Biodiversity Value of Potential Forest Fertilisation Stands, as Assessed by Red-Listed and 'Signal' Bryophytes and Lichens

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In Sweden ca. 20 000 ha forestland is fertilised each year. By using red-listed and 'signal' bryophytes and lichens as indicators, we investigated whether forest stands planned for fertilisation have a biodiversity value, and thus if restrictions due to conservation aspects are motivated. Species occurrences were registered in detailed line-transect analysis, with a record size of 10 × 10 m, in 74 coniferous forest stands with a mean age of 57 years in East-Central Sweden. On the 230 ha totally surveyed, 10 red-listed and 37 signal species were found. The mean number of records ha^{-1} of red-listed bryophytes and lichens was 0.26 ha^{-1}, which is considerably less than previously found in mature production stands and woodland key habitats. Red-listed species were found in 31% of the stands and signal species in 95%. More than 70% of all records of red-listed species and 30% of the records of the signal species were found in moist micro-sites. If rare bryophytes and lichens are to be preserved in fertilisation stands, improved instructions regarding avoidance of important micro-sites are needed.

Keywords biodiversity, conservation, hemi-boreal forest, Sweden, threatened species
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1 Introduction

As a result of the Convention on Biological Diversity in 1992, the interest in biodiversity conservation has increased, not the least in forest ecosystems, which harbour two thirds of the terrestrial species on earth (World Resource Institute 2000). There has been an increased awareness of the changing and vanishing flora and fauna caused by forestry in various parts of the world.

In Sweden consideration is now taken to plants, animals and habitats in day-to-day forestry to a considerably larger extent than before, and new management and planning methods have been introduced (Angelstam and Pettersson 1997, Fries et al. 1997).

The uncommon and decreasing species are in focus in biodiversity conservation since they usually represent the vulnerable part of the flora and fauna. In Sweden Red Lists, i.e., lists that identify species with small and/or decreasing populations, have been compiled for about 25 years and are regularly updated. The importance of maintaining all indigenous species in viable populations has been acknowledged in Swedish societal goals and environmental policies of forest companies as well as organisations of private forest land-owners. Consequently, red-listed species are a relevant tool for assessment of biodiversity values, and also for evaluation of the effects on biodiversity of different forest management methods.

In Sweden 'signal species', comprising bryophytes, lichens, fungi and vascular plants, together with structural characteristics like old trees, dead wood and uneven layering, are used to identify forest stands with special value for biodiversity, so called 'woodland key habitats' of which there are 60 000–70 000 in the country, covering about 1% of the productive forest land (National Board of Forestry 1998). The signal species, which have been identified based on expert opinion, are less common although frequent enough to be useful as indicator species.

Recently data have been collected on the abundance of red-listed vascular plants, bryophytes and lichens in Swedish forests. In production forests with a mean height > 15 m, 1.1–4.2 records ha^{-1} of red-listed bryophytes and lichens were found in three areas in the hemi-boreal region but red-listed vascular plants were found to be very rare (Gustafsson 2002). The mean number of records ha^{-1} of red-listed bryophytes and lichens in ca. 120 woodland key habitats spread over Sweden was found to be 5 (Gustafsson et al. 1999). In a study on 30 production stands dominated by *Picea abies* in boreal Sweden, Gustafsson et al. (2003) found as much as 6.5 records of red-listed bryophytes and lichens ha^{-1}, although the three most common species were not recorded, due to time restrictions.

Nitrogen fertilisation is practised on ca. 20 000 ha coniferous forestland in Sweden yearly, from the county of Uppsala and northwards (National Board of Forestry 2003). Ammonium nitrate with some dolomite added is the most commonly used fertiliser and is normally spread at an average of ca. 150 kg ha^{-1} (Pettersson 1994), and almost exclusively on mineral soils. Application is done in about equal amounts from helicopter or tractor, respectively (National Board of Forestry 2003). Fertilisation is usually performed once, twice or three times, starting at the time of first thinning when the stands are 40–60 years, and the last at least 10 years before final harvest which is carried out at the age of 70–100 years.

Nitrogen fertilisation usually causes vegetation changes, but the degree and nature of change is dependent on different factors like fertiliser type, application dose and vegetation composition. For ground vegetation the growth response of the dominant species following nitrogen application is generally a main driving force behind the change. In the coniferous forests that prevail in Sweden, there is a sequence in competitive ability from *Vaccinium vitis-idaea* over *V. myrtillus* to highly competitive grass species like *Deschampsia flexuosa* (Kellner 1993b). Lichens seem to be especially sensitive to N enrichment, e.g. reindeer lichens *Cladonia* spp. (Eriksson and Raunistola 1993) and nitrogen-fixing species (Nohrstedt et al. 1988). The reaction of bryophyte species seems to vary, with some species decreasing and others increasing (e.g. Dirkse and Martakis 1992). The effect on plant communities seems often reversible but for some communities it can be long-lasting, especially at high doses and with repeated application (Nohrstedt and Westling 1995, Strengbom et al. 2001, Skrindø and Økland 2002).

This study was performed as a part of the Swedish research program "N 2002" which was run between 1999 and 2002 (Högbom and Jacobson 2002). The background to this program was a paragraph in the former Swedish certification standard of FSC (Forest Stewardship Council), which stated that the environmental effects of nitrogen fertilisation needed to be better investigated. A number of studies were performed including aspects of forest productivity, soil chemistry and biology, and biodiversity. In the biodiversity part it was considered important to evaluate if potential fertilisation stands have a value for the flora, and thus if restrictions due to conservation aspects would be motivated.

The aim of the present study was to describe the occurrence of red-listed species and signal species of bryophytes and lichens in stands planned to become fertilised for the first time, and thereby assess the biodiversity value of such stands. If uncommon species are to be preserved and there are high values of such species in potential fertilisation stands, there might be a need to re-evaluate the fertilisation strategy. Further, if the values are less evident but concentrated to certain qualities in the stands, this knowledge is of importance when environmental guidelines connected to forest fertilisation are formulated. Since most stands scheduled for first-time fertilisation are newly thinned, medium-aged and homogenous, with few suitable micro-sites and structures for the species, we hypothesised that we would find very few occurrences.

2 Material and Methods

2.1 Study Areas

The study was performed in two closely situated areas in the north-eastern part of the hemi-boreal region (sensu Ahti et al. 1968). The northernmost study area was located 2–14 km south – south-east of the city of Gävle on the property of the forest company Korsnäs within their district Gimo, sub-district Valbo. The other was located 30–60 km south-east of Gävle on the land of the forest company Stora Enso, district Strömsberg, sub-district Dalälven. The mean temperature for January is –4...–6°C, for July +14...+16°C and the vegetation period (mean number of days with a mean temperature above +5°C) is 170–180 days. The mean number of days per year with snow cover is ca. 125. The mean precipitation is ca. 600 mm (all climatic data refer to the period 1961–1990; Raab and Vedin 1995).

All stands to become fertilised for the first time during 2000 were extracted from the databases of Korsnäs and Stora Enso, respectively. Of these all stands with the size between 1.0 and 5.0 ha were chosen for the study; in total 74. The reason for having a minimum size of the stands was for logistic reasons. Each unit-area of very small stands takes a very long time to survey, due to long travel time. A maximum size was set since we wanted to have a large sample size and thus capture as much as possible of the between-stand variation.

2.2 Red-Listed and Signal Species

The bryophytes and lichens of the Swedish national Red List (Gärdenfors 2000) as well as the signal species listed for the region "Northeast Götaland and East Svealand" (National Board of Forestry 1995) were searched for. The numbers of red-listed forest bryophytes and lichens occurring in the counties of Uppsala and Gävleborg, where the study areas were located, are 37 and 97, respectively. These figures include the categories 'resident', 'extinct' and 'formerly resident' (Gärdenfors 2000). The signal species list includes 45 bryophyte species and four collective genera (*Palustriella* spp., *Philonotis* spp., *Porella* spp., *Tayloria* spp.), and 75 lichen species and four collective genera (*Collema* spp., *Nephroma* spp., *Phaeocalicium* spp., *Sclerophora* spp.). Overlap among lists reduced the number of taxa searched for to 74 potential bryophyte species and four collective bryophyte genera, and 137 potential lichen species and four collective lichen genera. Apart from the species on the Red List of year 2000, we also searched for species occurring on the Red List of year 1995 (Aronsson et al. 1995), but which later had been removed, although we did not intend to include such species in the data analyses.

2.3 Recording of Species and Substrates

We searched for species in 30 m wide line transects placed adjacent to each other to survey the entire area of each stand. We walked in the centre of transects and looked 15 m in each direction. When necessary to improve visibility, the line transects were narrowed down to a minimum of 10 m. One observation was a quadrat sized 10×10 m surrounding the recorded species. Thus, the theoretical maximum number of observations

Table 1. The study areas. Standard deviation in parenthesis. *0, 1, 2–3, >3 denotes the number of moist depressions, with number of stands after colon.

Land-owner	Number of investigated stands	Mean area (ha)	Mean age (years)	Mean number of stems ha^{-1}	Mean growing stock (m^3 ha^{-1})	Number of stands with ≥70% volume of *Picea abies*	Number of stands with ≥70% volume of *Pinus sylvestris*	Number of moist depressions*
Korsnäs	33	3.0 (1.1)	59.5 (14.9)	675.8 (164.8)	225.4 (49.6)	0	28	0: 14 1: 13 2–3: 3 >3: 3
Stora Enso	41	3.1 (1.1)	54.2 (9.0)	803.8 (180.0)	193.9 (42.4)	1	35	0: 14 1: 14 2–3: 12 >3: 1
All	74	3.1 (1.1)	56.5 (12.2)	746.7 (183.7)	207.9 (48.1)	1	63	1: 2–3: >3:

was 100 ha^{-1}. All substrates accessible from the ground and up to 2 m were searched. The substrate was classified into one of five categories: ground, boulder, rock, tree or other. For trees the condition was recorded as living, partly dead, snag, stump or log. The occurrences of species in deviating micro-sites were noted, in the categories moist depression, herb-rich vegetation and along brook. The survey was performed May–September 2000.

2.4 Nomenclature and Data Analysis

The nomenclature follows Söderström and Hedenäs (1998) for bryophytes, Santesson et al. (2004) for lichens, and Karlsson (1997) for vascular plants. Data were analysed by SAS statistical package (SAS 1999). Multiple regressions were performed in procedure REG with automated fitting of all subsets (Quinn and Keough 2002). In order to avoid collinearity of variables, stand volume, proportion *Pinus sylvestris* and proportion deciduous trees were omitted from the analyses. χ^2 tests were performed by procedure FREQ. Species accumulation curves were constructed in the PC-ORD statistical package (McCune and Mefford 1997) in order to evaluate the adequacy of sample size.

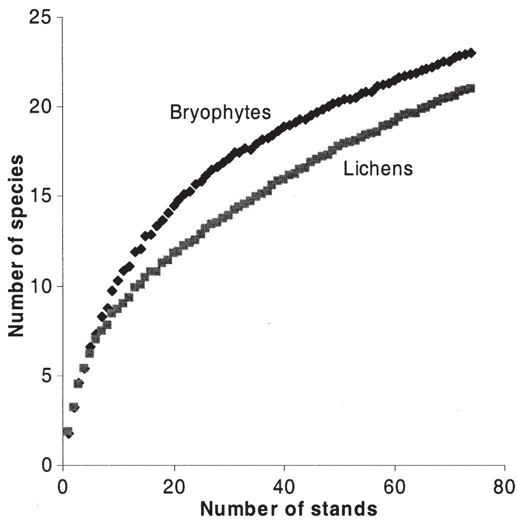

Fig. 1. Species accumulation curve, constructed in PC-ORD (McCune and Mefford 1997).

3 Results

3.1 Investigated Stands

In total 74 stands were investigated, with a mean size of 3.1 ha. Eighty-five percent of the stands were dominated by *Pinus sylvestris* (>70% of the volume consisted of this species), only one stand was dominated by *Picea abies*, while the rest of the stands were mixed. The mean age of

Table 2. Recorded species. NT = near threatened, VU = vulnerable, DD = data deficient, following Gärdenfors (2000). The lichen *Acrocordia cavata*, was included on the 1995 Red List but not on the one from 2000

	Category of threat	Signal species	Number of records	Frequency*
BRYOPHYTES				
Anastrophyllum hellerianum	NT	x	7	7
Buxbaumia viridis	NT	x	1	1
Calypogeia suecica	VU	x	6	5
Dicranum flagellare		x	1	1
Geocalyx graveolens		x	1	1
Helodium blandowii		x	1	1
Herzogiella seligeri		x	81	30
Herzogiella turfacea	NT		26	12
Homalia trichomanoides		x	6	5
Homalothecium sericeum		x	4	4
Hylocomiastrum umbratum		x	6	4
Jungermannia leiantha		x	13	11
Lejeunea cavifolia		x	1	1
Lophozia longiflora	NT		7	6
Mnium stellare		x	1	1
Neckera complanata		x	10	10
Nowellia curvifolia		x	3	3
Orthotrichum gymnostomum	NT		4	3
Plagiomnium medium		x	1	1
Pseudobryum cinclidioides		x	19	12
Rhytidiadelphus subpinnatus		x	11	7
Sphagnum wulfianum		x	8	1
Tortella tortuosa		x	2	2
Subtotal			220	
LICHENS				
Acrocordia cavata			3	3
Acrocordia gemmata		x	2	2
Alectoria sarmentosa		x	6	5
Arthonia leucopellaea		x	25	14
Arthonia spadicea		x	2	2
Bacidia rubella		x	1	1
Bryoria furcellata		x	19	15
Calicium parvum		x	69	29
Cladonia parasitica	NT	x	2	1
Cliostomum leprosum	VU		2	2
Conotrema populorum	DD		1	1
Graphis scripta		x	35	25
Hypogymnia farinacea		x	27	18
Lecanactis abietina		x	32	15
Leptogium saturninum		x	1	1
Leptogium teretiusculum		x	1	1
Micarea globulosella	NT		2	1
Microcalicium ahlneri		x	20	15
Nephroma parile		x	1	1
Parmeliella triptophylla		x	1	1
Thelotrema lepadinum		x	1	1
Subtotal			253	
Total			473	

* Number of stands, out of a total of 74, in which the species was found

the stands was 57 years with a range between 37 and 97 years. The mean number of stems ha^{-1} was 747 and the mean timber volume was 208 m^3 (Table 1).

3.2 Recorded Species

3.2.1 Bryophytes and Lichens

In total 10 red-listed species and 37 signal species were found. The number of records ha^{-1} was, for red-listed species 0.26, signal species 1.89 and all species 2.09 (some species are red-listed as well as signal species and thus the sum is less than the total; Table 2). Thirty-one percent of the stands had red-listed bryophytes or lichens, 27% had red-listed bryophytes and 5% had red-listed lichens. Ninety-five percent of the stands had signal species (bryophytes or lichens), 69% had signal bryophytes and 81% had signal lichens. There was no statistically significant correlation between density, i.e. number of records ha^{-1}, of red-listed bryophytes and lichens ($r = -0.32$, $p = 0.14$) or signal bryophytes and lichens ($r = 0.07$, $p = 0.57$) in the stands in which these species were found.

3.2.2 Bryophytes

Six red-listed species and 20 signal bryophyte species were found (Table 2). Of the red-listed species five were in category NT = near threatened and one in VU = vulnerable. The most frequent species were the signal species *Herzogiella seligeri* and the red-listed species *Herzogiella turfacea*. The signal species *Pseudobryum cinclidioides*, *Jungermannia leiantha* and *Neckera complanata* were also rather frequent. Sixty-nine percent of the stands had red-listed or signal bryophytes. The mean number of records ha^{-1} of red-listed species was 0.23 and of signal species 0.81. All recorded red-listed species were found on trees, except one find of *Herzogiella turfacea* which was made on soil. Ninety-two percent of the species recorded on trees were found on dead wood. Of all records of signal species 55% were from trees, 33% from soil and 13% from boulders. Of the records of signal species on trees, all except one were from dead wood.

3.2.3 Lichens

Four red-listed lichen species and 17 signal lichen species were found (Table 2). The red-listed species were very rare and only 7 records were found in total. Of these, two were in category NT, one in VU and one in DD = data deficient. The most common signal species were *Calicium parvum*, *Graphis scripta*, *Lecanactis abietina*, *Hypogymnia farinacea* and *Arthonia leucopellaea*. Seventy-eight percent of the stands had red-listed or signal lichen species. The mean number of records ha^{-1} was 0.03 for red-listed species and 1.08 for signal species. All seven finds of the red-listed species occurred on trees and of these three on dead wood, three on the trunks of living Norway spruce and one on a living aspen. The recorded lichen signal species were also exclusively found on trees; 90% on living trees and the rest on dead wood. The most common living host trees were *Pinus sylvestris*, *Picea abies* and *Alnus glutinosa*, harbouring 35%, 33% and 16% of all signal lichen species, respectively.

3.2.4 Deviating Micro-Sites

Seventy-one percent of the records of the red-listed species and 33% of the records of the signal species were found in moist micro-sites within the stands. For the signal species, one percent were also found in herb-rich micro-sites and along brooks, respectively.

3.3 Species in Relation to Stand Properties

The degrees of explanatory power of the multiple regression models varied between 13% and 36% for different combinations of bryophytes, lichens, red-listed species and signal species. Age as well as area were the most important predictive variables and both were positively correlated with density (number of records ha^{-1}) as well as number of species for several of the species subsets. Nevertheless, for red-listed bryophytes number of moist depressions as well as proportion of *Picea abies*, seemed more important. Lichens were negatively correlated with number of stems ha^{-1} (Table 3).

Table 3. Relation between stand variables and density (number of records ha^{-1}) and species number, based on multiple regressions with automated fitting of all subsets. Strongly correlated variables were omitted. Variables with $p<0.10$ are shown. Red-listed lichens are not included since they were very few. (–) denotes a negative relation.

	Density of bryophytes and lichens	Density of bryophytes	Density of lichens	Number of bryophytes and lichens	Number of bryophytes	Number of lichens	Density of red-listed bryophytes	Number of red-listed bryophytes
R^2	0.36	0.28	0.35	0.31	0.31	0.30	0.17	0.13
Age	0.001	0.004	0.002	0.008	0.045	0.018	–	–
Area	<0.001	0.025	0.005	0.002	0.010	0.008	0.067	–
Number of moist depressions	–	–	–	–	0.029	–	–	0.057
Stem number ha^{-1}	–	–	0.024(–)	–	–	0.011(–)	–	–
Proportion *Picea abies*	–	0.010	–	–	0.006	–	0.047	0.049

There were almost no detectable differences between the stands of the two land-owners. No differences were found regarding number of records of signal species, red-listed species or total species in relation to number of stands ($\chi^2=0.22$, p=0.64; $\chi^2=0.02$, p=0.89; $\chi^2=1.63$, p=0.20).

4 Discussion

The main result from this study was that the biodiversity value of the potential forest fertilisation stands was low, as estimated from the density of red-listed and signal species of bryophytes and lichens. The mean number of records of red-listed bryophytes and lichens ha^{-1} was 0.26, which is nine times lower than the mean for production stands with a mean tree height >15 m, in three managed forest landscapes in southern Sweden, and 18 times lower than woodland key habitats in the same landscapes (Gustafsson 2002). In some studied boreal coniferous production stands with a mean age of ca. 100 years, the density was at least 25 times higher than in the studied fertilisation stands (Gustafsson et al. 2003).

Most of the investigated stands were middle-aged and had been thinned. In a number of them this was done rather shortly before the inventory; the forest residue was still visible at the sites. Deciduous trees and dead wood occurred very sparsely, and the trees were evenly spaced and of the same age. Scots pine dominated all but one stand and this tree species is known to host fewer red-listed lichens than Norway spruce. The results indirectly support the widely acknowledged notion that forests should be heterogeneous, structurally diverse; have rich occurrences of deciduous trees, dead wood and old trees, in order to host threatened species (e.g. Berg et al. 1994), and species richness more generally.

On the other hand, it is surprising that at least some red-listed species were found, considering the poor prerequisites for these species. It could indicate that the assessments of rarity and population decline for some species on the Red List are overestimated. For instance, it was unexpected that one red-listed bryophyte species *Herzogiella turfacea* had as many as 26 records and was found in 12 stands. And also that the red-listed bryophytes growing on dead wood, *Anastrophyllum hellerianum*, *Calypogeia suecica* and *Lophozia longiflora*, were found in 7, 5 and 6 stands, respectively. Further studies are needed to reveal if the populations of the red-listed species are viable, and not rather remnants of larger populations in the former less intensely managed forest landscape, and prone to become locally extinct.

The results from the multiple regressions indicate that the observed bryophytes as well as lichens were favoured by large area and high age. The significance of stand area is in agreement with many studies on species-area relationships (e.g. Rosenzweig 1995), although it can be noteworthy that a difference was found even within the small span of 1–5 ha. Also the positive relation with stand age was not unexpected; most red-listed as well as signal species are by definition connected to old forests. The importance of high age to some lichen species has been found in several earlier studies (e.g. Esseen et al. 1997).

During the multiple regressions, effort was made to keep only uncorrelated variables in the models, since collinearity can have detrimental effects on estimated regression parameters (Quinn and Keough 2002). Still, there was a significant negative correlation between age and stem number ($p = 0.001$) and a positive between area and moist depressions ($p = 0.002$). The latter correlation suggests that the number of moist depressions increases with area and thus that area actually is the fundamental factor. Bryophytes were positively affected by the proportion *Picea abies*, most likely since this tree species creates more shady and closed stands than *Pinus sylvestris*, and bryophytes generally prefer rather dark environments with high air humidity. The data on lichens suggest, on the contrary, that these species are favoured by more light, since there was a negative relation between this species group and number of stems ha^{-1}.

The species accumulation curves were similar for bryophytes and lichens. They both had a tendency to flatten out but still increased rather sharply. This indicates that if more stands had been added, several additional species would have been found. Nevertheless, our sample size of 74 stands with a total area of almost 230 ha is much larger compared with many other studies on bryophytes and lichens in Nordic coniferous forests.

The biodiversity value of the fertilisation stands must be viewed in a long time-perspective. It is likely that there will be a colonisation of uncommon late-successional species as the stands grow older and thus that the biodiversity value will increase over time. In order to analyse how the species populations change over time, it is necessary to study stands that were fertilized when they were middle-aged and now are mature for harvest, i.e. where the first fertilisation was carried out 20–40 years ago. Unfortunately, the records of the forest companies on former fertilisations are incomplete and it is not likely that the large sample needed could be attained. Further, the mature stands of today were less intensely managed when they were middle-aged, e.g. thinned to a lesser degree, compared with those of today. This would complicate the interpretation of data.

Another important aspect is how the uncommon species could be affected by the fertilisation. Numerous studies have been carried out on the effect of N fertilisation on plants but in almost all cases common species have been studied. One exception is the rare vascular plant *Pulsatilla vernalis* which responded with increased production of shoots and flower buds following fertilisation (Kellner 1993a). Experiments on the reaction of red-listed and indicator species to N fertilisation would be valuable but are often restricted by the low populations of such species; it is hard to find enough material for the experiments. In our study, we marked the sites for the species occurrences on maps and thus it will be possible to make follow-ups in the future.

Many of the occurrences were found within deviating micro-sites and most of all in moist depressions; more than 70% of the red-list occurrences were found within this habitat. Thus, if uncommon species can be expected to be disfavoured by fertilisation and if they are to be preserved, it is important that fertilisation is avoided in such micro-sites. The environmental guidelines of the forest companies are rather short but state that shallow soils on bedrock, outcrop of bedrock, moist and wet sections and sections with deciduous trees should be excluded (Korsnäs) as well as valuable small biotopes (Stora Enso). Unfortunately, it seems that the education in biodiversity consideration at fertilisation has not been completely successful. At some occasions during the field work, fertilisation actually had been carried out only one or a few days before. We then observed that fertilisers had been spread within parts of stands that should been avoided under the guidelines. Furthermore, even if the instructions were rigorously followed, it remains to be shown that fertilisation in the vicinity of the deviating microsites does not affect the species in a negative way.

This study was designed to assess if fertilisation stands have a value for biodiversity, as part of the large research program N 2002. The results indicate that the value for bryophytes and lichens generally is low, especially in the younger stands. Still the value cannot be neglected since red-listed species were found in 31% of the stands and signal species in 95%. Further, the present conservation policy in Swedish forestry implies that biodiversity should be considered in all steps and components of forest planning and management. This implies that conservation aspect should be regarded also in fertilisation stands. If the flora is to be considered, measures should be directed towards excluding important micro-sites like small moist depressions from fertilisation. In order to accomplish this, the instructions regarding fertilisation need to be developed and, perhaps most importantly, measures need to be taken to ensure that the staff performing the fertilisation follow them.

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