Summary

Alternatives for sod-cutting wet heaths Effects in the medium-long term

Synthesis

Introduction
The restoration of the quality of the habitat in wet heaths is an important task on both a national and European level. This not only requires hydrological restoration, but also a careful assessment of the various measures for vegetation management and restoring the buffer capacity (Wallis de Vries *et al.,* 2016a). Small-scale sod-cutting while leaving remaining populations intact is a common measure in this respect to breach grass encroachment by *Molinia* (De Graaf *et al.*, among others, 2004; Bobbink *et al.*, 2004). Because of the far-reaching effects of sod-cutting on the soil, the vegetation and the fauna, this study examines choppering and rotational grazing as possible alternatives. It also examines the effect of liming as an additional measure. Liming has been examined as a measure to counteract the already present acidification, but also as a measure (Dorland *et al.*, 2005b) against the temporary ammonium peak that occurs in acid heaths immediately after sod-cutting (De Graaf *et al.*, 1998a; Dorland *et al.*, 2003; Bobbink *et al.*, 2004) and that may make it difficult for characteristic species to re-establish themselves (De Graaf *et al.*, 1998b).
The effects in the short term (two years after the implementation of the measures) are discussed in an earlier study (Wallis de Vries *et al.*, 2014). The influence of the disturbance caused by the implementation was still a dominant factor in choppering and, of course, in sod-cutting as well. More interesting from the viewpoint of restoring the habitat are the influences in the longer term. Which is why this study is an assessment of the effects in the medium-long term (six years after the implementation of the measures).

This synthesis examines the effects of sod-cutting (1.2) as a (regular) measure and those of the alternatives choppering (1.3) and rotational grazing (1.4) (see table 1.1). The additional influence of liming (1.5) is discussed separately. Based on the findings, recommendations are provided for making a choice between the various measures (1.7).

Experimental research was conducted in order to obtain more insight into the effects of rotational grazing and choppering as alternatives for sod-cutting. The research involved measurements *before* and *after* the implementation of measures. The experiment entailed a comparison of 8 treatments, namely 4 measures – choppering, rotational grazing, sod-cutting and a control – without and without liming. Liming is applied in a dosage of 2 tonnes calcium/magnesium carbonate per hectare. The rotational grazing took place during four seasons using Kempen heathland sheep. A scale of approx. 20x20 m was observed for the implementation of each treatment: small enough to allow for repeats within a plot and large enough to be able to measure the response of the fauna on a practical (management) scale. The research was conducted in triplicate at two locations in Noord-Brabant: Kampina (Natuurmonumenten) and Strabrechtse heide (Staatsbosbeheer).

The study addressed the key question: are choppering and rotational grazing good alternatives for sod-cutting in wet heaths with a view to effectively restoring abiotic factors, vegetation and fauna in the medium-long term?
Secondary questions included:

i. Does acidification still obstruct the development of vegetation and affect the quality of food for herbivore fauna following rotational grazing or choppering?
ii. Can liming be used in combination with rotational grazing and choppering to counteract acidification without resulting in eutrophication?
iii. Are characteristic plant species, macro-fungi and animal species able to re-establish themselves?
iv. Do the effects of choppering, rotational grazing and supplementary liming differ between groups with different ecological functions?

A few possible limitations in the study can be addressed prior to answering the above-mentioned questions. These mainly lie in the limited size of the test plots and the specific starting situation that was examined. However, both of these limitations do not appear to detract from the broad outlines of the findings.
The size of the test plots was limited to 20x20 m (and even to a mere 10x10 m in one section at Kampina). This is sufficiently large to determine the effects on the soil, vegetation and the myco-flora. However, concerning the fauna, there is the question of the degree to which the observed species are bound to the test plots. This depends upon the spatial scale of the habitats of the species and their mobility. Mobile species with large habitats will probably scarcely be bound to a specific test plot of 20x20 m. They may possibly use the plots for specific purposes: butterflies, for example, may forage on the relatively numerous nectar plants without reproducing and lizards, for example, could use the half-open structure of the choppered spots for hunting, whereas they can withdraw into the closed vegetation for protection or perhaps hibernation.
The drawbacks of the modest size of the test plots as described do not however appear to be a huge issue. First of all, a considerable portion of the sampled fauna is bound to a small spatial scale: regarding the ants found, Diptera (sampled with emergence traps!) as well as ground beetles and locusts that either cannot fly or are bound to specific biotopes, it is very likely that they reproduce on the scale of the test plots; evidence of reproduction was also found for butterflies, such as the silver-studded blue *Plebejus* and the Alcon blue *Phengaris alcon*, in the form of caterpillars and small eggs, respectively. It is therefore likely for these species that significant effects of the treatments do have relevant effects on the quality of their habitat. Secondly, the same appears to apply to species for which significant effects were found, but which operate on a larger scale: it is also likely for these species as well that these effects lie in the specific habitat quality on the test plots, such as an abundant supply of food. But it must be considered for these species that they may also be dependent of other sources for their existence (protection, hibernation and the like) that fall outside the test plots. Thirdly, we have partially overcome these drawbacks by also classifying species according to habitat preference and characteristics and by analysing the variation in species diversity between the treatments for these groups. And so the effects that were found are less dependent of the coincidental response of an individual species. Fourthly, the size of the test plot also does justice to the heterogeneity in the heath landscape – larger test plots would not be advisable as these would entail extra terrain heterogeneity, which would cloud the results – and also does justice to the scale upon which present-day terrain management takes place – current management occurs as much as possible on a small scale with a view to maintaining the fauna and remaining populations. Therefore, larger test plots would not have been a realistic option where it concerns translating the results into actual management practice.

The second possible limitation concerned the starting situation that was studied: that of a moist to wet heathland dominated by *Molinia.* This is a situation that is clearly changed compared to the reference used as a species-rich wet heathland. It can obviously be assumed that the species diversity of the wet heath has also strongly deteriorated (Van Duinen *et al.,* 2014). However, the number of characteristic species of (myco) flora as well as fauna in the situation studied was sufficient enough to assure a representative part of the heathland community. Moreover, we have strived to reach an overall picture in this case as well by grouping species with a similar habitat preference or similar characteristics. We can therefore assume that the effects observed in this situation will also apply to heathlands with similar abiotic conditions elsewhere in the Netherlands.
It should be pointed out that species that demonstrate a limited dispersion and that are dependent upon a higher buffering capacity in heath soils are probably underrepresented in this study because of the acidified starting situation. However, this mainly applies to species in acidic grassland environments (see Van der Zee *et al.,* 2017) and less to the species in wet heathlands.

Sod-cutting
Large amounts of organic matter and nutrients are removed as a result of sod-cutting. This was also ascertained in this study: the content of organic matter, nitrogen and phosphate was significantly lower. The concentration of phosphate that was available to plant life, however, did not differ significantly from the control after six years, but the concentration of unstably bound phosphate (P-NaCl) still did. The concentrations of calcium and magnesium did not, however, show a significant decrease and the pH was sooner higher than lower after sod-cutting. This contrasts with dry heathland, where the sensitivity for acidification is higher due to the lack of influence of groundwater (Vogels *et al.*, 2016; Bobbink *et al.*, 2017;). The Al/Ca-ratio was found to be considerably higher after sod-cutting (without liming), which indicates possible toxic effects of aluminium. Because of the lower concentration of organic matter, leading to a lower adsorption capacity of cations, the amount of exchangeable potassium had also reduced after six years.
In terms of the chemical composition of the plant (*Erica tetralix*), the change in soil chemistry demonstrated itself in an increased content of both calcium as well as aluminium and a decreased concentration of nitrogen, resulting in a higher C/N-ratio. However, the P-concentrations and the N/P-ratio did not change as a result of sod-cutting.

With respect to the vegetation, around half of the species characteristic of the local type of vegetation were found to still be present. Sow-cutting results in the re-establishment of species from the soil seed bank. As a result, the coverage with target species and red list species was much higher than when the control treatment was applied. Marked species of pioneer environments, cattle trails and open spaces, such as *Rhynchospora fusca* and *Drosera intermedia*, highly benefited from the sod-cutting measures, among others. Both species are characteristic of wet heathlands but appear not to be particularly susceptible with respect to other abiotic factors. They were found to most frequently profit from sod-cutting management in an earlier study by de Kort-Langeveld *et al.* (2012) as well. In addition to these pioneer species, many plants that are normally found in older heathlands also re-established themselves following sod-cutting, although in lower coverage percentages in first instance. Nevertheless, a number of characteristic species, which could be found in the surrounding area, had still not returned six years after the choppering and sod-cutting. This concerns liverworts, *Marchantiophyta*, and peat moss, *Sphagnum*, in the moist sections and lichens in the drier sections. The marsh gentian, *Gentiana pneumonanthe*, also scarcely re-established itself after applying sod-cutting.
The myco-flora is more sensitive to sod-cutting than the vegetation. In contrast with vascular plants, a rather varied myco-flora was found to be present in the grass encroached baseline situation. Sod-cutting resulted in the deterioration of species that are common in soil litter and, to a lesser degree, typical heathland species as well. There were no signs of recovery after 6 years.

Sod-cutting results in a lasting unsuitable ecotope for the fauna that is typical of the late ecological succession stages of wet heathlands. Both the species diversity as well as the numbers of species of older heathland stages had declined drastically two years after the implementation. Although still lower than prior to the implementation, the rather small scale implementation of this management experiment showed a clear recovery of the species diversity six years after the implementation. The numbers of individual species were still low as well. Sod-cutting did result in a revival of pioneer species in the short term, but the species diversity of this group was often no longer significantly higher six years after the implementation. High numbers in the sod-cut plots continued to be found only for species such as *M. maculatus*. The effect of sod-cutting as a management measure was still present in the medium-long term within the more divers species group of ground beetles and spiders, but a shift from the community to a species composition common to conditions with a greater buffering capacity could be observed here as well.
The extremely wet sod-cutting treatments on Kampina demonstrated the steering effect of sod-cutting on the fauna community in more detail: the species composition of the young as well as the old sod-cut plots were characterised by mobile species that are capable of quickly fleeing from unfavourable situations. Virtually all of these species are also highly moisture-loving and can be characterised as marked species of waterside environments. A clear gradient in the moisture conditions was found between the various blocks on the Strabrechtse heide, resulting in different outcomes of the management measures. Marked moisture-loving species increased in the drier environments following sod-cutting, whereas the mobile species of pioneer- and waterside-environments increased in the short- and medium-long term, as was the case at Kampina.
It was also evident from the analysis based on the trophic groups that sod-cutting results in a strong decrease in the number of herbivore and detritivore Dipteran. This decrease could still be clearly observed in the medium-long term.

Choppering
Compared to sod-cutting, the extent of the removal of nutrients is lower for choppering due to the superficial nature of the treatment. A lower decrease in organic matter, nitrogen and potassium was indeed observed compared to sod-cutting and the phosphate level remained the same. The pH also remained stable and the Al/Ca-ratio did not increase, contrary to sod-cutting, which is a favourable difference. The decrease in potassium was, however, found to be significant after six years.
The plant quality did not differ compared to the quality following sod-cutting and also demonstrated higher concentrations of calcium and aluminium after six years, but the increase in nitrogen concentration was somewhat less obvious.

The effect of choppering on the flora is almost as positive as that of sod-cutting, but after six years there were still no signs of any re-establishment of fungi. *Gentiana pneumonanthe* established itself more quickly following choppering compared to sod-cutting. The proximity of seed sources is most likely a condition in this respect, maar it is also possible that less seed and fewer root remnants are removed in the case of choppering. The (re-) establishment will in any event be stimulated by the higher moisture-retaining capacity of the organic soil that remains behind. It is furthermore striking that choppering results in fewer tree root suckers compared to sod-cutting.

Regarding the fauna, choppering and sod-cutting led to an equally strong increase of pioneer species in the short term, but choppering showed less deterioration of mature stage heathland species. Six years after the implementation of the measures, the species diversity of both groups no longer differed from the diversity *prior to* the implementation. The silver-studded blue, *Plejebus argus,* was once again the most plentiful on the chopped plots six years after the implementation and caterpillars – as proof of reproduction – could also be found in the young heathland vegetation. The *Phengaris alcon* also reproduced in the chopped plots, but because of the poor development of the population in general in the course of the past years (probable due to extreme climate conditions), it was not possible to

ascertain whether this promising development could continue. The Viviparous lizard, *Zootoca vivipara*, and the Euro-Siberian ant, *Myrmica scabrinodis,* were furthermore most commonly found in the chopped test plots. Both species possibly benefited from a warmer micro-climate in the more open vegetation that offers shelter for the lizard, whereas the ant can nestle in the clump structures that remained behind.
The analysis of the species in the communities of ground beetles and spiders showed a similar result: the community once again developed towards the control and the plots subjected to intensive grazing did so much quicker after choppering compared to after sod-cutting. The composition of the sod-cut and choppered treatments was still virtually the same shortly after the implementation (in 2013), but the year 2017 showed a strong shift towards more mesophile and low-mobility species (a development towards the control and the intensive grazing treatments) after choppering compared to sod-cutting.
The analysis based on trophic groups showed a similar reduction in the number of herbivore and detritivore Dipterans after both choppering and sod-cutting, but this no longer applied to the detritivores six years after choppering, contrary to sod-cutting. These results also suggest a quicker succession following choppering compared to sod-cutting.

Intensive rotational grazing
Intensive rotational grazing does reduce the biomass, but no nutrients are removed. This is essentially a possibility if the sheep are only deployed during the grazing period and subsequently moved elsewhere for resting and rumination (see Nijssen *et al.*, 2016 for experiences with this situation on calcareous grassland), but this is more laborious in practice. This was not the set-up in the current experiment, which is why large amounts of dung were deposited in the test plots. And so, without supplementary liming, intensive rotational grazing did not show any significant change in the soil chemistry.

The plant chemistry did show a significant effect of intensive rotational grazing, namely higher P-concentrations and subsequently a lower C/P-ratio, as well as a lower C/N-ratio to a lesser degree. This is most likely the result of a higher availability of nutrients due to the input of dung.

Intensive rotational grazing did result in a more open vegetation structure and a reduction of the tree root suckers, while the microrelief was also maintained, but the litterfall was not broken open and *Molinia* remained dominant. And with that, the restoration of the flora target species failed to occur. The effect on the myco-flora was minor as well. Better results were obtained on dry heathland, where intensive rotational grazing was found to be more effective in restoring the vegetation (Van Beek, 2005; Verbeek *et al.*, 2006), particularly when combined with burning (Vogels *et al.*, 2017); however, species with a low dispersion capacity and no long-term seed bank scarcely re-establish themselves. The already present *Gentiana pneumonanthe* did appear to blossom in larger numbers in the more open vegetation following intensive rotational grazing compared to before.
The sheep dung that remained behind after intensive rotational grazing did result in a clearly enhanced establishment of species characteristic of the more nutrient-rich disturbed environments, such as the dandelion, *Taraxacum officinale,* and the annual nettle, *Urtica urens.* This revival lasted longer compared to the sod-cut and choppered plots and involved more perennials. Yet the overgrowth without liming remained limited to a cover of 5%.

Intensive rotational grazing had surprisingly few consequences for the fauna. A positive side of this is that the relatively large group of species characteristic of older heathland did not significantly decrease, as could be feared beforehand. The Alcon blue, *Phengaris alcon,* failed to deposit eggs during the years of intensive rotational grazing due to a lack of flowering *Gentiana pneumonanthe*. This obstacle was eliminated after the intensive rotational grazing ended and the marsh gentians that were present blossomed once again, but a recovery for the butterfly could not be ascertained due to the reduced population of *Gentiana pneumonanthe.* No effects were found within the Dipterans on trophic levels compared to the

control and the composition of the ground beetle and spider communities was also highly comparable to the composition of the treatments throughout the years of research. This was characterised by scarcely mobile species, both moisture-loving and shade-loving, and/or species that are bound more strongly to a well-developed vegetation structure characteristic of later stages of succession.

So it appears that intensive rotational grazing is scarcely effective on wet heathland in the medium-long term in counteracting the dominance of *Molinia.* It is possible that such can be achieved in the long term. There is one documented example to that effect, namely that of the parking pasture (where the sheep spend the night) of the sheep herd on the Strabrechtse heide, where intensive sheep-grazing has occurred starting in 1970. A botanically species-rich wet heathland has been restored, along with rather large numbers of animal species characteristic of open and young heath environments (Wallis de Vries *et al.,* 2014). There are furthermore indications that the combination of intensive rotational grazing following burning is more effective in counteracting *Molinia* and restoring both the floristic as well as the faunistic species diversity (Wallis de Vries *et al.,* 2014; Vogels *et al.,* 2017), but here too it appears that such is more difficult to achieve on wet heathland compared to dry heathland.

Liming

In each case – sod-cutting, choppering, intensive rotational grazing and doing nothing – liming resulted in a higher pH and increased availability of magnesium and calcium. The effect was only minor at first, but it increased in the medium-long term. Part of the dologran had likely not yet dissolved and absorbed into the soil after two years, whereas such was the case after six. The higher availability of magnesium was demonstrated by the magnesium concentrations in the cross-leaved heath, *Erica tetralix*; this was not the case for the higher availability of calcium. This may be due to *Erica tetralix*; other field studies (Weijters *et al.*, 2018) also show *Erica tetralix* to have no higher calcium concentration following liming, whereas this was the case for sheep's sorrel, *Rumex acetosella,* and wavy-hair grass, *Deschampsia flexuosa.* Also consistent was the effect of liming on the N/P-ratio (lower) and (applying sod-cutting and choppering) on the P/K-ratio (higher).

Liming resulted in an increase in pH of around 0.4 units to a pH-NaCl of 4.0. This pH along with an exchangeable calcium concentration of around 4800 µmol/l soil rendered the pH and buffering capacity very suitable for the development of the wet heathland community *Ericetum tetralicis* and the plant community of inundated club moss, *Lycopodiella inundata,* and the white beak-sedge, *Rhynchospora*. Thanks to the increased concentration of alkaline cations that was brought about in this way, the system was also better equipped to counteract the acidifying effects of future nitrogen deposition and any aluminium toxicity.

Concerning the flora, liming resulted in an increased establishment and survival of species characteristic of nutrient-rich disturbed environments and seedlings of trees and shrubs, except in the cases of taking no measures at all in highly grass encroached situations. The combination of intensive rotational grazing and liming led to a highly increased fructification of fungi. This treatment in particular – and to a lesser degree liming with no further interference – resulted in a significantly higher number of fruiting bodies of litterfall-decomposing fungi. The establishment of disturbance-indicators, however, did not proceed after sod-cutting or choppering. Only the combination with intensive rotational grazing resulted in a certain degree of overgrowth (with an average cover of less than 10%). Liming, however, also led to the establishment of species characteristic of acid grasslands, specie-rich wet heathland and buffered marshes; this applied to vascular plants, mosses and fungi. *Gentiana pneumonanthe* best developed on limed and choppered plots. Newly established fungi included a considerable number of rare species, but the establishment of vascular plants and mosses remained limited to a few, mostly common grassland species This indicates that rarer species of wet acid grasslands and species-rich wet heathland have

difficulty reaching places of this kind, for example heath milkwort (*Polygala serpyllifolia*) and lousewort (*Pedicularis sylvatica*).

Liming had no demonstrable consequences for the species diversity of the fauna or their numbers with respect to characteristic species. On the level of trophic groups, the positive effect of liming on the numbers of detritivore Dipterans after choppering and on herbivore Dipterans after sod-cutting proved to be only short-term. The numbers of carnivore Dipterans, on the other hand, were not found to be lower in the choppered and sod-cut plots until after six years. Liming may indirectly have positive effects on the herbivores that are dependent upon plant species characteristic of slightly buffered environments, such as the Alcon blue.

Conclusion

The effects of the treatments of vegetation and liming on the abiotic conditions, the vegetation and the fauna have been summarised in Table 1.1.

Soil- and plant chemistry
Sod-cutting and choppering result in the removal of nutrients, whereas such is not or only scarcely the case with intensive rotational grazing. The removal of nutrients due to choppering is somewhat lower compared to sod-cutting, as less of the soil top layer is removed. Intensive rotational grazing even appeared to result in a higher nutrient availability. Despite the fact that soil analyses did not show a higher nutrient availability as a result of intensive rotational grazing, both the higher nutrient concentrations in *Erica tetralix* as well as the higher cover with species with a preference for an eutrophic environment and the increased activity of saprotrophic fungi suggest that more nutrients were possibly available to the plants.
Because of the higher nutrient concentrations in *Erica tetralix* following intensive rotational grazing, both the C/N- as well as the C/P-ratio in the plant were lower. The nutritional value of these plants for herbivores is therefore possibly higher following intensive rotational grazing compared to the sod-cut and choppered plots. Liming also had a positive effect on the nutritional value for plants due to a lower N/P-ratio, which is most probably the most decisive factor for the plant quality within the range measured (Elser *et al.*, 2000).

Table 1.1: *Overview of the medium-term effects of non-intervention, sod-cutting and intensive rotational grazing or choppering as management alternatives to sod-cutting –with or without liming – on aspects of soil chemistry, soil and vegetation and fauna. Non-intervention without liming serves as a reference for all effects (signs indicate the direction of the effect with green for desirable effects and red for undesirable effects from a restoration perspective).*

Measure	Control		Rotational grazing		Choppering		Sod-cutting	
Liming	–	+	–	+	–	+	–	+
Soil chemistry								
pH		+		+		+		+
Alkaline kations		++		++		++		++
Available Aluminium		−−		−−		−−	+	−−
Available Phosphate			(+)	(+)			–	–
Nitrogen (ammonium)			(+)	(+)	–	–	−−	−−
N/P in plants	–			–		–		–
Magnesium in plants				(+)		+		+
Soil and Vegetation								
Microtopography			–	–	−−	−−	−−	−−
Vegetation density			–	–	−−	−−	−−−	−−−
Grass encroachment					–	–	−−	−−
Vascular plants					++	++	++	++
Bryophytes					(+)	(+)	(+)	(+)
Macrofungi		++		+	–	+	−−	(+)
Disturbance indicators		(+)	+	++		(+)		(+)
Bush encroachment			–			+		+
Fauna								
Pioneer species*					(+)	(+)	+	+
Species of mature heaths					(-)	(-)	–	–
Carabid beetle and spider community								
Species from open banks, wet oligotrophic conditions						+	++	++
Species from wet heaths and moors, late successional			+?	+?	(-)	(-)	–	–
Species from driftsands and low-intensity agricultural lands			+	+			+/=	+/=
Species from dry heaths			+?	+?	–/+	–/+	–/+	–/+
Highly mobile species							++	++
Xerophilic species							–/+	–/+
Mesophilic species								
Hygrophilic species					+/–	+/–	+/–	+/–
Diptera								
Carnivores		(–)				–		–
Herbivores					–	–	−−	−−
Detritivores / Fungivores							–	–

*including mobile, fast colonising species that may also be present in later successional stages

Both sod-cutting and choppering may lead to a lower availability of nitrogen, potassium and phosphorus for plants. As the removal of nitrogen is the only intended result, this could lead to problems regarding the intake of phosphorus or potassium (Vogels *et al.*, 2016). However, this study showed no effect of sod-cutting or choppering on the ratio of nitrogen and phosphorus, or on the ratio of nitrogen and potassium in the plant. This is in contrast with dry heathland, where this effect was clearly demonstrated (Vogels *et al.*, 2011, 2017). The results therefore suggest a difference between dry heathland and wet heathland with respect to the N/P-ration following sod-cutting, in which the P-limitation following sod-cutting in wet heathland is much lower compared to the limitation following sod-cutting in dry heathland. Liming did not result in an immediately measurable higher availability of nutrients. Whereas there is often concern that liming will have an eutrophicating effect, this study shows that liming with 2 tonnes/ha of dologran in moist or wet heathland systems – in a grass-encroached situation as well as on the choppered or sod-cut soils – does *not* lead to a higher availability of nutrients such as to justify the concern for eutrophication. Other studies in which heathland is treated with a similar dose of lime also show no signs of overgrowth with undesired species (Weijters *et al.*, 2018). However, experiments involving the liming of forest soils in which larger amounts were used only resulted in a (considerable) effect of overgrowth of undesired plant species when amounts exceeding 3-4 tonnes/ha of lime were used (Bobbink *et al.*, in preparation). The risk of undesired overgrowth due to liming in moderate amounts therefore appears to be minor even when organic matter has accumulated in the system.

Liming by means of dologran that contains magnesium and calcium in a ratio of 1:1 did not result in a decrease in the availability of magnesium, whereas it is known that many -mineral- adsorption complexes that calcium is a better adsorbent compared to (for example,

Suarez & Zahow, 1988; Van der Heijden *et al.*, 2014). The magnesium concentration in *Erica tetralix* increased significantly after liming with dologran, whereas the concentration of calcium in the plant did not increase as a result of liming. Liming experiments involving dolokal or some other lime mixture with a much higher proportion of calcium compared to magnesium also often showed a relatively higher increase of the magnesium concentration compared to calcium (Weijters *et al.*, 2018). And so there appears to be a rather small risk of a shortage of magnesium in other types of lime are used as well. There was a significant decrease of Zn in plots treated with lime and after sod-cutting or choppering, which suggests a strong competition with respect to the intake of Ca and Mg on the one hand and Zn on the other. This effect was also found in a previous study into the liming of dry heathland (Vogels *et al.*, 2016), in which the concentrations of metal ions such as Zn (II), Mn (II) and Fe (II) decreased in the treatments with lime. It should be mentioned that these effects were more significant in dry heathlands compared to the minor changes in this study.

Liming by means of dologran did not lead to a decrease in the amount of potassium bound to the adsorption complex, despite the fact that the calcium (II) ions and the magnesium (II) ions are better adsorbates than singly charged cations such as potassium and could therefore cause the displacement of potassium to the adsorption complex. The plant chemistry of *Erica tetralix* also showed no signs of a decreased potassium availability.

Liming did however have significant effects on the plant chemistry in a relative sense. The N/P-ratio (lower) and the P/K-ratio (higher) in the plant were significantly different in all treatments as a result of liming. This means that liming leads to a shift in the relative intake of various elements. A lower N/P ratio suggests a shift from the limitation of P towards N-limited growth conditions, although the ratios in the sections treated with lime were also still in the range of primarily P-limited growth (Koerselman & Meuleman, 1996; von Oheimb *et al.*, 2010). The precise mechanism behind this decrease in the N/P-ratio cannot be discovered on the basis of this study, but the results do correspond with relationships previously found between soil buffering and N/P-ratios in plants on the Strabrechtse heide and the Dwingelderveld (Vogels *et al.*, 2011). This shift to lower N/P-ratios can also have a positive effect on the quality of food for the herbivore fauna (Vogels, 2013; Vogels *et al.*, 2017). This study showed no clear evidence to that effect, however, seeing that the positive response of herbivore Dipterans to liming was only short-term.

All in all, sod-cutting in combination with liming created the best abiotic starting point for the development of a species-rich wet heathland. These conditions were closely achieved with choppering; both the availability of nitrogen decreased and the saturation with bases increased. This makes choppering in combination with liming a very favourable alternative for sod-cutting in acidified wet heathlands. Intensive rotational grazing is not a suitable measure for restoring the abiotic conditions in wet heathland and may possibly lead to a slight degree of overgrowth with undesired species. Liming alone without any additional measures (sod-cutting, choppering) to counteract (too high a level of) eutrophication does not appear to be worthwhile in heavily grass encroached wet heathlands. This measure increases the buffering capacity of the soil and the pH, to be sure, but because the dominant *Molinia* also thrives under those circumstances, the application of liming alone will not effectively counter the dominance of *Molinia*. However, liming with no additional measures can be a good method to counteract acidification at locations that are only acidified, but not encroached with grass species and overgrown with other undesired plant species (Weijters *et al.,* 2018). It is evident from our experiments (in grass encroached heathland) that this sufficiently restore the pH and the buffering capacity, without resulting in overgrowth of undesired (grass) species.

Vegetation

The variation in terrain and the larger diversity that can achieved by a combination of sod-cut plots and non-sod-cut plots can also be achieved by means of choppering. Regarding vegetation, choppering appears to be a good alternative for sod-cutting. The regrowth of

Molinia occurs somewhat quicker, but the grass encroached sections appear to stabilise amidst sections dominated by heath after a few years. There were fewer tree root suckers in the choppered plots compared to the sod-cut plots. Choppering will likely require specific subsequent management practices in the form of (regular) grazing in the medium-long term to long term so as to keep the expansion of *Molinia* in check.
Six years after choppering, however, a number of characteristic species that could be found in the surrounding terrain had not yet re-established themselves. This is comparable to sod-cutting and indicates that choppering too is a far-reaching measure for some species that are characteristic of older, more mature heaths. This applies to a greater extent to fungi that are characteristic of wet heathlands, as they often live off accumulated humus. The mycoflora received a blow as a result of sod-cutting and had not in the least recovered after a period of six years. The situation was not much better following choppering.
Even after four seasons of implementation, the measure intensive rotational grazing on wet heathland did not result in countering the dominance of *Molinia* and creating open germination environments. And with that, the restoration of the target species for the flora failed to occur. There were also signs in the vegetation, but particularly in the mycoflora, that sheep dung does indeed have an eutrophicating effect. And with that, intensive rotational grazing does not appear to be as effective in countering grass encroachment on wet heath compared to the effect on drier heath (Van Beek, 2005; Verbeek *et al.*, 2006), where the combination of intensive rotational grazing and burning also results in a more species-rich vegetation (Vogels *et al.*, 2017). There are however indications that the use of heavier grazing stock, such as ponies, can lead to the same positive result on wet heathland. (Wallis de Vries *et al.*, 2014).
Liming of the humus layer accumulated by *Molinia* resulted in an increased decomposition with higher numbers of litterfall-degrading fungi, but it also improved the buffering capacity and subsequently the development of a nutrient-poor, acidic aspect. The results for the mycoflora were even spectacular, demonstrated by the establishment of dozens of rare and often threatened species. Liming therefore has a favourable effect on some species, but also involves the risk of eutrophication. Overgrowth with undesired (grass) species did not occur, however, after choppering. The combination of liming and intensive rotational grazing did have that result, however, due to the dung that remained behind. What is concerning is that the overgrowth mainly concerned perennials after six years, and so this development could be long-term in nature.

Fauna
The fauna of wet heathland comprises more (older) mature stage species than pioneer species. Many mature heath species prefer undisturbed, shaded and/or more grown over habitats with a moist microclimate. Which is why they were often found in the grass-encroached heath of the zero situation. Habitats with little value from a perspective of vegetation (*Molinia caerulea*, or moist heath highly dominated by *Molinia*) could still provide very suitable living conditions for the fauna and accommodate many characteristic species. The implementation of management measures such as choppering and sod-cutting can however create suitable conditions for fauna species that are characteristic of moist, open pioneer environments. However, species that are bound to more mature heath developmental stages are put at a major disadvantage by applying sod-cutting and choppering, in which respect the current study showed that restoration occurs sooner following choppering compared to sod-cutting.
Species typical of undisturbed heath largely remained present following intensive rotational grazing due to the minor disturbance and the fact that the tussock structures remained intact. This emphasises the importance of permanently maintaining parts of the grass-encroached vegetation, seeing that these offer important places of refuge for many species that are characteristic of (among others) wet heathland.

On the level of trophic relationships, the far-reaching methods sod-cutting and choppering had a major negative influence on the density of herbivore and detritivore Dipterans in the medium-long term. Liming immediately after the implementation of far-reaching measures

showed a modest positive response of herbivore and detritivore Dipterans. However, there were no indications that liming led to a prolonged stimulation of detritivores, possibly due to an increase in the decomposition of organic material by moulds.

Answering the research questions

The study began with addressing the following four main questions. These are answered in short below on the basis of the discussion of the results above. The answers to the sub-questions are summarised in Table 1.2.

i. *Does acidification still hamper the development of vegetation and limit food quality for the herbivore fauna after implementing intensive rotational grazing or choppering?*
   Yes, both measures do not result in the restoration of the buffering capacity. The pH remains below 3.5 and that is not sufficient for the successful recovery of the vegetation and the fauna.
ii. *Can liming be used to counteract acidification in combination with intensive rotational grazing and choppering without leading to overgrowth with undesired species (eutrophication)?*
   Yes, such is the case for choppering, but not for intensive rotational grazing, unless the accumulation of dung can be avoided (liming of grass-encroached vegetation without any further measures did result in the restoration of the buffering capacity, but scarcely any overgrowth with undesired species)
iii. *Are characteristic species of plants, fungi and animals able to re-establish themselves?*
   In part. This is scarcely the case with intensive rotational grazing, although mature heathland species are (moderately) spared. More species return after choppering (and more quickly compared to sod-cutting), but a number of mature heath species are still scarce or lacking six years after the implementation. Species with a limited dispersion capacity only re-establish if there are seed sources or source populations in the immediate vicinity. If such is not the case, then one must consider actively reintroducing these species.
iv. *Do the effects of choppering, intensive rotational grazing and supplementary liming differ between groups with different ecological functions?*
   Yes, intensive rotational grazing in combination with liming was found to stimulate litterfall-decomposing fungi and led to overgrowth with undesired species in some cases, but the effects on the fauna were few and minor. Detritivores, herbivores and carnivores all decrease considerably in numbers and diversity as a result of choppering and sod-cutting. Detritivores are able to recover in the medium-long term, but this takes longer for herbivores and carnivores.
   Sod-cutting (in the medium-long term) and choppering (in the short term) result in the coming about of environments that lead to an obvious shift in the composition of the fauna community. Depending upon the location of the moisture gradient, this concerns communities with species of waterside environments and wet pioneer environments and/or species of dry xerotherm environments. Both communities can be characterised as species characteristic of young succession stages that will be succeeded in the course of time by a community dominated by more mature stage species.

Table 1.2: *Summarising overview of the answers to the research questions.*

	Intensive Rotational grazing	Choppering
Abiotic conditions:		
Sufficient reduction of availability of nutrients?	No	Substantial
Pressure point for availability of phosphate and minerals?	No	No
Pressure point food quality for the fauna?	No	No
Acidification reversed by liming?	Yes	Yes
Negative effects of liming due to mineralisation?	Yes	No
Vegetation development:		
Return of characteristic species?	No	Substantial
Tree root suckers pushed back?	Not a major problem	Slightly stimulated by liming
Sufficient variation in soil- and vegetation structure for the restoration of mosses?	No	Not as yet
Sufficient restoration of humus layers and fungi characteristic of wet heath?	Partially in the case of liming	Not as yet
Fauna restoration:		
Is the micro-relief spared?	Yes	No
Greater variation in vegetation structure following sod-cutting?	Yes	Somewhat
Do the effects differ between the different ecological groups?	Pioneer species remain absent, mature heath species are spared	Pioneer species present in small numbers and restoration of mature heath species. Herbivores yet to be restored.
Positive effects on the characteristic heath fauna?	No	Partially

Final conclusion

Grass-encroached heath is considered of little value from the perspective of botanical diversity. Yet it can accommodate an important diversity of species of mosses, fungi and animal species. Sod-cutting reduces this diversity strongly in the short and medium-long term. Mature heath fauna and mosses had only ever so slightly returned after a medium-long period (six years after implementation), while mature heath fungi still lacked completely. Instead, pioneer species of open habitats benefit from the circumstances. These species began to show a decrease in numbers and species diversity after six years due to natural succession (which is facilitated by the still relatively high nitrogen deposition in the province of Noord-Brabant).

Choppering and intensive rotational grazing were examined here as possible alternatives so as to avoid the far-reaching effects of sod-cutting on the flora and fauna of the heath. Intensive rotational grazing is the least effective in the medium-long term where it concerns increasing the botanical diversity and promoting species characteristic of young heath stages. What's more, intentional rotational grazing appears to involve some risk of overgrowth with undesired species. The effectiveness of intensive rotational grazing on breaking the dominance of *Molinia* appears to be significantly lower compared to the results

with dry heathland. Intensive rotational grazing does spare the mature heath species to a moderate extent, although such is not the case in the short term for a species such as *Phengaris alcon,* the host plant of which suffers under intensive rotational grazing. Choppering is shown in this study to be a more effective restoration measure than intensive rotational grazing, particularly in combination with liming. After six years, the fauna community had recovered considerably from the intervention compared to the fauna of structure-rich, shaded and micro-climatologically buffered heath and the botanical qualities had strongly increased as well. Only mature heath stage mosses and fungi still lacked after six years.

From the perspective of abiotic conditions, grass-encroached wet heath is generally acidic and enriched with nitrogen (with water depletion also having a role). Liming of non-sod-cut grass-encroached heath results in a noticeable restoration of the buffering capacity, but scarcely leads to any changes in vegetation due to the unaltered dominance of *Molinia.* This study did show the establishment of many rare fungi characteristic of acidic grasslands. Sod-cutting is the most effective measure for removing an excess of nitrogen, but supplementary liming is almost always necessary in order to also counteract the negative effects acidification. Choppering removes less organic matter and nutrients, but the abiotic conditions are still considerably restored in combination with liming. Intensive rotational grazing sooner results in a higher rather than a lower availability of nutrients due to the dung that remains behind. However, the micro-relief is maintained and the structure of the vegetation becomes more open in nature. Liming in combination with intensive rotational grazing, however, results in an increased availability of nutrients and the risk of eutrophication. The effects on the food quality for the fauna appear to be positive rather than negative in moist to wet heaths, contrary to the continued effect in dry heath.

Remaining knowledge gaps

The study that was carried out provided answers to many questions, but also left a number of these unanswered. In the case of choppering, the main question is whether or not and within which time frame the species that are still lacking after six years will actually return. This applies to liverworts, fungi, poorly expanding vascular plants and the herbivore fauna (including the endangered *Phengaris alcon*). It is also still unclear whether choppering will allow for the subsequent development of a nutrient-poor, yet not highly acidic humus layer, of which endangered heath fungi are dependent.

An unexpected result of the study was the discovery that a highly divers myco-flora can establish itself following the liming of grass-encroached heath. The mechanisms behind this and whether or not this is a pattern is as yet not sufficiently clear. This question is particularly relevant in view of the plans to apply rock dust, among other things, in the heathlands on a large scale.

It is important with respect to intensive rotational grazing to ascertain whether the effectiveness can be increased, as this appears to be insufficient as yet in wet heathland. One of the first questions is whether the grazing intensity can be increased while simultaneously reducing the accumulation of dung. Another question is whether the effectiveness can be increased by applying the measure burning prior to intensive rotational grazing. A third question is whether the effectiveness of intensive rotational grazing can be increased by using heavier grazing stock, such as ponies, the trampling of which will break open the turf, creating opportunities for target species to establish themselves (as was the case on the Lankheet, for example; Wallis de Vries *et al.*, 2014).
Also unclear is the time frame in which the development of characteristic communities for the heath fauna will occur further to sod-cutting, choppering or (possibly) intensive rotational grazing, and what will be the composition of the fauna community once it is stable. This knowledge is valuable in coming to an effective management cycle and is particularly relevant within the framework of the PAS.

Should it be found that a continuous high nitrogen deposition renders restoration management necessary sooner than is desirable on the basis of the restoration capacity for flora and fauna, then this will be an additional argument for the further reduction of N-emissions.

Recommendations regarding restoration measures

Previous studies by Wallis de Vries *et al.* (2014) sketched a picture of sod-cutting, choppering and intensive rotational grazing as supplementary measures for the restoration of the biodiversity in wet heathlands. From a perspective of that kind, choppering and intensive rotational grazing are not so much alternatives for sod-cutting in the sense of being a substitute, but rather alternatives for either restoration measures on a large scale, in which sod-cutting is too drastic, or with a lower intensity for a more gradual restoration. The study in hand confirms this perspective.
The various measures have various effects and can even be considered complementary to one another. The choice for a particular measure depends strongly on the goal of the management. Sod-cutting has too many disadvantages to be used on a large scale, but it can be effectively used on a small scale in wet heath to achieve two goals: creating suitable environments for pioneer stage species (Association of *Lycopodiella inundata* (club moss) and *Rhynchospora alba* (white beak-sedge) with corresponding fauna) and bringing about conditions suitable for the establishment of species of species-rich wet heath with little competitive strength so as to achieve a varied vegetation in the long term. Choppering is a good alternative for sod-cutting in that respect where it concerns breaking the dominance of *Molinia.* The measure leads to a quicker succession to wet heath with a quicker recolonization by mature stage species, although to the disadvantage of young stage species. Intensive rotational grazing can be used as an adjustment measure in the normal management, in which the species of well-developed wet heath are to be spared, or when damaging the soil is not an option (if objects of archaeological value are present, for example). In addition to restoring the buffering capacity, liming also stimulates species characteristic of nutrient-poor environments.
It can furthermore be emphasized that wet heath that is dominated by *Molinia* is also of value to the biodiversity and that it offers refuge in the current situation for many fauna species and fungi that have difficulty or cannot survive in pioneer environments. Active management is therefore not always necessary or desirable, spatial zoning and phasing in time, on the other hand, all the more.
The insights acquired provide the manager with a broad range of measures with which to promote the quality if wet heathlands. The trick is to opt for a type of management that, based on an adequate assessment of the situation and the likelihood of success, is optimally in keeping with the goals for the region concerned.

The type of measure must also be geared to the cause(es) of the problems. It is important in this respect to ascertain whether the overgrowth and/or acidification is caused by the atmospheric deposition of nitrogen alone, or whether a decrease in the supply of slightly buffered groundwater also plays a role. Sod-cutting (on a small scale) – and, as evident from this study, choppering – are measures that can be used to adequately counteract overgrowth in wet heath in the first case (De Graaf *et al.*, 2004; Bobbink *et al.*, 2004, among others). If acidification occurs as a result of a lack of a sufficient supply of (slightly) buffered groundwater, then additional hydrological measures will also be necessary. Concerning terrains in which the buffering capacity could be maintained thanks to a supply of base-rich water, restoring the hydrology will be effective in counteracting the effects of acidification (Jansen *et al.*, 2010, among others). If it is not possible to sufficiently restore the hydrology, then one may opt for 'catchment liming'. The acidified section of the terrain itself is not limed, but rather its infiltration area, allowing for a supply of bases via local seep, instead of by means of directly applying lime (Dorland *et al.*, 2005a).

Direct liming can be applied at locations where hydrological restoration does not apply or is not an option. In addition to the traditional method of liming with calcium- and magnesium carbonates (lime'), such as dolokal and dologran, there are currently experiments with so-called 'rock dust': finely ground silicate minerals that, depending upon their origin, also add a whole range of (trace) elements that have been leached out from the heath terrains due to acidification (Bergsma *et al.*, 2016; Vogels *et al.*, 2016; Bobbink *et al.*, 2017). Because research into the positive and negative effects of various types of rock dust is still underway, which type of rock dust is best used in a certain situation is not known as yet. It is known that the nutrients from rock dust are released much slower compared to lime, so that one may consider also applying lime in addition to rock dust so as to facilitate a positive effect om the acidity with a term of a few years (Bobbink *et al.*, 2017; Weijters *et al.,* 2018).

Sod-cutting may be the preferred method in wet heath if the area is heavily grass-encroached, whereas the seed sources for tree root suckers are found at an ample distance. A small-scale, preferably manual, implementation with notches comprised of residual populations is essential in order to facilitate re-colonisation. Liming is desirable, unless it is clear up front that the soil is already sufficiently buffered.
As the micro-relief disappears, there is a high risk of inundation and re-acidification in the event of stagnant water. This risk is reduced by sod-cutting elongated strips across a latitude. In order to avoid too much contrast with the surrounding vegetation and to improve the habitat quality of the bordering zone, one may consider mowing a strip of the adjacent vegetation. It is furthermore desirable regarding species with little dispersion capacity to actively return these to the area.

Sod-cutting as a restoration measure is advised against in areas with a high degree of grass encroachment and requiring a larger scale approach, such because of the long-term negative effects on the fauna, the soil development and the macro-fungi. A good alternative is choppering in combination with liming. As this measure is far-reaching in the short term, it should be implemented on a relatively small scale in this case as well, but it will be possible to treat larger surfaces at the same time compared to sod-cutting. The recommendations above also apply to sod-cutting where it concerns the further implementation.

Intensive rotational grazing can be recommended for wet heath if the grass encroachment is moderate and if one opts for restoration within a more prolonged period (the intensive rotational grazing will have to take place for a number of years), or of soil-disrupting measures are not possible. Additional liming is not recommended if the soil is reasonably buffered. If the soil is acidified, then liming (or possibly rock dust) is an option, in which case the sheep-grazing must be restricted as much as possible until the effective grazing period, after which the sheep must be removed so as to avoid overgrowth due to the accumulation of dung. This can be achieved with tended herds of sheep. Intensive rotational grazing through flex-networks requires sharply-defined agreements concerning the deployment and removal of the animals. As the results with intensive rotational grazing in wet heath are not positive as yet, it is still a challenge to adequately optimise this measure in terms of frequency and scale. The results may possibly improve by mowing or burning the vegetation once prior to the implementation of intensive rotational grazing, but this will require further research.

Finally, the study in hand shows that liming using a low dosage (2 tonnes of dologran per hectare) is an option for restoring the buffering capacity of acidified heath soils in the short term without any other far-reaching restoration measures. If the characteristic species of wet heath are present, then extensively implementing normal management measures will suffice.

Rapport nr. 2018/OBN221-NZ:
Alternatieven voor plaggen van natte heide Effecten op middellange termijn