

▶ **Monitoring of the Fen orchid:** this species present at the Levresses has seen its population truly "explode" (multiplied by 10) following the works (e). Even if the population barely changed in 2019 in quantitative terms (no doubt the result of the exceptional drought of 2018), the spread remained the same. A new area was even found in a new water flow generated by work upstream.

▶ **"Syrph the net" monitoring:** an inventory was done in 2018 (seven years after the works). This monitoring therefore needs to continue after the Life programme to make sure conclusive evidence is provided, via other public policies.

▶ **Piezometric monitoring:** Seven piezometers were installed in 2004, as part of J. Guyonneau's study in the zone concerned by the works (f).

The Levresses peat bog has never been equipped with recording piezometric sensors, so the monitoring is only done via manual measurements, which, due to a lack of human resources, have only been performed sporadically.

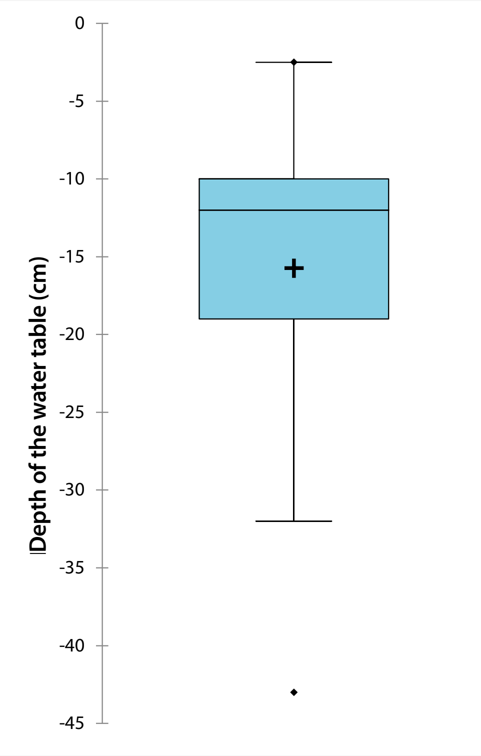
The measurements take account of the height of the water in the piezometer tube and the height of the tube in relation to the ground, given that the tube is not anchored in the subsoil and fluctuates with the variation in water pressure.

Before - After

Measurements have only been taken regularly enough to carry out statistical processing since 2016 (one reading every fortnight from 15/04 to 15/11). Piezometer 22 is situated in a transition mire which was blocked by dams at the south and west outlets in 2011 and 2013. The boxplot for the period 2016-2020 g, post-works, shows a bog with a reduced water table fluctuation (between -10 cm and -20 cm in the soil), and a median close to -10 cm in the soil, so quite close to the surface, which is compatible with a transition mire.

However, the extreme drought values can approach -30 to -40 cm: these were all measured during the 2018, 2019 and 2020 droughts, with a worrying recurrence. The periods of the peat bog's groundwater recharge no longer seem to be sufficient to make up for the periods of severe drought with high evapotranspiration due to very high temperatures (regularly >30°C since 2018).

It seems important to continue the efforts to monitor this peat bog - both piezometric monitoring and monitoring of the vegetation - to identify whether the effects of the cumulated droughts and heatwaves will have a modifying effect on the flora in the medium to long term. Vole tunnels are beginning to appear in certain bogs which are considered to be in good condition in successive episodes of extreme drought, with impacts on the vegetation.



g *Boxplot of the water table elevation at station 22 on the Levresses bog after the works*

The central ditch before the works - 2004

The bog under water after the works - February 2021

Useful documents

MAGNON, G. 2011. *Compte-rendu de travaux – fermeture des fossés de la tourbière des Levresses Contrat natura 2000*. Communauté de communes Frasne-Drugeon. 16 p.

GUYONNEAU, J. 2004. *Le marais des Levresses, Réserve naturelle régionale des tourbières de Frasne - 25 : Etude de la végétation et renaturation hydrologique*. Mémoire de stage, Université de Nancy I, Institut national polytechnique de Lorraine, Université de Metz. 38 p. : Bibliogr. p. 40-43 + annexes.

Contact

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The Forbonnet peatland

Aerial view of the Forbonnet peatland

Fact sheet

Natura 2000 site: Drugeon Basin

Ramsar site: Peatlands and lakes of the Jura mountains

Regional nature reserve: the Frasne-Bouverans peatlands

Project owner: EPAGE Haut-Doubs Haute-Loue

Research station: site equipped since 2008 as part of the National Observation System (SNO)

Period of works: 2015-2016

Municipality concerned: Frasne (Doubs)

Accessibility of the site: site subject to an order classifying it as a regional nature reserve (access limited to the public paths) and a Prefectoral biotype protection order.

Area of the peatland complex: approx. 270 ha

Altitude: 820-840 m

Usages :
- Old intense peat extraction (from 19th to 20th century)
- Forestry operations

Species of interest: String sedge (*Carex chordorrhiza*), bog-sedge (*Carex limosa*), bog rosemary (*Andromea polifolia*), Rannoch-rush (*Scheuchzeria palustris*), subarctic darner (*Aeschna subarctica*), moorland clouded yellow (*Colias palaeno*), among others.


Moorland clouded yellow
Colias palaneo

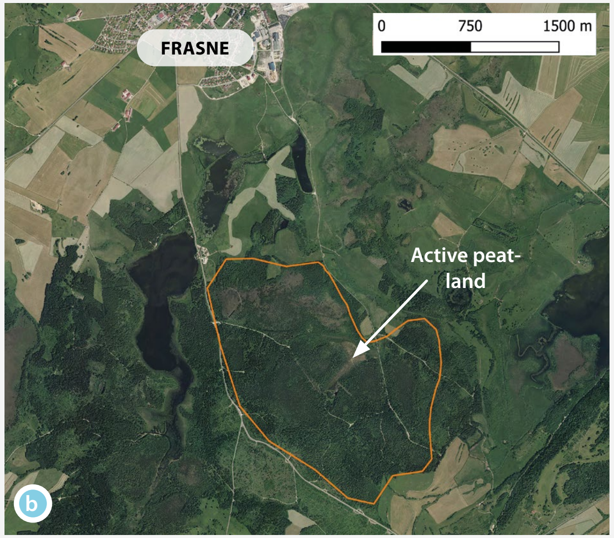
Background

The Forbonnet site (a) is a vast marshy geomorphological entity (270 ha), consisting of phytosociologically different peats, which are coalescent, but were previously undoubtedly independent and disjointed. The overall formation of this peatland complex is closely linked to the geomorphology of glacial origin, characterised by thick morainal deposits that generated multiple barrages or obstacles slowing the water flows. These rest on a fractured limestone massif characterised by losing streams or rising springs typical of the Jura mountains and sometimes in direct contact with the peat. The peatland complex, with peat thicknesses varying from 1 to 7 metres, is extremely large and consists of 16 hydrological sub-watersheds.

Due to the size of the site, preliminary work was carried out on the scale of the entire peatland complex to define the conservation issues and restoration potential (*Grosvernier P., 2011*). This study was designed based on:

- identification of the conservation values involved (species, habitats, water, carbon) by means of precise diagnostic studies;
- definition of the problems and identification of the causes of the dysfunction;
- the need for intervention qualified by: the need to intervene, the urgency of an intervention, the importance of the values to be conserved, the restoration potential or scientific and technical feasibility of an intervention, the political and economic feasibility of an intervention.

In the north-east of this vast peatland complex, the sector known as the Frasne active peatland (b, next page), covers approximately 6 hectares and includes a peat bog and fen vegetation facies in a mosaic pattern. It was defined as the zone in which the conservation issues were a priority, from the point of view of the flora and the remaining peatland habitats. However, the functioning of the active peatland is disturbed, and the centre of the peatland has been rapidly invaded by mountain pines and spruce.



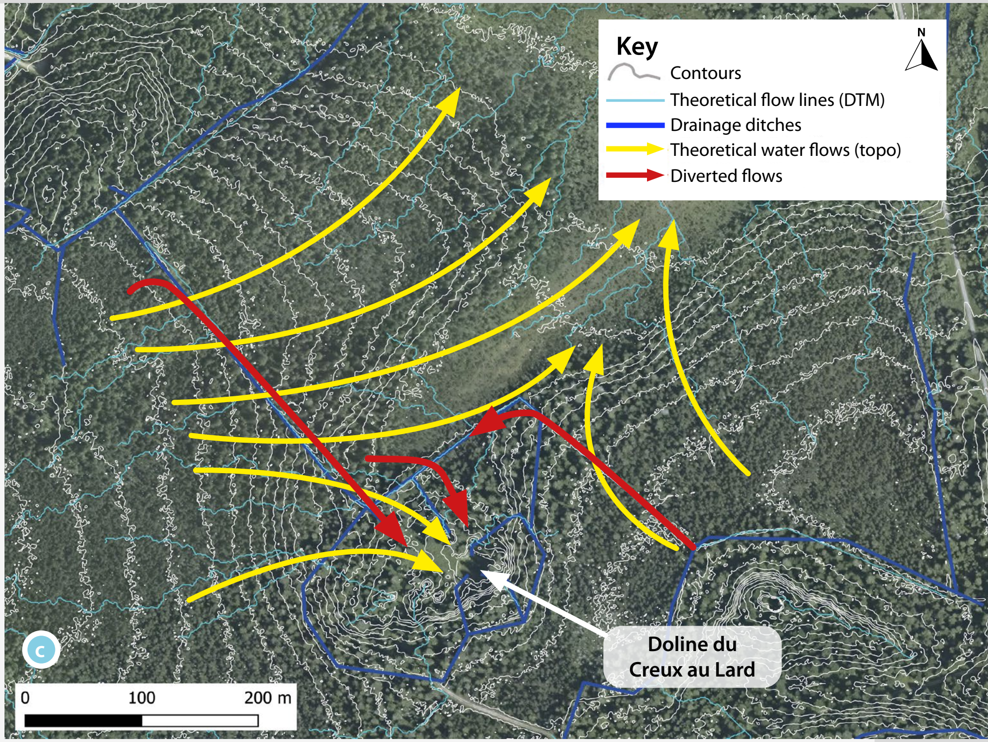
Situation of the Forbonnet peatland complex (Frasne, Doubs)

Diagnosis

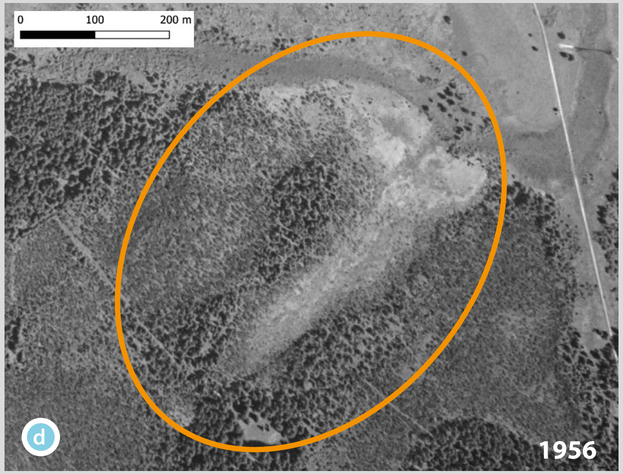
IDENTIFICATION OF THE PROBLEMS

► A substantial drainage network: earlier analyses, confirmed by the analysis of the digital terrain model c, produced by LiDAR scanning, prove that there is a sizeable drainage network which is contributing to drying out the peatland and which may have facilitated the colonisation by spruce.

► Rapid spruce colonisation: the historical analysis (old forest management work conducted by the national forestry commission (ONF), 1797-1951), coupled with a diachronic analysis of the aerial photos available (1956 d - 2016 e) show an invasion of the open spaces in the peatland by pine and then spruce.



Hydrological flows on the active peatland diverted by the drainage network (LIN'eco, 2014)



Aerial views of the Forbonnet active peatland in 1956 and in 2016

FUNCTIONAL ANALYSIS AND RESTORATION POTENTIAL

The drainage network which was established for silvicultural reasons has altered the lines of flow, intercepting some of the surface waters from the active peatland's watershed to divert them towards a network of dolines, including the main one, the Creux au Lard. In addition to the drainage channels themselves, the subsidence of the terrain due to the drying out caused by the drainage has probably modified the topography immediately surrounding the Creux au Lard.

Beyond the issues relating to surface flows, the challenging question that had to be explored was: where is the natural limit of the original watershed of the so-called "live" peatland?

A series of pedological surveys performed in conjunction with topographical profiles (*Grosvernier P., 2015 and Collin L., 2016*) allowed the contours of the gradual emergence of the depression to be outlined f (contours descending towards the so-called "live" peatland) This exploration allowed the natural watershed of the active peatland to be defined, along with its geomorphology, thereby providing solid bases for the construction of the restoration project.

The hydrological type of the active peatland is similar to a sloping (soligenous) and percolation peatland, supplying a peatland in a hollow g (limnogenous) (*Grosvernier P., 2011*).

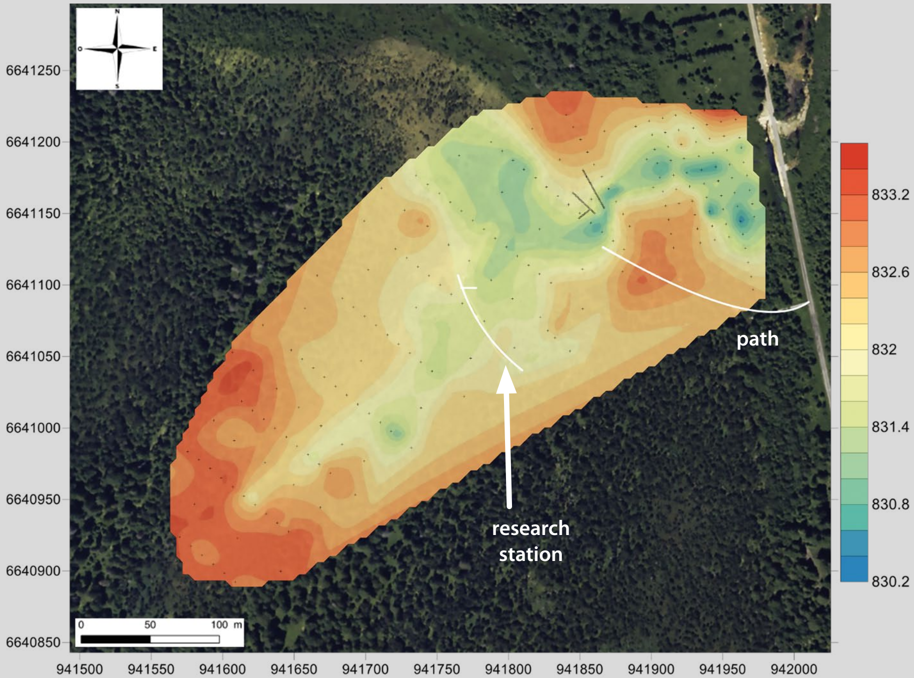
CHALLENGES OF THE SITE

▶ **Biodiversity:** the peatland, although hydrologically disturbed and increasingly closed off by conifer colonisation, remains a major biological reservoir: the cranberry fritillary (*Boloria aquilonaris*) has already disappeared from it, while the water violet (*Hottonia palustris*) and Rannoch-rush (*Scheuchzeria palustris*) are threatened. The purple pitcher plant (*Sarracenia purpurea*) planted in the 1960s is also threatening local species due to excessive colonisation. Furthermore, in the wooded peatland, account must also be taken of the hazel grouse (*Bonasa bonasia*), since the development of spruce is prejudicial to it.

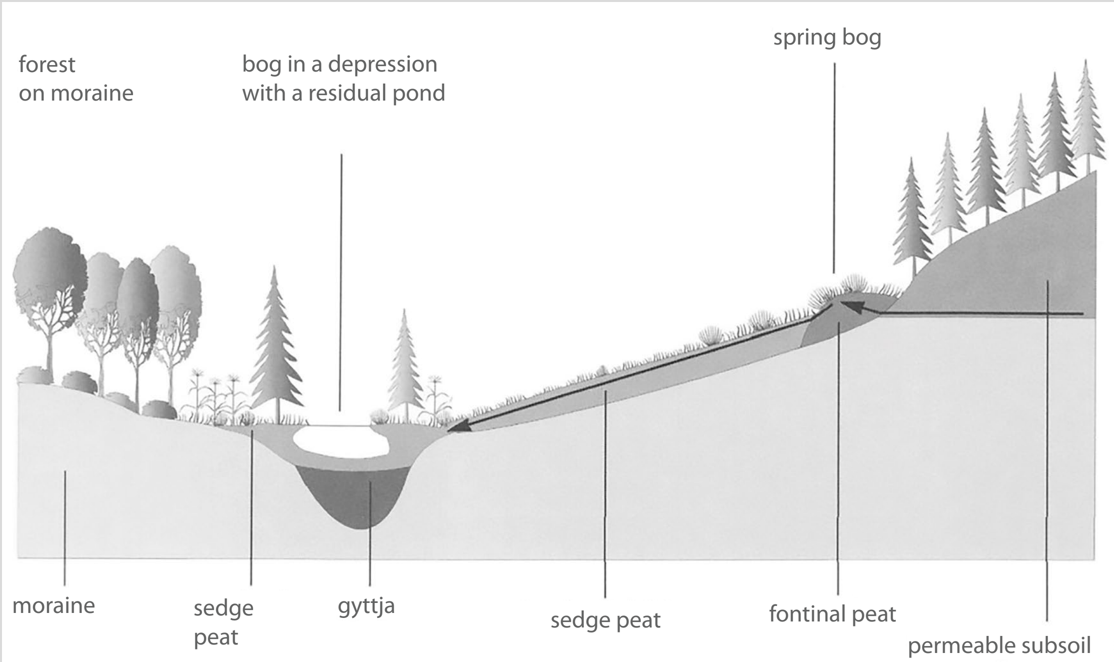
▶ **Water supply:** the flows that formed the peatland can be mobilised once again to re-supply the active peatland in a diffuse way, which will mean taking account of the large-scale watersheds. There is therefore real potential for rewetting.

CONSEQUENCES

The result is an extensive marshy, peaty complex, dried out by the deviation of the water flows created to improve the silvicultural system. The situation is evolving rapidly towards afforestation with conifers and subsidence of the peaty surface dried out by the drainage around the Creux au Lard, which is accelerating the evacuation of the water flows.



f *Map of the mineral relief underneath the layer of peat (Collin L., 2016)*



g *Hydrological type of the active peatland (Steiner G-M., 2005 ; Grosvernier P., 2011)*

Rannoch-rush
Scheuchzeria palustris

Works

The restoration potential was high given the large volumes of peat still present on the site. The project therefore consisted of:

- eliminating the drainage effects to slow the water flows;
- restoring the original watershed by artificially reconstituting the water level in the subsided area peat (close to the Creux au Lard). If this did not take place, neutralising the ditches would not change the direction of the flows towards the doline;
- redirecting all the water flows deliberately diverted towards the Creux au Lard by human intervention back towards the active peatland.

Installation of the worksite: the works, which were to be very extensive and take place over a period of two years, started with the clearing of the trees from all the access points, work zones and rewetting zones on the edge of the structures, with the elimination of all the ligneous species (h) (spruce, mountain pine, birch).

REGULATORY FACTORS

▶ Procedure under the Law on Water and Aquatic Environments:
Since the area concerned by the works was between 0.1 and 1 ha, the reporting procedure under sections 3.2.3.0 (creation of water bodies) and 3.3.1.0 (backfilling) was applicable. The restoration compensation measure concerning 8,300 m^2 of wetlands imposed by the authorities in fact corresponded to the works themselves, which were rewetting the wetland area.

▶ Natura 2000 impact notice:
Concerning the areas impacted in the short term by the worksite leading to an improvement in the conditions for maintaining species and habitats of community interest in the medium term, no significant impact threshold was identified.

▶ Protected species:
No protected species were directly impacted by the works themselves. However, the medium-term impact of the works was deemed positive for the protected species.

Removal of timber using an appropriate skidder

The work in figures

Periods:

- Tree cutting: July 2015
- East ditch and dyke: from September to November 2015
- South-west ditch: from May to July 2016

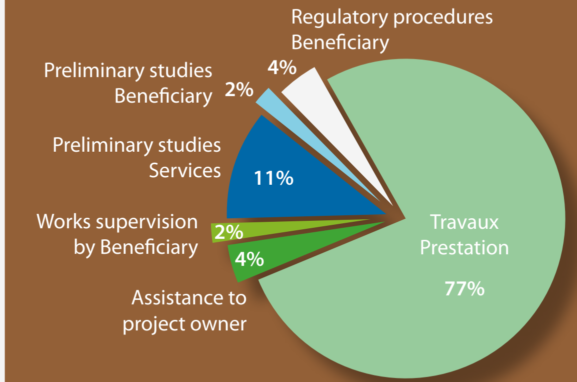
Length and surface area:

- Tree clearance 3.4 ha
- Neutralisation of 745 m of drainage ditches
- Impact expected: 10 to 15 ha of rewetted ground in the medium and long term

Contractors: Lin'Eco and SCOP Sagnes for the study and technical support, Jura Natura Services for the hydrological works, L. Mathieu/ETF Rinaldi/Nature Bois Energie/ONF for the tree cutting

Total cost of the Life actions: €338,188 incl. VAT *

- Works (green): €279,365
- Preliminary actions (blue + grey): €58,823



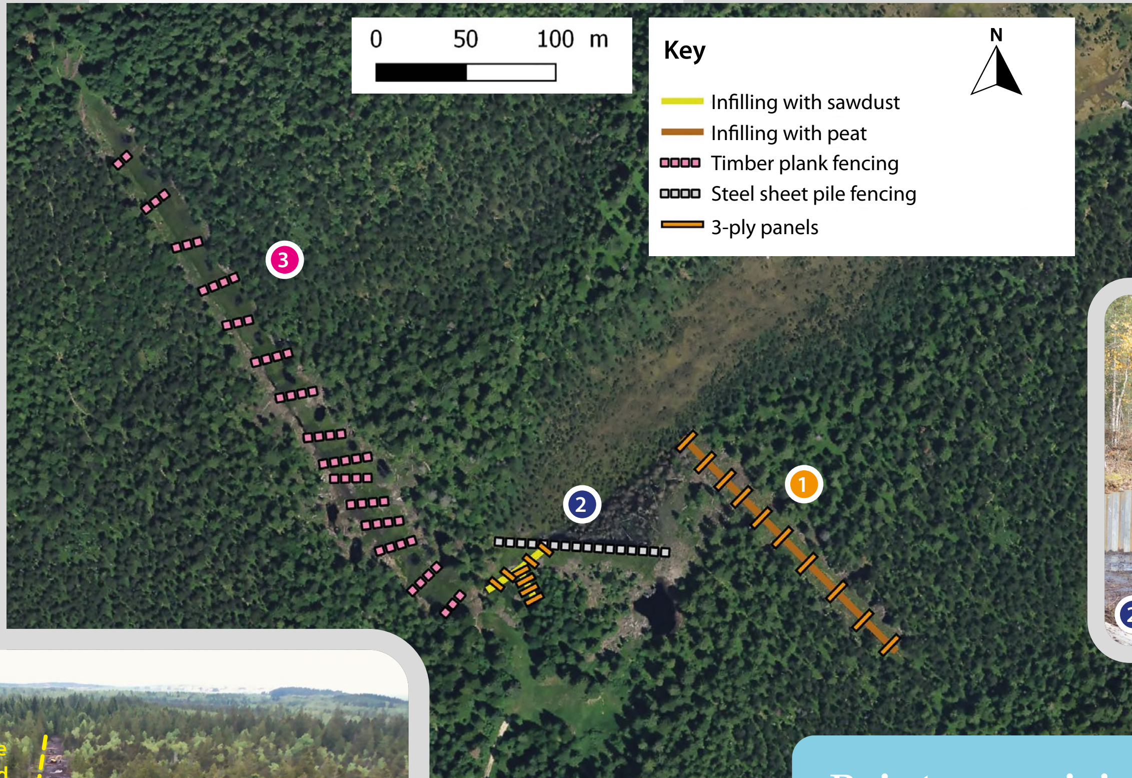
** The preliminary studies were carried out outside of the LIFE programme before 2014, as part of the funding of the nature reserve*

1 The ditches with the steepest slopes were neutralised by **blocking with wooden panels/fences and completely filling in with peat** (given that the resource was available on site)

Online

The hydrological restoration works

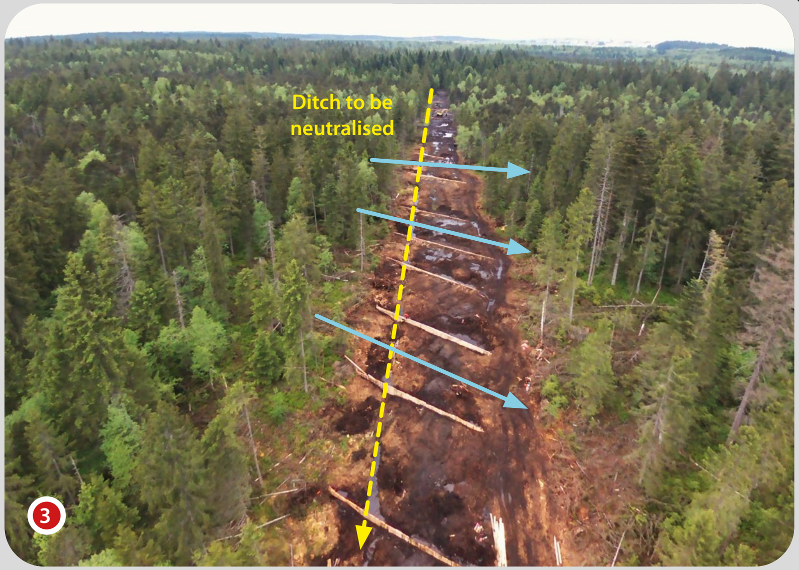
Plans for the works to rewet the Forbonnet active peatland



2 To compensate for the subsidence of land surface due to drying out, a dyke was built in the area of where the watershed in the active peatland naturally emerged.

Given the presence of a thick layer of wood at the base of the peat, a **dyke made of steel sheet piles**, which are sharp-edged, was chosen so as not to push this wood into the substrate and risk impacting the watertightness of the substrate (making it porous).

Metal topographical compensation dyke, covered with peat



3 **Long timber plank fences** were created to neutralise the drainage ditch and redirect all the south-west water flows towards the peatland (blue arrows).

15 timber plank dykes to divert the flows

Points requiring particular attention

- **Topography:** a great deal of care was taken regarding the movement of the vehicles/machinery. Nevertheless, the repeated passage of the vehicles/machinery at the only possible point of passage did lead to the compaction of the peat by a few cm, which affected the desired water circulation. As a result, certain fences had to be extended.
- **Anchoring of the steel fence:** the anchoring of the fence on a watertight, but not very thick substrate (only about 30 cm of clay over fractured limestone) had to be calculated very precisely based on a thorough pedological survey over the 90 m where the fence was installed. A dimensioned plan showing the exact place where each steel sheet pile was to be driven in had to be respected by the contractor and regularly checked by the main contractor.

Results

MONITORING SET UP

▶ Flora and vegetation monitoring: 10 plots of vegetation (pre-/post-works) The aim is to evaluate the impact of the works on the vegetation based on phytosociological surveys. The evolution of certain characteristic species should provide some indication of any modifications generated by the works. Only surveys at one year before the works and two years after the works are available, which do not show any real change so far, except for a regression of *Andromeda polifolia*, which is very marked in the zone flooded by the works, in favour of sphagnum mosses. This monitoring there needs to continue after the Life programme to make sure conclusive evidence is provided, via other public policies.

▶ "Syrph the net" monitoring: an inventory was done in 2017 (one year after the works). This monitoring should be continued after the Life programme to identify any changes in the populations, via other public policies.

▶ Piezometric monitoring: 10 piezometers equipped with recording sensors were installed in the peatland in 2014 to measure fluctuations in the water table and to evaluate any changes before and after the works.

▶ Hydrological monitoring of the flows at the peatland outlet (peatland observation scheme, SNO): the rating curve is currently being worked out and the results cannot yet be used, but ongoing work on a doctoral thesis should provide some information on the hydrological modifications by 2022.

▶ Monitoring of the carbon measurements (peatland SNO): installation of an eddy covariance mast in 2018, after the works. There will be no pre-/post-works comparison, but long-term monitoring of the carbon exchanges in the peatland (*Lhosmot A., in prep*).

▶ Topographical monitoring, with the pre-/post-works DTM: updating the DTM should allow the changes in the direction of the surface water flows to be evaluated. A new flyover took place in 2020, which explicitly showed the new circulation of the flows towards the active peatland, as planned. A photogrammetry test carried out in 2019 did not give reliable enough results, given the tree cover.

Before - After

Before the hydrological works: clearing for the fencing - July 2015

Impact of the flooding of the fencing - dying off of the ligneous species and development of sphagnum mosses - 2019

Useful documents

GROSVERNIER, P. 2014. *Fermeture de fossés au Creux au Lard, tourbière du Forbonnet (Commune de Frasne, France)*. Compte-rendu d'étude du cabinet LIN'eco. SMMAHD. 16 diapositives.

GROSVERNIER, P. 2011. *Enjeux de conservation et potentialités de restauration de la tourbière du forbonnet (Commune de Frasne, France)*. Compte-rendu d'étude du cabinet LIN'eco. SMMAHD. 22 diapositives.

GROSVERNIER, P. 2005. *Expertise hydroécologique de la tourbière du Forbonnet (Commune de Frasne, France)*. Compte-rendu d'étude du cabinet LIN'eco. SMMAHD. 7 p.

GUYONNEAU, J. 2010. *Relevés floristiques réalisés sur les carrés permanents de la combe tourbeuse de la RNR Frasne-Bouverans (25)*. SMMAHD.

MAGNON, G. & CALVAR, E. 2012. *Eléments constitutifs en vue d'une demande de classement d'un site en Réserve Naturelle Régionale, site des tourbières de Frasne-Bouverans (25, France)*. SMMAHD. 139 p.

GOUBET, P. 2016. *Résultat d'expertise de l'analyse des macrorestes de carotte de tourbe de la tourbière de la Seigne des Barbouillons (25, France)*. SMMAHD.

GOUBET, P. 2015. *Résultat d'expertise de l'analyse des macrorestes de carottes de tourbe de la tourbière active de Frasne (25, France)*. SMMAHD. 9 p.

BRIOT, M. 2004. *Restauration des capacités biogènes des tourbières : Etude hydrogéologique, hydrologique, et pédologique d'une zone sous influence d'un drain dans la Réserve Naturelle de Frasne (Doubs, France)*. Rapport de stage, SMMAHD. 30 p. + annexes.

COLLIN, L. 2016. *Etablissement d'un modèle conceptuel du fonctionnement hydro-écologique de la tourbière de Frasne (25, France)*. Rapport de stage, SMMAHD.

LHOSMOT, A. En préparation. *Réactivité du carbone dans les interactions combinant l'atmosphère et les tourbières : combiner l'analyse hydrogéochimique et des flux de gaz à effet de serre à l'échelle des microsites pour contraindre la variabilité spatio-temporelle des fonctions puits et émetteur de C de la tourbière de Frasne (25)*. Thèse de doctorat, Laboratoire de chrono-environnement, Université de Franche-Comté.

Contact

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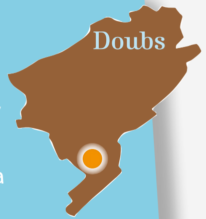
The Lac de Malpas peatland complex

Fact sheet



Natura 2000 site: Lac de Malpas and peatland, the Partot meadows and the Belin reach

Ramsar site: Peatlands and Lakes of the Jura Mountains

Project owner: EPAGE Haut-Doubs Haute-Loue

Municipality concerned: Malpas (Doubs)

Period of works: 2019-2020

Accessibility of the site: site not open to the public (private land) - way-marked walking trail round the Lac de Malpas (Circuit 6)

Area of the peatland complex: 8 ha, part of a peatland complex of over 30 ha

Altitude: 920 m

Usages :

- Peat probably extracted until the 19th century
- Water drained to supply a sawmill water wheel until the 19th century
- Grazing and manual hay cutting still practised into the 20th century
- Waste water from the village sewers flowed into the environment until mains sewers were installed in 1980
- Environment receiving rainwater

Species of interest: Bog rosemary (*Andromeda polifolia*), slim-stem small reed grass (*Calamagrostis stricta*), round-leaved sundew (*Drosera roduntifolia*), common butterwort (*Pinguicula vulgaris*), large heath (*Coenonympha tullia*), Violet Copper (*Lycaena helle*), marsh fritillary (*Euphydrias aurinia*), among others.

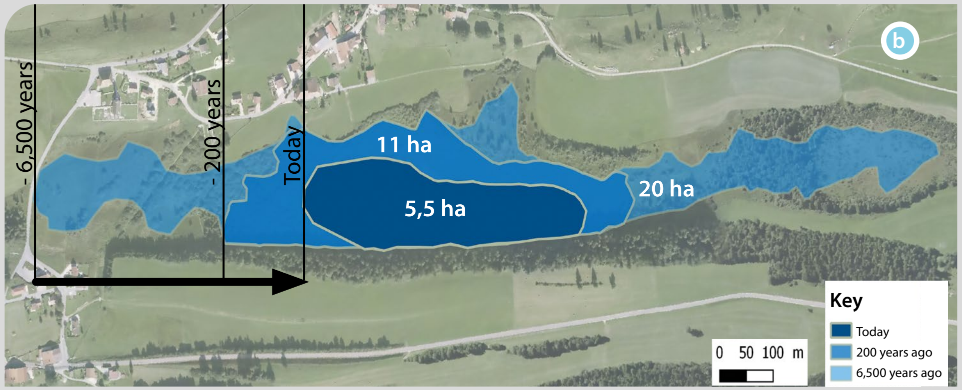
Large heath Coenonympha tullia

The Lac de Malpas peatland complex seen from above

Background

The Lac de Malpas peatland complex a occupies a vast lacustrine depression covering more than 20 ha. It shows all the stages of aggradation of a water body through to a wooded raised peat bog b.

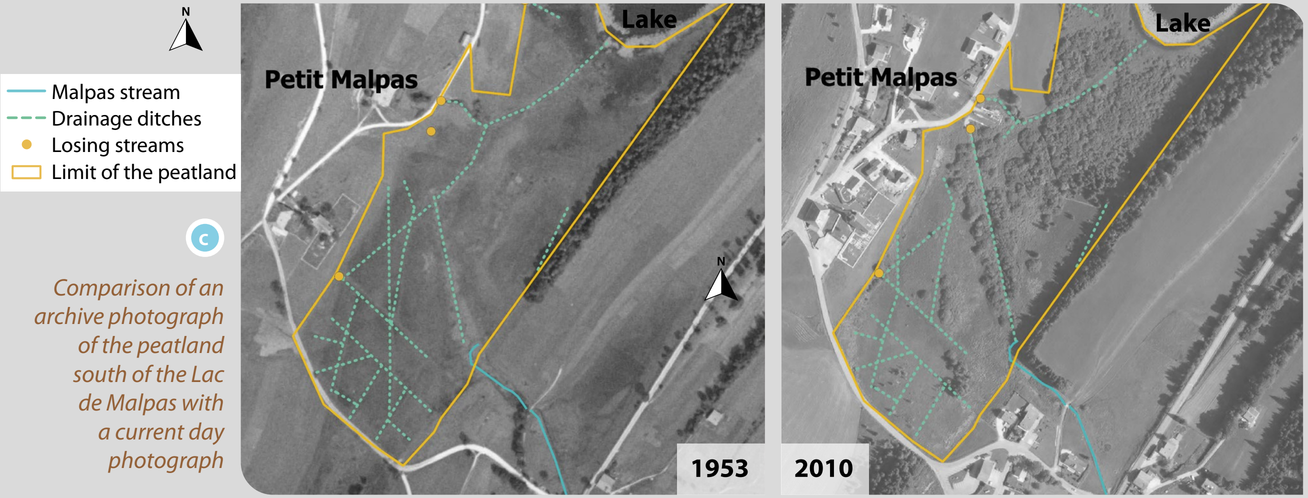
It is the overdeepening caused by the Würm glacier that allowed the retention of water and formation of a lake. The originality of the site lies in the prominent role played by losing streams in the formation of peat bogs. Indeed, the maximum level of the water in the lake and the associated marshes seems to be fixed by the presence of these natural outlets along the west side of the lake, between Valanginian fractured/cracked limestone and morainal deposits.



The natural aggradation process has accelerated over the last few centuries, as evidenced by carbon dating and archive documents, according to the chrono-environment lab.

The geomorphological and topographical context is conducive to the collection of the waters from the watershed, spring waters and precipitation, which has led to a mosaic of habitats typical of these different sources. The Malpas stream also flows into the peatland. Thus, formation of the peatland complex can be likened to a limnogenous or soli-limnogenous formation evolving locally towards a limno-ombrogenous type of formation. The peat depths vary from 2.5 m in the south to 6 m in the raised bog to the north of the lake.

The worst deterioration of the peatlands was observed in southern part of the complex: it was this functional unit that was the subject of a detailed diagnostic study and the works carried out as part of the Jura Peatlands Life programme.



c

Comparison of an archive photograph of the peatland south of the Lac de Malpas with a current day photograph

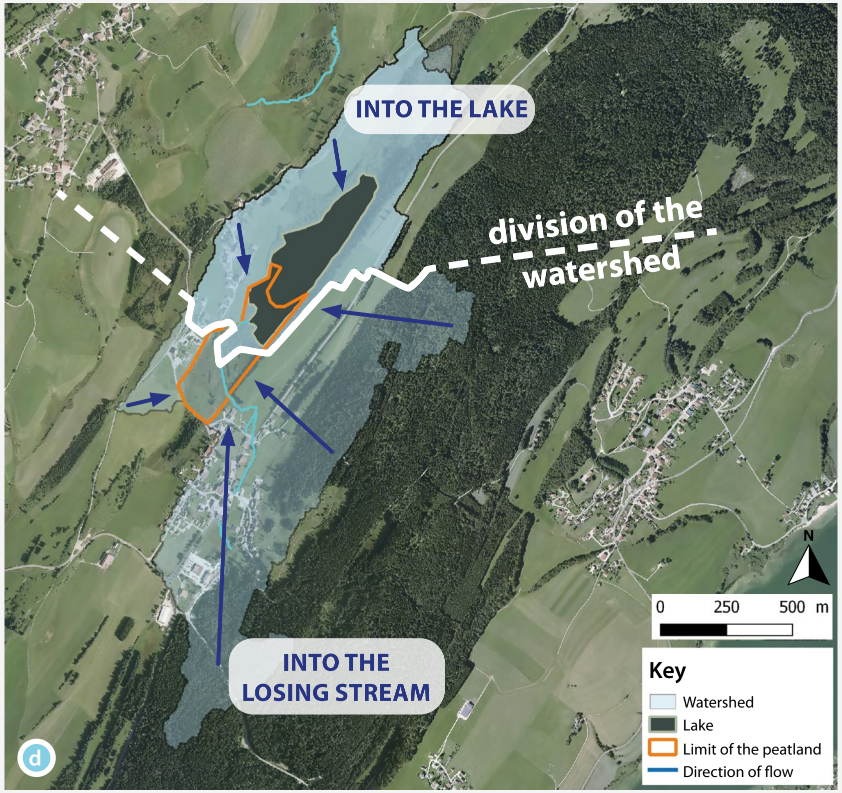
Diagnosis

IDENTIFICATION OF THE PROBLEMS

The Lac de Malpas peatland complex has, like many peatlands in the Jura mountains, seen rapid colonisation by ligneous species (willow mainly) over the last 40 years, as can be seen in the aerial photos from the archives c. But it is the replacement of the sedge meadows to the south of the lake by a degraded mountain megaphorb (*Urtica dioica, Epilobium sp*...) which has underscored the scale of the hydrological dysfunction: for 70 years, this zone, as well as being dried out, has seen its trophic load increase.

The origin of the disturbance seems obvious once on the ground c: a central ditch 4 m wide and 2 m deep f cuts through the peatland from south to north draining the stream waters directly towards a losing stream whose natural elevation has been deliberately lowered. Several other smaller ditches were observed and seemed to be active.

These regulation works carried out in the 1960s were particularly effective: the mineralised black peat observed in the top 50 centimetres has a grainy texture, devoid of fibres and macroremains. From a piezometric point of view, the findings are consistent with this: in the vicinity of the central ditch the water table shows variations in the order of one metre, evidence of serious hydrological dysfunction. An analysis of the piezometric gradients showed that this ditch drains water from the lake in periods of drought: the influence of these regulation works would therefore appear to extend to the entire peatland complex. The ditches have also reshaped the watershed topographically and therefore today are also affecting the water flows: the hydrosystem is divided into two, the water supply is no longer reciprocal d.



Consequence of digging the central ditch: the original watershed was divided into two

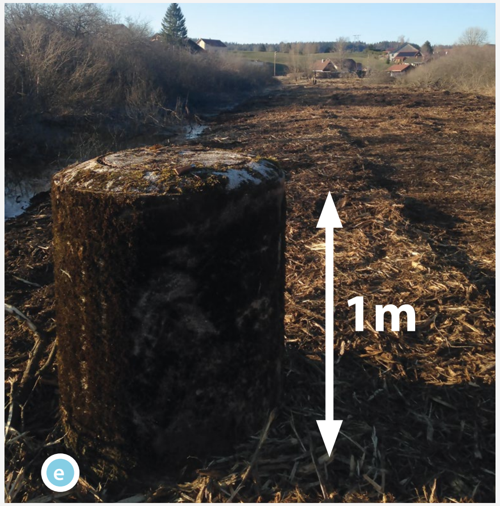
The main purpose of these works still remains unclear, but it would seem that the primary motivation was to collect the waste waters from the village and direct them towards the losing stream. Indeed, no agricultural gain was observed, and in fact hay meadows and grazing have disappeared since the ditch was dug.

The increase in the eutrophisation of the site is no doubt a consequence of the significant mineralisation of the peat and, more hypothetically, the discharge of waste water (from sewers) into the central ditch. The trophic and water-related modifications have favoured the emergence of wet nitrophilous species as well as scrub encroachment.

CHALLENGES OF THE SITE

Human pressures have played and still play a decisive role in the evolution of the habitats in the Lac de Malpas peatland complex. The biodiversity challenges are considerable with the presence of several protected species of animals and plants and a wide variety of habitats of heritage interest which are in the process of turning to scrub or of over-eutrophisation. This site probably constitutes a significant source of CO_2 due to the mineralisation of the dried-out peat. It is estimated that 2,500 to 5,000 m³ of peat have disappeared over the last 40 years e.

The "quality and quantity of water" challenge is intrinsically connected to the "biodiversity" and "CO_2" issues since it is the hydraulic works that are the cause of the hydro-ecological dysfunctions observed on the complex. Water supply is fundamental to the conservation of the peat, and the water flows that allowed the formation of the peatland complex are still present: stream, springs, lake, meteoric waters. The situation - both geomorphological and topographical - of the site is, furthermore, conducive to the collection and accumulation of water: it is the drainage via the hydraulic installations that has



Evidence of subsidence and the mineralisation of the peat: appearance of sewer manholes

Central ditch in the peatland to the south of the Lac de Malpas after shredding of the willow stand and before neutralisation

created a negative water balance. Since a separate sewer system was created, the physical-chemical quality of the water in the central ditch has improved. In view of these favourable parameters, a restoration project for the peatland south of the Lac de Malpas could be envisaged.

Works

The measures proposed were intended to reconnect the three hydrological units - peatland, lake and stream - in order to stop the mineralisation of the peat and potentially restart peatification.

▶ **Modification of the hydraulic structures:** the drainage ditches needed to be neutralised and the discharge elevation of the Scie losing stream raised to what was judged to be its "natural" elevation to prevent the water running out too fast. The rewetting of the peatland as things stood would mean charging the village's stormwater pipes: this network therefore had to be raised to avoid any risk of such charging. The new drains would also allow the deviation of the waters on the left bank of the central ditch onto a flat zone, facilitating the rewetting process. The waters from the ditch were being discharged into the Scie losing stream via two structures protecting it. The maximum outflow capacity of the Scie losing stream was equal to that of structure 1, which would therefore allow the neutralisation of structure 2 without any notable hydraulic consequences whilst reducing the cost of the operation.

▶ **Hydro-ecological restoration of the peatland:** once the pipes had been modified, the work on the peatland could be started:

- the substantial and meticulous infilling of the upstream (southern) part of the central ditch f to prevent the capture and concentration of the flows (stream, rainwater) by this ditch whilst facilitating the transfer of the water towards the lake;

- the cutting out of the top layer of the mineralised peat in the southern part of the peatland would create a context topographically favourable to the spreading out of the water, to rewetting and to the reduction of the erosive force. In addition, in periods of high water, the flows towards the lake would be facilitated;

- since total infilling of the central ditch was impossible given its size, the construction of a double fence in the intermediate zone would help to retain and structure the materials used to fill in the upstream part whilst helping to redirect the water towards the lake;

- the removal of the old embankments of dredged material has helped to increase the overall topographical coherence of the peatland and with the surface and sub-surface water flows.

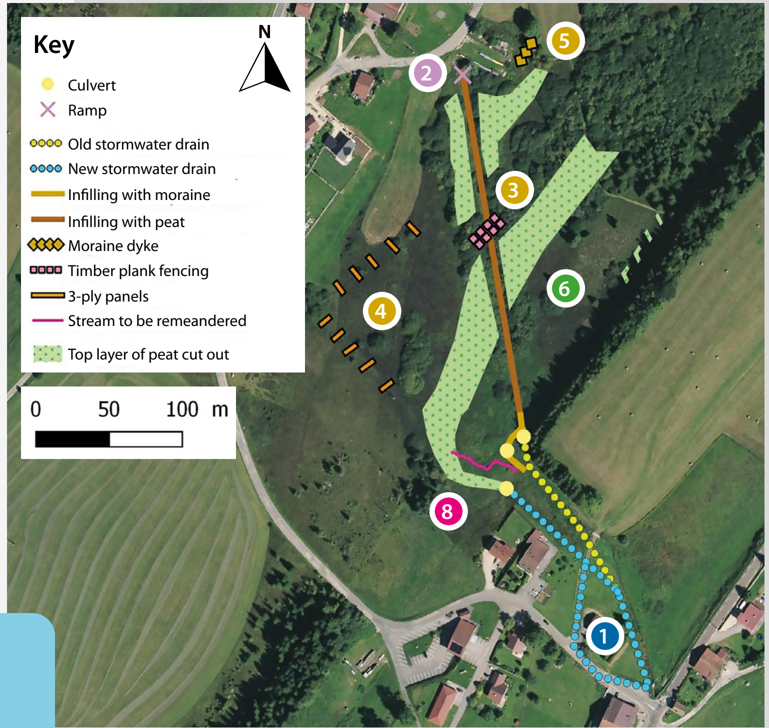
▶ **Remeandering of the Malpas stream:** the downstream part of the Malpas stream has been diverted and remeandered in the direction of the rewetting zone.

Points requiring particular attention

▶ **Relationship between hydraulic structures/restoration measures:** the new configuration of the stormwater system has allowed the water table elevation to be raised in the peatland. The entire restoration project rested on the topographical consistency of the upstream part (stream and stormwater drains) with the downstream part (the Scie losing stream) guaranteeing the rewetting of the peatland and its reconnection to the lake, whilst preserving the water flows and avoiding flooding the drains. The altitude of all of the operations (removal of superficial peat, fencing, infilling, etc.) was therefore carefully calculated, then the level of each item was checked on site. Access was forbidden to certain zones (marking off) to avoid them being compacted by vehicles/machinery liable to cause changes in the topography.

Briefly, the works consisted of:

- raising the stormwater drains 1;
- raising the elevation of losing stream protective structure 1 2 (the Scie losing stream);



Operations carried out as part of the hydro-ecological restoration of the peatland to the south of the Lac de Malpas

Construction of the double fence on the central ditch

- neutralisation of the central ditch 3: total infilling upstream and partial downstream of the double fence with material collected following the removal of the top of the embankment of dredged material;
- neutralisation of the secondary ditches 4: wooden panels or cutting of the top layer and constitution of embankments;
- neutralisation of losing stream protective structure 2 5 by constitution of a mineral dyke;
- cutting of the top layer of peat for re-spreading and redirecting the waters 6;
- remeandering 8 of the downstream part of the Malpas stream.

Deviation and remeandering of the downstream part of the Malpas stream (left) and opening of the new stormwater drains in the village of Malpas in the rewetting zone where the top layer of peat has been removed (right)

Online
The hydrological restoration works

Modification of 190 m of the stormwater drains in the village of Malpas

The work in figures

Periods: Two phases, autumn 2019 and spring 2020

Length and surface area:

- Neutralisation of 440 m of drainage ditches
- Rewetting of 3 ha of peatland
- Hydrological reconnection of a 20 ha complex

Equipment used:

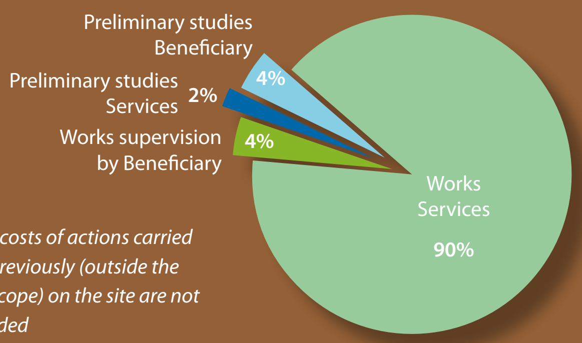
- Contractor for the peatland work: Two 23-tonne wetland excavators, two tipper trucks, one Kubota
- Contractor for the work on the drains and the losing stream protective structure: Two 23-tonne excavators including one rock breaker, one tipper truck
- 1,200 m³ of peat or clayey material used for infilling
- 30 m of timber planking
- 60 m² of wooden panels
- 37 m of 600 mm drain pipes, 123 m of 1000 mm drain pipes

Contractors: Setec Hydratec for the design of the losing stream protective structure (raised), Jura Natura Services for the peatland work and Boucard TP for the stormwater drain work

Total cost of the Life action: €256,860 incl. VAT *

- Works (green): €241,842
- Preliminary actions (grey): €15,019

Peatland works: €84,000 ex VAT, stormwater drain works: €98,000 ex VAT, design of the losing stream protective structure: €4,900 incl. VAT



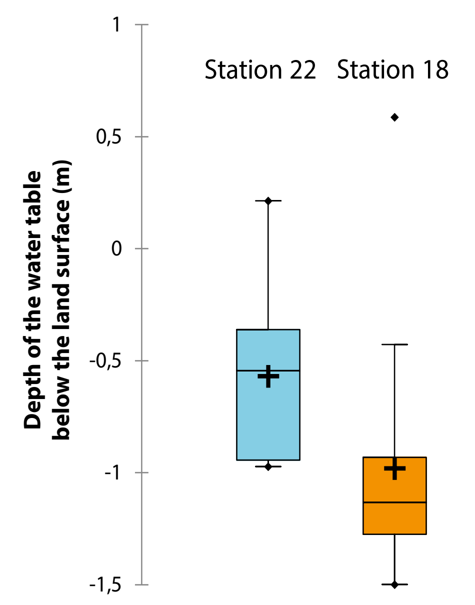
** the costs of actions carried out previously (outside the Life scope) on the site are not included*

Results

The works were completed on 28 May 2020. The post-works floristic and entomological monitoring will be carried out in the coming years. Piezometric monitoring has been in place since May 2015. This allowed a piezometric diagnosis to be carried out before the works and the hydrological disturbances on the site to be identified. Data acquisition is still ongoing.

MONITORING SET UP

- ▶ Flora monitoring: vegetation mapping done in 2006
- ▶ Entomological monitoring: inventory of Lepidoptera and Odonata in 2018
- ▶ Piezometric monitoring: 5 piezometers monitored (since 2015)

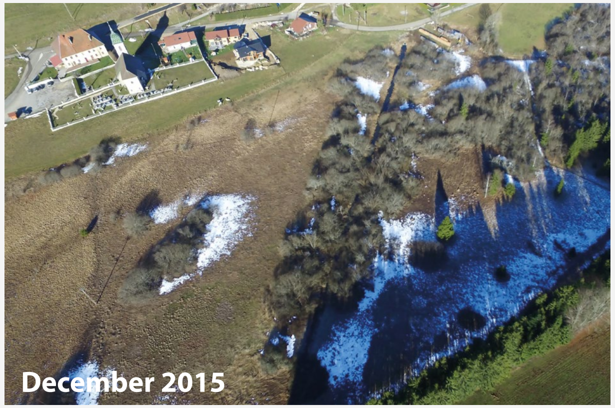


Elevations of the water table at stations 18 and 22 in the peatland to the south of the Lac de Malpas before the works

Piezometer 18 is situated immediately next to the central ditch. It shows a water table fluctuation of an amplitude of 1 m and a median situated at -1.2 m below the land surface, which underscores the draining effect of the ditch. Piezometer 22 is situated in the centre of the peatland. Even though it is a long way from the ditches, it still shows piezometric behaviour reflecting hydrological disturbance.

Before - After

Aerial view of the Lac de Malpas peatland complex



Useful documents

- COLLIN, L. 2018. *Tourbière du lac de Malpas : Diagnostic hydro-écologique*. SMMAHD. 15p.
- COLLIN, L. 2018. *Tourbière du lac de Malpas : Etude avant-travaux AVP PRO*. SMMAHD. 28p.

Contact

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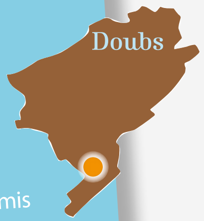
Le Crossat peatland

Fact sheet



Natura 2000 site: The Drésine and Bonavette valleys

Ramsar site: Peatlands and Lakes of the Jura Mountains

Managing organisation: Association Les Amis de la Réserve Naturelle du Lac de Remoray

Period of works: 2017 and reinforcement in 2018

Municipality concerned: Remoray-Boujeons (Doubs)

Accessibility of the site: site closed to the public (Prefectoral order of 16 July 1982 supplementing the ministerial order creating the Lac de Remoray nature reserve)

Area of the peatland complex: 10 ha

Altitude: 850 m

Usages :
- Biodiversity
- Previously family peat extraction (19th and 20th centuries)

Species of interest: Bog rosemary (*Andromeda polifolia*), sphagnum moss (*Sphagnum sp*), *Cetraria sepincola*, moorland clouded yellow (*Colias palaeno*), violet copper (*Lycaena helle*), marsh fritillary (*Euphydryas aurinia*), white-faced darter (*Leucorrhinia dubia*), large white-faced darter (*Leucorrhinia pectoralis*), *Pipizella mongolorum*, among others.

Marsh fritillary *Euphydryas aurinia*

a *Aerial view of the Crossat peatland*

Background

The Crossat peatland (a), rossed by the Bonnefontaine stream, is a peat bog situated to the south-west of the Lac de Remoray (Doubs). It was formed following the silting up of Quaternary palustrine formations in the lacustrine basin (large lake underneath the Würmian glacier) (*Bichet et al., 2008.*).

Its vegetation consists of a sphagnum-dominated spruce stand. In a few sectors there are mountain and other pines found in evolved, non-wooded peat bogs.

The peatland had already undergone some restoration work in the southernmost part:

- in the 1990s, trees were cleared to encourage the maintenance of certain species of Rhopalocera and Ordonata (*Colias palaeno*, *Leucorrhinia dubia*, *Leucorrhinia pectoralis*). These species were saved just in time, at least in the short term.
- in 2005, a 40-metre long drainage ditch was filled in. This allowed the creation of five ponds, four small ones along the length of the drain and a larger one nearby to extract the peat needed for the infilling.

In 2007, some larger-scale work was done on some dry, gently sloping heathland dominated by *Calluna vulgaris*, *Vaccinium uliginosum* and *Molinia caerulea* and dotted with old peat extraction pits vegetated by transition mire plant groups. Nine shallow open water basins were created, arranged in a terrace pattern and separated by dykes, with the objective of restarting the peat formation process from these water storage zones.

Diagnosis

IDENTIFICATION OF THE PROBLEMS

Antoine Magnin wrote back in 1904: "At Le Crossat, no trace of tree vegetation is reported at the beginning of the 20th century." Traces of numerous extraction pits and drainage ditches bear witness to a family peat extraction operation at the end of the 19th and beginning of the 20th century. This led to hydrological disturbances that seriously disrupted the natural functioning of the peat bog. The peat has become mineralised on the surface, favouring the development of non-peat forming flora (*Molinia caerulea*, *Caluna vulgaris*…) to the detriment of sphagnum mosses. Afforestation has been accelerated.

The entire peatland has been altered by trophic enrichment caused by disturbance of the topography and water flow disruptions (drains) leading to accelerated afforestation.

FUNCTIONAL ANALYSIS AND RESTORATION POTENTIAL

From 2014 onwards, the restoration investigations focused on the fen sector situated to the north-west of the Crossat peatland on the left bank of the Bonnefontaine stream.

The analysis of the digital terrain model produced by LiDAR scanning of the peatland (b) clearly showed a network of ten parallel ditches in the fen zone accelerating the evacuation of the water towards a large feeder drain in the east. It is interesting to note that these ten ditches, almost invisible on the ground, actually become very visible at the beginning of the spring, when the marsh-marigold (*Caltha palustris*) comes into flower, evidence that there is flowing water (c).

The 10 ditches visible due to the lines of Caltha palustris before the 2014 works

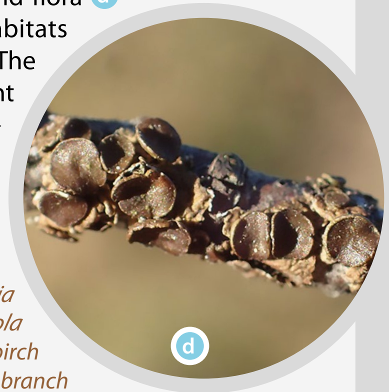
Obliterating the ditches therefore seemed indispensable to slow the flow of water as much as possible and guarantee a better flow of water throughout the peatland. This work was carried out in October 2014.

In the east, the large feeder drain carried the water from the old extraction pits away to the Bonnefontaine stream 80 metres lower down. Another consequence was that it was intercepting the flow of water that should naturally have been percolating through the peatland in the east, towards the lake (b). Rewetting by blocking the upstream pit, completed by obliterating the ditch was intended to reduce the drainage of the western part of the peatland and improve the flow towards the east. The presence of sphagnum mosses in the vicinity is a very favourable condition for restarting the peat-forming process.

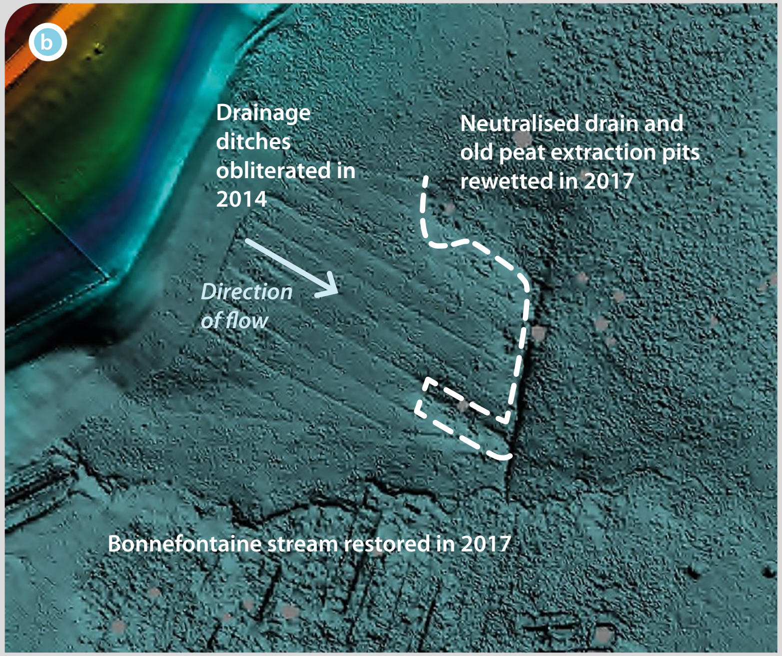
CHALLENGES OF THE SITE

► **Biodiversity:** the Crossat peatland comprises priority habitats of community interest: Bog woodland (91D0*) and Active raised bogs (7110*).

Certain species of fauna and flora (d) associated with these habitats are classed as remarkable. The nature reserve management body is working to maintain their population.



Cetraria sepincola on a birch branch



Digital terrain model, 2012

CONSEQUENCES

In spite of the mineralisation and deterioration of the surface layers, the identification of the hydrological disturbances shows that it is possible to improve the functioning of certain sectors of the Crossat peat bog. The presence of sphagnum mosses suggests that peat formation will restart if the hydrological conditions are improved.

Works

The work to fill in the ten ditches in the fen was completed in 2014 under a Natura 2000 contract.

Given the density of the ditches and the damage to the top layers of the existing peat, it was feared that the hollows created by taking peat on site would have difficulty retaining the water. It was decided to fill in the ditches completely with 250 m^3 of spruce sawdust, reinforced by 60 wood panels.

The work conducted in 2017 as part of the Jura Peatlands Life programme, completed this restoration and were intended to:

- neutralise the draining effect of the ditches;
- rewet old peat extraction pits;
- allow the water to flow laterally, towards the east.

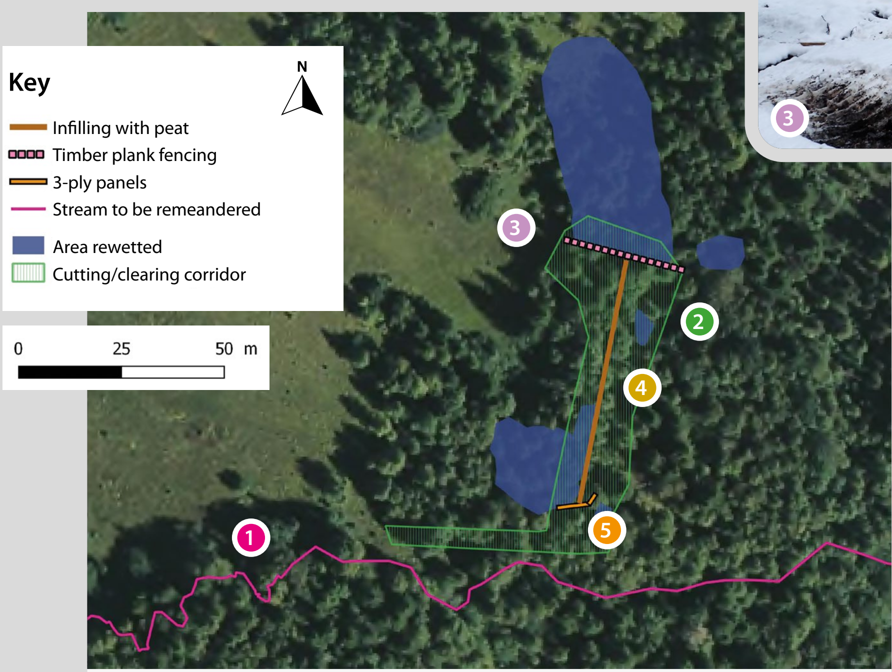
DYSFUNCTION

During these works, several phases were not carried out optimally, for various reasons and this led to certain dysfunctions.

1 **Morphodynamic restoration of the water course**: creation of new meanders upstream and replenishment with riverstones/gravel in the Crossat peatbog, as far as its confluence with the lake.

2 **Trees cut back** in the sector.

Wooden fence before being covered with peat



Plan showing the works conducted as part of the restoration of the Crossat peatland

3 **Timber plank fence**
30 m long, 3.50 m high. The structure was covered by peat extracted immediately downstream of it. It should be noted that the lacustrine enclosing bedrock is situated at a depth of 5.20 m.

4 **Partial infilling of the ditch** with old excavated peat present alongside the drain.

5 Arrangement of **two 5-metre long wooden panels** to form a plug 8.50 m wide (1.50 m overlap) and 2 m high. The structure was covered by peat which was extracted nearby.

Installation of wooden panels

▶ **Hydrological and meteorological conditions unfavourable to the works:** the works were performed at the end of the autumn and beginning of the winter. During the works, snow and cold set in. Such conditions are far from favourable to the mobilisation of the quantities of peat needed to cover the structures. In addition, this was immediately followed by heavy rains. The non-stabilised peat quickly became saturated with water and "slipped down" the structures e.

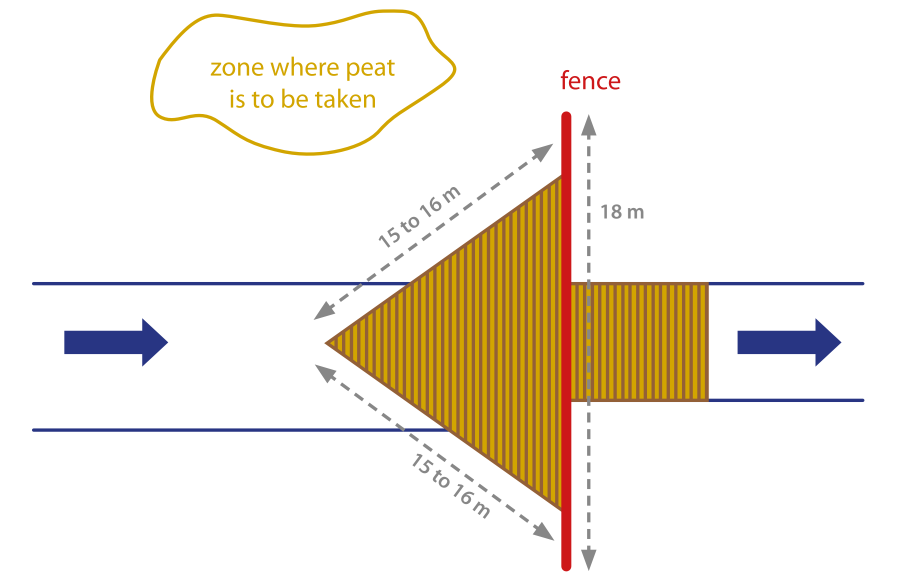
Work being carried out in unfavourable weather conditions

▶ **Timber fencing not anchored in the mineral layer and peat was taken from the wrong places:** for budgetary reasons, with the idea of increasing the length of the fencing, it was decided to reduce the height of the planks to 3.50 metres whereas the lacustrine enclosing bedrock was detected at a depth of 5.20 m.

Furthermore, due to flooding, vehicle and machinery access to the site was hampered, resulting in the peat used to cover the fencing being extracted 5 m downstream, 4 m away from the end of the fencing.

After the very rapid rewatering of the downstream pit, within a fortnight the water level had fallen again by about a metre. After analysing the situation, it was found that water had started to flow underneath the fencing, in the middle of the fence, re-appearing in the hollow from where the peat had been taken. The level upstream stabilised at the level of the downstream extraction hollow. The upstream hydraulic load, probably added to high hydraulic conductivity of the peat, is the most likely explanation for this dysfunction in the structures f.

The water passed underneath the fencing, which was not anchored in the watertight substrate, re-emerging by artesian flow at the weak point created by the hollow from where the peat was taken



g *Diagram showing the consolidation works: offsetting the hydraulic loading point*

Solution found: to correct the problem with the large timber dyke, there were two possible solutions:

- either to create a second dyke, anchored in the enclosing substrate, at least for the central part of the fencing - the solution most likely to succeed, but deemed too costly;
- or to move the hydraulic loading point far upstream of the fence in order to minimise the risk of preferential flow within the peat.

For this solution, the mound of peat that covered the fence was completely rearranged into a triangle upstream of the fence in order to offset the hydraulic load by more than 10 metres g. The peat was taken was a zone upstream of the structure, to avoid interfering with its functioning. The fencing peat mound was entirely covered by hay harvested from the fen to facilitate its stabilisation and vegetation.

The consolidation works took place at the end of November 2018 and were a great success h. From the first rains, the old extraction pit filled up with water.

Consolidation works at the end of November 2018

In spite of the very dry heatwaves in the summers of 2019 and 2020, the water table remained very close to the land surface. However, the level of the fencing does not allow full lateral flow of the water on the left bank due to the topography of the mineralised, wooded peatland. A slight circumventing flow is observed on the right bank, in a sector that was not actually disturbed by the passage of vehicles/machinery, and it does not seem to be generating any erosion. Large numbers of trees have withered or are in the process of doing so due to the constant flooding. A return of the sphagnum mosses, which are present nearby, is expected in the near future.

▶ **Undersized downstream dyke:** the structure was not dimensioned to retain the unexpected flow of water that occurred due to the dysfunctions upstream (the water should have percolated sideways). The water circumvented the structure and very quickly caused some slight lateral erosion i.

Erosion at the downstream dyke

Solution found: it was decided to extend the downstream panel structure using offcuts from the planks used for the upstream fence j and to cover them with a mound of peat so that they there would be no overflow onto the zones disturbed by the passage of vehicles/machinery. This small intervention turned out to be highly effective. Since then the structure has been blocking a large quantity of water and therefore rewetting a large area of peatland.

Extension of the dyke using plank offcuts which were then covered by peat

The work in figures

Periods: November - December 2017 and November 2018 for the consolidation of the fence

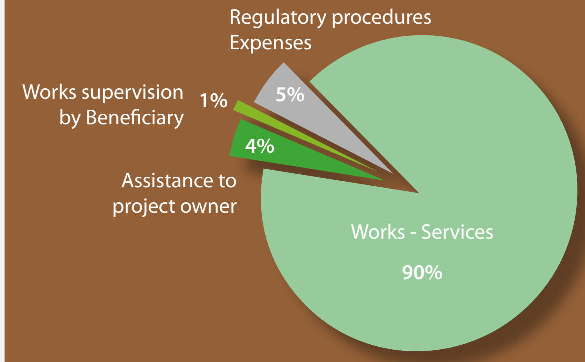
Length and surface area:

- Neutralisation of 76 m of drainage ditches
- Rewetting of 0.28 ha of peatland

Contractor: Jura Natura Services

Total cost of the Life action: €94,672 incl. VAT *

- Works (green): €90,331
- Preliminary actions (grey): €4,341



** the costs of actions carried out previously (outside the Life scope) on the site are not included*

Results

Several positive effects are already visible in the peatland

- toppling and withering of the birches and spruces;
- increase in the water level;
- vegetation of the structure downstream k ;
- recolonisation of the site by fauna: amphibian egg-laying from the very first spring, numerous invertebrates establishing colonies, presence of waterfowl.

Downstream structure after two seasons of vegetation September 2019

MONITORING SET UP

► Photographic monitoring

► Piezometric monitoring

Before - After

Le Crossat peatland - upstream of the fence

1/ Before the consolidation works - January 2018

2/ After the works – March 2019

3/ After the works – July 2019

4/ After the works – November 2019

Contact

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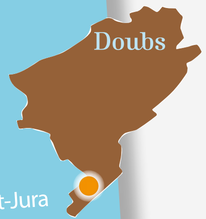
Le Moutat peatland

Fact sheet



Natura 2000 site: Mouthe peatlands and springs, source of the Doubs

Ramsar site: Peatlands and Lakes of the Jura Mountains

Project owner: Parc naturel régional du Haut-Jura

Period of works: 2017

Municipality concerned: Mouthe (Doubs)

Accessibility of the site: partially developed; unregulated

Area of the peatland complex: approx. 20 ha

Altitude: 855 m

Usages :
- Agricultural meadows on the outskirts of the site
- Downhill skiing on the outskirts of the site
- Creation of a viewing platform and a path around the periphery of the site

Species of interest: Violet copper (*Lycaena helle*), marsh fritillary (*Euphydrias aurinia*), glossy sickle moss (*Hamatocaulis vernicosus*), among others.

Glossy sickle moss
Hamatocaulis vernicosus

a *Aerial view of the Moutat peatland*

Background

The Doubs has its source at the foot of the vast Noirmont anticline which marks the border with Switzerland. Over its first kilometre, it encircles the Moutat peatland a before flowing on to the village of Mouthe.

The peatland has developed on sandy, not very impervious lacustrine sediments. When it was first formed, the water supply from the karst, as a result of the thrust front of the Noirmont anticline over the Mouthe syncline, must have been more active. The clearly visible circular form to the south-west of the peatland is evidence of an old sublacustrine spring coming through the sediment and forming a pockmark.

Like virtually all the peatlands in these mountains, the Moutat peatland was exploited for domestic heating in the past. Here, however, it appears to have been very intense in view of its modest area.

Diagnosis

IDENTIFICATION OF THE PROBLEMS

The Moutat presents almost all the disturbances that have been identified in the Jura Peatlands Life programme.

▶ Drainage by straightening water courses: the Doubs itself saw its first meander "short-circuited" as early as the end of the 19th century. This meander that bathed the north-eastern part of the peatland was moved further north.

▶ The fen situated between the old meander and the peat bog sectors was also intensively drained, from the beginning of the 20th century onwards, probably to allow ridge planting.

The entire historical peat bog was exploited, so that all that remained were the peripheral areas and two access strips to the extraction pits. The pits were wide open on the downstream side. On the most southerly of them, the drainage is accentuated by a ditch leading to the Doubs and passing through the pockmark.

FUNCTIONAL ANALYSIS AND RESTORATION POTENTIAL

By cutting off the meander in the Doubs, the length of the river's course in this section was divided by three. On the "short-circuit", the steeper slope and more homogeneous aquatic habitats have led to a reduction of about 30% in the trout population compared to the control stretch with its balanced environment just upstream. Rewetting the old meander, still clearly visible on the ground, has restored a more balanced morphodynamic profile. It is hoped that it will minimise the draining effect on the peripheral part of the peatland.

At the same time, the six ditches b, between them totalling a length of more than a kilometre, were drying out the entire northern fen. Complete infilling should mitigate this effect. However, in view of the past disturbances, the results will probably not be significant for some time.

Ditch before the works

The large extraction pits in the peat bog are wide open on the downstream side, therefore difficult to obliterate, and so few cost-effective improvements are reasonably feasible. Only drainage in the large, most southerly pit was accentuated by a fairly active ditch that flows that discharged into the pockmark. Its obliteration should allow the water level to be raised in the bottom parts of the pit generating a lateral outflow of the water stored southwards.

CHALLENGES OF THE SITE

▶ **Biodiversity:** there are few real peatland heritage species on this site However, the mix of habitats does offer an interesting amount of diversity. The sphagnum moss dynamics are strong and it looks as if it may be interesting to encourage this.

▶ **Tourist appeal:** the source of the Doubs is a well-known site in the Jura mountains. A path runs alongside the Doubs, encircling part of the peatland up to a viewing platform. There is a camp site and children's centres nearby. This peatland therefore has considerable educational value.

▶ **The Doubs:** probably the most emblematic river in the French part of the Jura. Restoring its first meander near the source also has symbolic value.

Works

REGULATORY FACTORS

The remeandering of the Doubs and the restoration of the Moutat peatland required a procedure under the Law on Water and Aquatic Environments and **Decree No. 93-742** of 29/03/1993 consolidated on 18 July 2006 - Subject to the declaration regime for the following sections:

- **3.1.2.0.:** installations, structures, works or activities modifying the longitudinal or cross-sectional profile of the low-water channel of a watercourse.

- **3.1.5.0.:** installations, structures, works or activities, in the low-water channel of a water course of a nature to destroy the spawning grounds, growth zones or feeding zones of fish fauna, crustaceans and amphibians.

- **3.3.1.0.** : drying, rewetting, sealing, backfilling of wetlands or peat bogs.

The rewetting of the meander was considered as flooding a wetland.

The work in figures

Period: August 2017

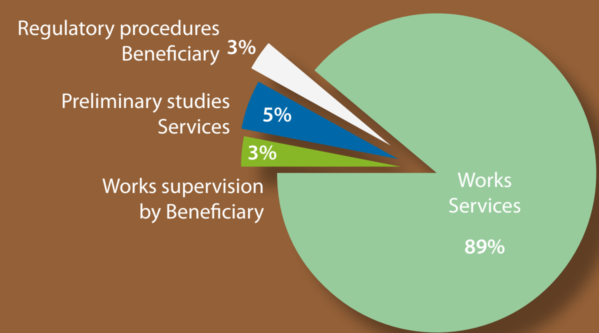
Length and surface area:

- Obliteration of 1,100 m of ditches in the fen
- Rewetting of 0.5 ha of old extraction pits
- Recreation of about 230 m of water course.

Contractors: preliminary study done in-house and Jura Natura Services for the works

Total cost of the Life action: €119,599 incl. VAT *

- Works (green): €109,745
- Preliminary actions (blue + grey): €9,854



** the costs of actions carried out previously (outside the Life scope) on the site are not included*

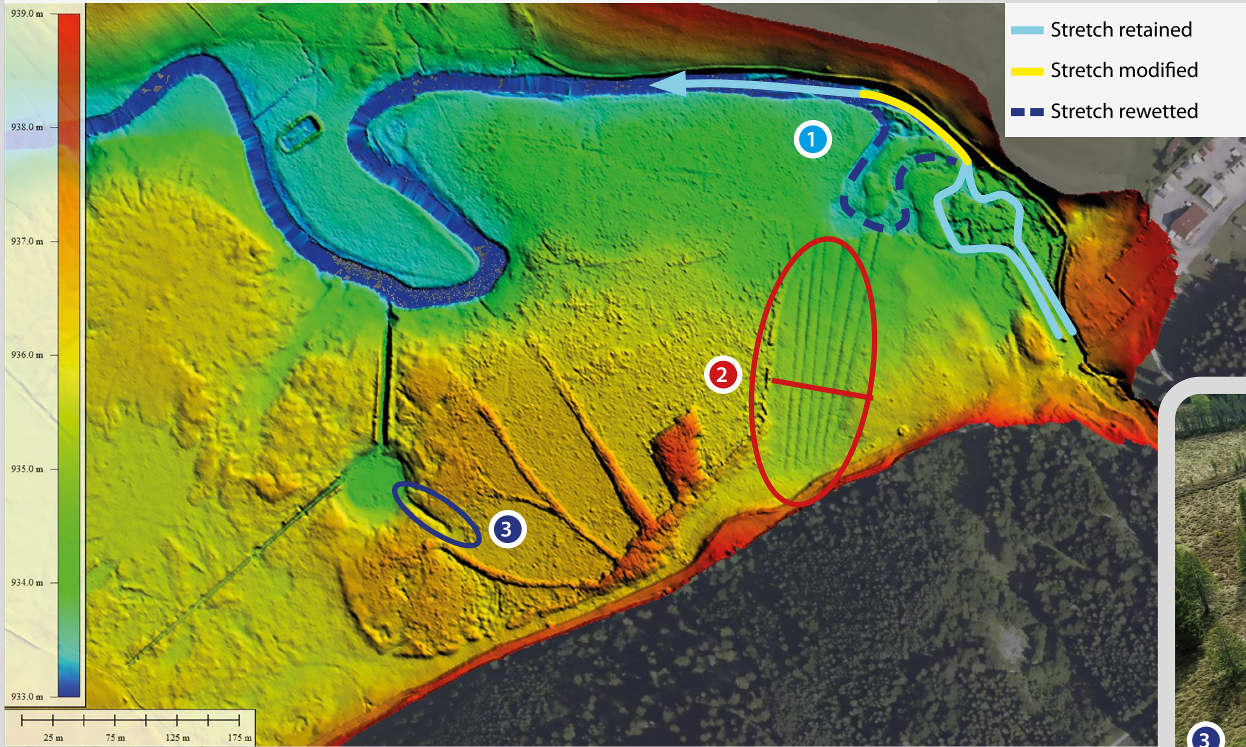
Online

The functional restoration works

1 Rewetting of a former meander of the Doubs :

the course of the former meander was just "cleaned up" by removing the vegetation and mud that had built up due to its being short-circuited, before removing the artificial plug that was blocking its entrance. The straight segment that bypassed the meander was completely filled in over an 80-metre stretch, in order to restore the flow in the meander. The length of the meander restored is 230 metres.

Works carried out in the Moutat peatland, seen on the DTM



3 Obliteration of the ditch draining a peat extraction pit:

given the width of the pit, accentuated by the local mineralisation splaying the edges wider, this ditch was blocked off by a timber plank fence 25 metres long and two metres deep. It was covered by about 50 m³ of peat taken from nearby sites.

The fence blocks off the ditch that was draining the extraction pit. A pond was created where the peat was taken (between the trees, on the left)

Installation of a temporary cofferdam to divert the water towards the recreated meander so that the dry straight bed could be filled in

2 Infilling of a network of six ditches in the fen:

these ditches represented a total length of 1,100 metres. Each ditch was cleared out to lay bare the peat before infilling, taking care to set aside the vegetation that constitutes the bottom of the ditches.

Four three-ply wooden panels (3.5 m x 1 m x 22 mm) were placed in each ditch. As the peat was not very thick, it was not possible to take peat on site for the infilling. The ditches were filled in with 850 m³ of peat brought in from other works on other peatlands. The vegetation from the ditches that was set aside was carefully placed over the peat.

DYSFUNCTIONS OBSERVED

The ditch and the pit were rewetted the first time it rained c. However, they were empty again after about a month with no precipitation d. It seems that the contact zone with the underlying sand is sufficient to let the stock of water seep away. It is hoped that deposits of organic material will seal the sediment.

On the left, the pit rewetted in May 2018, totally empty in August, on the right

Results

MONITORING SET UP

▶ Monitoring of the habitats in the fen zone to estimate how much management there needs to be. Mapping two years after the works.

▶ Monitoring of the butterflies in the fen with transect counts. Visit two years after the works.

▶ Monitoring of the benthic micro-fauna and the thermal regime of the Doubs.

Contact

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Before - After

Restored meander of the Doubs (May 2018), showing the old straight course filled in but not yet vegetated.

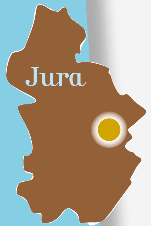
In the restored meander, the Doubs flows in hydrostatic equilibrium with the surrounding peatland

By infilling the ditch draining the extraction pit, the water is flowing into and rewetting the sectors that had become afforested due to drying out in the past (May 2018)

The Entrecôtes-du-Milieu peatland


Aerial view of the Entrecôtes-du-Milieu peat bog

Fact sheet



Natura 2000 site: Entrecôtes-du-Milieu - Malvaux

Managing organisation: Conservatoire d'espaces naturels de Franche-Comté (CEN FC)

Year of works: 2020

Municipality concerned: Foncine-le-Haut (Jura)

Accessibility of the site: access pontoon from the forest track crossing the site

Area of the peatland complex: 18.7 ha

Altitude: 1,035 m

Usages :
- Previous exploitation: peat extraction, pasture
- Peatland crossed by a forest track

Species of interest: Hudson bay sedge (*Carex heleonastes*), bog rosemary (*Andromeda polifolia*), round-leaved sundew (*Drosera rotundifolia*), marsh fritillary (*Euphydryas aurinia*), violet copper (*Lycaena helle*), moorland clouded yellow (*Colias palaeno*), among others.


Round-leaved sundew
Drosera rotundifolia

Background

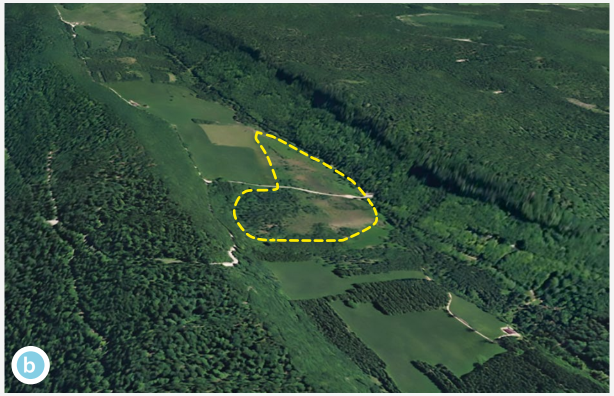
The Entrecôtes-du-Milieu peatland (a) lies in an anticlinal valley which is typical of the Jura, with steep slopes bordered by cliffs. This mixed peatland, basically consisting of a peat bog surrounded by fens, was produced by an old lake formed by glacial overdeepening and moraine blocking off the back of the valley. The Entrecôtes stream runs through the full length of the peatland.

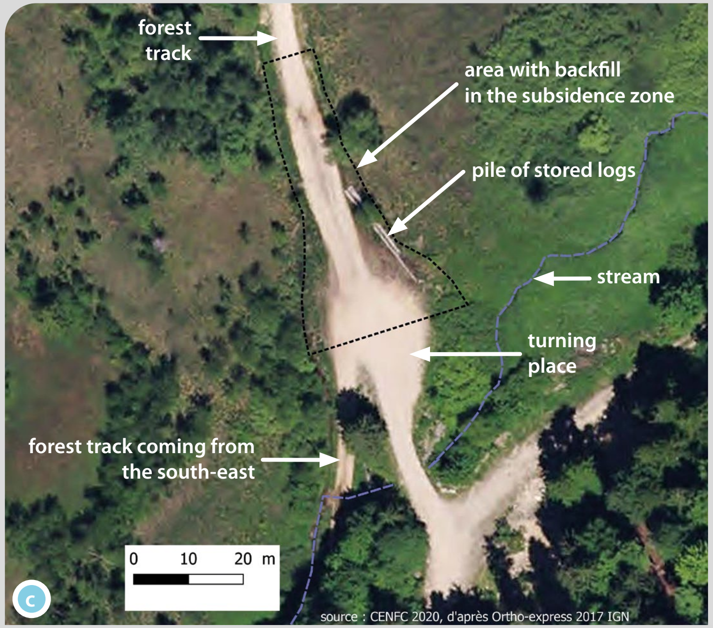
Diagnosis

IDENTIFICATION OF THE PROBLEMS

This peatland, although still rich from an ecological point of view, presents a certain number of functional disturbances: relatively large-scale extraction of peat from the bog, straightening and incision of the Entrecôtes stream, and the end of farming activities on the fens (causing them to evolve towards purple moor grassland, a megaphorb and then forest).

It is also crossed by about 150 metres of forest track (b), one portion of which (50 metres) would regularly subside (c, next page), causing a deviation of the underground waters and redirecting them preferentially towards the stream (drainage effect), in particular in high water periods.


3D aerial view from the north of the Entrecôtes anticlinal valley. The road can clearly be seen (in white) crossing the peatland (outlined in yellow)



Location of the subsidence of the forest track

The road in a period of flooding (November 2015)

In addition, a wider section of the forest track at this point allowing vehicles to turn to go down another track (turning place), was also used to store logs c, leading to a risk of pollution for the stream which passes just next to them (treatment of the logs, leachate).

It is because roads on peat are not very common in France that we decided to devote an information sheet to this issue (and why we will not describe in any more detail the other issues at this site and the work done to address with them).

The subsidence of the track had therefore led the local authority to regularly add material to the portion concerned over the last few decades d. In spite of these efforts, the track continued to subside, and all the more so as the weight of the filling material used was gradually increasing each time it was filled, therefore increasing the deviation of the waters towards the stream and the induced drainage.

A geotechnical survey carried out in 2012 provided an explanation for this phenomenon, showing that the backfill (approximately 1.8 m thick) was on top of some highly compressible material (peat and muddy clays) over 17 metres deep.

PRELIMINARY REFLECTIONS

As the partners did not wish to divert the track up or downstream of the peatland (which, moreover, would have led to other undesirable disturbances), it was decided to undertake a modification of the track itself as part of the Life programme. This modification therefore required combining the improvement of the peatland's hydrology with the current uses of the track (passage of timber lorries, in particular). At the time, two solutions had been proposed by the geotechnical consultants:

- to reinforce the ground by including rigid elements: a very expensive solution (in cost-benefit terms) with no guarantee of success (due to the substantial thickness of the compressible materials);
- to continue regularly building up the surface of the track: subsidence was thought to be of the order of 0.75 m, with refilling spread over more than 40 years.

An examination of the bibliography on roads with a peat substrate, in particular in America and Northern Europe (*Moncorgé S. & Cotte B., 2016*) led to another solution being considered for a period, based on:

- lightening the backfill, by removing the existing gravel material and replacing it with a lighter material, in this case peat, taken from the site;
- reinforcing and rigidifying the bearing layer, by laying a bed of round logs and/or poles, a very old technique still widely used in the Nordic regions.

In particular, this solution would maintain the hydrological continuity between the upstream and downstream parts of the track.

However, these reflections, which continued during the drawing up of the preliminary project (*Moncorgé S. & Langlade J., 2018*) with input from forest infrastructure experts at the French forestry commission, ONF, identified a certain number of problems with this technique:

- the need for the portion of track concerned to be straight, which was clearly incompatible with the need to be able to turn into the forest track leading south-east, which would have required a deviation of that track, a relatively complicated and therefore costly undertaking,
- a high risk of damage due to towing the logs;

- the fact that the track is very wide (up to 30 m at the turning place), leading to difficulties achieving rigidity of the bearing layer;

- a high cost (around €100,000 before VAT) as well as uncertainties and risks during the works phase (subsidence, getting bogged down).

So after discussions between the partners, it was decided to abandon this solution and opt for a much less satisfying solution less from a hydraulic point of view, but which was much simpler, with a substantially longer lifespan and considerably lower cost.

Works

An "assistance to project owner" mission was therefore entrusted to the ONF, which enabled a new project to be devised (*ONF, 2020*) based on:

- a replenishment of the track surface e with a final thickness of 90 cm, but over a reduced width, creating a passable track 3.5 m wide;

- the installation of impermeable geotextiles f, in the form of sheets placed vertically every five metres, perpendicular to the road axis, in order to stop the circulation of the water within the filler material and the drainage effect;

- the elimination of the storage area in favour of a new one 300 metres away (on a plot belonging to the Conservatoire d'Espaces Naturels de Franche-Comté (Conservatory of natural areas), as well as the reduction of the size of the turning place, with the partial digging out of the backfill (creating a pond);

- the placing of metre blocks along the edge of the new track to clearly delimit it.

Replenishment with hard limestone aggregate, size 80/150, over a permeable geotextile

Installation of a sheet of low-permeability geotextile. Embedded every five metres, these sheets prevent the water from circulating longitudinally in the filling material (limiting its draining effect) and direct it preferentially to the other side of the road, towards the downstream peat

The work in figures

Period: the works were carried out between 31/08/2020 and 03/09/2020

Length and surface area:

- Length of track concerned: 50 m
- Material deposited: 180 m^3
- Extracted materials (digging out of filler material to create a pond): approx. 20 m^3
- New log storage area created: 400 m^2

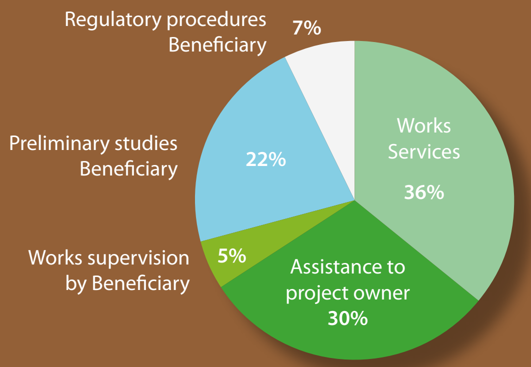
Project owner and main contractor:

- Project owner: Local authority with responsibility delegated to: Conservatoire d'espaces naturels de Franche-Comté (CEN FC)
- Assistant to project owner (AMO) and main contractor: Office national des forêts (ONF)

Contractor: Benetruy TP (Lemuy, Jura)

Total cost of the Life action for the modification of the track: €42,070 incl. VAT *

- Works: €29,873
- ONF assistance: €12,198



** the costs of actions carried out previously (outside the Life scope) on the site are not included*

Results

The works carried out will allow this portion of the track to continue to be used, whilst limiting its draining effect on the peatland, which was at risk of worsening. The backfill will continue to subside and it is possible that it will need to be replenished in a few years' time until it finally stabilises.

This project was marked by the abandonment of a technique that appeared to be interesting from a hydrological point of view (lightening the filler material and rigidification of the bearing layer), but the final solution was the best compromise that we were able to identify that allowed us to reconcile a long lifespan for the road, the limitation of its hydrological impact, and the safety and cost of the restoration g.

Points requiring particular attention

▸ **Networks:** a medium voltage (20,000 V) electric cable buried underneath the track was identified from the outset, so the operator ENEDIS could be consulted before the work began. A reminder of the importance of not neglecting these preliminary investigations and in particular the filing of the Declaration of Planned Works (DT) as far ahead of the implementation of the project as possible.

The track six months after the works

Useful documents

GEORGET, S. 2013. *Etude géotechnique préliminaire de site, chemin, Foncine-le-Haut (39)*. Alios ingénierie ; Commune de Foncine-le-Haut. 18 p. + annexes.

MONCORGÉ, S. & COTTE, B. 2016. *Route forestière de la tourbière de l'Entrecôte à Foncine-le-Haut (39), Choix du principe de réhabilitation et techniques envisagées*. Conservatoire d'espaces naturels de Franche-Comté ; Union européenne ; Agence de l'eau Rhône-Méditerranée-Corse ; Conseil régional de Bourgogne-Franche-Comté ; Conseil départemental du Jura. 5 p.

MONCORGÉ, S. & LANGLADE, J. 2018. *Route forestière de la tourbière de l'Entrecôte à Foncine-le-Haut (39), avant-projet détaillé – version provisoire*. Conservatoire d'espaces naturels de Franche-Comté ; Union européenne ; Agence de l'eau Rhône-Méditerranée-Corse ; Conseil régional de Bourgogne-Franche-Comté ; Conseil départemental du Jura. 22 p. + annexes.

ONF. 2020. *Restauration de la route forestière dans la tourbière d'Entrecôtes, projet. Version du 17 février 2020*. Commune de Foncine-le-Haut ; Conservatoire d'espaces naturels de Franche-Comté. 13 p.

Contact

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Les Douillons peatland

General view of the Douillons peatland during the works

Fact sheet

Natura 2000 site: Grandvaux

Ramsar site: Peatlands and Lakes of the Jura Mountains

Project owner: Parc naturel régional du Haut-Jura

Period of works: 2015-2018

Municipality concerned: Nanchez (Jura)

Accessibility of the site: not developed, unregulated

Area of the peatland complex: 21 ha

Altitude: 855 m

Usages :
- Agricultural grazing on the outskirts of the site
- Hiking and Nordic ski trails on the outskirts of the site

Espèces d'intérêt : Large white-faced darter (*Leucorrhinia pectoralis*), violet copper (*Lycaena helle*), among others.

Large white-faced darter
Leucorrhinia pectoralis

Background

This peatland (a) is situated at the extreme south of the Grandvaux syncline. The pericline was filled in partly by the silting up of a body of water in the bottom of the depression (limnogenous component), and partly by constant percolation of water from springs and seepages in contact between fractured limestone beds and marly beds (soligenous component). With the increase in the thickness of the peat in the top part, to as much as five metres, the vegetation gradually found itself further and further removed from contact with the minerotrophic waters. The growing proportion of meteoric waters favoured the appearance of acidic groups, including sphagnum mosses leading to the formation of a raised peat bog (ombrotrophic component).

After exploitation by families from Chaux-des-Prés and agricultural drainage from about 1969, semi-industrial peat extraction began in 1973. A permit to create a horticultural peat quarry was granted by the Prefecture. This exploitation was rapidly halted a year or two later.

Diagnosis

IDENTIFICATION OF THE PROBLEMS

The digital terrain model (DTM) based on data from LiDAR scanning clearly shows several topographical elements, including:

- the fronts where the peat was cut, with clear rectangular shapes towards the northern edge of the peatland;
- the presence of a large north-south ditch running along its eastern flank;
- the incisions of the drainage ditches running into the feeder drain at the bottom of the thalweg on the southern edge of the peatland.

During the attempt to mechanically exploit the site for horticultural peat, a roadway made of wooden railway sleepers treated with creosote was laid for the vehicles to run on, then abandoned in the middle of the peatland.

In the 1980s, some first attempts were undertaken to restore the site. The resources invested in the project were insufficient and the results not entirely satisfactory. :

- in the mid-1980s, the first phase of these works consisted of a "restoration after exploitation" and was supposed to flood the old industrial pits, but the plugs installed were too porous and generated water retentions with fluctuating levels;

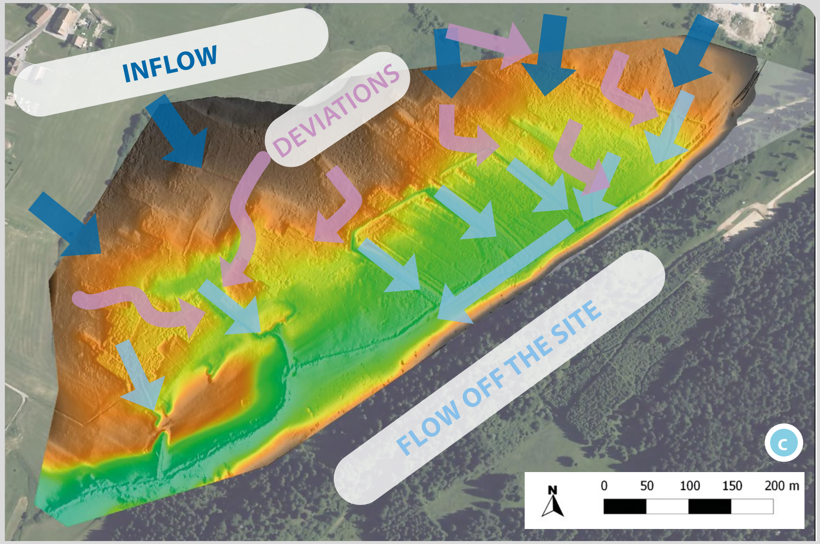
- a restoration phase, conducted by the Haut-Jura Regional Nature Park at the beginning of the 2000s, consisted firstly of harvesting the spruces that had been planted on the peatland and, secondly, of blocking the ditches with manually-installed panels. Although they were effective for a few years, these installations were quickly circumvented and become inoperative b. The two main pits were filled in with morainal material.

After that, for one of the pits, an overflow was formed on the structure, which was quickly eroded and disappeared. For the other, the topography allowed lateral overspill, which was more diffuse and did not damage the structure.

FUNCTIONAL ANALYSIS AND RESTORATION POTENTIAL

After analysing the topography, the major trend that took shape was a natural supply of water to the peatland from its north-east to north-west flanks. But the extraction of the peat caused substantial modifications to the topography and the water retention and flow conditions c. Although the small number of small extraction pits (blocked up in some places) contributed to recreating, here and there, water stagnation conditions favourable to peat accumulation, the network of drainage ditches, dug as the exploitation of the site had progressed, continued to disrupt its functioning. The ditch running round the edge of the peatland intercepts virtually all the incoming peripheral surface waters. The inner network evacuates the water towards the peripheral feeder drain.

In addition, the large pits dug out mechanically around 1973 deprive a whole central section of the peatland of water. This has resulted in severe drying out and consequently a mineralisation of the peat accumulated over thousands of years. The mineralisation of the peat in turn generates a eutrophisation of the environments. The drop in the average elevation of the groundwater and the eutrophisation have lead to an invasion of the peatland by ligneous species, with the result that maintaining the heritage species of the open-country environments can no longer be guaranteed.



The analysis of the surface topography resulting from the exploitation of the peatland allows the points of disturbance that are diverting the water from its natural course to be identified

Old wooden panel, circumvented, no longer serving its purpose as a dam

CHALLENGES OF THE SITE

► **Biodiversity:** the water body generated by the obliteration of one of the industrial extraction pits was quickly vegetated, with the installation of rafts of floating plants in particular. In 2012, it had one of the largest populations of large white-faced darters in the Jura mountains. The fragility of the rewetting and the isolation of this population, however, made it fragile. The works were therefore intended to stabilise this body of water and allow the water to be restored to other pits to multiply the number of sites favourable to the species and make it less dependent on a single water body and therefore less fragile.

Works

Before beginning the works on the site, ligneous species were cut down and shredded, concentrating mainly on the trees hindering the access to the worksites.

To remove the roadway used during the industrial exploitation of the peatland, some 800 timber railway sleepers were removed from the peatland. This waste was removed, treated and disposed of by SNCF in accordance with the regulations.

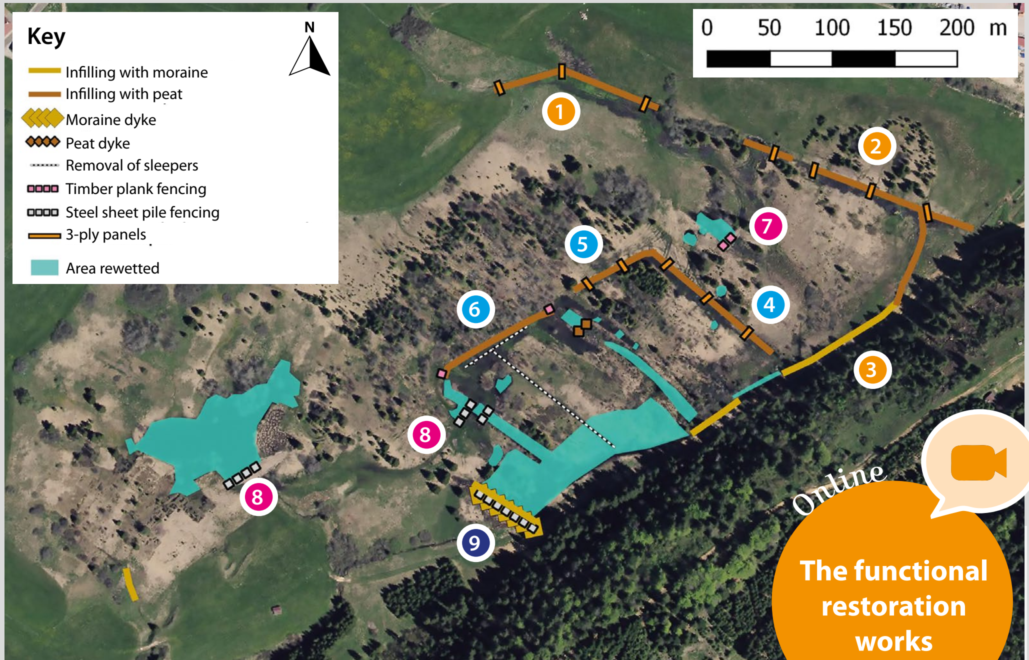
Obliteration of the peripheral ditches, to stop the interception upstream of the waters coming from the edge of the peatland and to slow the drainage towards the system outlet downstream:

- ditches 1 and 2, about 1.5 m wide and 1 m deep were filled in as far as possible with peat taken on site, reinforced by three-ply wood panels. This ensured a better lateral dispersion of the water than a succession of basins;
- the main feeder drain in the south 3 was filled in with morainal material whilst maintaining a zone under water between two infilled stretches (150 m filled in and 200 m blocked off).

Moraine was chosen to fill in the south feeder drain as the volume involved was large, access was easy and the ditch was situated along the slope, therefore largely influenced by mineralised waters

Obliteration of the ditches in the interior of the peatland, to eliminate the drainage and limit the "islands" in the middle that are drying out:

- ditches 4 and 5 were filled in entirely with peat taken on site, forming hollows 3 and 4 and reinforced by a three-ply wood panel structure;
- ditch 6, which was over 2.5 m wide and 2 m deep, was entirely filled with damaged peat taken from the ridges of peat from the cleaning out. The ends were reinforced by planks of spruce to ensure watertightness and solidity.



Works carried out between 2016 and 2018 on the Douillons peatland

Online

The functional restoration works

Rewetting of old peat extraction pits

- 8 by installing steel sheet piles, when the depth of the waters retained exceeded 1.5 m. The volume of covering material required was considerable. To make up for the lack of available peat, part of the material used came from morainal deposits and the final covering was done with peat taken from an old hummock on a "raised peat bog" or from hollow 10.
- 7 by installing a spruce planking fence, when the depth of the water retained was less than 1 m. The peat used to cover the fence was taken from nearby (hollow 2). The two dykes were covered with straw, actually hay harvested from the Combe du Nanchez fen to protect them from drying out too quickly and encourage revegetation.

Stabilisation of the water level in the peatland, downstream, by creating a buried moraine dyke placed on top of the enclosing clay 9. The scale of this structure is such that in the long term it should restore the assumed pre-drainage water level and make up for the subsidence of the peatland, whose surface level has dropped due to erosion and the mineralisation of the peat.

Points requiring particular attention

▶ **Topography:** it must be remembered that any low point generating an overspill onto a structure or a preferential flow in the evacuation of the water, will inevitably cause erosion, which will jeopardise the survival of the works over the more or less long term.

d

▶ The rewetting of mineralised peat can mean that solutions of nutrients are formed and transferred into the hydrosystems. Certain hollows can be covered temporarily by duckweeds or filamentous algae due to eutrophication d.

REGULATORY FACTORS

The feeder drain, although created in 1969, had the features that meant it met the regulatory definition of a water course. It was considered as such in the procedure.

Under the Law on Water and Aquatic Environments and **Decree no. 93-742** of 29/03/1993 consolidated on 18 July 2006, it was subject to the authorisation regime for the following sections:

- **3.1.1.0.:** : installations, structures, backfilling and groynes in the low-water channel of a water course constituting an obstacle to the flow of flood waters or to ecological continuity;

- **3.1.2.0.** : installations, structures, works or activities modifying the longitudinal or transverse profile of the low-water channel of a watercourse.

- **3.1.5.0.** : installations, structures, works or activities, in the low-water channel of a water course of a nature to destroy the spawning grounds, growth zones or feeding zones of fish fauna, crustaceans and amphibians.

Subject to the declaration regime for the following sections:

- **3.2.3.0.** : creation of permanent bodies of water;

- **3.3.1.0.** : drying, rewetting, sealing, backfilling of wetlands or peat bogs.

Results

DYSFUNCTION

Two of the structures installed in 2016 have shown dysfunctions:

▶ 8: from 2016 to 2018, the pit would fill up from heavy precipitation and then empty again after periods of about a month without rain. It would seem that the exploitation in the past had attacked the entire body of peat in some places, reducing its capacity to retain water and allowing it to reach gravelly moraine that is not totally impervious. From 2020 onwards, in spite of very low water levels, the pitch remained filled with water. Have the organic deposits built up to seal the bottom of the pit?

▶ Moraine dyke 9: from the first winter 2016–2017, an overspill point was observed on the dyke, probably the result of some subsidence due to the weight of the morainal material on the enclosing clay. A low point was created. Once the overspill had taken hold, the dyke was very quickly breached.

9

The overspill on the dyke very quickly generates a breach by erosion

In March 2018, the dyke was reinforced with a 70-metre long steel fence, with a low point chosen and stabilised to allow a four-metre outflow, on the left bank, along the slope rather than onto the peat..

9

Reinforcement of the dyke by installing a curtain of steel sheet piles. This would then be covered with peat and become vegetated.

MONITORING SET UP

▶ Flora and bryophyte monitoring: 21 plots monitored annually since the year of the works and complete mapping in 2020.

▶ Hoverfly monitoring: 2016/2019, before and after the works.

▶ Monitoring of the Odonata and especially *Leucorrhinia pectoralis*. For this species, in 2019 no notable increase in its population was observed, although it was dispersed across a large number of pits. Finally in 2020 the positive impact of the works on the population of *Leucorrhinia pectoralis* was confirmed when 168 imagoes were observed across the whole site (number up 60% compared to 2016, spread between nine hollows) and with the collection of about a hundred exuviae on two new water bodies.

Before - After

The work in figures

Periods: between December 2015 and September 2016. The structure was 9 repaired in March 2018.

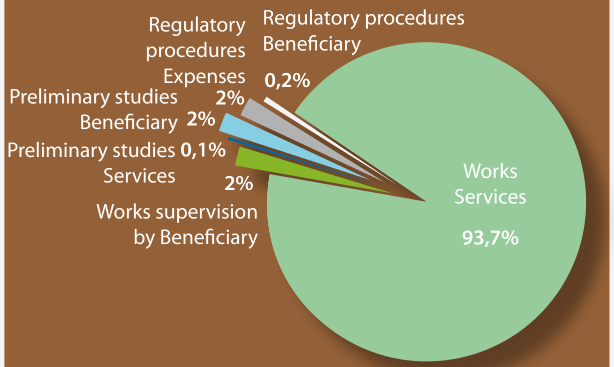
Length and surface area:

- Neutralisation of 1,170 m of drainage ditches
- Rewetting of 2.27 ha of old extraction pits
- Control of about 0.8 ha of ligneous species colonising the areas along the ditches and water courses

Contractors: LIN'eco for the study and Jura Natura Services and Goyard TP for the works

Total cost of the Life action: €211,153 incl. VAT *

- Works (green): €202,024 (including €26,600 for the dyke repair)
- Preliminary actions (blue + grey): €9,129



** the costs of actions (including the preliminary study) carried out previously (outside the Life scope) on the site are not included*

Contact

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Complete obliteration of the ditch 6

Water retained in the lower part of the peatland 9

Rewetting of the old peat cutting pits by installing a fence 8

Les Rousses peatland

Noir reach, Lac des Rousses and Les Rousses peatlands

Fact sheet

Natura 2000 site: Orbe valley

Ramsar site: Peatlands and Lakes of the Jura Mountains

Project owner: Parc naturel du Haut-Jura

Year of works: 2018

Municipality concerned: Les Rousses (Dept. of Jura)

Accessibility of the site: Partially developed for pubic access, unregulated

Surface **area of the peatland:** approximately 100 ha beside a 90 ha lake

Altitude: 1,160 m

Usages :

- Agricultural meadows on the outskirts of the site
- Nordic skiing of the outskirts of the zone and one trail crossing the peatland
- There is a discovery trail with a raised boardwalk and interpretation boards in one small area
- Water sports centre on the lake nearby - Golf courses upstream and partially on the peatland

Species of interest: Violet copper (*Lycaena helle*), dusky dark blue (*Phengaris nausithous*), marsh fritillary (*Euphydrias aurinia*), Geyer's whorl snail (*Vertigo geyeri*), round-mouthed whorl snail (*Vertigo genesii*), glossy sickle moss (*Hamatocaulis vernicosus*), among others.

Violet copper
Lycaena helle

Background

The Orbe flows across the border from the Lac des Rousses (a) in France to the Lacs de Joux and Brenets in Switzerland before being lost in the karst. This closed 30-kilometre long valley corresponds to a steep-sided syncline channel. The bottom of the valley is one of most extensive and richest peatlands in the Jura mountains.

The peat deposits in the Rousses peatland are highly limnogenous, meaning they developed on a lacustrine infilling (*Magny M. & Richard H., 1987*), which has seen the surface area of the lake being reduced by two-thirds in 15,000 years. Certain sectors have progressively evolved into an ombrotrophic peatland. Generally peat formation seems to have started only at the beginning of the Christian era. The thickness of the peat in the valley varies considerably depending on the context of the deposits, reaching 4 metres in places.

The Rousses peatlands were extensively exploited for domestic heating, at least into the 1970s. Some rare peat extraction continued into the middle of the 1990s.

Diagnosis

IDENTIFICATION OF THE PROBLEMS

The peatlands and particularly the raised peat bogs are "striped" with ditches delimiting the blocks of peat to be extracted. In the Berthets peatlands, these ditches are about 15 to 30 metres apart and would have been about 1.50 metres deep. The peat extraction pits were dug following these ditches, moving up from the lake towards the valley slopes. Under the effect of the drainage, the parts that were relictual peat bog were rapidly afforested, forming mountain pine woods. There is evidence of woodland in the past, with the presence of wood in the peat. But was it so dense? It is unlikely.

It is difficult to tell what is natural and what is inherited from the exploitation of the entire La Gouille à L'Ours alkaline fen, where the Noir and Février reaches flow together. Straightening and deepening of the water courses, resulting partly from a drop in the level of the lake, contributed to the drying out of certain sectors of this peatland.

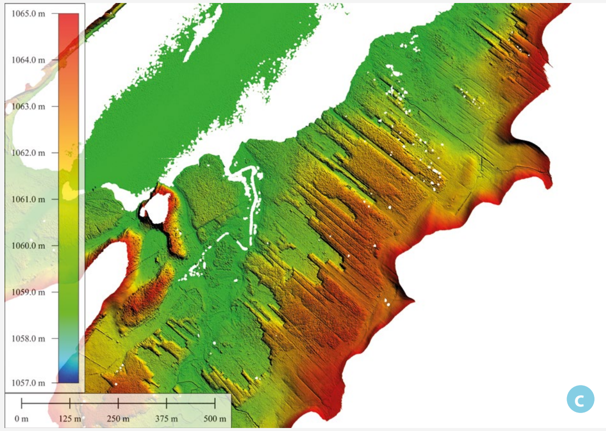
FUNCTIONAL ANALYSIS AND RESTORATION POTENTIAL

Within the peatland, two functional ensembles must be distinguished: the raised peat bogs and La Gouille à l'Ours, an area of alkaline fen with two streams running through it.

Ditch rendered visible again when its water supply was restored. Before the obliteration work, the hollow was always dry and concealed by vegetation

► The **peat bog** is largely occupied by a mountain pine wood, replaced in places by a birch or spruce stand in the vicinity of the extraction pits. The presence of these woods means it is very difficult to get a clear idea of the exact topography, especially across a peatland of this size. The network of ditches revealed by the DTM produced by LiDAR scanning is often difficult to see on the ground. As they are often not very wide, they are often clogged up on the surface, while continuing to have a draining effect deeper down. Heath coverage also often helps to mask slight depressions b.

The scale of this drainage network would not have become apparent without the LiDAR survey c. The dryness on the surface and the invisibility of the ditches in the peat bog may have led to doubts as to whether its obliteration was a good idea.



Scale of peat extraction and the drainage network revealed by the LiDAR survey

Associated with this network of ditches, a collection of peat extraction pits, open on the downstream side, has also caused serious drying out in the high peripheral zones. Obliteration of the outlets could help to restart peat formation inside these pits themselves where the water can be kept at a high level and to reduce the drainage of the peripheral zones.

► The **fen sector** corresponds to the place where the Février and Noir reaches converge. This zone has been profoundly disrupted by peat extraction, which has shifted the bed of the Février reach up against the peat extraction face. Gauging the situation before the peat was extracted is impossible. Any hope of returning to that previous situation is also illusory. The analysis of the vegetation has shown a tendency towards drying out and trophic enrichment near the water courses. These water courses were generally deeply cut and oversized, operating as drains. At low water, the nappe of water was very shallow and a long way from the groundwater table d. A functional improvement would therefore require an altitudinal rebalancing of the water courses.

Noir reach at low water, operating as a drain in the fen

To re-establish a water level consistent with the functioning of the peatland and slow the flows as much as possible, the preferred option was remeandering. For the Février reach, which was very straight, it was decided to redraw its course completely, with a smaller gauge. For the Noir reach, which was still winding and of substantial in size, it was opted to create a few meanders in certain straight stretches. The altitudinal calibration points for the stream bed have allowed the entire water line to be raised leading to a better equilibrium between the water table and the water course.

CHALLENGES OF THE SITE

▶ **Catchment area:** water is taken from le Lac des Rousses to supply six municipalities with potable water. The network of drains generates direct exchanges between the agricultural land on the slopes and the lake, potentially facilitating the transfer of organic matter into the body of water. In addition, the quantity of peat extracted from around the perimeter of the lake can be estimated at about 150,000 m^3. In addition to this, a further quantity of peat has disappeared through mineralisation. The stock of water that has disappeared corresponds to about 20% of the annual withdrawals of potable water.

▶ **Biodiversity:** overall the site hosts a remarkable diversity of species typical of the Jura peatlands. Seven of the nine Fauna and Flora Habitats Directive species targeted by the programme are found on the site e. The mosaic of environments favours a wide diversity of species. The most emblematic species are mainly situated in the most functional parts of the peatland. This is not where the interventions were targeted.

▶ **Tourist appeal:** Les Rousses is an undeniably attractive tourist resort. In winter, the extensive peatland and pine woods bordering the lake give a Scandinavian feel to the site. It is used for Nordic skiing in winter. This factor had to be taken into consideration during the reflection on what actions to take. In this case, it was the skiing activity that was adapted to the restoration issues, in partnership with the resort, in order to preserve an itinerary that is important for the use of this natural environment.

Works

▶ **Peat bog sector:** the works involved obliterating several ditches and rewetting the peat extraction pits.

▶ **Fen sector:** the two reaches that converge in the fen were reworked to restore the relationship between the water table and the water course, whilst favouring the retention of water as far as possible. In order to guarantee a better equilibrium during low-flow periods, the size of the water courses was deliberately limited, with a square cross section and vertical sides. Over time, the profile should return to a more natural shape. But this could take a long time in the peatlands, where the water courses are not very powerful as they quickly overflow, and where they carry virtually no sediments.

As a first step, the ligneous trees were cut down and shredded in the two sectors, concentrating on the trees hindering access to the worksites. It was necessary to lay out pathways for the vehicles/machinery moving around the peatland. The felled trees were cut up, piled up and abandoned on site.

Given the dispersion of the works over a very wide area, the large quantities of materials to be delivered, the transport distances involved and the sensitive nature of the ground in both the surrounding meadows and the peatland itself, the spruce planks (26.4 m^3) and 34 3-ply wood panels were brought in by helicopter. This allowed all the materials to be dropped into place within about 45 minutes, compared to at least six days which would have been needed had they been brought in overland with, in addition, a risk of causing much more damage to the ground.

Black darter
Sympetrum danae

REGULATORY FACTORS

The remeandering of the Noir and Février reaches required a procedure under the Law on Water and Aquatic Environments and Decree No. 93-742 of 29/03/1993 consolidated on 18 July 2006 - Authorisation regime for the following sections:

- **3.1.2.0.: :** Installations, structures, works or activities modifying the longitudinal or cross-sectional profile of the low-water channel of a watercourse.

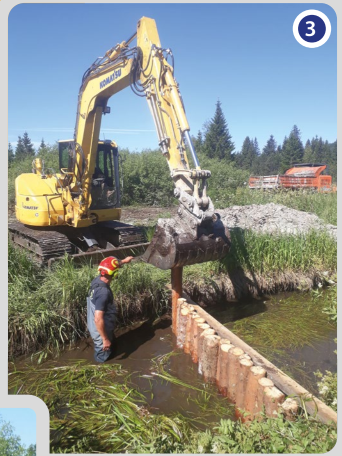
- **3.1.5.0.: :** installations, structures, works or activities, in the low-water channel of a water courses of a nature to destroy the spawning grounds, growth zones or feeding zones of fish fauna, crustaceans and amphibians.

The rewetting of a peat extraction pit led to the flooding of bog-rosemary plants, a species protected at national level. Considering that the number of plants concerned represented a negligible proportion of the large population in the peatland, that evolution of the pit in question would eventually be unfavourable to the species and that the environments to be recreated would be more favourable to the species around the edge of the rewetted zone, the DREAL (regional environment department) granted an exemption from the protected species regulations.

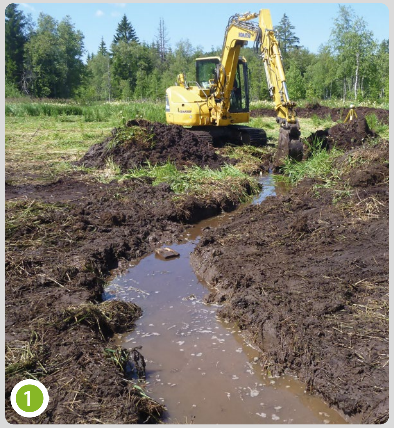
Points requiring particular attention

▶ **Rewetting of the extraction pits:** given the substantial differences in ground level across the peatland and the topographical effects generated by mineralisation around the edges of the pits, often it was not possible to totally re-flood the pits. This then affected the reduction in the lateral drainage.

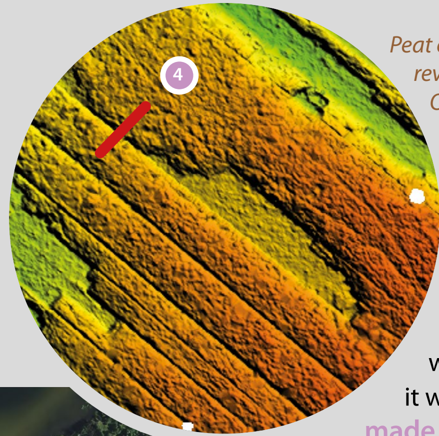
The course of the Noir reach is subject to considerable fluctuations in its level, directly linked to water level drawdowns in Lac des Rousses. A stream bed ramp was put in place downstream of the work area 3 to avoid significant headward erosion at low water. To limit the amount of material that needed to be brought in, it was decided to create two curtains of stakes made from spruce cut on the site and to fill them with lacustrine clay taken from underneath the peat. Unfortunately, the gaps between the spruce stakes were too large and the clay was too soft and the structure was quickly eroded. It had to be redone.



As the course of the Noir reach had not undergone any drastic modifications, the works mainly involved reconnecting the elevation of the water table with that of the water course. To achieve this, a few meanders were recreated here and there 1 to raise the entire water line again. The project concerned 660 m of water course. Six stretches were created, with a gauge of 70 x 40 cm, over a total of 342 m while 265 m were filled in. Each intersection was reinforced with a fascine of dead wood. This will gradually degrade, once the infill has stabilised. The work was carried out by an 8-tonne excavator operating on ground mats. The reaches conserved should be quickly colonised by helophytes which will progressively reduce the cross section which is currently oversized.

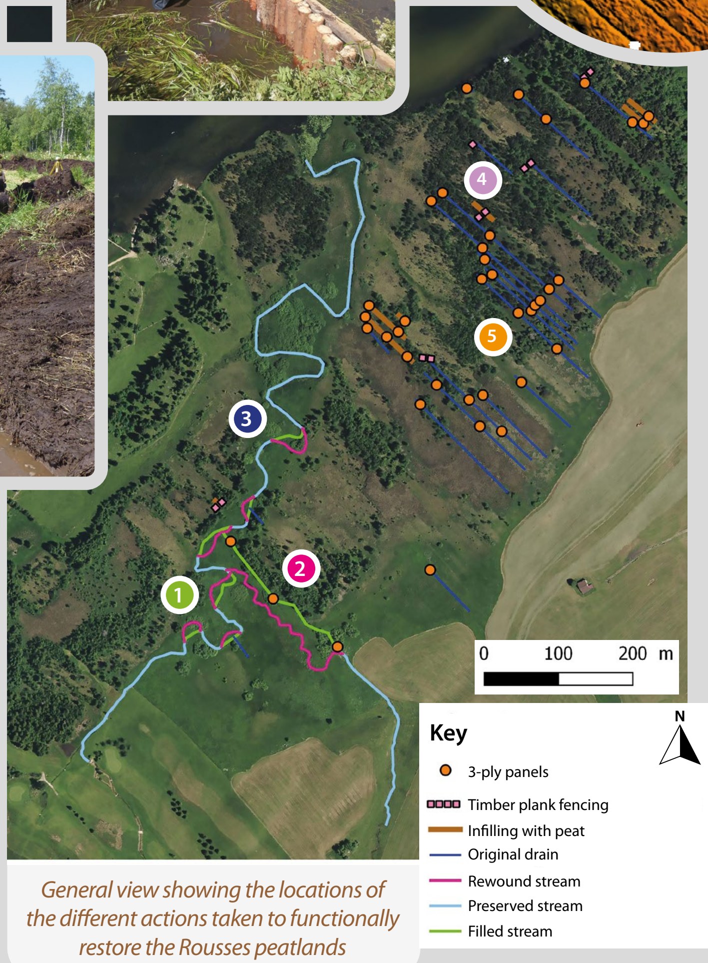


In the case of the Février reach, the damage was severe. The water course had been displaced up against the peat extraction face. A new course was created over a 285-metre stretch 2. Given the profound changes to the topography resulting from peat extraction, the recreated stream bed was not able to follow a previous natural course. A meandering course was chosen for its compatibility with the current topography and because it was in keeping with the hydrodynamic equilibrium sought. The guide bed was dug out with a gauge of 40 x 30 cm using a mini-excavator operating on ground mats to avoid making any ruts near the stream bed. The abandoned straightened bed was completely filled in over a 250-metre stretch using peat retrieved from a relictual peat bog hummock with no prospect of being revitalised given its topographical isolation. This took about 100 m³ of material.



Peat extraction pit in a forest setting, revealed by the DTM. Obstruction by a fence placed on the outlet.

4 Six peat extraction pits were rewetted by obliterating their outlets Given the dimensions of the outlets and the nappe of water intended to be retained, it was decided to install fences made of spruce planks. These were anchored in the underlying lacustrine substrate, at a depth of 4 metres, and are 8 to 15 metres long.



General view showing the locations of the different actions taken to functionally restore the Rousses peatlands

The relatively small dimensions of the ditches, 1.50 m deep by 50 cm wide meant that it was possible to obliterate them with peat plugs reinforced by a wood panel structure 5. Over time, the "mouth" of the ditches had flared out due to mineralisation, their widths reaching about 1.50 m in places. The panels used were, in most cases, 4 m wide and 2 m high. The peat used for the plugs was taken from downstream to allow a length of about 20 m of ditch to be filled, 10 m on either side of each plug. The vegetation extracted from the area where the peat was dug was set aside and re-used on the surface of the plugs to cover the peat. The shortest ditches or those draining an extraction pit, were completely plugged. 35 plugs were thus created.

The work in figures

Periods: between March and July 2018

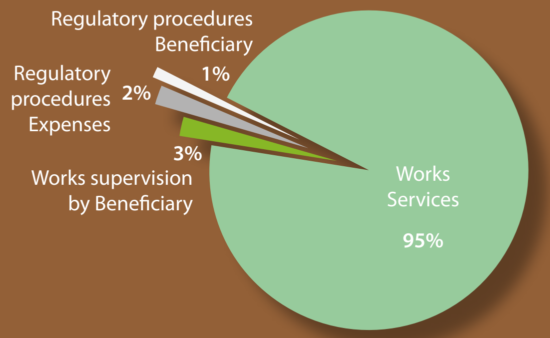
Length and surface area:

- Obliteration of 2,812 m ditches in the peat bog
- Rewetting of 1.6 ha of old peat extraction pits
- Re-creation of about 650 m of water course, to rebalance just over 1,000 m

Contractors: Biotec for the study and the regulatory documents concerning the water course part and Jura Natura Services for the works

Total cost of the Life action: €272,172 incl. VAT *

- Works (green): €264,804
- Preliminary actions (grey): €7,368



** the costs of actions (including the preliminary studies) carried out previously (outside the Life scope) on the site are not included*

Results

The rewetting of the pits in the peat bog was very rapid, in spite of the dry weather in 2018. This proves the interest of obliterating the ditches, even when they do not seem to be active on the surface.

The colonisation by sphagnum mosses including *Sphagnum angustifolium is not homogeneous.* If there are individuals present in the vicinity of the rewetted zones, colonisation can take place very fast.

MONITORING SET UP

▶ Monitoring of the flora and bryophytes by mapping the coverage over nine plots measuring from 200 to 1,770 m^2.. This should document the evolution of the impact of rewetting according to the distance from the zones actually worked upon. Initial status in 2018. Repeated in 2020 and again after that, no time to be defined.

▶ Hoverfly monitoring: 2015/2018 initial status.

▶ Piezometric monitoring on a transect along a set of peat bog ditches

Before - After

Evolution of a peat extraction pit after obliteration - Works done in May 2018

June 2018
Rapid appearance of water following a big storm

May 2019
Pit completely full of water thanks to winter precipitation

August 2021
Pit entirely covered by a raft of sphagnum angustifolium

Useful documents

BIOTEC. 2016. *Restauration du bief Noir et du bief Février, affluents du lac des Rousses, commune des Rousses*. Dossier d'autorisation au titre des articles L.214-1 à 6 du Code de l'Environnement.

CLAUDE, J. ; TISSOT, B. ; GENS, H. & SPEIGHT, M. 2016. *Diagnostic écologique de la tourbière des Rousses (Les Rousses - 39) par la méthode « Syrph the Net » : Etat initial avant travaux de réhabilitation*. Rapport d'étude, Les amis de la réserve naturelle du lac de Remoray. 27 p. + annexes.

GENS, H. ; TISSOT, B. ; CLAUDE, J. & MAZUEZ, C. 2019. *Diagnostic écologique de la tourbière des Berthets (Les Rousses - 39) par la méthode « Syrph the Net »*. Rapport d'étude, Les amis de la réserve naturelle du lac de Remoray. 29 p. + annexes.

HUGONNOT, V. 2021. *Suivi de la végétation vasculaire et des bryophytes après travaux de restauration hydrologique - Tourbière des Rousses (les Rousses-39) - Année n+2 - 2020*. 45 p.

Contact

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Part 3

Focus on techniques

Restoration techniques used

Introduction

This part of the digest is not intended to present the thought process that guided the choices behind the use of different techniques, since that aspect is largely covered by the site information sheets. Rather it aims to present the techniques most often used and some that are more original, the operational methods involved, their advantages and drawbacks, their costs, etc.

Several of the techniques used to neutralise drainage ditches or peat extraction pits in the Life programme are based on Swiss experience in the field, as detailed in what is the reference work, the "Guide de régénération des haut-marais" published by the Federal Office for the Environment (*Grosvernier & Staubli, 2009*), completed by the experience acquired during the LIFE "peatlands" programme and that of other specialists consulted during the implementation period.

These technical methods were implemented specifically as part of the Life Jura peatlands programme, in particular geological and hydrological contexts so that they can in no way be considered as "formulas", but they can certainly provide input for consideration when preparing other projects.

Two main categories of situations guided the choice of these techniques:

▶ Situations requiring the neutralisation of drainage ditches: the techniques were adapted to take account of the slope and size of the flow, their remoteness and the difficulty of gaining access with machinery and the availability of materials necessary for infilling. Total neutralisation of the drainage channel is always preferable, but the specific constraints of a site can lead to adjustments.

▶ Situations requiring the flooding of old peat pits or zones of subsidence or modification of the topography due to mineralisation: the techniques were adapted to take account of the dimensions of the pit and the hydraulic load induced by the dam, the nature of the soil/subsoil, the materials available in the vicinity, etc.

neutralisation of the drainage ditch in the Lac de Malpas peatland

Preamble: accessibility and access routes

▶ The accessibility of the site and the issue of transporting supplies to the work areas were **severe constraints** on feasibility at all the sites in the Life programme.

The structure of peat, which essentially consists of plant fibres, does not have the same resistance to the repeated pressure of machinery and vehicles depending on whether it involves the hummocks of a peat bog or a fen. Working in drier conditions (which is strongly advised) only partially limits the risk of machinery and vehicles getting bogged down, and it is the resistance of the peat's structure to repeated passages that will guarantee a certain bearing capacity. This is very variable and must be investigated before starting any work.

It is necessary to take careful account of and anticipate:

- the sensitivity of the surface vegetation: the existing plant cover, and in particular sphagnum mosses, can be very sensitive, on the one hand to compression and, on the other, to being torn out by vehicle tracks;

- the weight of the supplies brought in overland must be limited to reduce pressure on the soil, which generates extra return trips;

- repeated return trips by vehicles/machinery, even when of an appropriate type or travelling on ground mats, generate pressure on the soil that can alter the topography of the ground and generate unwanted water flows which could jeopardise the project.

The majority of the materials for the Life work sites were brought in overland. The tracked vehicles used always had a ground pressure load of less than 350 g/cm² 1. In addition, elastomer-type flexible tracks were used to reduce the damage to the soil and vegetation.

Site information sheets concerned: Gouterot, Les Levresses, Malpas, Crossat, Moutat, Entrecôtes-du-Milieu, Douillons

▶ On sites that were particularly waterlogged and/or where the terrain had been altered by past peat cutting, or which were especially sensitive, the contractors were required to have their vehicles and machinery travel exclusively on ground mats, which increase the bearing capacity of the ground and protect the vegetation 2. This generates much longer supply times. For the most delicate supply and circulation zones, passageways of ground mats were installed to cover the entire sensitive route

Site information sheets concerned: Forbonnet

▶ On the driest sites and those with a better bearing capacity (forest plantations with drainage which had seriously dried out the soil), machinery with "standard" metal tracks and robust enough to resist branches and tree trunks travelled on a bed of logs cut on site could be used without any significant impact on the soil 3. The bed of logs was removed on completion of the works.

Site information sheets concerned: Villeneuve-d'Amont

▶ In some very specific situations - difficult-to-access work sites a long way from the roadside, particular sensitivity of the peat and/or peripheral terrain (agricultural land, for example), large quantity of materials to be transported - it was decided to bring in the supplies by helicopter 4. This solution was used either because there was no realistic alternative or because it offered the best cost/effectiveness/preservation ratio:

- use of machinery limited to that needed to construct the structures;

- limited fuel consumption in spite of the use of helicopters: no long overland transport requiring several machines (depositing/transporting/picking up equipment);

- intervention time kept down a few hours compared to several days or weeks, helping to keep costs under control;

- a substantial gain in terms of the preservation of the peatland.

This method requires a prior cost study, although the ecological cost, for substantial quantities of supplies, is advantageous in any case.

Site information sheets concerned: Cerneux-Gourinots, Grande Seigne, Les Rousses

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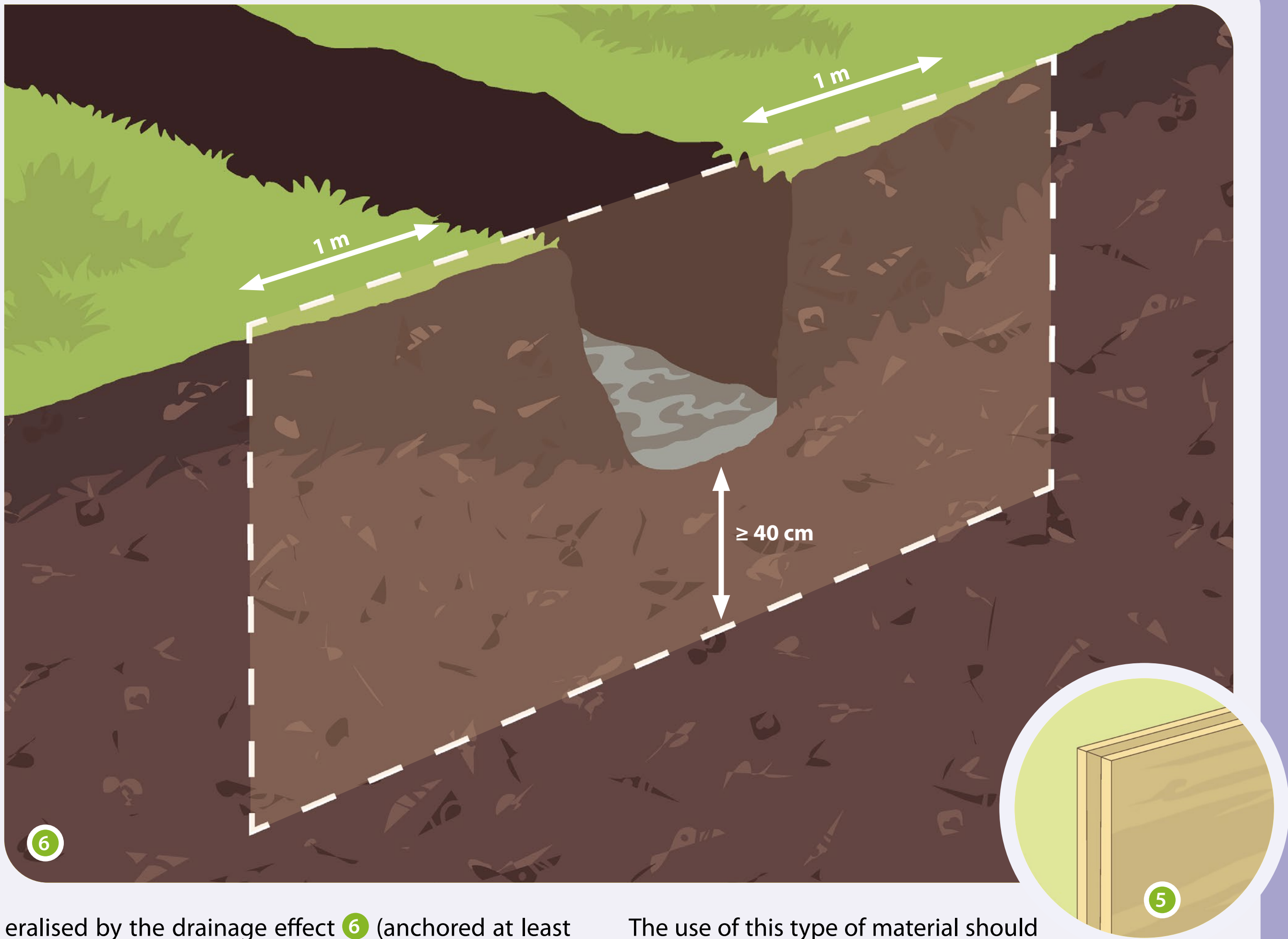
1/ Points blocked with solid wood panels

► **Principle:** the drainage of the surface peat and the peat around the ditch leads to mineralisation, which makes it more porous. The purpose of installing blockages in the ditch is to stop the water vertically and horizontally and disperse the flow by forcing it towards the surface through the entire column of peat and as widely as possible laterally. The installed structures have to be in sufficient number and close enough together, in view of the up/downstream and lateral topography (left bank/right bank) to effectively block the flow of water.

► **Characteristics of the panels:** solid wood panel, type 3-ply, 5 at least 22 to 30 mm thick made of solid wood (untreated, no formaldehyde glue). The maximum dimensions that are available on the market are 5 m x 2 m, while any smaller size is possible.

► **Context of use and installation:** totally immersed in the water and peat soil, these panels are used in shallow ditches of medium width. It is necessary to take account of:

- the need to anchor the panel at a depth of at least 40 cm 6 in a watertight or very low hydraulic conductivity substrate (mineral substrate or very good quality peat) to avoid any risk of the water flowing under the panel (all the more important if the panel is used as a simple dam with infilling);
- the need for lateral anchoring beyond the zone mineralised by the drainage effect 6 (anchored at least 1 m into each bank after clearing out the highly mineralised part of the bottom and sides of the ditch);
- The ratio between the very limited thickness and the considerable width of these panels means there is a high risk of them breaking when they are driven into place, so their use must be reserved for peat that offers low resistance when they are driven through it and that is rather loose, free of roots and very dense fibric layers (such as sedge).



The use of this type of material should be reserved for moderately sized ditches, up to a maximum width of 2.5 m and a bank height of 1 m.

After the groundwater is reloaded, the wooden panel will be totally immersed in the water and peat and therefore should not be affected by decomposition if, and only if, the peat protects the panels to a sufficient depth and does not mineralise over time.

▶ **Cost per m²:** the relative cost of the material used is low (about €25 exc. VAT/m²), but the cost of installation varies depending on the distance to the site and the difficulty of installation.

Site information sheets concerned: Villeneuve-d'Amont, Forbonnet, Crossat, Mouthe, Entrecôtes-du-Milieu, Douillons, Les Rousses

Point requiring particular attention

▶ Extra vigilance is required when the ditch is not completely filled in. Panels installed in isolation must be well protected against decomposition by a mound of peat. Even with a substantial mound of peat, it has been found that when there are repeated episodes of hot, dry weather these mounds can become highly mineralised so that they degrade and leave the structure exposed again. It is then necessary to immediately renew the protection.

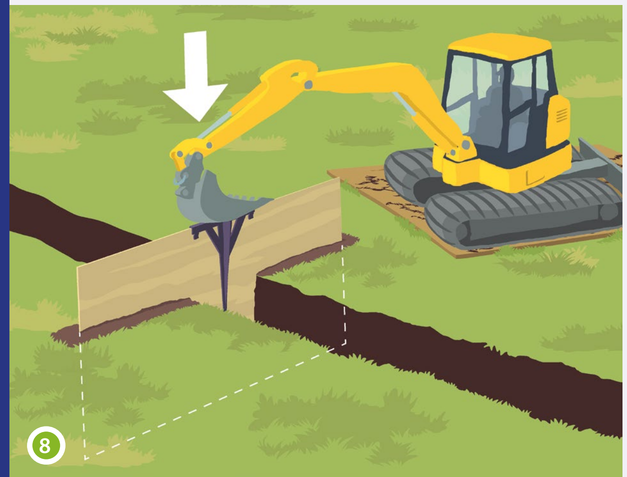
Method of driving in the panels

a Strip the top layer off the area where the panel is to be installed to lay the peat bare and set aside the vegetation removed.

b Use of a cutter: a metal blade attached to the excavator arm which can cut through the full thickness of the peat to prepare the installation of the panel 7. This technique is particularly necessary when the peat contains a substantial amount of wood residue, roots and very dense fibres. If this is not done, the presence of these plant-based obstacles in the peat can prevent the panel being driven in properly, and the risk of it breaking increases as the pressure from the excavator arm increases. In extreme cases, it may be necessary to cut through the obstacles in the peat with a chain saw in order to be able to drive in the panel (very dense, very resistant sedge peat). It is useful to take core samples in advance to evaluate the situation.

c Driving in the panel using pressure from the excavator arm: to limit the risk of breaking the panel, a metal tool placed on the edge of the panel and stabilised by long lateral "legs", attached to the excavator arm means the pressure can be applied over a longer length and the panel can be gradually pushed down into the ground 8.

d Covering the structure with peat and vegetation when the ditch is filled in 9 (*cf* p. 94: Infilling of ditches). If the ditch is not filled in, the wood panels must be protected against any degradation by a mound of peat (*cf* p. 91: Steel sheet pile fencing).



Succession of solid wood panels used to stop the water vertically and horizontally

SPECIAL CASE OF USE FOR A LARGER DITCH

In a very few cases, in order to optimise costs, assembling several panels with each was tested out:

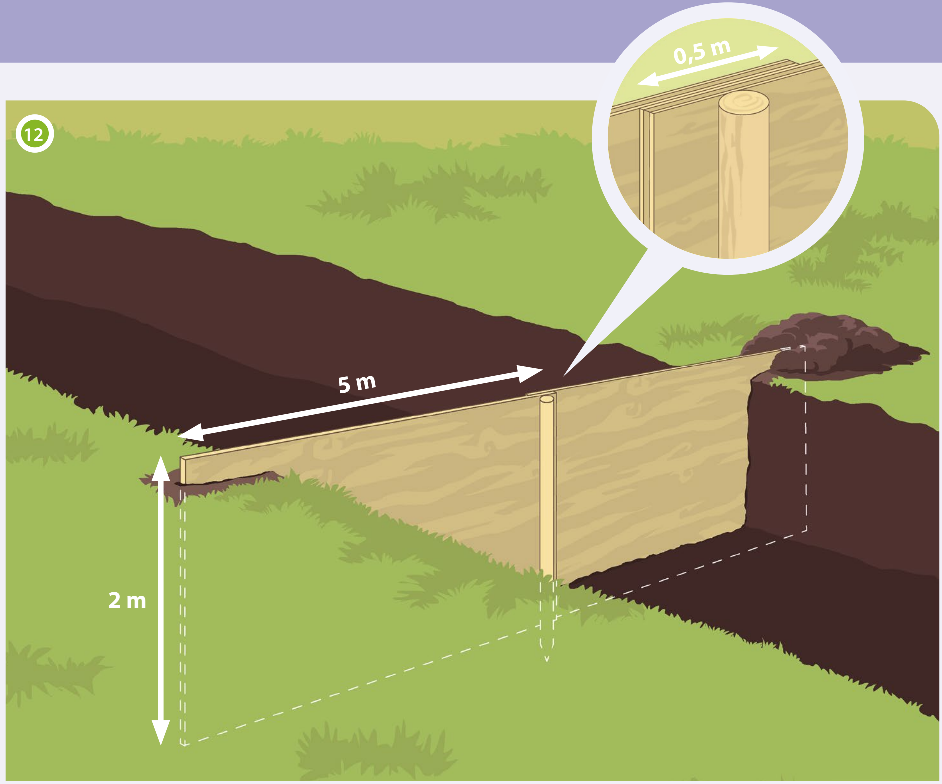
- assembly of two 5 m wide panels 10, to create a longer structure for a ditch that was not very wide, but highly mineralised in certain places, requiring blocking over a width of 7 m at certain points (Frasne, Gû peatland);

- blocking the outlet of an extraction pit with a line of five wood panels, where the hydraulic load was low (*cf* p. 23: The Cerneux-Gourinots peat bog) 11.

In both cases, the panels were installed with an overlap of at least 50 cm and up to 1 m. In the Cerneux-Gourinot peat bog, the panels were screwed together at their apex. On the same site, reinforcement planks (8 cm x 20 cm) were placed on the downstream side of the structure on the overlaps to increase resistance to the hydraulic load. Effectiveness relies in particular on perfect overlapping and total adherence between the two panels over a substantial area so that no water can get between them into the peat 12.

The difficulties encountered in installing individual panels were multiplied when assemblies were involved. If the panels are not perfectly glued together in the zones where they are superimposed due to the presence of peat, branches or roots, there is a risk of water seeping through and over time opening up a breach in the structure, which will then no longer be watertight. This technique therefore involves more risks and demands strict compliance with the installation instructions by the contractor and checking by the project owner.

Advantages	Disadvantages
• Low-cost material • Supplies easily brought to the site using small equipment (tracked wheelbarrows) • Ease and speed of installation of a panel, especially in non-wooded peat, using a mini-excavator	• Only suitable for modest-sized ditches • Difficult to drive panels into peat containing obstacles (roots, dense fibres, etc.)



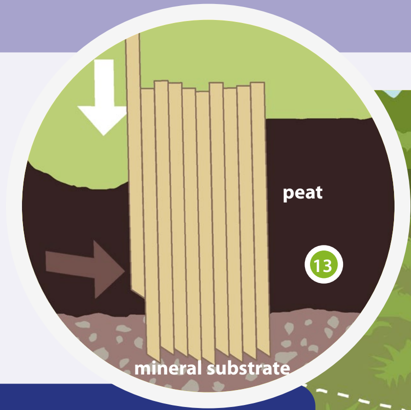
2) Timber plank fencing

▶ **Principle:** comparable to the previous point, this type of fence allows a draining point of flow (ditch, old peat extraction pit) to be neutralised, but it is applied to larger openings (wide or deep ditches) requiring deeper anchoring or needing to resist greater hydraulic loads. The structures installed have to be sufficient in number and close enough together, in view of the up/downstream and lateral topography (left bank/right bank) to effectively block the flow of water.

▶ **Characteristics:** these fences consist of solid untreated timber planks 16 to 20 cm wide and at least 10 cm thick, tongue-and-grooved, bevelled at the base 13. The species used in the Life programme is spruce, the local timber, which offers a good cost-effectiveness ratio.

The height of the planks is adapted to the depth of anchoring in the peat needed, but cannot exceed what an excavator arm can drive in and what the workers can handle, i.e. normally no more than 5 metres.

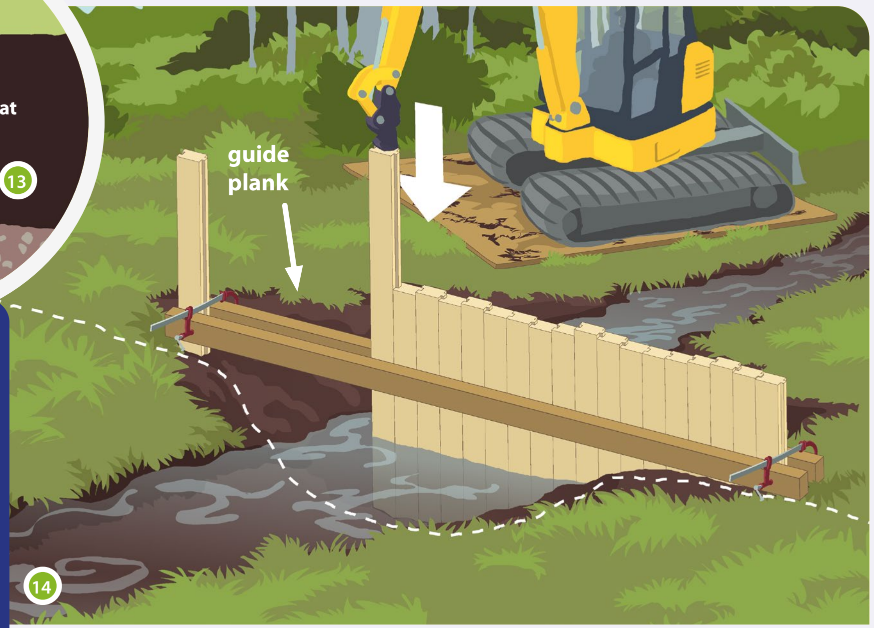
▶ **Context of use:** planking fences are used when it is necessary to anchor to depths of more than 2 m and/or if there is a need to resist fairly high hydraulic loads or when very wide structures are required. Consisting of a succession of planks, the length of fencing will depend on the size of the area to be rewetted. Thus, the longest structures created in the Life programme were 125 m long (the works at La Grande Seigne), but some, where deep anchoring was needed, are only 4 m wide.

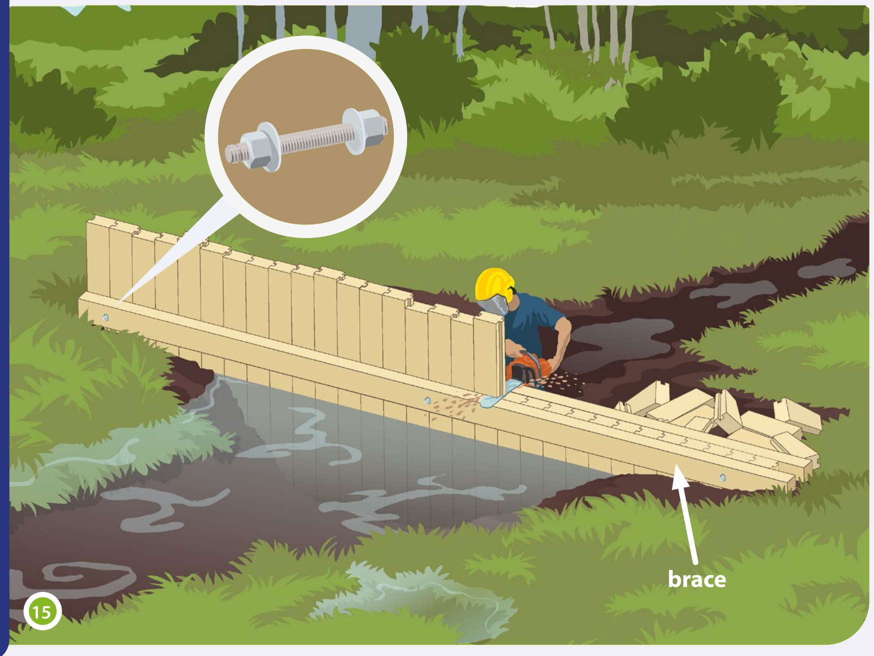


Installation

a ***Preparatory work:*** the area where the structure is to be installed (including the covering mound) is stripped to lay the peat bare and to ensure good cohesion of the mound of peat with the natural ground afterwards. In certain cases where there is purple moor grass in tussocks, the vegetation may be shredded first.

b ***Construction of the timber structure:*** the pre-grooved planks are slotted into one another and driven into the peat using the excavator arm 14. They must be driven at least 20 cm into the low-permeability underlying substrate 13 (mineral or non-mineralised peat), which will have been tested by taking core samples in advance. Guide planks are used to ensure the structure is straight, which is all the more important when the structure is a long one. When the construction is finished, the fence is reinforced with braces on both sides to ensure overall rigidity and cohesion. Finally, the planks are sawn off just above these braces 15, at a level slightly higher than the water level reached at high water. The off-cuts are disposed of off-site or buried in the ground.





▶ **Special cases:** where there are large concentrated flows requiring the spreading of the water over a large area and generating strong hydraulic thrusts, the fence can be doubled 16. The space between the two fences is filled with peat to add vertical support to the assembly. The entire structure is covered by peat, following the previous recommendations. This amount of peat used will therefore be all the greater. If the fence is particularly high, it will also need to be reinforced on the downstream side by bracing.

▶ **Cost per m²:** from €250 to €600/m, depending on the height of the planks (i.e. the quantity of timber)

▶ **Installation time per linear metre:** in the Life programme, at the very most 20 m/day of planks with two workers + one excavator driverr

Site information sheets concerned: Cerneux-Gourinots, Grande Seigne, Les Levresses, Forbonnet, Malpas, Crossat, Moutat, Entrecôtes-du-Milieu, Douillons, Les Rousses

Advantages	Disadvantages
• No limit on the length of the structure • Solidity of the structure • Can resist a high water level • More effective anchoring for deep peat • 100% plant-based material	• Cost higher than for panel structures • Preparation of the materials takes longer • Difficulties transporting and installing the planks the longer they are • The work needs to be carefully executed to ensure the planks are tightly joined together.

Points requiring particular attention

▶ This type of structure is subject to surface erosion, if water starts to flow over it. If this happens, the structure can very quickly be weakened. Overspills must be avoided at all costs on these structures and the desired dispersion of the water retained must be properly anticipated. In the specific case of the Grande Seigne works only, where the already very long fences were not dispersing the excess hydraulic load laterally, a prototype dispersive overspill system was created along the entire length of the structure (*cf* p. 31: La Grande Seigne peatland). Otherwise, steel sheet pile fencing can be used instead.

▶ When installing the planks and covering them with the mound of peat, it is essential not to let the machinery circulate on the borders next to the future structures so as to avoid creating low points and water flow points liable to lead to erosion.

▶ It is indispensable to anchor the fencing deep in the mineral subsoil or in very good quality low-permeability peat in order to:

- avoid one plank being driven in deeper than the previous one;
- guarantee that no water can flow underneath the structure (*cf* p. 59: Le Crossat peatland).

▶ Lateral anchoring of the structure in peat not influenced by drainage is indispensable to avoid it being circumvented laterally by the water. This means that the structure must extend far enough on either side of the ditch or pit to be neutralised.

▶ Anticipate the rise in the water level: the construction of such structures where there are substantial permanent flows or in unfavourable hydrological situations, can lead to virtually immediate flooding. It is therefore necessary to anticipate the problem either by continuously pumping the water to complete the structure, or by only partially driving in a plank in the middle 17 to ensure the water can continuously flow until the structure is finished.

▶ Monitor correct vegetation of structures in season following the works and check over the long term that the timber is not exposed, in particular due to the mineralisation of the peat (otherwise, reinforce the structure to ensure it will last).

▶ Digging out the points where peat will be taken: the surface vegetation removed before digging out the peat is set aside and re-planted on the banks afterwards. The point where the peat is taken must not reach the mineral base layer, so as not to interfere with the chemistry of the water. The sides should gently slope to facilitate the anchoring of colonising vegetation, and one or more of the deep points may provide a habitat favourable to aquatic insects.

3/ Steel sheet pile fencing

▶ **Principle:** in a similar way to timber plank fencing, steel sheet piles can be used to obliterate large draining features (large ditches or extraction pits). They were preferred for their better resistance, better anchoring in the mineral substrate or to allow an underlying flow.

▶ **Characteristics:** they consist of bare steel sheet piles connected to one another by slotting into U-channels, guaranteeing a solid installation of the structure. The sheet piles are not welded together.

▶ **Context of use:** steel fencing was preferred for different reasons:

- where the upstream hydraulic load was high (water column greater than 1.5 m) especially when the possibility of driving a structure into the subsoil was limited;
- for their thinness and solidity - steel sheet piles can be used in heterogeneous peat containing pieces of wood or hard layers. They are also more suitable if the underlying substrate includes a lot of mineral particles. If the ground is very resistant a vibratory hammer can be used;
- the technique used to slot the sheet piles together allows the construction of curved structures, which can be useful in certain circumstances;
- as steel is considerably less susceptible to degradation than wood when in direct contact with the air or water, steel fencing was preferred in contexts where it was not possible to avoid overspillage over the structure.

As with timber plank fencing, there is no limit on their length. To avoid water flowing under them and to guarantee their resistance if the hydraulic load is high, they need to be anchored in the mineral substrate to a depth of 15 to 30 cm 17.

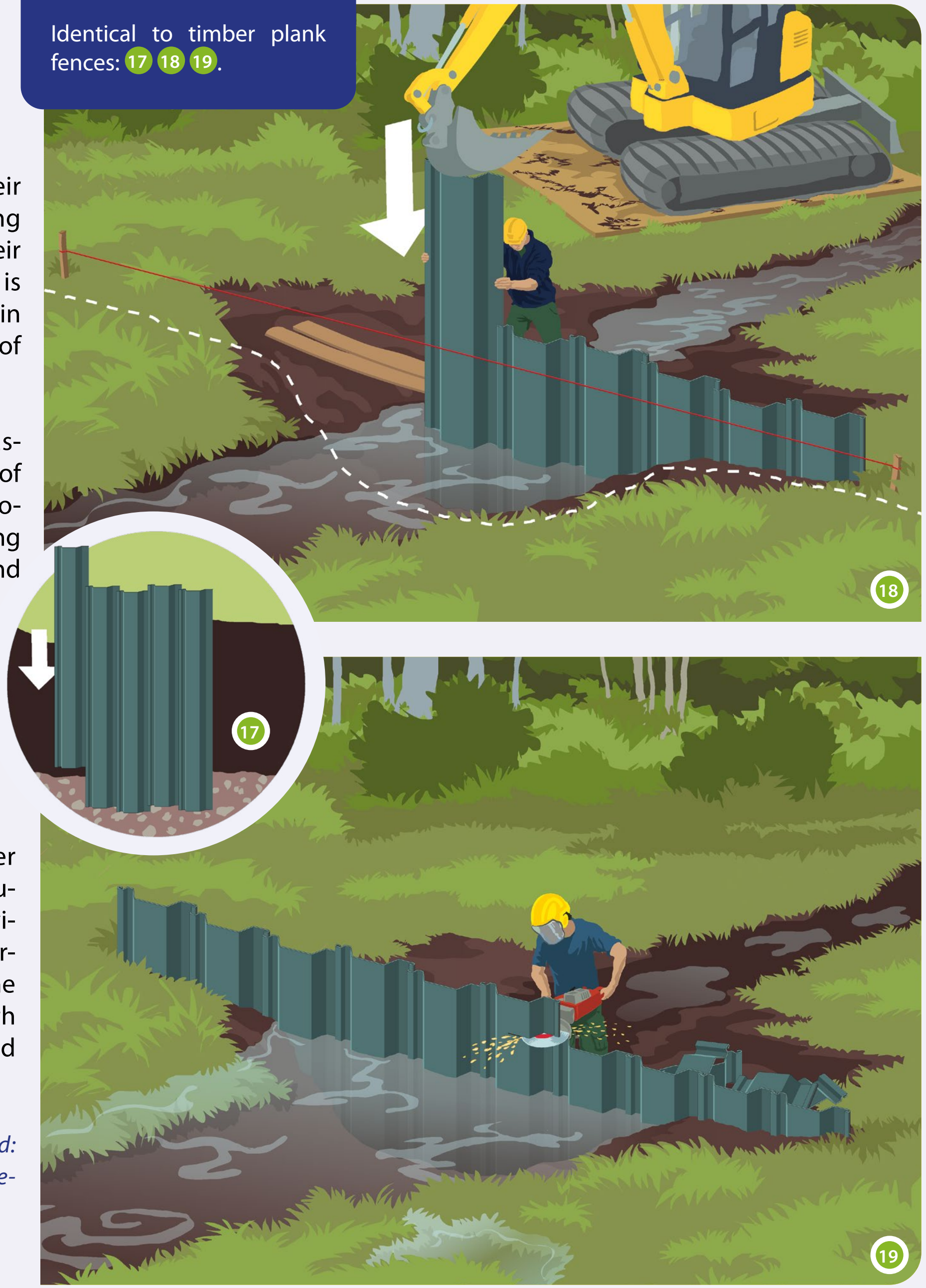
The question of the wisdom of using metal in peat in the presence of flowing water was raised. In anaerobic environments, steel sheet piling is widely used in water courses and canals. In saturated acidic peat, it seems that the metal remains relatively inert, bearing in mind that within the time scale of the restoration, there is little chance of any alteration being visible in a context of new peatification.

▶ **Special case:** as with timber fencing, in a context of high hydraulic thrust and where the imperviousness of the anchoring is uncertain, it is possible to double up the steel fencing and fill the gap with peat to guarantee a more solid and more effective plug.

Site information sheets concerned: Grande Seigne, Forbonnet, Villeneuve-d'Amont, Douillons

Installation

Identical to timber plank fences: 17 18 19.



Advantages	Disadvantages
• Solidity of the structure • Possibility of overspill over the structure • Easy to anchor in the mineral substrate • The structure can be curved • Can withstand a high water level upstream	• Cost higher than for wood panel or plank structures • "Non-natural" material • Weight of the sheet piles makes handling difficult • More difficult to cut to the right height

Covering the structure (timber or steel):

In order, first of all, to avoid the deterioration over time of the material above the natural ground level by alternating dry periods/flooding and, secondly, to facilitate the revegetation of the structure, a substantial amount of peat is used to cover over the structure 20. This consists of non-mineralised peat at least 40 cm deep, placed in a trapezoid mound (flat surface at least 1 m wide at the top). The sloping sides of this ridge of peat must be as well compacted as possible, with an incline of 1:2 to limit any risk of slippage or collapse. Given the height of the structure, the quantities of peat needed can be considerable, so the deposit where they are to be taken from must have been identified in advance by core sampling and be as close as possible to the structure to limit transportation, but nevertheless far enough away not generate further drainage, therefore necessarily upstream of the structure.

Finally, the peat is covered by the vegetation previously removed from the surface nearby. If this is impossible, it is important to cover the structure with hay to prevent drying out as far as possible and facilitate the germination of the vegetation.

4/ Mineral dykes

▶ **Principle:** many of the Jura peatlands were created as a result of the presence of a moraine bar. The reconstitution of similar contexts has been tested downstream of peatland complexes.

▶ **Characteristics:** a dyke consisting of mineral material, clay or morainal material with a high proportion of clay. The dyke is placed directly on top of the enclosing mineral substrate, after excavation of the covering topsoil (residual peat, very highly mineralised).

▶ **Context of use:** installation in contexts where the enclosing mineral substrate is close to the surface and where the surrounding peat is highly mineralised (possibly with general subsidence of the body of peat).

Site information sheets concerned: Malpas, Douillons

Points requiring particular attention

▶ The nature of the enclosing bedrock can also be important. If it is too ductile, a mineral dyke can sink under its own weight over time so that it no longer has the required elevation.

▶ This type of structure is subject to surface erosion, if water starts to flow over it. If this happens, the structure can very quickly be weakened. Overspills must be avoided at all costs on the structure and the dispersion points for the water retained must be properly anticipated.

Installation

ⓐ Excavation of a trench in the peat to expose the mineral substrate enclosing the width of the dyke to be created 21.

ⓑ Morainal materials placed directly on top of the mineral substrate to create a trapezoid dyke 22.

ⓒ Covering with excavated material to that the vegetation can take hold again and for better integration into the landscape 23.

Advantages	Disadvantages
• Easy to construct: earthworks • Materials easily available and transportable, potentially in large quantities • Low cost	• Only suited to minerotrophic contexts • Need to pay attention to the weight of the materials on the enclosing substrate and to relatively shallow peat

5/ Infilling of ditches

▶ **Principle:** when the drainage ditch has a substantial slope or the area immediately around the ditches is too mineralised, a succession of "reaches" of water will do little to achieve the required rewetting of the peatland. It is then necessary to completely fill in the ditch the draining impact of which is to be reduced.

▶ **Characteristics:** the nature of the materials used will depend on a combination of several factors: characteristics of the peat, ease of bringing in materials, possibility of obtaining them on the site, etc.

▶ **Context of use and installation:** Whatever the context of the installation, it is always necessary to clear out the ditch first, so as to "clean" the edges, removing any heterogeneous vegetation or severely damaged, porous peat. This limits the phenomena of preferential flows in contact with the materials in place and those used for the infilling. The residue that is cleared out will be re-used to cover the structure, and to encourage the vegetation to resume growing.

Blockage points to stop the water flow must be installed from upstream to downstream, using the methods previously described (solid wood panels, plank fencing dams). The infilling material, adapted to the geological, hydrological and pedological context, is then put in place in between the plugs that have already been created as the work progresses downstream.

It is important to anticipate the phenomena of swelling and settling of the infilling materials over time. The backfill should take the form of a marked rounded mound, which will settle over time, whatever the material used.

A/ DITCH ON THE EDGE OF A PEATLAND IN CONTACT WITH THE MINERAL SUBSTRATE

Suitable for peripheral ditches running round peatlands, originally created to intercept the water running onto the peatland from the surrounding area. The proximity of the enclosing mineral substrate means that the use of mineral material can be envisaged, such as scree or moraine, which is easier to obtain 24.

The water is then dispersed over the top of the infill or by "reaches" of water that have not been filled in.

B/ DITCH WITHIN THE BODY OF PEAT WHERE THE PEAT IS VERY THICK

Whenever possible, it is preferable to infill with peat which is locally sourced 25, allowing the hollows created to become ponds 26.

Points requiring particular attention

▶ Do not take peat from areas downstream of the water blocking structures so as not to weaken them and to encourage the water flows.

▶ Do not risk creating preferential drainage between the areas where peat is cut if they are too close to each other.

▶ Avoid cutting peat from areas on a slope so that the water is on the surface at all the edges of the pond or prefer a half-moon shaped pond to limit the drainage.

▶ Do not dig down to the mineral substrate when cutting the peat.

C/ DITCH WITHIN THE BODY OF PEAT WHERE THE PEAT IS NOT VERY THICK

In certain fens, there is not enough peat available locally.

In this case, a substitute material can be used: spruce sawdust from a sawmill 27.

The low porosity of compacted sawdust guarantees effective plugging, although less so than peat. Once buried and saturated with water, this plant-based material will not degrade. However, it should be covered over, at least by the residue cleared out of the ditches.

This solution can only be an alternative, and the difficulty of obtaining of large quantities of sawdust should not be underestimated. It can also be difficult to transport it to ditches in the middle of the peatland.

Points requiring particular attention

- Ensure that the sawdust comes from wood that was not treated with insecticides when the logs were stored.
- Use sawdust from a sawmill and not the chips produced by forestry shredders (the porosity of this coarse material is too high to act as a retainer of water).
- Sawdust is very difficult to lay if there is still a residual flow in the ditch when it is being obliterated.


27

Opening to the public

Depending on the local issues and objectives, several different types of public access facilities have been installed.

Raised boardwalk for general public access (suitable for pushchairs and wheelchairs)

► **Characteristics and installation techniques:** the purpose of this type of boardwalk is to provide easy access to the general public. It can be adapted to allow access for people with reduced mobility (creation of passing places, access ramps, adaptation of the furniture, signage, etc.).

The first step consists of preparing the route by cutting and clearing the area where the boardwalk will go. The foundations of the structure are then created by driving posts into the ground as far as the mineral substrate, or at least to a depth of 200 cm 1 2. The minimum section that contractors under the programme were required to use for these stakes was 120 x120 mm. The decking planks are fastened on joists (minimum 60 x 140 mm), which are themselves fastened


2


3


4


5

Advantages	Disadvantages
• Can be adapted for use by people with reduced mobility • Allows group visits (family, educational sessions, classes of schoolchildren, etc.) • Itinerary can be adapted to many peatland contexts	• Differing levels of impacts of the structures on the peatlands: during installation (equipment and workers) then in the medium and long term on the overall functioning of the sector (*cf* Pôle-relais toubières technical data sheet no. 5: « Ouverture et aménagement des zones humides pour l'accueil du public » - Opening wetlands to the public and providing visitor facilities)

onto the posts 3. The section of the planks used for the decking is, on average, 35 x 140 mm, with a width of 120 cm 4 5 6.

Leaning benches are installed at certain points along the boardwalk so that visitors can admire the scenery or read the eco-interpretation boards provided. The leaning benches generally have the following dimensions: length 4 m, height above the boardwalk 1.05 m, and consist of three posts (section 120 x 120 mm) onto which two horizontal rails (section 100 x 100 mm) are fixed with wood bolts.

The square-edged wood is then planed and the corners rounded off or chamfered. For all the fittings, the managers have chosen non-tropical species (except for some black locust) and the timber is not chemically treated or autoclaved. The timber in contact with the soil or water is generally black locust due to its natural durability (class 4 natural). The other timbers, which are not in contact with the soil or water, are mainly black locust or selected oak (pedunculate or sessile oak).

► **Cost per metre:** from 200 euros incl. VAT per metre in this programme


6

"Hiker" type boardwalk

▸ **Characteristics and installation techniques:** a lighter installation than the previous one, this rustic boardwalk is intended for hikers and is not suited to pushchairs or people with reduced mobility.

The paths consist of a double line of boards laid lengthways, 20 cm wide each, in the direction of walking, spaced to allow comfortable walking: about 1 to 2 cm apart 7. These boards are screwed or nailed onto sufficiently wide cross planks. The planks are placed directly on the peat, level with it, which means removing the surface vegetation in some places or a little manual banking up. It was chosen to use a span of 150 cm between the planks, but these should be adapted to the microtopography and changes of direction, where necessary. In some cases, the planks may be fastened to posts driven into the ground (about 1.5 m) in any sections liable to be flooded and therefore create a risk of floating 8.

The timber used is untreated, carpentry quality, rough sawn, with the bark and sapwood removed. In this programme, two species were tested out: Douglas pine and spruce.

▸ **Cost per metre:** from 24 euros incl. VAT per metre in this programme

7

8

Advantages	Disadvantages
• More discreet installation than the general public boardwalk: blends into the site better and allows for wilder itineraries • Installation without any major preparation of the ground or prior cutting back • Relatively easy to install • Lower impact on the environment • Economical: 5 to 7 times cheaper than a boardwalk for general public access	• Installation not suitable for people with reduced mobility, pushchairs, people who have difficulty walking - intended for hikers • Not suitable for mountain or other bikes (risk of falling)

Platforms

▶ **Characteristics and installation techniques:** generally accessed from the boardwalks, this type of installation can hold different sized groups of visitors depending on the size of the platform 9.

The platform often features eco-interpretation features providing information on the environment 10 (interpretation boards, discovery "furniture", etc.). The platform allows classes of schoolchildren, for example, to be gathered together when taking tours with a nature guide so that they can discover the peatland together.

Sometimes some earthworks are required to allow such an installation. The timber posts for the foundations of the structure are then installed, anchoring them in the mineral substrate. The platforms are installed in the same way as the boardwalks for the general public 11. Attention is paid to the rapid elimination of any humidity on or in the timber (e.g. top of the posts, cross members with a slope, assemblies with an evacuation feature, drip edges, etc.) and to ensuring that good ventilation of all the elements making up the structures is possible.

▶ **Cost per metre:** from 450 euros incl. VAT per metre in this programme

Advantages	Disadvantages
• Installation allows groups of varying sizes to gather • Installation that can be adapted to people with reduced mobility	• Differing levels of impacts of the structures on the peatlands: during installation (equipment and workers) then in the medium and long term on the overall functioning of the sector

Monitoring the works under the programme

The Monitoring component for each site is designed on the basis of the question asked by the manager and is therefore directly connected to the preliminary studies and the development of the rehabilitation project. The sites in the programme were not all monitored with the same objectives or the same intensity.

On certain peatlands where the stakes were high, monitoring began several years before the works and combined several indicators for the purpose of diagnosis: to improve knowledge of these sites, get a better understanding of their dysfunctions and introduce appropriate actions. This monitoring has been extended after the works and will continue for several years after the Life programme, wherever possible. In fact, although some initial results have been observed for a certain number of indicators, it will take years, decades even, to be able to quantify and analyse the effects of these works, in particular on the resumption of the peat formation process. The managers hope to be able to extend the monitoring of these sites for at least ten years in order to have enough hindsight to be able to draw relevant conclusions. Our hope is thus to be able, eventually, to produce an assessment of the impact of the works undertaken under the programme on the sites monitored over this period.

However, monitoring of this kind involves costs, in terms of material but especially human resources, that are not negligible. Regular data collection, processing and analysis and the maintenance of equipment are all particularly time-consuming tasks.

Given the number of peatlands rehabilitated under this programme, it has not been possible to implement such intense monitoring on all the sites. On certain peatlands, monitoring has, therefore, been limited to the direct impact of the works over a shorter period (two or three years) and based on one or two more relevant indicators (often piezometry and monitoring species of immediate concern). The objective was to be able to compare the situation that existed before the programme to that achieved as a result of the restoration work carried out as part of the project. Other sites, however, have not been monitored at all.

Malaise trap used during the Life programme for the Syrph the Net method

Several abiotic and biotic indicators were thus assessed during the programme: monitoring of piezometry, water quality and temperature, the Rhopalocera and Odonata of Community interest, the remarkable flora, the vegetation (including bryophytes), macro-invertebrates, etc. We have chosen not to present all of these types of monitoring in this document, as most of them have already been implemented by many managers. Instead we have chosen to share our experience on two indicators that were the subject of a great deal of reflection and discussion during this project: the Syrph the Net method 1 et and piezometry.

Chrysotoxum bicinctum

The Syrph the Net method

Between 2014 and 2019, 12 sites were the subject of a Syrph the Net (StN) diagnosis. The aim was to try out the StN method to monitor the impact of the project actions on the functionality of the peatland ecosystems (epigeal zone). This method is based on the study of populations of hoverflies, which belong to the order Diptera.

▶ **Why monitor hoverflies?** At the larval stage, hoverflies use restricted ecological niches and have strict requirements. They are considered as excellent bioindicators of the state of the environment (*Speight M.C.D., 1986 & 1989 ; Sarthou J-P., 1996 ; Good J.A. et al., 1996 ; Burgio G. et al., 2007*).

In France, the habitats, micro-habitats and life history traits of over 95% of hoverfly species are known (*Sarthou V. et al., 2010*). Using this taxon, it is possible to investigate not only virtually all ecosystems, but also a wide variety of their ecological niches and the three main trophic links: zoophagous, microphagous and phytophagous (*Castella E. et al., 2008*). This conjunction currently appears to be unique if we compare it with other groups of terrestrial insects (*Goeldlin P. et al., 2003 ; Sarthou J-P. et al., 2005 ; Fayt P. et al., 2006 ; Redon M., 2009*).

In Europe, 875 species of hoverfly (Diptera, Syrphidae) have been identified (*Pape T. et al., 2015*), 560 in France (*Speight M.C.D., et al., 2016*) and 340 in Franche-Comté (*Claude J., in prep*). To compare with other taxa more commonly used in monitoring: 253 species of diurnal Lepidoptera have been identified in France, 103 Odonata and 240 Orthoptera 2.

▶ **Objectives of the StN studies:**

- to conduct an initial diagnosis by measuring any alterations the site undergoes:
  - to characterise the hoverfly communities on the site,
  - to analyse and compare the species assemblages trapped using the StN method to the site's potential,
  - to identify and specify the conservation issues relating to habitats and potentially to hoverflies;

- to use the predictive capacities of the database to define objectives to be reached, which, if possible, will orient the restoration measures more precisely;

- to carry out a second, "post-works" diagnosis to compare the development of the hoverfly communities before and after the works.

1 / "SYRPH THE NET" - HOW DOES IT WORK?

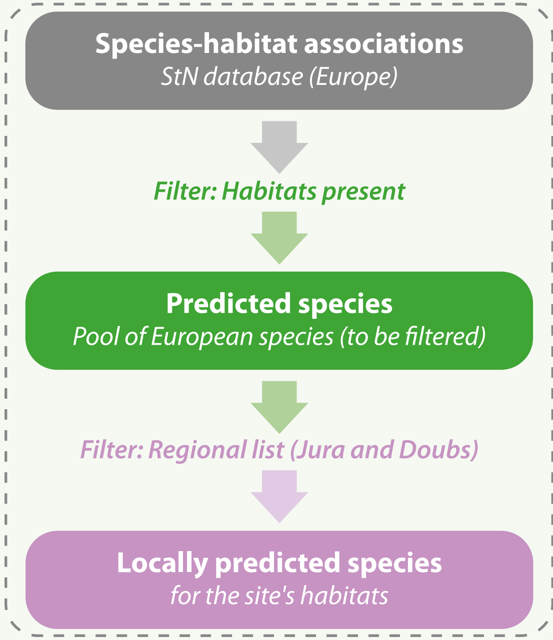
▶ StN is a synthetic, analytical method (*Speight M.C.D., 2017*) using a database in which species-habitat associations are encoded according to types of larval habitats:

- 0: no association;
- 1: minimal association (the habitat is only marginally used by the species);
- 2: medium association (the habitat is part of the normal range of the species);
- 3: maximal association (the habitat is optimally preferred by the species).

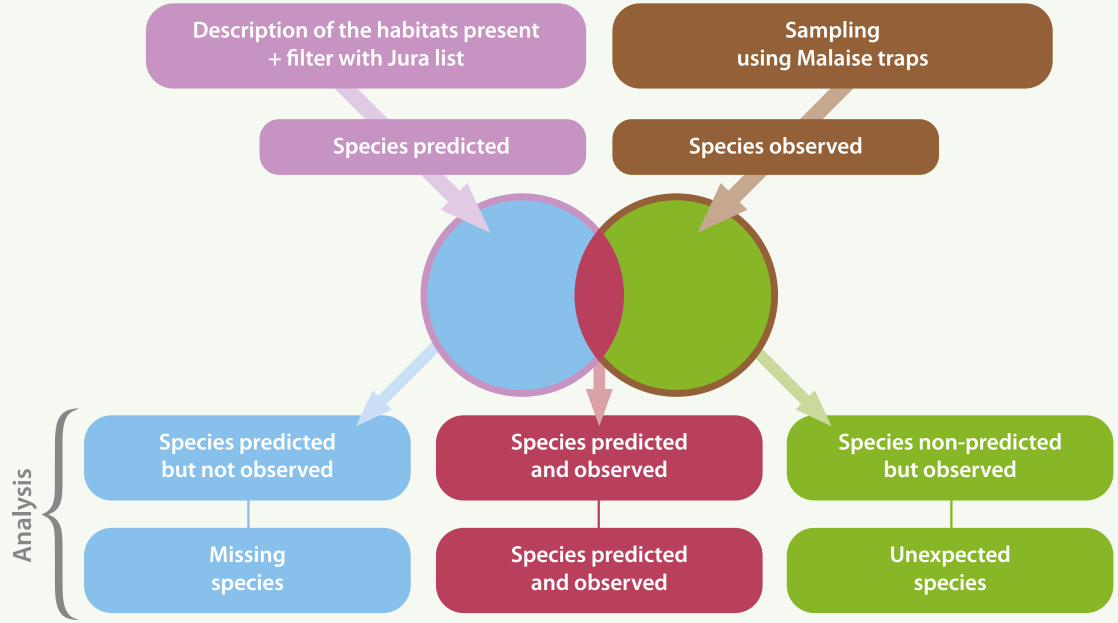
Based on the list of habitats present, a list of European species predicted in the habitats of the site was drawn up. The list of habitats is then filtered with the lists of regional species, which gives a list of regional species expected for the habitats of the site described 3.

Indicator	No. of species in France	Scope
Lepidoptera	253	Open environments
Odonata	103	Wetlands
Orthoptera	240	Open environments and edges of woods
Hoverflies	560	All habitats

2 *Place of hoverflies among the "usual" terrestrial entomological bioindicators*



3 *Diagram illustrating the principle of preparing the list of predicted species*



4 *Principle of comparing lists of species - Sources: Sarthou & Sarthou, 2010 amended*

By comparing the regional list of predicted species with the list of species observed, three types of lists of species are obtained 4.

The species observed expressed as a percentage of the species predicted are an indicator of the ecological integrity of the habitat or station studied based on the thresholds detailed below 5.

Interval	Integrity	Description
[0-20%]	Very poor	Very insufficient
[21-40%]	Poor	Insufficient
[41-50%]	Average	Average
[51-75%]	Good	Good
[76-85%]	Very good	Very good
[86-100%]	Excellent	Excellent

5 *Appreciation thresholds for different criteria*

The lists of species predicted and observed in the samples allow the quality of the description of the habitats and associated micro-habitats to be defined (notion close to that of the confidence interval - *Claude J. & Dussaix C., in prep.*).

2 / POSITIVE POINTS

► **Implementation of the StN diagnosis and its contribution**
On sites where very few studies have been conducted, StN provides the following:

- sampling of the species present;
- quantification of the functionality of the environment studied;
- identification of the strong/weak points, quantification of the dysfunction and/or limiting factors, and a ranking of these factors;
- an initial diagnosis before management, works or non-intervention.

On sites where numerous studies have already been carried out by the manager, StN provides:

- a quantification of the ecological functionality, comparable to other peatlands diagnosed;
- results that can be compared with the results of other studies, allowing them to be nuanced or questioned (e.g. studies on the state of conservation, floristic typology criterion in vegetation mapping, etc.).

► **Result of the StN ecological diagnoses**
Some of the peatlands in the Life programme were the subject of an initial diagnosis before the rehabilitation works.

The analyses of the hoverfly communities confirmed the existence of several types of disturbance/dysfunction (e.g. significant fluctuations in the water table, drying out of the top strata of the soil or woodland coverage that is relatively imbalanced/non-functional because it is too young and too homogeneous).

The interpretation of the results led to questioning whether the origin of these phenomena was anthropogenic or natural:

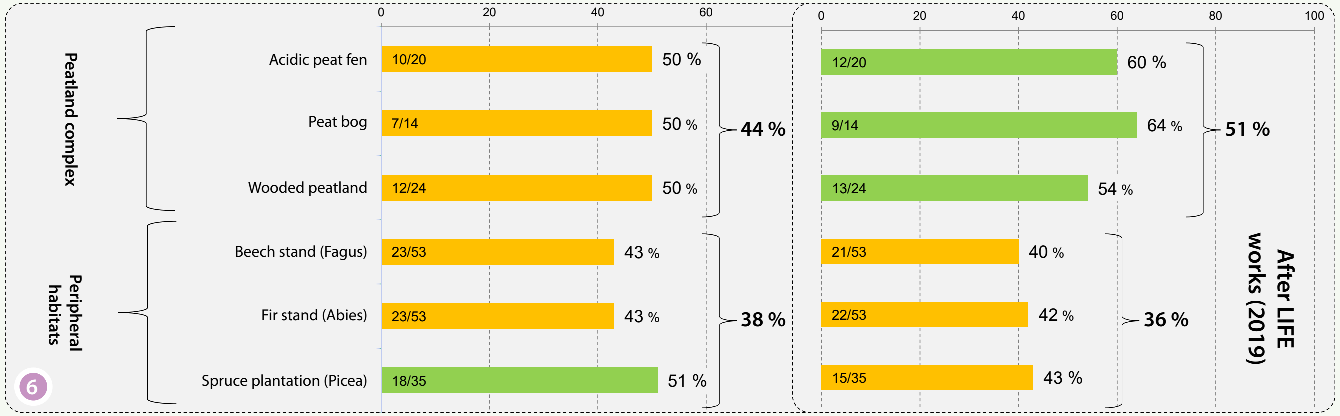
- dysfunctions due to anthropogenic impacts (e.g. drainage ditches, peat extraction, etc.);
- natural functional characteristics (e.g. drainage induced by the topography).

Due to the time constraints of the programme, only two "post-works" diagnoses were carried out.

On the Creugnots peatland (Bonnétage, Doubs), the ecological integrity rating of the site rose from 37% in 2016 to 39% in 2019. As expected, a reduction was observed in the ecological integrity of the spruce plantation, a non-targeted anthropogenic habitat, which was cleared or flooded. Above all, the diagnosis measured an increase in the functionality of the peatland habitats: with the hydrological restoration, ecological integrity increased from 44% to 51% 6. The populations of tyrphobiontic species increased tenfold, in spite of a climatic context unfavourable to wetland species at the time when the study was carried out (*Decoin R. et al., 2020*). The hoverflies seem to be responding well to the changes in the peatlands following the Life programme, the first sign of an improvement in ecological functioning immediately after the works.

On the Douillons peatland (Nanchez, Jura), the hydrological restoration work allowed the ecological integrity of the wetland habitats to remain stable (transition mire, fens, phragmites), in spite of a climatic context very unfavourable to wetlands over the last few years. Nevertheless, in spite of the rise in the water table, the number of species associated with waterlogged soils and/or peat and their populations has not yet increased. The slight reductions in the ecological integrity of several habitats (wet meadow, megaphorb, wooded peatland (*Betula/Pinus*)) are probably the result of the interannual effect of non-exhaustive sampling, a phenomenon that is even more present in studies conducted over a single year (*Decoin R. et al, 2020*).

For these two studies, the analyses confirm that several phenomena are still present: fluctuations in the water table, lack of maturity of the forest stands, paucity of flora in the fens (Creugnots peatland only). Due to the general time constraints of the Life programme, these post-works diagnoses were planned too early to detect any significant changes in the habitats and the appearance of slow colonising species (only one generation per year). Conducting diagnostic studies over the medium to long term (10/20 years after the works) could provide a wealth of information. It would give a clearer idea, for



Evaluation of the functionality of the six habitats of the Creugnots peatland (Bonnétage, Doubs) (species observed/predicted). The habitats achieve higher ecological integrity ratings separately than when they are interpreted together. This is explained by the dominance of euryecious species (those using several types of habitat) in the populations of hoverflies sampled. The missing species, on the other hand, are mainly stenoecious species (those using a restricted number of habitats).

example, of the recolonisation of favourable habitats by hoverflies, a phenomenon that continues to be understudied. Will the Life programme help to re-establish a network of peatlands which are functional for invertebrates?

► Significant contribution to knowledge of the regional and national entomofauna

As the result of the 12 StN studies conducted in the Departments of Doubs and Jura, knowledge of the peatland hoverflies significantly improved; almost 25,000 hoverflies were identified (the more complex identifications were confirmed by Dr Martin C.D. Speight, European expert) and were sent to the SIGOGNE biodiversity data geo-visualiser; six hoverfly species were added to the Franche-Comté fauna (*Cheilosia melanopa, Pelecocera tricincta, Platycheirus angustipes, Sphaerophoria chongjini, Trichopsomyia lucida, Xylota caeruleventris*). *Xylota caeruleventris* is also new for France. This tyrphobiont is under serious threaten at European level and is only present in three of the peatlands restored in the Life (*Tissot B. et al., 2019*). In the coming months, the considerable database which has been constructed will contribute to the establishment of a regional red list of threatened hoverflies, based on the IUCN criteria and methodology. This is a first in France for this family of insects.

A few figures

- **13,108** data items in total (52,413 individuals)
- **5,675** data items on the hoverflies (25,261 individuals/256 species)
- **7 433** data items on entomofauna other than hoverflies (27,152 individuals/~ 1,000 species)

The sampling for the StN diagnoses was performed using Malaise traps (*Malaise R., 1937*), which are passive intercept traps that efficiently catch flying insects. By thoroughly sorting numerous insect families (other than the hoverflies) and as the result of collaboration between a large number of specialists, a remarkable amount of insect data was gathered and exploited (27,000 insects and over 1,000 different species). The 7,500 data items obtained have been used as input for various projects such as atlases or revisions of the fauna of France. The entomological discoveries made as a result of the Life programme have been and will be the subject of further scientific papers (*Coppa G. et al., 2016 ; Dubois Q. et al., 2019*). These StN studies have made a major contribution to knowledge of the biodiversity of the Jura Peatlands.

3 / NEGATIVE POINTS

▶ Deadlines too short
Constrained by the duration of the Life programme (six years initially planned), the post-works diagnoses were scheduled too early (only three years after the works). Even though the hoverflies seem to be responding well to the changes in their habitats, the timeframe has been too short to see the appearance of slow colonising species (only one generation per year) (*Decoin R. et al., 2020*).

▶ Problem adapting the StN "wooded peatland" habitat to the Jura peatlands
Spruce is present on all the Jura peatlands and in virtually all the diagnoses a community of hoverflies associated with spruce was present. However, these species are not included in the StN "wooded peatland" habitat, which only includes *Betula* and *Pinus*.

▶ StN method and dependency on the quality of the vegetation mapping for the site studied
When diagnoses are carried out, the selection of the habitats studied depends on the vegetation mapping, which for some sites is not precise enough or too old. An update would have been desirable. As a result, although the StN method is based on the micro-habitats used by hoverflies in the larval stage, the results of the analyses remain at macro-habitat level (*Speight M.C.D. et al., 2020*).

▶ Methodological bias
Following some questions concerning ecological integrity ratings which were deemed to be too low, a study was carried out on the StN methodology during the Life programme (*Gens H. et al., 2019*). In peaty environments, sampling based on a single year is subject to a marked interannual effect. The conclusions of the diagnoses (dysfunctions identified) are similar, but the measurement of ecological integrity varies from one year to the next (probably because of the climatic conditions). This methodological bias limits the possibilities for making ecological integrity comparisons between the different peatlands.

▶ Species coding
Based on all these analyses, the ecology of certain species in the peatlands of the Jura mountains seems to diverge from their ecology encoded in the StN database. For example, *Eristalis rupium*, a species assumed to be found in wooded peatlands, is absent from all 13 sites studied. In Franche-Comté, it was only encountered in beech-pine stands (Grand'Côte/Massacre/Risoux). Although this singularity only concerns a few species, it can affect the ecological integrity ratings of certain habitats with a limited number of species. The Life programme will enable the StN methodology to be improved for peatlands.

4 / OVERALL POINT OF VIEW

▶ Knowledge of the site and relevance of the StN analyses
For studying peatlands, the "Syrph the Net" tool is easier to implement on sites about which much is already known, in particular where there is a detailed and operational habitat map. On the other hand, this tool provides more information on sites about which there is relatively little knowledge than on sites where thorough studies have already been carried out (LiDAR, hydrology studies etc.).

▶ Lessons in terms of management on the Life sites
Most of the diagnoses confirmed that there were hydrological dysfunctions and demonstrated the need to carry out works to rehabilitate the peatlands. Nevertheless, the StN method remains a quantified evaluation or monitoring tool, without claiming to explain the full functioning of a peatland. Like botanical studies, the StN diagnoses only study the "epigeal" part of the peatlands, through the fauna.. Only thorough hydrological and geological studies can provide a more detailed understanding of these peatland hydro-geo-ecosystems and allow conclusions to be drawn which can be applied to their management. The fact remains that monitoring the flora or the invertebrates remains essential to be able to measure the functional gains achieved.

5 / PROPOSALS FOR IMPROVEMENTS

The StN method was extensively tested during this Life programme, and different aspects could be improved in the coming years:

- thanks to the numerous data obtained, the ecological coding of some species of hoverfly could be reworked. The creation of a new "*Betula/Pinus/Picea* wooded peatland" habitat, better suited to the Jura peatlands, could be envisaged. These updates would refine the measurement of the ecological integrity of certain peatland habitats;

- following several tests, it was found that the most appropriate methodology consists of using two pairs of Malaise traps over two different years (four MTs in total), positioned in the middle of the peatland (*Gens H. et al., 2019*). As far as possible, it would be preferable to conduct sampling over two years in order to avoid interannual bias and have more robust sampling data to analyse.

Piezometry

The Jura Peatlands Life project set itself several rehabilitation objectives, to be measured by indicators such as the length of ditches filled in, the length of streams remeandered, surface area of peat extraction pits rewetted, etc.

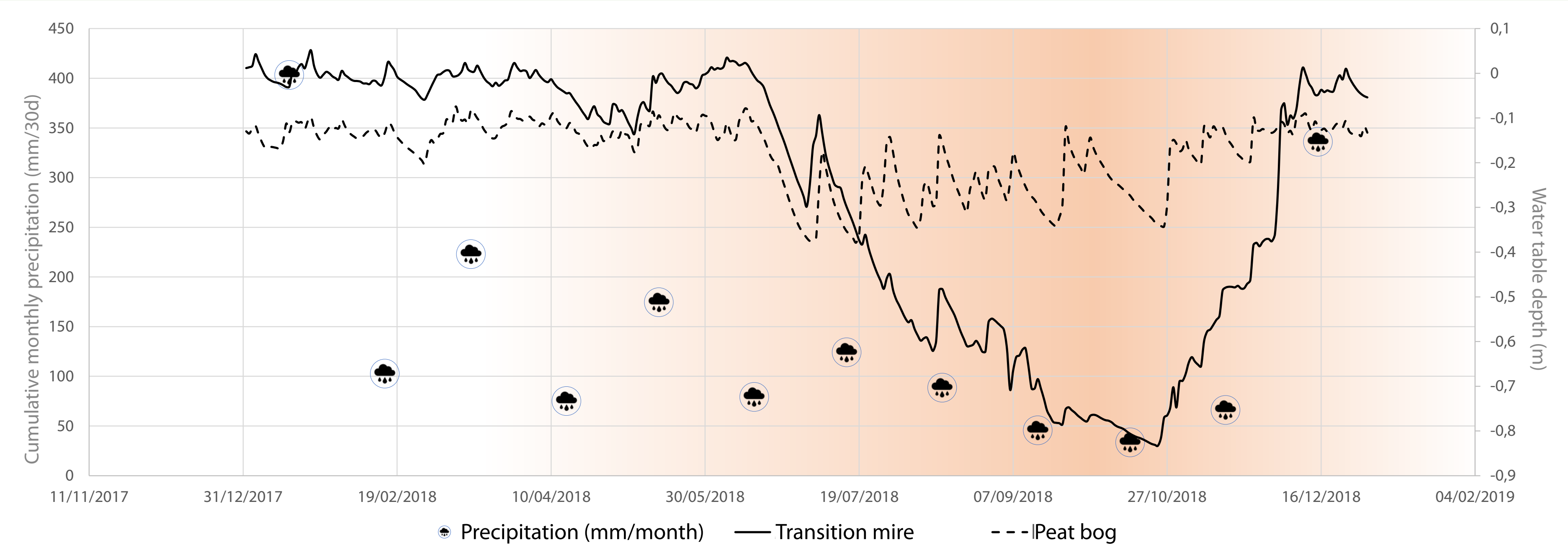
For a peat bog or a watercourse, diagnostic investigations are necessary to identify and quantify the disturbances. The degradation or disappearance of habitats and the regression or disappearance of typical species, structural and textural modifications of peaty soils (absence of fibres and macroremains) and the eutrophisation of surface waters are all signs of hydrological dysfunction: the amount of water entering the hydrosystem is not enough to make up for that exiting it. The components of this water balance must be identified in order to draw the necessary conclusions on the nature of the disturbance and to propose effective rehabilitation measures.

1 / WHY USE PIEZOMETRY?

Piezometry can identify and above all quantify the hydrological consequences of the disturbances during a diagnostic study. It can help to calculate the extent of the rehabilitation measures during the pre-works study 7. It can also measure the impact of the works carried out on hydro-ecological and hydraulic functioning.

The rehabilitation measures are intended to achieve a better habitat and/or functional status by improving the hydro-ecological conditions of a site. After the intervention, the water may circulate and be stored differently, but how can these changes be observed and measured? How can they be linked to the rehabilitation measures and how can the effectiveness of those measures be gauged? Phytosociological monitoring, for example, is indispensable for assessing the results in the medium term (two to ten years), but does not allow the effect of the rehabilitation measures to be assessed in the short term (zero to two years).

Piezometry is extremely useful in a Life programme because it allows the effect of the works to be identified very quickly. However, although it is possible to observe the water table rising in the months following the intervention, it is preferable to wait for a full water year before beginning a detailed analysis (graphic/empirical



7 *Changes in the depth of the water table in the body of peat of two bogs during one water year*

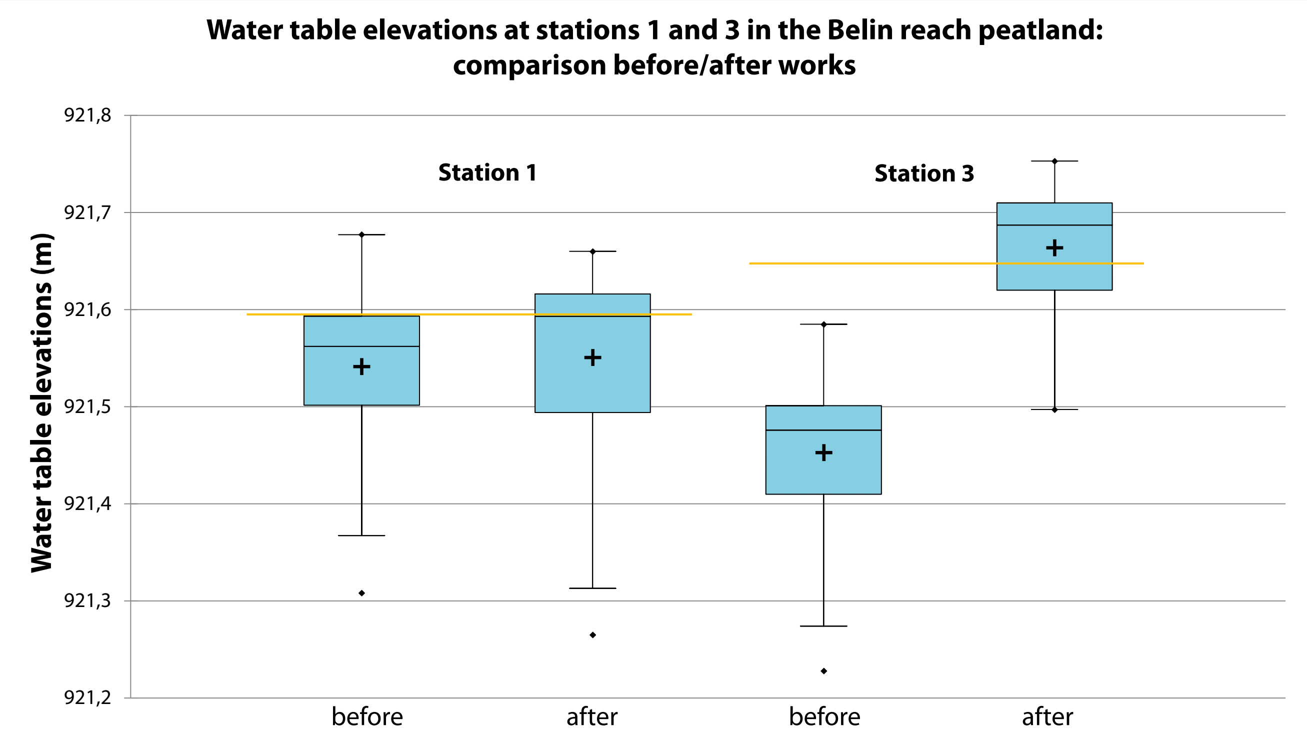
and/or statistical analysis) of the effects of the rehabilitation measures on piezometric behaviour. Further work can be carried out to extrapolate these results to future years and, for example, to formulate hypotheses on the recovery of the vegetation and its spatial structuring (x, y and z). Within this timescale, it is therefore perfectly possible to envisage making corrections to the restoration measures taken or learning lessons for future work.

Over the long term, the consequences of the rehabilitation operations on the hydrology and the natural habitats are uncertain. Piezometric monitoring can provide responses as to some of the reasons for the changes to the habitats observed and can provide precise hydrological information on the long-term consequences of the rehabilitation works and their effects on the resilience capacity of the hydrosystem.

2 / FROM THEORY TO PRACTICE

Piezometry is used to characterise the depth of the water table. It has many different applications and is used, in particular, when monitoring water stocks in aquifers from which water is abstracted. The literature barely touches upon the hydro-ecological dimension and there are therefore few references to it.As a result, the piezometric tool was not able to be effectively used on the peatlands at the beginning of the Life programme.

From 2014 to 2020, the way in which we set up instruments on the sites and collected, processed and interpreted the data changed over time. As in any scientific process, in order for the data to be usable, careful consideration had to be given to establishing and drawing up a protocol, without overlooking either the time or cost involved in setting it up, maintaining it and exploiting the data. The staff working on the Jura Peatlands Life project gradually appropriated this tool with the help of consultants and academics, in order to improve their technical skills and adapt the tool to the hydro-geo-ecological investigations in the peatlands and answer the scientific questions raised as best possible.



8 *Example of a box plot showing a pre/post-works comparison of piezometric data*

At the time of writing this document, the Pôle-Relais Tourbières is considering producing a technical guide which will enable managers to adopt the piezometric tool in the form of a "turnkey" solution. The Jura Peatlands Life project will share what it has learned with them.

3 / EXAMPLE OF PRESENTATION

In the information sheets containing the feedback from the works, the piezometric behaviour of the water table is presented in "box plot" form. This graphic representation has the advantage of being well-known so that most readers will be capable of interpreting it. It also has the advantage of presenting several pieces of information simultaneously in synthesised form: the minimum, maximum and extreme values as well as the 25th, 50th (median) and 75th percentiles, which allow the stability and residence time of the water table to be assessed. Several data ranges can be compared, such as water table elevation values before and after the works 8.

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Life Jura Peatlands, the webcast

In order to report on the 7 years of actions of this program, the Life Jura Peatlands team presented its results in a webcast. Divided into 3 parts of 1.5 hours each, this broadcast enabled the programme's intervention philosophy, the preliminary studies, the work carried out, the results obtained and the enhancement actions implemented to be presented in a dynamic manner, with around twenty speakers on set and in video.

This digital recording is divided into 3 parts:

- Programme 1: An ambitious program in tune with peatlands
- Programme 2: The work - some concrete cases
- Programme 3: Ecosystem responses & a (re)discovered heritage

The webcast is available for replay on www.life-tourbieres-jura.fr.

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This collection aims to share the experience acquired over the seven years of the Life program "Functional rehabilitation of Jura peatlands in the Jura massif". It is divided into three parts:

- a general presentation of the program, the peculiarities of the Jura peatlands, then the different approaches and tools used to design the work;
- a selection of 12 concrete examples of rehabilitation work carried out, illustrating the diversity of the problems encountered;
- a review of the different techniques used, from rehabilitation to monitoring, including sites'opening to the public.

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