LIFE+ LIMNOPIRINEUS: CONSERVATION OF AQUATIC HABITATS AND SPECIES IN HIGH MOUNTAINS OF THE PYRENEES

TECHNICAL REPORT

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~ Restauration of Font Grossa mires ~

RECOVERY OF MIRES AT THE RESERVOIR OF FONT GROSSA, ESPOT

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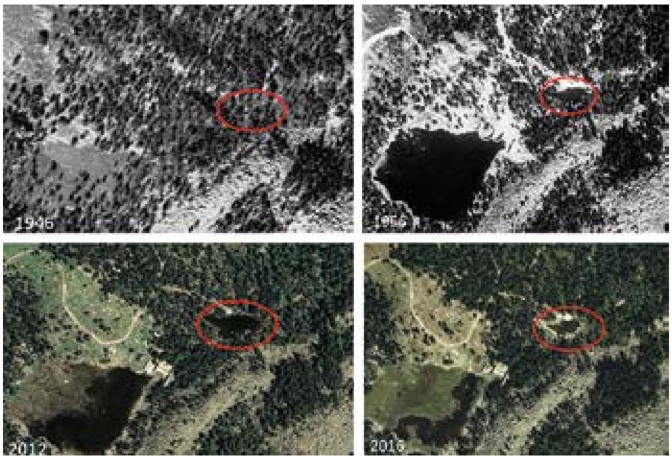
ABSTRACT

The Aigüestortes i Estany de Sant Maurici National Park has numerous hydroelectric infrastructures that modify the structure and function of the aquatic and semi-aquatic habitats. Within the framework of the LIFE+ LimnoPirineus project, we have taken the small reservoir of Font Grossa, disused for years, as an example of ecological restoration of mire habitats. Specifically, we have laid the foundations for the development of two types of Habitats of Community Interest, transition mires (HCI 7140) and sphagnum bogs (HCI 7110*). Given the little knowledge available regarding the restoration of Pyrenean mires, we have carried out a series of experiments focused on the structural plants of these types of mires, specifically *Carex rostrata, C. nigra, Juncus filiformis* and four species of *Sphagnum*. We have tested their growth capacity under different conditions of flood and competition, in order to select the most suitable for each situation. The experiments started under controlled conditions (growth chamber, greenhouse) and were finally developed at the Font Grossa site, under field conditions. Then, the restoration activities for the target HCIs were performed in the appropriate areas, which took place in the summers of 2017 and 2018. The monitoring and subsequent actions, carried out until summer 2019, corroborated good implantation of the *C. rostrata* population and foresee partially good implantation of the *Sphagnum* populations. However, the assembly of more or less stable communities is predicted to proceed slowly, constrained by extreme events such as strong increases in water flow (due to snowmelt in spring or heavy rains) or occasional extreme droughts.

INTRODUCTION

The use of high mountain lakes and rivers as hydropower producers has often led to alterations in the surrounding vegetation. The flooding of the lake shore, due to the regrowth of the bodies of water with the construction of dams completely eliminates the previous ecosystems, among which, different types of wetlands and humid meadows are often found. When you want to reverse this situation, and return to the natural water level, you have to face the difficulties of regenerating the vegetation and soils that were previously there (Moreno-Mateos *et al*., 2015). To begin with, there is not usually enough information available about the previous ecosystems, and in addition the exposed wasteland that surrounds the lake is a space of very different characteristics to those that existed before the flood. Rebuilding a mire on the new shore of the lake will only be possible if the morphology is conducive and a more or less high water table can be maintained in the new soil. In addition, although there are sufficient experiences of restoring mires in boreal and Atlantic areas (Budelsky *et al.,* 1999; Caporn *et al*., 2018; Quinty & Rochefort, 2003), there is very little information regarding Alpine systems, and none concerning the Pyrenees.

In the Peguera basin, in Espot, the elimination of the dam of the small reservoir called Font Grossa and its associated infrastructure in 2012, led to the opportunity to address mire restoration action (Figure 1). Thus, the LIFE+ LimnoPirineus project (2014) proposed that a demonstrative restoration of two mire Habitats of Community Interest (HCIs) be conducted at this location to serve as a real trial for other possible similar actions. Here it is necessary to consider the high number of hydrological alterations of different types found in the National Park and in the rest of the Pyrenees, which are likely to fall into disuse over the years, and therefore to be worthy of restoration.



▲ **Figure 1.** Ortho-images of the whole of Lladres and Font Grossa, in the Peguera basin, in Espot, on four key dates. In 1956 the two dams that generated the Lladres reservoir, which flooded a relatively large area of peaty meadow (1946 image) and that of Font Grossa, forested but probably also hiding another peaty area (1946 image) had already been built. A few years later, the Lladres reservoir progressed to its current status (lower images), which is usually almost empty. The reservoir at Font Grossa remained full until 2012, when it was reduced by the partial demolition of the dam (2016 image).

PURPOSE

The objective defined in the LIFE+ LimnoPirineus project is the restoration of transition mires and sphagnum bogs, two Habitats of Community Interest (HCI 7140 and HCI 7110* respectively). These are habitats of particular significance within the National Park for their relative abundance in this space and for their rarity in the Catalan Pyrenees (Pérez-Haase & Ninot, 2017). The two types of mire are well represented in the Trescuro lakes, located just above the Font Grossa and within the same basin, so it was decided to restore these two habitats and not others.

DIAGNOSIS

To carry out this restoration in a well-founded manner, we studied the characteristics of the Font Grossa environment, both of the strip exposed from under water in 2012 and the immediate environment. In the summer of 2014, we installed nine phreatometers to monitor the oscillations of groundwater and analyse it, we gathered vegetation relevés from the adjacent mire system, which is fed by lateral springs, and we drew up a detailed map of habitats (following the same methodology as Colomer *et al.*, 2019).

The strip exposed from under water following the elimination of the dam was quite irregular, containing numerous granite blocks. Among these, there was a set of relatively soft surfaces, formed by a sandy-silty substrate. Here, the water table remains relatively superficial, determined by the seasonal oscillation of the new water surface and subjected to sporadic highs and lows caused by the hydroelectric use of the water diversion to the Lladres dam. In fact, what would correspond to the Peguera ravine course runs through the bottom of the old reservoir. The water is retained by the base of the old dam and by rubble caused by its demolition, which leads to an almost natural pond. In addition, there is a significant upwelling between the granitic blocks of the SW, and some diffuse sources that already maintained a small mire prior to the reservoir, of which the part above the flood level was preserved.

In 2014, this sandy area was largely in the process of fairly active colonisation by more or less opportunistic mire plants, especially *Juncus articulatus*. Outside this exposed strip, a rather interesting wetland mosaic stretched up the eastern hillside, which included *Trichophorum cespitosum* fen (*Pediculari-Scirpetum cespitosi*), *Carex rostrata* populations (*Caricetum rostratae*), a few small stand of this carex with sphagnums (*Sphagno-Caricetum rostratae*) and remarkable sphagnum bogs with *Ericaceae* (*Vaccinio-Sphagnetum capillifolii*; Pérez-Haase *et al.*, 2012). Specifically, these last two communities correspond to HCIs 7140 and 7110*, targets of the restoration.

During the summer period of 2014, the water table remained between 35 and 47 cm below the surface above the sphagnum bogs, while in the rest of the communities it ranged mainly between 3 and 13 cm below the surface of the soil. It should be noted, however, that in the communities located at the lowest level (mainly those of *C. rostrata*) the water level would have been above ground until 2012, at least temporarily or partially, and so, that in 2014 and even now these plant communities respond in good part to past conditions.

As for the groundwater, these are poorly mineralised (between 17 and 67 µS/cm, most with only 5 to 15 ppm of calcium) and acidic (pH between 4.5 and 5.5).

PLANT MATERIAL FOR EXPERIMENTATION

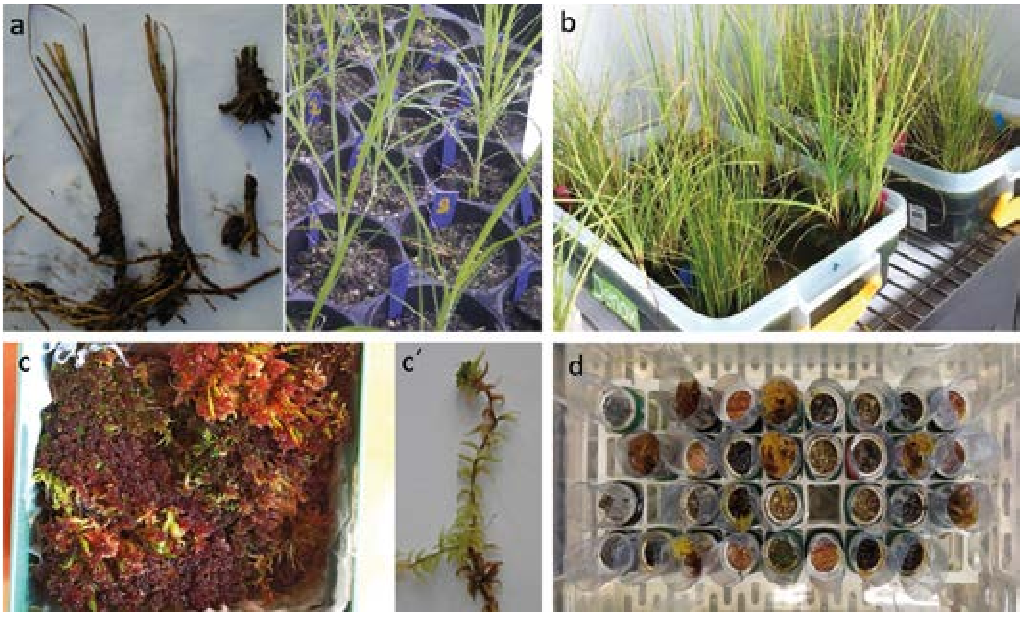
Once the vegetation of mires around Font Grossa and Trescuro had been studied (Colomer *et al.* 2019; Colomer *et al.*, this volume), we selected some species as potential builders of the new habitats in the area to be restored. In all cases, they were species that have a structural role in one community or another, covering a certain range of the ecological gradient prevailing in mires, mainly that of flooding. In addition, they were clonal species, i.e. capable of forming large populations from the lateral expansion of one or few individuals (Keddy, 2010).

Most of the plant material was obtained from the surroundings of the Lladres reservoir, very close to Font Grossa (Figure 1). This reservoir serves to divert the water that flows down the Peguera river to the conduit channel in the Espot hydroelectric power station. According to the demand for energy, more or less water is released through the ravine towards Font Grossa, although most of the time the Lladres reservoir is almost empty. Therefore, its bed is colonised by populations of *C. rostrata* and other mire plants resistant to disturbance, mainly temporary immersion.

In the case of vascular plants, we used *C. rostrata*, dominant in semi-flooded mires and on lake shores; *C. nigra*, abundant in mires of various types, generally less flooded; and *Juncus filiformis*, locally abundant in mires subjected to notable water table oscillation (Carrillo & Ninot, 1992). Of the three, in the autumn of 2014 we obtained hundreds of cuttings (basal regrowths with a rhizome fragment) from the populations that abound in the Lladres reservoir mire, as well as numerous infructescences with mature seeds from the same environment. During the following winter, in the greenhouses at the University of Barcelona, we produced numerous juvenile plants from the cuttings, and seedlings from the seeds (Figure 2a). As a general result, the low level of germination from the seeds obtained in all species and the long time it took to grow the seedlings led us to discard sowing in order to restore habitats with minimum efficiency. In contrast, most of the cuttings (between 49% and 89%, depending on the species) produced a juvenile plant, which in a few months had numerous leaves and had produced some regrowth.

Regarding mosses, we choose three sphagnum species: *Sphagnum teres*, typical of substantially flooded environments; *S. capillifolium*, typical of the upper part of the sphagnum bogs, in relatively dry conditions; and *S. magellanicum*, which is found in an intermediate spectrum of hydrological conditions, but which frequently form bogs. In the case of *S. magellanicum*, the fact that it is a species classified as Vulnerable in the Iberian Peninsula (Garilleti & Albertos, 2012) adds interest to the general restoration goal. From the three species we obtained small swards (few square centimetres) in the fall of 2014 and 2015, which we also grew and multiplied in the greenhouse (Figure 2c). Under these conditions, the sphagnum grew quite actively, both in height and forming new shoots.

From the plant material produced, over the last four years we have evaluated the ability of the different species to germinate and grow, both in pure culture and in pairs, and under different ecological conditions, especially related to the level of flooding. A first block of experiments was conducted in culture chambers, with temperature and light conditions that mimicked those of early summer in the subalpine belt (16 hours of light at 22 °C, and 8 hours of darkness at 15 °C). Then other experiments were conducted directly in the field, in the natural environment and looking for the same conditions of the habitats we wanted to restore.



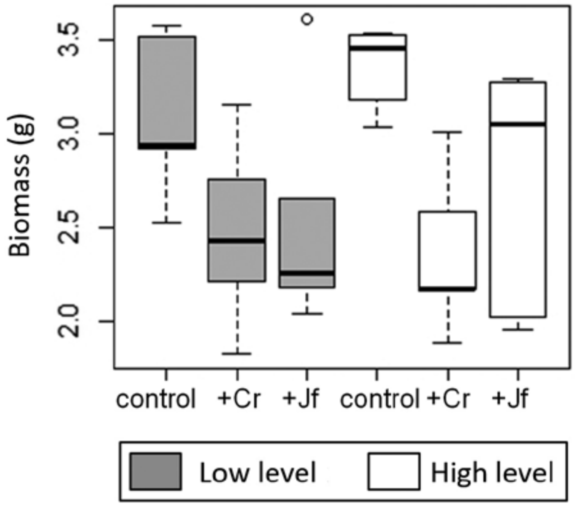
▲ **Figure 2.** Details regarding experimentation with plant material: *Carex rostrata* cuttings and *C. nigra* seedlings (**a**); chamber culture of *C. nigra* and *C. rostrata* under different flood conditions (**b**); small sward (**c**) and individualised plant (**c**) of *Sphagnum*; and chamber culture of *Sphagnum* fragments on different types of substrate (**d**).

EXPERIMENTAL CULTURES

Sedges and reeds under controlled conditions

In spring 2015, 90 of the plants produced in the greenhouse of each of the three species (*Carex rostrata, C. nigra* and *Juncus filiformis*) and 90 seedlings of *C. nigra*, produced in the germination chamber, were used. They were placed in plastic containers with sterile and uniform substrate, in different combinations containing 3 + 3 plants of two different species; and batches of three plants of the same species were arranged in other containers as a control. All types were grown in a chamber for three months under two flood conditions, with water 2 cm above ground level and with water 5 cm below this level (Figure 2b).

At the end of the experiment, growth (leaves, rhizomes) was optimal in adult plants of the three species in pure culture. When two species coexisted, on the other hand, all species in general reacted to competition in the form of lower growth: the interaction between *C. nigra* and *C. rostrata* resulted in lower final values of aerial biomass (leaves) than those obtained in a control situation, while the interaction between *C. nigra* and *J. filiformis* caused lower growth in *J. filiformis*, but did not affect the sedges (Figures 3 and 4). The sedges were not affected by the water level, while *J. filiformis* grew less with a low water level. With respect to *C. nigra* seedlings, both flooding and interaction with adult plants affected them negatively, in the form of poor growth or mortality. We associate the inhibition of seedling growth to root anoxia in flooded conditions and the absence of light in the company of adult plants (Pladevall, 2015).



▲ **Figure 3.** Response of *Carex nigra*, evaluated as dry weight of the aerial part of the plants of each container, to the different cultivation conditions: pure population (control), with *C. rostrata* (+ Cr) or with *J. filiformis* (+ Jf); and with low or high water level.

Species	Effect of water level
Carex nigra	Flooded = Not flooded
Carex rostrata	Flooded = Not flooded
Juncus filiformis	Flooded > Not flooded

Species	Effect of competence
Carex nigra + *Carex rostrata*	Control > Competence
	Control > Competence

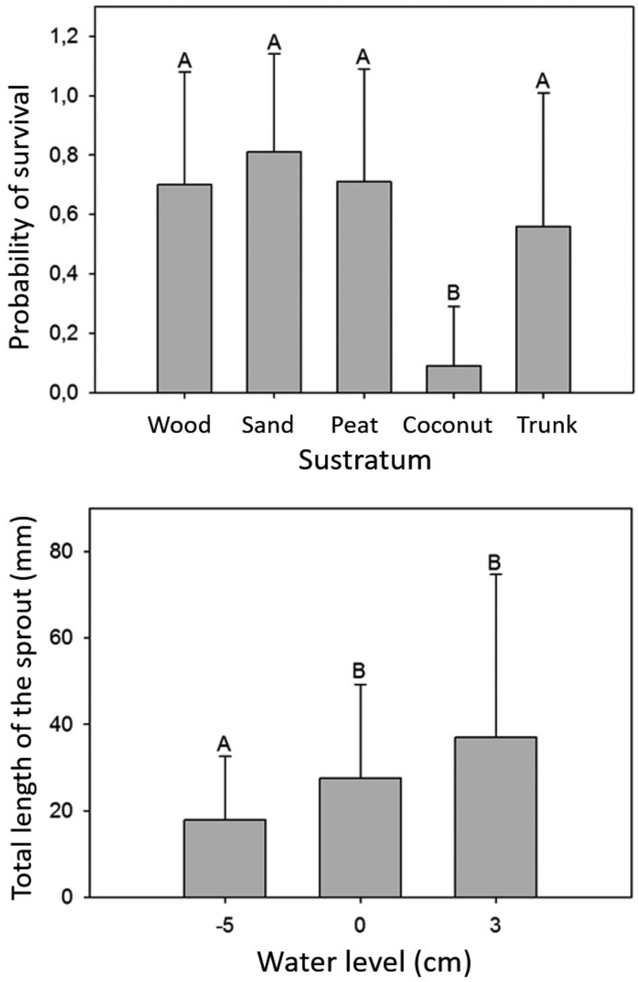
Carex nigra + *Juncus filiformis*	Control ≈ Competence
	Control > Competence

▲ **Figure 4.** Summary of the response, relative to the dry weight of the aerial part, of the adult plants of the different vascular species tested, under distinct growing conditions.

Sphagnums under controlled conditions

In the spring of 2016, we assembled small culture containers, where fragments of sphagnum propagules were arranged, in the form of caulidia segments of 2 mm in length. Similarly, in the case of vascular plants, different combinations of pairs of species were arranged, based on 3 + 3 propagules for each container, and pure culture containers were also arranged for each species. With regard to the flood factor, three levels were established (5 cm below the substrate surface, at the substrate level, and 3 cm above). As the ability of the substrate to conduct water by capillarity is key in mosses, we experimented with different materials (new wood, partially decomposed wood, sand, peat and coconut fibre; Figure 2d).

After three months of cultivation, the survival of the three species was significantly affected by the type of substrate, with general preference for peat and sand. The type of substrate also gave differential growths in the two less hydrophilic species (*S. magellanicum* and *S. capillifolium*), which responded better to peat and wood, while *S. teres* responded to the water level, specifically growing more in more flooded conditions (Figure 5). In contrast, we did not detect effects of interaction between species, probably because they had not grown enough to exert competition.



▲ **Figure 5.** Response of *Sphagnum teres*, evaluated as plant survival and length, to different growing conditions; only the coconut fibre substrate and the lower water conditions gave significantly worse results than the other conditions.

To test the role of competition between the three species, a second experiment was conducted with a design similar to the previous one. In this one, larger fragments of

2.5 cm in length were used, which included the head (apical part of the sphagnum where the lateral branches are concentrated). The same three groundwater levels were established and only peat was used as a substrate. For all three species, the survival of the fragments was almost total. Growth was significantly affected by the level of flooding, and the three species grew more with water at the same level as the substrate. At this water level, the interaction between *S. magellanicum* and *S. capillifolium* affected them negatively, compared to when each of these two lived with *S. teres* (Espuny *et al*., 2018).

Based on the results of the two experiments, for restoration it is preferable to use large fragments, since they are more vigorous, and the type of substrate should be considered, since it has an important role in the survival of the fragments. A constant level of humidity favours growth of the three species, but the chemical composition of the water should not be ignored, because the *Sphagnum* species that form the bogs may be affected by the calcium in the lake water, although it is found in low concentrations. Competition between species may impair growth, and therefore should be considered when establishing location in restoration actions.

▲ **Figure 6.** Details related to field cultures: **a**, *Carex rostrata* plants at the end of summer 2015, the result of cuttings planted in June of the same year in different flood situations; **b**, planting of *C. rostrata* cuttings as the basis for the restoration of the transition mire; **c**, small peat containers with *Sphagnum* shoots ready to be transplanted; **d**, small population of *Sphagnum* growing from the containers through the protective mesh fixed with wooden stakes.

Cultures under field conditions

At the beginning of the summer of 2015, an experiment was set up with sedges and reeds considering two factors, flooding and competition, comparable to that carried out in the controlled conditions chamber, regarding adult plants of the same three species (Figure 6a). This experiment was monitored until the end of summer 2016.

Some of the blocks (where the soil was coarser-textured) showed very poor growth, including mortality of some plants, especially as a result of a dry season that occurred in mid-summer 2015. The rest grew well in both water level conditions. After two summer periods of growth, we could conclude that *C. rostrata* lives better in flood conditions, regardless of whether it has competition, while *C. nigra* grows less in the company of *C. rostrata*, in both situations. *Juncus filiformis* did not respond to different experimental situations. Therefore, *C. rostrata* showed good capacity for implantation and establishment from cuttings in the environment to be restored, both out of and in the water.

In mid-summer 2015, the rest of the plants produced in the greenhouse were also transplanted, mainly *C. rostrata* and *C. nigra*, but also *J. filiformis*, *Carex panicea* and other mire species. In late summer, 100 more cuttings of *C. rostrata* were used to transplant them to five blocks at different points that were conducive to them, in a status of mild flooding (few centimetres underwater).

In general, there was a good response from the three main species, for both survival and growth, until early summer 2017. However, some of the *C. rostrata* plants planted in the water towards the entrance of the reservoir disappeared, most likely dragged by the flow during the most flooded periods.

As for the sphagnum, small containers of pressed peat were prepared, each with four shoots of one species of *Sphagnum* or another (Figure 6c). In the summer of 2016, these containers were semi-buried in appropriate microenvironments on the shore, already planted the previous year with *C. rostrata*; and another set were placed in the same plots as the factorial experiment plants, once these were collected. The containers, in groups of four, were covered with a wide-mesh natural fibre hessian, and fixed to the substrate with untreated wood picks (Figure 6d).

Throughout the summer of 2016 there was a certain mortality in these sphagnums, affected by the surface drought of the substrate. In addition, between the autumn of 2016 and the spring of 2017, some were disturbed, or disappeared, due to episodes of greater intensity in the water current. This highlights that the restoration of populations of sphagnum encounters more obstacles than that of vascular plants, especially due to unfavourable episodes such as relatively dry periods in summer or overflows following thaws or strong storms.

Restoration actions

In summer 2017, most of the actions aimed at restoration were carried out, following a protocol based on the experiences described and documentation (Ferland & Rochefort, 1997; Quistberg & Stringham, 2010; Wittram *et al.*, 2015). This protocol defined the actions of conditioning and planting for different species, following a mapping scheme (Figure 7). Its main action was to establish lax populations of *C. rostrata*, which should be the construction base of the transition mire (HCI 7140), leaving the implantation of hydrophilic sphagnum for the second phase and, eventually, implantation of other mire plants. Also, we left for this second stage the creation of nodules for the bog development of *S. capillifolium* and *S. magellanicum* with *Ericaceae* (HCI 7110*).

▲ **Figure 7.** Plan of the restoration of Font Grossa, where the outermost blue line indicates the perimeter of the reservoir before demolishing the dam. Blue, free water; blue-green, planting area of *C. rostrata* semi-flooded; yellow, planting area of the same species out of the water, and creation of sphagnum bogs; grey, formerly flooded area, not suitable for target mire habitats (subject to spontaneous recolonisation by meadow and opportunistic plants).

In August 2017, the planting area was conditioned with stakes and boards of untreated wood, in order to protect the sediment from water currents during the rooting and growth period of *C. rostrata*, and a small lax palisade was also installed in the water, which will reduce the current during episodes of regrowth. As a preventive measure against trampling and herbivory by livestock, the entire restoring area was surrounded with electric fencing (Figure 8).

Meanwhile, about 5000 cuttings of *C. rostrata*, similar to those used in the experiments, were obtained from the neighbouring Lladres reservoir and transplanted in a lax plantation framework (about 15 cm between plants) on the surfaces to be restored (Figure 6b). These made a total of about 135 m^2, in the form of a strip of land, more or less wide according to the morphology of the shore, that has a flooded part and a part out of the water. In autumn 2017, small containers were transplanted with *S. teres* and *S. subsecundum* (a species ecologically similar to *S. teres*) protected by a hessian mesh. They were located in the middle of the *C. rostrata* plot, to ensure stability of implantation before the spring thaw.

The creation of sphagnum bogs (HCI 7110*) began the same summer of 2017 with the accumulation of pieces of dead wood from the surroundings, interspersed between the replanted areas. We tried to place them on the outside of the *C. rostrata* formation and outside the direct influence of the reservoir water.

The definitive introduction of small swards of four different species of sphagnum, typical of the two HCIs to be restored, was done in late spring and early summer 2018, once the methodology used had been evaluated. In the transition mire (HCI 7140) we introduced small nodules (small groups of cuttings) in peat containers such as those already described, with *Sphagnum teres* and *S. subsecundum*. The containers were planted in groups of four and fixed to the substrate with hessian and wooden picks, as described above (Figure 6d). We arranged them following three levels of flooding, and in seven different sectors of the *C. rostrata* formation. In a part of the containers we added seeds and cuttings of species from

◀ **Figure 8.** Partial view of the restoration of Font Grossa at the end of summer 2017. Semi-submerged boards and stakes protect the transplanted population of *C. rostrata*, which occupies the soft edges from a few cm below the water to a few cm above. Electric tape protects the whole from herbivory and occasional trampling.

this habitat (*Carex canescens, C. rostrata, Viola palustris*).

For the sphagnum bogs, we use a methodology similar to that of the previous habitat, but using *S. capillifolium* and *S. magellanicum* as building species. In summer of 2018, we transplanted container blocks with different combinations of the two species, also fixed with hessian and picks; and we introduced some species from this habitat, both cuttings (*Calluna vulgaris*) and seeds (*Potentilla erecta, Drosera rotundifolia*). In this case, the containers were placed in the peripheral area of the pond, especially in the part where there are diffuse springs and on dead wood or sheltered by it, to act as a growth nodule of the ombrophilous sphagnum.

Monitoring

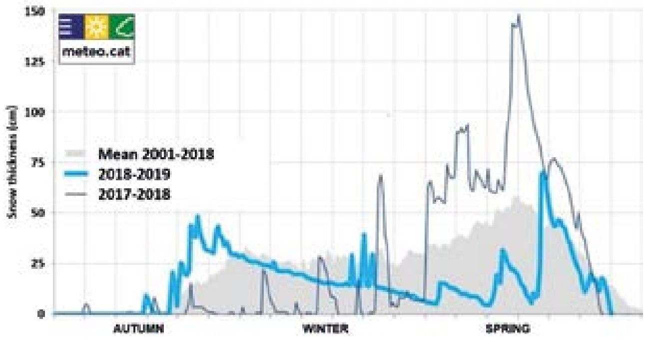
The first results regarding the establishment of the *Carex rostrata* population (HCI 7140) were good. There was continuous monitoring, more frequent in 2017 and less so in 2018 and 2019, of different control plots and of the system in general, based on images.

There was rooting and new regrowth, and the plants survived two very strong floods in the summer of 2018: that from the thaw, which was very intense due to the large amount of snow accumulated in this year, and that caused by one extraordinary rainfall during the month of August. Both caused a sudden rise in level and, especially the second, a strong current of water that damaged a small part of the protections, moved large stones and dismantled part of the wood arranged to facilitate the creation of bogs. The sedges were all still in place, although in some sectors they were half buried by flood debries.

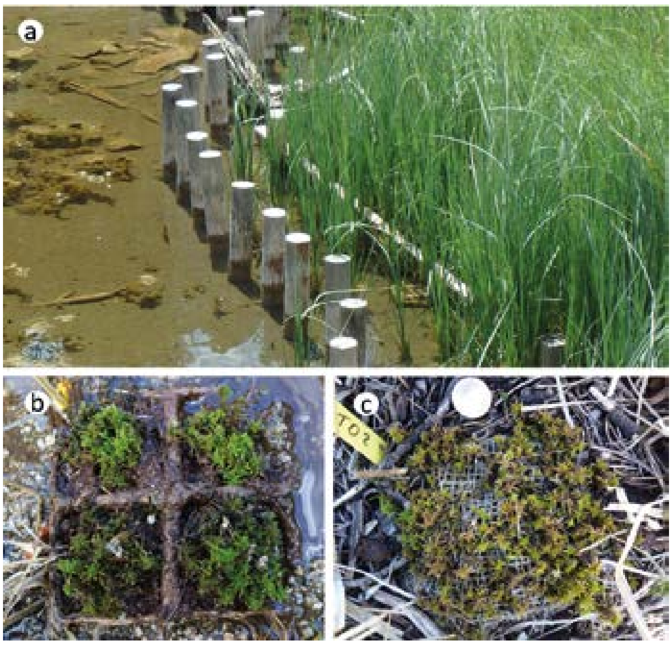
2019 had poor rainfall in winter and spring (Figure 9). The relatively low arrival of snow melting water, together with low rainfall and high temperatures during the first half of the summer made the water level in Font Grossa low throughout the summer, since the beginning. For this reason, the outermost strip of *Carex* had weak development, and the individuals in the most flooded sector continued to grow within the reservoir. Despite these extreme episodes, the dynamics of extension and densification, together with the fact that individuals introduced in 2017 have already flourished and fructified, allows us to consider the *C. rostrata* population consolidated and fully capable of structuring habitat 7140 (Figure 10a).

The sphagnum, despite being more recently introduced (June and July 2018) have remained in place, and grow by breaking through the hessian mesh that protects them. This protective mesh has been a key element to avoid the displacement of the small swards with the floods and to give some protection to the young plants against an excess of radiation and high temperatures.

One part (one in seven batches) of the Sphagnum introduced in the transition mire was buried by sand and gravel arriving with the flood of August 2018, and another small part was covered by a thin layer of sediment. The rest, and those of the bogs, reached autumn 2018 in good condition. At the end of May 2019, the different batches were monitored with overhead images and height measurement. In the case of the sphagnum located within the Carex rostrata plot, except for the samples affected by the flood last August, most were alive and growing well, although they showed differences between the three flo-



▲ **Figure 9.** Dynamics of snow thicknesses at the alpine station of Espot (2,519 m) for the two years of restoration work and, on average, the previous nine years (graph from the Servei Meteorològic de Catalunya [Catalonia Meteorological Department). The abundant snowfall of spring 2018 led to strong water currents and high levels at Font Grossa in early summer, fed by the rapid melting of snow. On the other hand, the low snow reserve of 2019, together with the little rain and high temperatures of the beginning of the following summer, caused a low water level from the beginning of that summer.



▲ **Figure 10.** Favourable development of structural species: **a**, *Carex rostrata* population densified and well-established in the summer of 2019, two years after implantation, and which in some places expands spontaneously (central part of the image) through water beyond the protection table; **b**, one of the sphagnum nodules already installed, just before covering it with hessian in June 2018; **c**, the same nodule, in May 2019, rising above the mesh.

od levels. Since the water level was generally high in the summer 2018, those further in the pond showed poor growth and some mortality. On the contrary, the high temperatures and the low water level of the summer 2019, meant that those farthest from the water had problems for growth and survival. Thus, the samples in the middle zone are the ones that have been best established; in some cases, the sphagnum, in addition to exceeding the hessian have begun to extend laterally out of the containers (Figures 10c and 11).

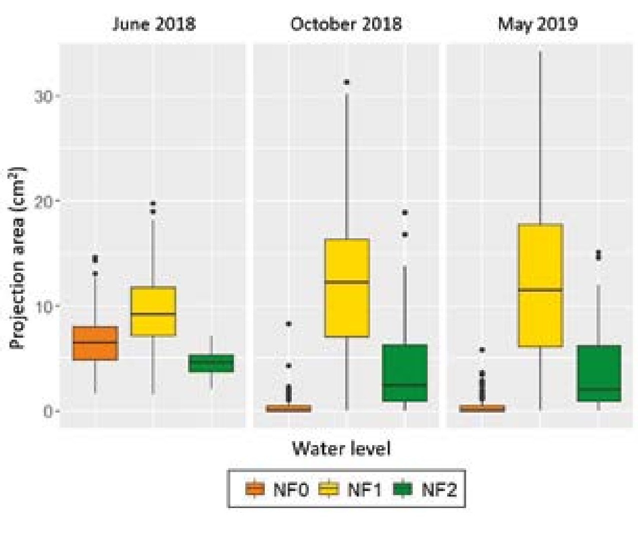
As for the sphagnum bog (HCI 7110*) regeneration nodules, a small part already presented problems at the beginning of summer 2019, mainly those that were established on dead wood, as opposed to those established on peat, which survived well throughout the first year. Most likely, the heat episode that has affected much of the Pyrenees and the European continent in July has caused difficulties in the growth and survival of the sphagnum in general. It should be considered that, although Sphagnum capillifolium, and even S. magellanicum, are sphagnum tolerant to temporary desiccation (they are usually found in places with low water level), they may not survive exceptional drought conditions, since they depend specifically on rain water. We have detected poor vitality and injuries in well-established natural bogs in areas near Font Grossa and in different places in the central Pyrenees.

Of the vascular species implanted in summer 2018 among the sphagnum nuclei, at the beginning of summer 2019 the Viola palustris and Calluna vulgaris cuttings had progressed reasonably well. On the other hand, very little generalised germination was observed, perhaps due to erosion of the seeds by water currents.

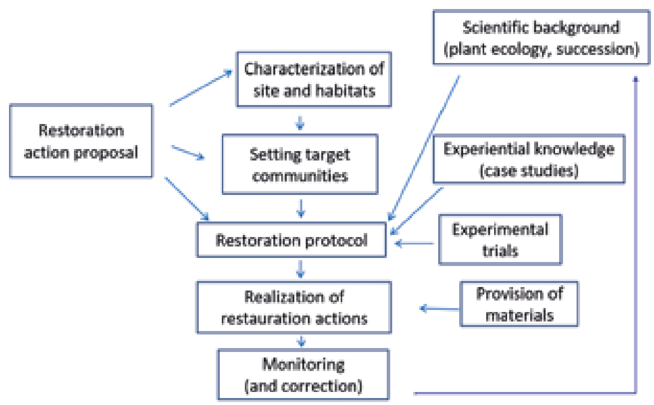
Perspectives and general context

We expect both the *Carex rostrata* mire with sphagnum (HIC 7140) and the sphagnum bogs (HIC 7110*) to develop relatively slowly, depending on the different components of these plant communities. Thus, the *C. rostrata* populations were satisfactorily established in a short time, offering a relatively stable structure to the other components, while for the sphagnum populations we expect a rather slower and more random process, depending on environmental conditions. Simultaneously, several vascular wetland plants (*Carex flacca, C. lepidocarpa, Pinguicula grandiflora, Potentilla erecta,* etc.) were spontaneously introduced. In addition, even with a short monitoring period, the weight of extreme weather events in the course of succession has been verified. The temporality and intensity of these periods may substantially change the forecasts.

Here, we want to emphasize the importance of monitoring the peat system of Font Grossa, especially as we do not have similar experiences in the Pyrenees. This monitoring is key, not only to be able to assess the progress made, but to describe the plant succession in reasonable detail. In a more general context, it should be considered that restoration actions and ecological knowledge of natural systems must coexist and strengthen each other (Figure 12). Just as it is unreasonable to begin restoration actions without a minimum knowledge of the structure and function of ecosystems, this ecological knowledge also feeds from management and restoration actions. And it does so consistently, only if these actions are based on a reasonably precise protocol, and if proper monitoring of the system is conducted.



▲ **Figure 11.** Progression of the *Sphagnum* propagules used in the restoration experiments (measured as the projection area of the group planted in each container) throughout the first year, in the shoreline sand of Font Grossa, according to the three water levels considered: NF0, planted a few cm underwater; NF1, approximately at water level; NF2, few cm above the water.



▲ **Figure 12.** Conceptual summary of the actions undertaken following the restoration of mires on the shores of the Font Grossa reservoir. From the characterisation of habitats to the monitoring, as well as the studies and experiments, most respond well to the proposed restoration target, while the monitoring and results of these studies are important as a test, and as a scientific basis in ecology of communities.

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