UIC "Vegetation Control" Project
Final Report

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- Acknowledgments -

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http://www.uic.asso.fr/d_environnement/environnement_en.html

Summary

Aim and Approach of the Project

Vegetation control along railway lines should not harm the environment. This and the increasing pressure to cut costs for vegetation control motivated several railway companies to start various activities to reduce the amount of herbicides used. These activities were supported even more when some herbicides and their degradation products were detected in ground and surface water and the issue was taken up by non-governmental organisations in some European countries (e.g. Germany). They postulated a general stop of herbicide use in railway facilities.

Furthermore the use of herbicides for vegetation control in railway installations over many years showed that they only have a short-term effect (approx. one growing season) on the vegetation cover present. Additionally, using one or two active substances their application leads to a change in the plant community present. More and more plants grow that are undesirable.

Against this background, the UIC's Environment Working Group organised several conferences on vegetation control. After several discussions and meetings the UIC project on vegetation control was started in 2000 and ended in 2001. The following points were focused on in four subprojects:

- Subproject 1: Need for vegetation control (scope for accepting a certain amount of vegetation for a given category of track).
- Subproject 2: Recommendations for the application of non-chemical methods in "herbicide-free areas" where either the use of herbicides is restricted or herbicides are ineffective.
- Subproject 3: Description of fundamentals for a vegetation management system.
- Subproject 4: Communication of the findings via a seminar and a report.

The findings are based on a survey, a literature study and the knowledge of railway experts.

The survey was divided into three steps. In the first step a general questionnaire was sent to 49 UIC railway companies. Given the more specific questionnaires in step two, the number of railways responding fell to 12 (Subproject 1) and 21 (Subproject 2) respectively. The third step was used to clear up any misunderstandings and/or unanswered questions.

The survey showed that the use of herbicides on railway lines is ruled by governmental regulations. In various European countries the application of herbicides is limited

- to only one active substance such as Glyphosate
- as regards the amount of active substance used per area or track length
- to certain areas, and is banned in so-called "herbicide-free areas". The number of "herbicide-free areas" is expected to increase in the future.

Most railways expect tighter regulation in the near future. This and the controversial effects of herbicides have led to studies of non-chemical methods and selective use of herbicides. In

Europe about 130 € per track kilometre is being spent in 2002 for vegetation control maintenance and about 390 € per track kilometre for the maintenance of the embankment. Europe's railways have a total of 400,000 km of track, which means about 2,560 km^2 of track area and between 2,000 and 4,000 km^2 of embankments in total.

Need for vegetation control (Part A)

The question about the need for vegetation control is linked to the development of plants and has to be viewed under two aspects. One is the differentiation into **embankment and track** areas the other one the **short and long-term effects**.

In general plants tend to colonise all vegetation free areas and have developed various mechanisms adapted to various growing conditions. The basic needs of plants are light, nutrition and water. These growing factors have to be available for plants in differing degrees, depending on the plant species. There are a number of means of eliminating these growing factors or at least managing them in such a way as to control growth.

Plant growth on **embankments** is more or less influenced by the natural soil and climatic conditions. Thus, only very few possibilities exist of managing the basic needs of vegetation. Embankments are usually covered by plants. Such vegetation coverage is welcomed by railway companies as a means of, for instance, preventing erosion. But there is also a need to keep the growth of plants within certain limits, and therefore to cut down shrubs and trees, if signal sighting is impaired or the safety of workers no longer guaranteed for instance. The development of vegetation takes place on both a short and a long-term time-scale, but the earlier plants are managed in these areas the cheaper the process is. For instance, carrying out mowing or mulching continuously and regularly leads to wished-for grass becoming established. This reduces the vegetationpressure encroaching onto the track area and minimises the need for vegetation control measures there. In the **area between the track and the embankment** an efficiently functioning/well-maintained drainage system such as ditches (not a common vegetation control measure!) will ensure dry conditions for the track area. Hence only a few slow-growing plants that are well adapted to such conditions will survive. Together with lateral plant barriers such as suitably positioned cable troughs, these measures protect the track against in-growing plants from the embankment. They lead to a reduced vegetation burden within the track itself and therefore vegetation control activities in the track area may be reduced.

The **track area** itself is a technical construction using specified materials which have to fulfil the various technical demands of railway companies. Thus, the occurrence of plant has differing effects. On the **short-term time-scale**, the safety of workers and the sighting of low signals have to be guaranteed in walkways for instance. This can be supported by controlling the shrubs and trees on the embankment so as to cut in-growing plants out. Furthermore, cutting back shade-giving trees leads to intensive exposure of the track area to sunlight. This leads to high temperatures, dry conditions and hence minimised plant growth. An additional means of raising temperatures involves using dark material for walkways, as was demonstrated in experiments. Almost no plants can be allowed onto the ballast bed in the short term if it increases the risk of fire, fouls brake systems or hinders inspection of rails.

Beside these short-term effects of plants, **long-term effects** are shown to exist as well. The development of vegetation along the track is different in the walkway than in the ballast bed. The best growing conditions for vegetation exist in the walkways, where plant growth usually starts first. When the vegetation reaches the base of the ballast slope, it closes the coarse ballast pores. This may lead to reduced drainage of the ballast bed. In consequence the moisture content increases and sub-layers beneath the ballast may start to weaken.

The ballast bed is usually a dry and hot place. Hence it is hard for plants to survive under such conditions. The grinding together of ballast stones by passing traffic leads to an increase in fine material. As a result, the moisture content starts to increase, growing conditions improve and the sub-layer may be weakened as well.

In both cases a reduced carrying capacity linked with a pumping up of fine material from the sub-layers into the ballast will be observed. This leads to further plant growth as well, because of improved growing conditions. Because these effects tend to occur in tandem with other adverse factors bearing upon the track, the one cannot be clearly separated from the other. Even so, railway companies have to guarantee a stable track and a constant carrying capacity based on a stable sub-layer deriving from good drainage of the track.

The railway companies have various reasons and requirements for vegetation control depending on their infrastructure. Due to the existing gaps in knowledge about the direct link between plant coverage and stability in the long term, no railway company is able to set limit values for plants drawing on an objective database. The issue is complex because so many influences affecting each other have to be taken into account. Even so, some railways have started to establish quality standards concerning plant coverage, though not drawing on an objective database.

In the short term there is a need to avoid fouling of rail traffic by plants as already described above. Hence vegetation control measures are needed even though we are not able to differentiate between effects relating to vegetation and other factors in the long term. The possible methods in the various track areas and the recommended combination of possible methods used are shown further on.

Methods for vegetation control and proposed combinations (Part B)

An overview of different methods known at the moment is given. Different characteristics for each of the 34 methods (technical data, vegetation control area and operating conditions, costs and environmental effects) are listed in a catalogue.

The survey showed that chemical methods are the ones most used by the railway companies. Non-chemical measures are used in a supplementary way or where the use of herbicides is prohibited. The reason: no satisfactory non-chemical maintenance methods for the track area (ballast and walkway) are known today. Most of the methods tested did not lead to satisfactory results. They are either too slow (hindering railway traffic), have not the desired effect on plants or are too expensive. One exception may be constructional methods, which also belong to the non-chemical methods. Their positive effect for vegetation control is shown in several cases. These preventive measures have to be taken into consideration when building new or renewing old lines. The efficiency of constructional methods can be improved by applying maintenance measures such as mulching on the embankment in addition. High efficiency of the methods is only guaranteed if applied at the right time (e. g. time of year/day, plant age).

It is mentioned by most of the railway companies that the tendency to establish “herbicide-free areas” such as groundwater protection zones is increasing and the use of herbicides will be more greatly restricted in the near future. Thus, the **development of new** and the **improvement of existing methods is very important**. Improvement should extend to the methods, whether they are non-chemical or chemical, themselves. Besides improving the methods themselves, there is a need for research into new herbicides meeting the current requirements for railways such as becoming more environmentally friendly. Commonly applied maintenance methods also have an influence on vegetation control even though they are not used primarily for vegetation control. Those methods should be investigated for that purpose in the future as well (e. g. ballast cleaning and replacement).

The application of one single method, when used very frequently, leads to the development of a one-sided vegetation community, which can include so-called problem plants. Thus, a well balanced **combination of various vegetation control methods** is obviously necessary. The emphasis should be laid on preventive methods such as constructional ones, which means taking vegetation control measures into account when planning re-constructionsor new-build schemes. The **regular application of maintenance methods**, e.g. mowing at least once a year, has a preventive effect too. Furthermore a vegetation control strategy should include all areas, from the embankment to the ballast bed, since the vegetation control method used in one area has an influence on the other areas as well.

Fundamentals for a vegetation management system (Part B)

The foundations for the Vegetation Management System should include an overview of the methods available, their time of application and proposed combination. The first step in setting up a management system is to record the amount and kind of vegetation present, and to check if other maintenance is needed as well and whether it might be carried out at the same time as vegetation control measures. The management system should aid the choice of an appropriate method or combination thereof for a specific situation. Thus, a **tree diagram** of a more general nature has been developed that is also available in an electronic version. For the daily use it has to be adapted to the exigencies obtaining for a given railway company in respect of legislation, organisational structures and methods available. Some railway companies already have experience or are starting to build up such systems.

Seminar (Part C)

The findings from the three subprojects were presented at a seminar. Additionally, some practical examples for each subproject were demonstrated.

Further Work

Experience shows that much of the theoretical knowledge is not being transferred to the practical or management spheres yet. This can be remedied as follows:

- The managers **responsible for maintenance budgets should attach the required importance to vegetation control**. Neglecting vegetation control sooner or later has a negative effect on the track (e. g. reduced sighting of signals or natural hazards from trees damaged in storms, track availability). Dealing with such undesired effects is far more costly than regular maintenance.

- An **exchange of theoretical knowledge and practical experience** is important and can be achieved by means of an intensive training programme for staff in charge of vegetation control. But on the other hand they should have the possibility to communicate their practical experience as well. Educating executives responsible for the budgets needed for effective vegetation control is important too.

- The UIC can help to provide the information needed for such education. This report is the first step.

- The UIC "Vegetation Control" Project showed that an exchange of experience on vegetation control issues between the various railways is needed. This helps the single railway to use synergies and therefore to cut costs for studies. Thus, a permanent "reference group" at the UIC should be established in the future. Their task is to discuss vegetation control issues and exchange information regularly besides continuously updating a literature/information database that was likewise set up as part of this project.

- The seminar recommends that a technical leaflet funded by the Infrastructure Commission and based on the project findings be elaborated in 2002. Recommendations for constructional methods should be incorporated into the leaflet.

Table of Contents

Abbreviations

Railway companies

Abbreviation	Name of railway company	Country
BC	British Columbia Railway	Canada
BDZ	Bulgarian State Railways	Bulgaria
BS	Danish National Railway Agency	Denmark
BV	Swedish National Railway Administration	Sweden
CD	Czech Railways	Czech Republic
CFL	Luxemburgische Eisenbahngesellschaft	Luxembourg
CNCF CFR SA	Romanian National Railways	Romania
CH	Greece Railways	Greece
CIE	Coras Iompair Eireann / Irish Transport Company	Ireland
CP	Canadian Pacific Railway	Canada
DB AG	German Railways	Germany
FS	National Italian Railways	Italy
GySEV	Györ-Sopron-Ebenfurth Railway	Hungary
IR	Indian Railways	India
JBV	Norwegian National Rail Administration	Norway
JR	East Japan Railways	Japan
JZ	Community of Yugoslav Railways	Yugoslavia
LDZ	Public Joint-Stock Company “Latvijas Dzelzcesh”	Latvia
LG	Joint-Stock Company “Lithuanian Railways”	Lithuania
MAV	Hungarian National Railways	Hungary
MOR/PRC	Ministry of Railways	China
NS	Netherlands Railways	Holland
ÖBB	Federal Railways of Austria	Austria
QR	Queensland Rail	Australia
Refer EPE	Rede Ferroviària Nacional	Portugal
RENFE	National Spanish Railways	Spain
RFF	Résau Ferré de France	France
RIB	Railinfrabeheer	Holland
RHK	Finnish Rail Administration	Finland
RT	Railtrack	Great Britain
SBB/CFF/FFS	Federal Railways of Switzerland	Switzerland
SNCB/NNBS	National Railways of Belgium	Belgium
SNCF	National Railways of France	France
SZ	Slovenia Railways	Slovenia
TCDD	TCDD Genel Müdürlügü	Turkey
ZSR	Railways of the Slovak Republic	Slovakia

List of Figures

List of Tables

1 Introduction

1.1 History

The use of herbicides for vegetation control in railway installations over many years led to several problems arising. Since the use of herbicides is only a method of combating the symptoms, it only has a short-term effect (approx. one growing season) on the plant cover present. The application of herbicides leads to changes in the plant community present, when using one or two active substances. More and more plants grow that are undesirable. Because of the negative effects of certain substances the railways had to find new substances and methods. Meanwhile the use of herbicides for vegetation control objectives was focused on by the public. The detection of some herbicides and their degradation products in ground and surface water was taken up by non governmental organisations (NGOs) in some European countries to postulate a general stop of herbicide use in railway facilities. The use of herbicides is ruled by governmental regulations. In some European countries the application of herbicides is limited, for instance,

- at least to one active substance such as Glyphosate (e. g. Denmark, Switzerland)
- in respect of the amount of active substance used per area or tracklength (e. g. Germany, Sweden, Switzerland)
- by requiring an increase in “herbicide-free areas” (e. g. Germany, Switzerland)

At the same time several railway companies started various activities to reduce the amount of herbicides. This includes objectives such as

- application reduced to areas where vegetation occurs
- treatment of the track area only
- searching for non-chemical methods of maintenance
- examination of preventive measures such as constructional methods

The UIC Environment Group was also aware of this subject and organised a first international conference on “Vegetation Control” in Berlin in 1997. A follow-up conference in Switzerland in 1998 and the first findings from a survey [114] showed that the main vegetation control measure adopted for the track itself is the application, using a variety of devices, of herbicides. Discussion led to the call for a study as to whether a certain amount of plants, variable by track category, might be tolerated by railway companies if it did not entail restrictions for their operations (similar to the principle of economic damage limitation, often used in agriculture). On the other hand, it was evident that there is a need to figure out which non-chemical methods are recommended for application by railway companies in “herbicide-free areas”. The situation at that time was set out in a state-of-the-art report entitled “Vegetationskontrolle auf Bahngleisen” [7].

1.2 UIC Vegetation Control Project

The UIC's "Vegetation Control" project is based on the report mentioned above. The project was divided into four subprojects:

1. "**Need for Vegetation Control Measures**" with the main objective of figuring out the consequences and effects of neglecting vegetation control.
2. "**Optimising and Improving the Effectiveness of Alternative/Supplementary Vegetation Control Methods**" with the main task of gaining an overview of all vegetation control measures (regardless of their stage of development) inclusive of a description of their operating conditions.
3. "**Vegetation Management System**" is based on and linked directly to Subproject 2: The main goal of this subproject is to show synergies between different methods that can be used by the railway companies to develop their own vegetation control management systems to suit their specific conditions.
4. "**Communication and PR**" will be used to publish the findings from the other three subprojects within various print media and to present the project's findings at a seminar for the UIC railways.

The procedure for collating and evaluating data was divided into three steps:

1st step - a general questionnaire covering the Subprojects 1 to 3 was sent to all UIC railway companies in three languages (English, French and German)

2nd step - after evaluating the data from Step 1, more specific questionnaires were sent to the railway companies based on their responses. The language was as used in the answers given by the railway companies.

3rd step - misunderstandings or unclarified questions brought to light by evaluation of Step 2 were to be resolved here with the aid of more specific questions.

Besides the survey, all literature available was taken into account.

When checking the list of participating railway companies, it can be seen (see Appendix on page 128) that the survey does not claim to be fully representative.

All collected data are summarised in the present report. The findings were also presented in lecture-form, together with examples from the practical sphere, at the seminar held on the 29th and 30th of November 2001 in Paris.

1.3 Overview of the Present Report

The present report is divided into tree parts:

Part A addresses the questions as to which kinds of colonisation strategies are used by plants and how vegetation influences the operation of traffic. It gives some general suggestions about the use of vegetation control measures. Thus, Part A is the basis for Part B of this report.

Part B contains an overview of available methods alongside a generally applicable decision maker's tree diagram in respect of the measures to be adopted. The overview shows methods commonly used by railway companies, but also methods under investigation at various development stages or abandoned measures as well. They are characterised according to economic, efficiency, operational and environmental factors. Additionally the application areas are also mentioned. The knowledge about vegetation control in total and hence possible combination of measures even though they are not common vegetation control methods will be given within a tree diagram.

Part C focuses on the seminar in Paris 2001. Summaries of the presentations and the accompanying discussions are recorded.

The **Appendix** contains particulars of the questionnaires used, a list of plant names in the UIC languages, their predominant propagation behaviour and a detailed catalogue of all measures used and/or investigated so far.

1.4 Guidelines for the Reader

The reader of this report should bear in mind that the evaluation it arrives at is subjective, since the three authors know the situation at their own railway companies best (DB AG, SBB). Thus, every railway company might conduct its own evaluation slightly differently.

Besides that, it has to be mentioned that many railway companies are applying methods for maintenance reasons other than vegetation control. They do not declare these methods as vegetation control methods even though they have a strong effect on the presence of plants (e. g. ballast cleaning, embankment maintenance).

A comparison of different methods presupposes a **definition** of the various track areas. For the purposes of this report, they are defined visually (Figure 1) and verbally as follows:

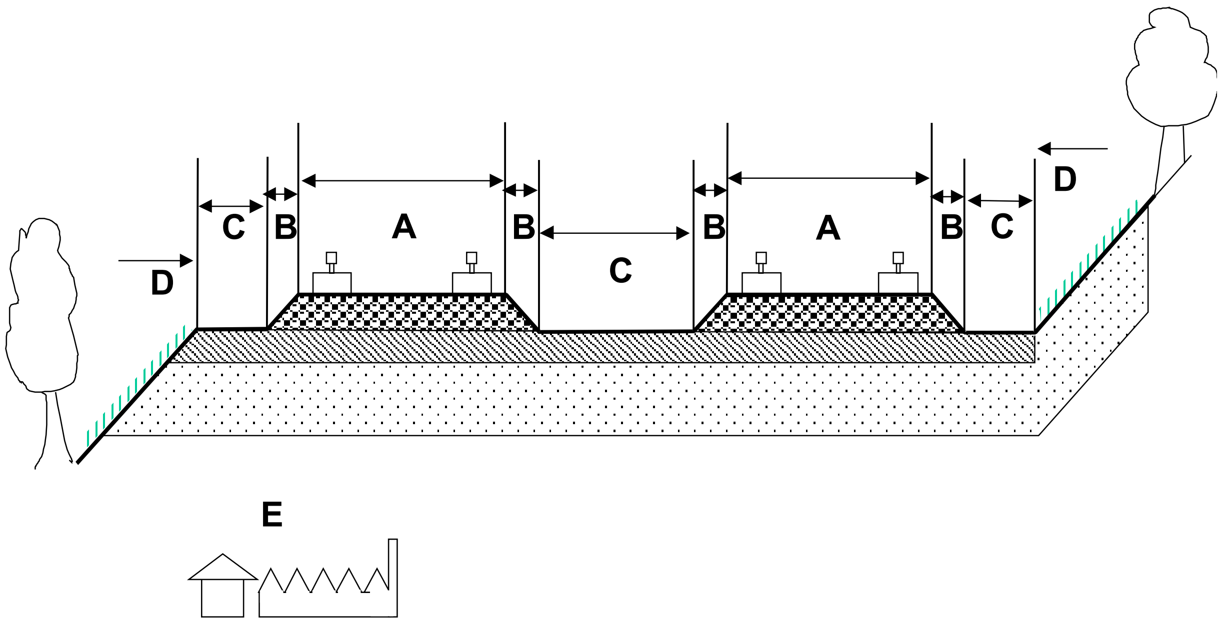


Figure 1: Areas of Application for Vegetation Control Methods - schematic representation

Plants	All plant species not acceptable within defined vegetation control areas in terms of railway company requirements.
Vegetation Control Areas	Selected track areas. Most of the railway companies separate their railway lines into several sections to reflect differing vegetation control measures adopted, frequency of application, the varying durations of application and in some cases shared organisational responsibilities (see areas A to D). The areas belonging to railways away from the track area are also included (see Area E).

Area A	Ballast bed: part of the track-bed made of ballast or gravel including embedded sleepers and rails.
Area B	Ballast shoulder: part of the track-bed covering the slopes on both sides of the ballast bed.
Areas A and B	Slab track: concrete track-bed construction
Area C	Transition area: part of the track abutting the slope on both sides of the ballast bed, includes walking path for maintenance reasons/ inspection walk way and areas between two tracks (double and more lines). Drainage ditches are also built in Area C in some cases.
Area D	Embankment: the slopes alongside the track away from the track adjoining Area C
Area E	Outside the track area: all other areas not directly linked with the track such as paths, areas around power supply stations, loading areas, station platforms, parking sites, ...

Part A: Need for Vegetation Control Measures

2 General Description of Colonisation Strategies by Plants

Plants tend to colonise vegetation free areas such as rocks, stones, gravel or sandy areas in general. Even areas which are mainly influenced by human activities such as roadways and walk ways cannot withstand colonisation by plants unless one prevents plants growing by removing or killing them. A distinction needs to be made between the soil, i.e. the growing substrate, and the actual plants with their differing growing patterns in order to understand the process of colonisation by plants [2, 9, 26, 67, 85, 93, 118].

2.1 Growing conditions

Light, nutrients and water are the basic needs for plant life. The intensity or amount of these factors needed varies from species to species. The mechanisms developed by plants have to fulfil the conditions of a given location so they can survive or even spread into new areas. The better adapted a plant is to local conditions, the higher the probability it has of winning out against the other plants present [26, 85].

2.1.1 Soil/water conditions

The soil as the growing substrate provides plants with water and nutrients. The availability of these two factors depends on the characteristics of the soil and the surrounding climate, on a global as well as on a local scale [85, 102].

A **gravel or stony soil** is usually a dry, hot and nutrient-sparse location. It is not able to store water for long periods. Hence this important growing factor is not available to plants over a longer period. These dry conditions may be offset by higher amounts of and/or more frequent rainfall. Nevertheless, these are poor growing conditions which may be improved by a higher groundwater level close to the soil surface. Nutrient-rich groundwater may have an additionally positive effect on conditions.

On the other hand a **sandy loam or humus** rich material for example is known to be a good growing substrate offering pleasant temperatures. It has a reservoir of nutrients and a high capacity for storing water in readiness for plants [43, 59, 85, 102].

A gravel or stony soil is equivalent to a new, clean ballast bed with low nutrient content and low water-storage capacity. Growing conditions for plants are very meagre. By contrast, a sandy loam or humus-enriched soil material is comparable to an old ballast bed containing a lot of fine material such as humus. This leads to a higher water content alongside higher amounts of nutrients, i.e. enhanced growing conditions for plants.

2.1.2 Light/sun orientation

The struggle for sunlight may affect plants in two ways:

a) direct radiation of plants by sunlight

b) indirect influence from exposure of uncovered ground surfaces

The focus here will remain on b), since it has the main impact on plant growth in a railway environment whilst a) relates to how plants compete for sunlight in general.

The better exposed a ground surface is to sunlight, the warmer and thus dryer it is. A dark coloured ground surface reinforces this tendency.

Exposure to the sun of a south-facing embankment will lead to higher temperatures than is the case with its north-facing counterpart. Temperature differentials of 5° C for air and up to 25° C for soils were measured between south and north-facing embankments [14, 15].

Consequently, growing conditions for plants deteriorate on a track well exposed to sunlight. Only a few specialist species adapted to dry and hot environmental conditions are able to grow, albeit usually rather slowly on account of the extreme conditions [85].

2.2 Plant growing strategies

The plants themselves have developed different mechanisms for propagation and growth under given local conditions. In general, a distinction needs to be made between **generative propagation by seeds** and **vegetative propagation by different plant parts** [85].

2.2.1 Generative propagation

In the case of generative propagation the plants have to flower and mature. The various kinds of seeds are carried by air, water, animals and human beings to other places. The extant spectrum of seeds is very broad and involves a rich variety of shapes and sizes [85].

2.2.1.1 Small seeds

Transport by air calls for lightweight, “parachute-type” properties (see Figure 2). Hence the reservoir of nutrients is small while, at the same time, the total number of seeds produced by such plants is huge. Endowed in this way, the seeds can be conveyed over long distances. Wherever they come to rest, they have to cope with the growing conditions obtaining at that particular location. If soil and climate are hostile to the germination conditions needed, the seeds will die. An example of this kind of plant species is the Cranesbill (Geranium sp.) [26, 85].

It is almost impossible to protect the track against incoming small seeds, because they may originate from locations far away from the track. By contrast, conditions unfavourable to the growth of such species can be maintained along the track with the aid of an efficient drainage system, good exposure of the track to sunlight and the use of dark materials for side paths to intensify the radiation effect.
If these plants do materialise in the track area, it is advisable to initiate vegetation control measures at an early stage to prevent a huge seed potential building up.

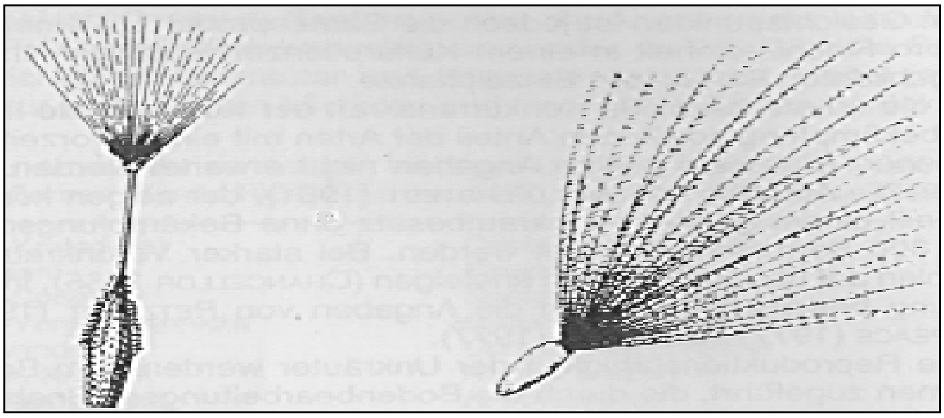


Figure 2: Seeds propagated by air [26]

2.2.1.2 Large seeds

Large seeds have a much bigger reservoir of nutrients and can be transported over short ranges only. These plants produce a lower number of large seeds compared to the small seeds referred to above. At the same time, seedlings have a far greater chance of maturing owing to their being able to survive for longer periods and grow down into soil zones containing water and nutrients before their reservoir is depleted (see Figure 3).

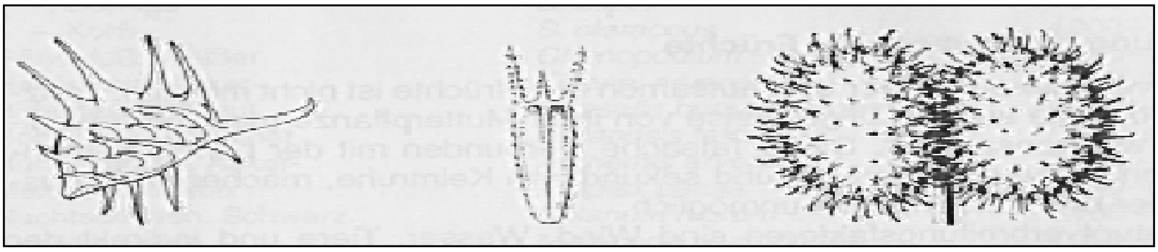


Figure 3: Seeds propagated by animals and humans [26]

An example is the acacia, a member of the Leguminosae family, even if its main colonisation strategy is by vegetative propagateion (see Chapter 2.2.2.). This plant has an additional advantage. It lives in symbiosis with a special bacteria population. These bacteria are able to convert nitrogen in the air into a form in which functions as one of the most important nutrients for plants. Hence, for example, a low-nitrogen environment can be colonised by acacia more easily. Additionally, the soil will be enriched with nitrogen by leaf fall from the acacia (Robinia pseudoacacia). This eases the growth of other subsequent plants [26, 85].

Most large seeds originate from areas close to the track such as the embankment. Thus, one option is to remove plants from the embankment that may be a problem along the track by conducting continuous, regular maintenance in the form of, for instance, mowing. Conditions unfavourable to the growth of such species can be maintained along the track by means of an efficient drainage system, good exposure of the track to sunlight and the use of dark materials for side paths to intensify the radiation effect. But the effect is none too strong owing to the plants' nutrient reservoir. Thus, it is advisable to commence vegetation control measures at an early stage, i.e. as soon as such plants are detected, to obtain best results.

2.2.2 Vegetative propagation

Vegetative propagation is another form of plant propagation that is an important contributor to close-range colonisation, of roadways in this context. To describe how it functions, it is necessary to subdivide it into sub-ground and above-ground elements.

2.2.2.1 Above-ground propagation

Above the ground surface the shoots of some plant species produce **shoot runners** as a common way of spreading out. If these parts of the plants come into contact with the ground, root growth will be initialised. The runner will be fixed and a “new plant” may develop. This “new plant” is still linked to the mother plant and so it is able to survive even if the growing conditions for the “new plant” are less than ideal. The bramble (*Rubus sp.)* is the most familiar example of this kind of plant (see Figure 4) [26, 85].

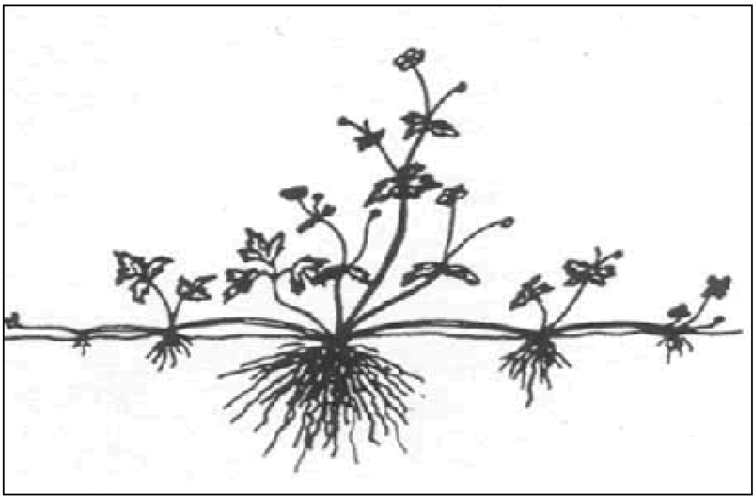


Figure 4: Shoot runners [26]

2.2.2.2 Sub-soil propagation

For the sub-ground region, two distribution mechanisms are known: sub-ground shoot runners and root runners. **Sub-ground shoot runners** belong to the plant shoot and, besides being an organ of propagation, perform a kind of storage function. They produce roots and in each growing season a shoot penetrates the soil surface. These shoots are continuously growing plant constituents, but die back every year once the growing season has finished. They usually grow close to the soil surface and feature bifurcations and buds (example: Quack grass (*Agropyron repens*) (see Figure 5) [26, 85]).

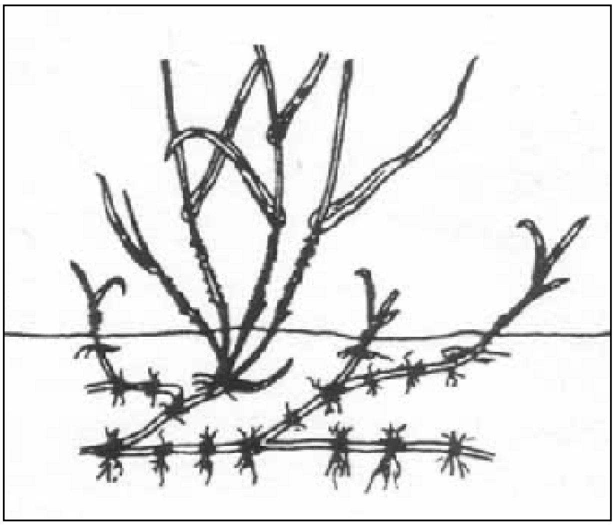


Figure 5: Sub-ground shoot runners [26]

The **root runner** is a typical organ of the root system, fulfilling the basic work of roots (taking up water and nutrients) and functioning as a means of nutrient storage at the same time. It can establish networks of roots at varying soil depths, extending down several metres in the case of the horsetail (*Equisetum arvense*). Another example of this kind of plant is the common thistle (*Cirsium arvense*) (see Figure 6) [26, 85].

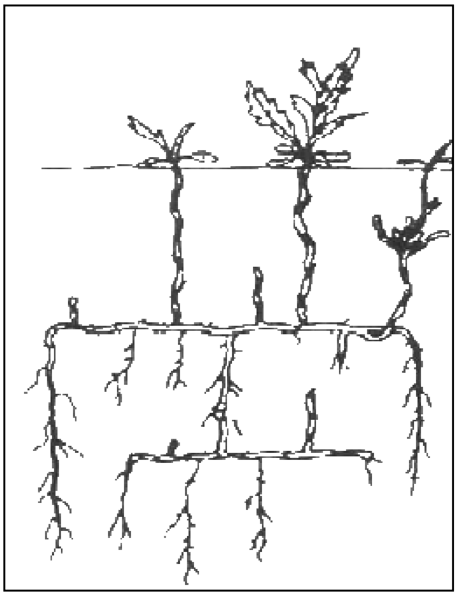


Figure 6: Root runners [26]

2.2.2.3 Storage systems

Besides strategies for colonising new areas, plants have evolved further means of surviving short or long-term periods in unfavourable conditions (e. g. cold or dry periods). Producing seeds to survive until growing conditions change for the better is a common mechanism, beside the aim of propagation. Besides this procedure, various kind of organs such as tubers, bulbs and tap-roots (e. g. dandelions *[Taraxacum officinale]*) are used to survive dry seasons (see also Figure 7: Tap root [26]) [26] and [85]).

An overview of various plant species and their types of propagation is given in Appendix 3.

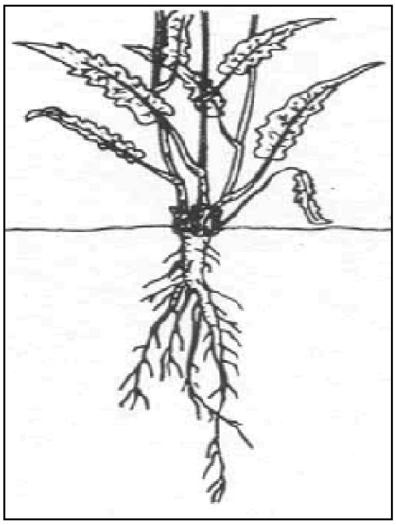


Figure 7: Tap root [26]

*Most plants found along the track that are propagated by means of shoot runners, sub-ground shoot runners and root runners originate from areas close to the track. **Conditions along the track unfavourable to the growth** of such species can be maintained with the aid of an efficient drainage system, good exposure of the track to sunlight and the use of dark materials for side paths to intensify the radiation effect. But the effect is not very pronounced as long as the plant is linked to the mother plant on the embankment. Thus, it is advisable to **maintain the embankment continuously** and regularly by, for instance, mowing when plants with shoots runners are identified. This leads to a dense growth of grass that stifles plant species such as brambles.*
*In addition, **vertical plant barriers** are an constructional measure that have a preventive effect on in-growing sub-ground shoot runners and root runners. Over and above this, continuous and regular mowing or the like is necessary to vanquish such plants in the long term. One-off measures may be counterproductive, propagating plants by spreading parts of them about.*

3 Impact of and Need for Vegetation Control

The possible impact of plants on railway services and infrastructure will be shown in the following Subsections. Given that the use of slab track is not very widespread, the knowledge acquired relates to experience with ballasted track.

The information used derives from the surveys, railway companies, the knowledge of railway experts and a literary research (see also LITERATURE).

3.1 Track Area

The influence of plants on the defined areas A (ballast bed) to C (transition area) (see definitions in Subsection 1.4) will be described separately, while the conclusion for all three areas will be drawn in a common chapter.

3.1.1 Area A - Ballast Bed

The ballast bed is one part of the track area, is made up of ballast or gravel and includes the embedded sleepers and rails.

In describing the possible impact of plants and the need for vegetation control measures in Area A, two scenarios have to be treated separately owing to their differing ballast behaviour and growing conditions for plants:

a) a new unsoiled[1] and

b) an old soiled ballast bed[2]

3.1.1.1 New ballast bed

The new ballast bed consists of a ballast layer approximately 25 to 75 cm thick (BV, DB AG, JBV, SBB). On new lines the ballast bed rests on a highly compacted mineral layer, while on older lines these sub-layers consist more or less of the original soil material [29]. The coarse material of the ballast bed is conducive to good drainage of water. At the same time, its material characteristics meet the other demand made of ballast by railway companies, namely good elasticity enabling it to conduct incoming forces from rolling stock into the sub-soil [30, 31, 32, 33, 34, 40, 64, 106, 110].

Its high drainage potential and tendency towards low heat conductivity yields high temperatures during daylight, but low values during the night. Air temperatures, measured over rails in Germany range between minus 30 and plus 60 °C. The temperature regime at the actual ballast surface is not likely to be very different [14, 15].

These conditions are the most inhospitable for vegetation, because plants have to withstand dryness and extreme temperature regimes. Accordingly, only a few specialised plants are able to survive these conditions and it is mostly lichen and other slow-growing plants that

[1] unsoiled = clean ballast almost free of fine material - cf. 2.1.1

[2] soiled = ballast highly contaminated with fine material - cf. 2.1.1

become established here [14, 15]. These species do not contribute to the fine material of the ballast in a significant way, because of low biomass production.

Besides this slow rate of colonisation by plant seeds, sub-ground and above-ground runners may reach the track area from adjacent areas much faster. At the same time these plant species produce more biomass and may create shadows in the usually shadeless area of the track as well. The extreme temperature variations as described earlier are reduced and humidity is probably higher due to shading too [14, 15, 65, 67, 93].

3.1.1.2 Old soiled ballast bed

Besides the effects caused by plants described above, the natural ageing process whereby pristine ballast in the track-bed becomes old and soiled also takes its toll, causing growing conditions as well as the behaviour of the ballast to change. The increasing amount of fine material leads to a higher water content and a raise in temperature conductivity. The thicker the fine material layer in the ballast bed the bigger the changes [31, 32, 33, 40, 59, 64, 102, 106].

The higher the proportion of fine material in the ballast, the more conditions begin to resemble those of soil. This is due to the increasing age of the track. Conditions become increasingly hospitable to plant life as moisture levels improve whilst, at the same time, temperatures and their degree of fluctuation are reduced. Hence almost every seed plant is able to settle under these conditions, whether it has a nutrient reservoir or not. Competition between different plant species now straightforwardly revolves around rooting depth and access to light. In a cumulative process, established vegetation is able to produce higher amounts of biomass as a result of better growing conditions. As a result, it can ultimately contribute large amounts of fine material [26, 85].

An overview of possible plant effects on the railway system for Area A is given in Table 1.

Table 1: Effects of plants on railway systems in Area A, ballast bed [114, 30, 62, 89, 106]

Short-term effects (in random order)
• Forms rust on fastenings (by creating more shade and hence more humid conditions) • Shortens useful life of wooden sleepers (degradation by in-growing roots increases humidity thus encouraging fungi that attack the wood) • Impedes regular inspection of the track by railway workers and automated inspection systems (by concealing fixing points) • Increases risk of fire (by increasing the amount of flammable plant material under dry conditions) • Reduces workers' safety (work paths made slippery, unevenness due to sub-ground runners, reduced sighting of signals) • Diminishes braking and starting power of trains (bits of plants on rails) • Affects electrical signal systems along the track (by increasing humidity and thus electrical conductivity)
Long-term effects (in random order)
• Impairs resistance to frost (by reducing drainage efficiency of ballast bed) • Weakens sub-layers and so enables material to be pumped up to the surface (by

impairing drainage)
• Increases maintenance tasks involving track stability (by weakening sub-layers)
• Shortens cleaning intervals (by increasing amount of fine material along the track)

3.1.2 Area B - Ballast Shoulder

The ballast shoulder is another part of the track-bed. It encloses the slopes on both sides of the ballast bed. It ranges from the head of the sleepers over the slope down to the working path. The angle of the slope is the result of a material constant, the inner angle of friction, varying from material to material.

The conditions in Area B concerning the growth of plants are not as strongly related to age as described for Area A (ballast bed). The part of Area B close to the tops of sleepers (top of ballast shoulder) is similar to Area A, because of thickness and behaviour. In the part of Area B (bottom of ballast shoulder) that is close to Area C (transition area), conditions are a combination of A and C. That is why the bottom of the ballast shoulder is a special part of the track.

The base or sub-layer beneath the ballast normally consists of the same material as in Area C (transition area) [25]. The material used is much finer than the coarse ballast stones and has therefore a higher water storage capacity. On railway lines built nowadays this material is a mixed material with specified components (more or less free of organic material). Additionally it is highly compacted during the construction process and, as a result, a certain proportion of rain water runs through the ballast stones, along the base layer and out of the track area. In former times the original soil or soil material from the surroundings was used as a base layer. The degree of compaction is likely to be much lower on such older lines than on more recently built track [39, 89].

This base layer is covered by ballast stones. The thickness of this coverage varies. It starts with a single-stone layer of 3 cm or so at the bottom, increasing to between 30 and 75 cm (see also 3.1.1) at the ballast shoulder.

Drainage water flowing out of Area A (ballast bed) has to bypass Area B (ballast shoulder) as well before reaching Area C (transition area or walkway). The ballast stones in Area B form a cover of varying thickness. Hence at the bottom of Area B this layer will dry very quickly, because of thin coverage and intense sun radiation. At the top of Area B, more in the direction of Area A, there is a certain zone in the ballast slope where the drying process is rather slow and where there is still enough sunlight to allow germination of seeds [43, 59, 102].

These special conditions lead to the **first colonisation** by plants on the ballast in that zone of Area B as already observed [6]. Plant growth in the coarse pores of the ballast stones leads to decreasing porosity and reduced drainage. Hence moisture levels rise and the growing conditions for plants will improve. The density of plants will increase with time, and the accumulation from organic material of dying roots etc. takes place [59, 102].

The effects of vegetation in Area B on railway operations and maintenance are given in Table 2.

Table 2: Effects of plants on railway system in Area B: ballast shoulder [114, 30, 62, 89,

106]

Short-term effects (in random order)
• Reduces workers' safety • Increases risk of fire • Restricts sighting of ground signals • Affects electrical signal systems
Long-term effects (in random order)
• Reduces resistance to frost • Weakens sub-layers and pumps material from there up to the surface • Increases maintenance tasks involving track stability • Shortens cleaning intervals

3.1.3 Area C - Transition area

Area C is defined as the transition area and it follows the slope on both sides of the ballast bed: It is mostly a walkway used for maintenance/inspection, but areas between two tracks (within double or multiple lines) are assigned to Area C as well. In some cases drainage ditches are also built in Area C.

The material in Area C mostly consists of the same components as the base or sub-layer beneath the ballast bed as already described in Subsection 3.1.2. The capacity of the material in Area C to store water is higher than that of ballast material due to the fineness of the material (even though it is highly compacted). Additionally, some railway companies supplement the base layer in Area C with a covering material. This can be characterised as fine material as well [39, 43, 59, 102].

These factors lead to a more moderate temperature regime than in Area A. The colour of the material in use additionally influences temperatures. Dark material gets hotter than a bright material during sunny periods owing to higher absorption rates, which can make for a dryer location [43, 59, 102].

Thus, the speed of colonisation depends primarily on the material at the surface, the degree of compaction and the degree of exposure to sunlight. The higher the water content and the better the nutrient storage capacity of the material used is, the easier and faster plants may grow in that part of the track. This process will be accelerated if such areas are additionally shaded by trees etc.[26, 85].

Plants in Area C tend to colonise the ballast as well, but the extent to which this occurs depends on the conditions in Area B especially at the bottom of the slope as described in Subsection 3.1.2.

The effects of plants in Area C (transition area) lead to a reduction of drainage as already shown for Area B [89]. The process of colonisation by plants and their effects on the structure of both areas B and C are shown in Figure 8, while the effects named by the railway companies are given in Table 3.

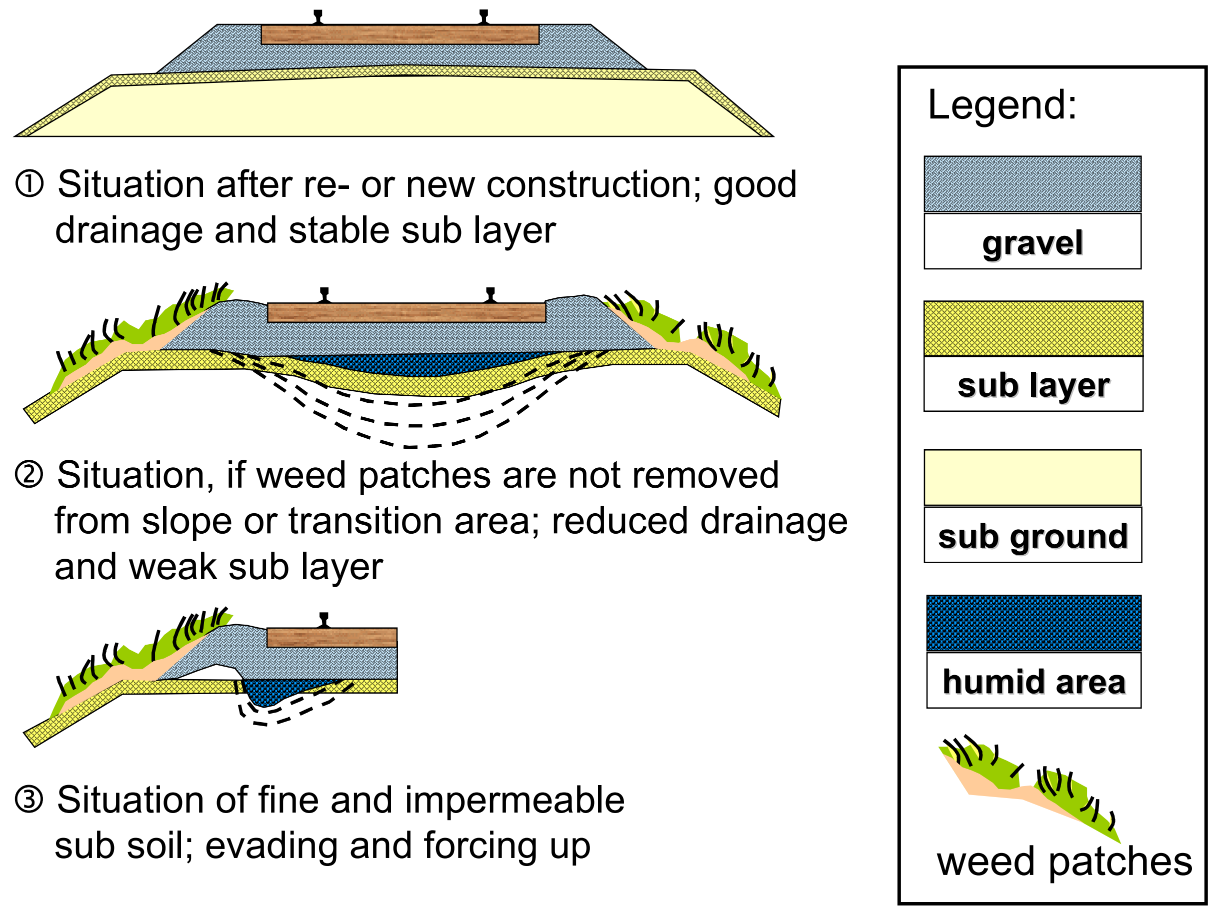


Figure 8: Development of track under the influence of plants (after [89])

Table 3: Effects of plants on railway system in Area C, transition area [114, 24, 45, 89]

Short-term effects (in random order)
• Reduces workers' safety • Closes emergency routes • Increases risk of fire • Restricts sighting of ground signals • Affects electrical signal systems
Long-term effects (in random order)
• Reduces resistance to frost • Weakens sub-layers and pumps material from there up to the surface • Increases maintenance tasks involving track stability • Shortens cleaning intervals

3.1.4 Conclusions

It is evident that vegetation control measures are needed in the track area for several reasons, while a differentiation into short and long-term time-scales is necessary. The understanding and acceptancy of short-term effects is better than in the case of long-term effects, because the former can be observed earlier. Reasoning on the long-term effect of weed is blurred by other circumstances affecting the track and is not therefore proven as yet.

It is clear that treatment should start at a very early growing stage of plants. The maintenance costs for vegetation control measures increase if bushes and small trees reach an adult stage, because it is then harder to remove them. The earlier any treatment starts (independent of method) the higher the efficiency and the lower the costs.

At the same time one should take into account that, before in-growing plants reach the ballast bed (Areas A and B), they have to negotiate all the other areas including the transition area (Area C). Thus, step-by-step vegetation control by track area is recommended. When considering vegetation control measures, one should include the embankment as well.

In future the focus should be laid more on preventive measures such as constructional methods to minimise the growth of vegetation along the track. At the same time this process has to be supported by measures avoiding the in-growing of plants.

3.2 Embankment

3.2.1 Area D - embankment

Area D is defined as the embankment of the permanent way whether it be a slope or a cutting. These are areas away from and alongside the track abutting Area C which are linked to the permanent way.

The growing conditions for plants vary greatly in that particular part of the permanent way - from good nutrient and water-content soils to simple rock surfaces. Mostly the natural soil surfaces are found at those locations, but also in some cases the surface may have been modified during engineering. These widely varying conditions lead to a huge spectrum of different plants growing there, from slow-growing lichens to fast growing trees such as birch (*Betula sp.*) [20, 21, 22, 23, 65, 46, 93, 111].

Area D (embankment) is usually covered by vegetation that is different to the areas A to C described above. Almost all railway companies use methods of biological engineering to protect their banks and cuttings against erosion etc. Most schemes include the sowing of a special mixture of grass, which leads to a first protective vegetation coverage. Bushes or trees are planted additionally. The development of the vegetation in these areas is strongly influenced by the surrounding landscape and the plant species present [23].

The vegetation in Area D causes problems if plants or parts of them grow into spaces where they interfere with traffic. The possible problems are given in Table 4.

Table 4: Effects of plantson railway system in Area D (embankment) [114, 18, 20, 21,22, 23, 95, 97, 101, 111]

<table>
<tr><td>Positive effects (in random order)</td></tr>
<tr><td>

Soil coverage against erosion
Biologically active areas, sometimes colonised with rare species, corridor function for rare species
Protection against wind, snow, sighting and trespass
Emergence of flora and fauna along the permanent way
Links different landscapes leading to a genetic exchange

</td></tr>
<tr><td>Negative effects (in random order)</td></tr>
<tr><td>

Safety or operational risks posed by plants or parts thereof, which may

hinder workers’ safety, as they negotiate paths for instance
affect the availability of the track, if

↳ old or diseased trees foul the catenary or block the permanent way
↳ stones loosened by plant roots in rocky cuttings

reduce sighting of the track and/or signals
damage rolling stock

Spread of “problem plants” such as Giant Hogweed (Heracleum mantegazzianum)

</td></tr>
</table>

3.2.2 Conclusions

Area D is one of the most important areas for vegetation control because, on one hand, the vegetation functions as a shield against erosion on the embankment whilst, on the other, it has to be kept within certain limits to guarantee undisturbed traffic operation. Besides this obvious need, there are other important factors justifying vegetation control. Inhibiting plants from growing in towards the track area prevents shading of that area and helps keep it warm and dry. As a consequence, growing conditions in the track area tend to deteriorate.

Besides typical vegetation control measures on the embankment, one should also focus on other maintenance tasks such as efficient drainage systems as a means of keeping growing conditions poor.

It is evident that vegetation control measures are needed for two main reasons:

- to keep desirable vegetation within certain limits so as to guarantee rail traffic operation, and
- to exploit the synergy effect for the track area deriving from continuous regular maintenance of Area D.

3.3 Outside the track area

3.3.1 Area E

Area E includes all areas away from the track (not linked with track operation directly) such as foot paths, areas around power supply stations, loading areas, station platforms, parking sites etc.

Growing conditions for plants in these areas vary greatly depending on the engineering/ material in use. In general, a distinction can be made between hard and soft-cover surfaces - a more detailed overview is given in Table 5.

Table 5: Area E - Possibilities of different surface types and materials in use [114, 118]

hard cover	soft cover, permeable to water
a.) fully sealed surfaces: • Concrete • Asphalt	• original soil material • sand • gravel • mixture of sand and gravel
b.) partly sealed surfaces covered with paving slabs (with joints of different size) out of • wood • concrete • natural rock	
c.) partly sealed surfaces to drain rain-water covered by paving slabs made of • concrete • plastic material for greening	

These areas are mostly dry places, because a highly compacted surface requires a good drainage system. Thus, penetration by plant roots is restricted to the degree of compaction within the surface and sub-layers. Conversely, there are types of construction, where a grass vegetation is wanted for various reasons such as water penetration or aesthetics as given in Table 5 under c.) [113, 118, 63].

Thus, the maintenance objectives are different - an overview is given in Table 6, because the focus of this report is directed at areas connected with railway operations (Areas A to D).

Table 6: Maintenance objectives for Area E - Outside the track area [114, 113, 118]

• avoid - plant contact with electrical installations - structural damage such as loose paving slabs on paths and platforms - in-growing of plants, scrub and trees • guarantee

- free view of signals
- good drainage of rainwater, e.g. root-free drainage system
- non-slip conditions for customers on stairs, platforms etc. in railway stations
- clearance for human passage and vehicle operation

- check
  - old or diseased trees for safety reasons regularly
  - whether measure is really needed for maintenance reasons or “merely” on aesthetic grounds

3.3.2 Conclusions

E-category areas are not covered by this report, because they are not directly impinge upon railway traffic. It is evident that there are basic needs for vegetation control measures in these areas as well, because plants may destroy the drainage system and the surface of sites leading to a higher risk of accidents. Besides, it is obvious that bushes and trees in the surrounding area may lead to a higher risk of danger. Thus, they have to be inspected regularly and decisions regarding treatment need to be made on a case-by-case basis.

The general case for carrying out any vegetation control measure in such areas is more complicated. The first question to be answered should be whether the reason is one of aesthetics or objective need. The latter should constitute the only motivation for carrying out vegetation control measures.

4 Discussion

The question of whether and to what extent vegetation control measures are needed came up recently when the use of herbicide was restricted by legislation and budgets were also reduced. The following discussion will be divided into three parts dealing, respectively, with the track area, the embankment and areas away from the track.

4.1 Track area

4.1.1 Organic material (weeds)

The drainage potential of ballast is reduced by organic material in respect of plantsgrowing along the track [30, 62, 64, 89, 106, 110]. Thus, it is reasonable to argue that wet and moist conditions enhance plant growth whilst dry conditions are less conducive to this [30]. This in turn leads to differing amounts of organic material being generated.

A more detailed illustration (see page 36) of the influence of plantson the track is provided by [30]. The main problem caused by plants along the track is reduced to vegetationpatches growing from Area C into Area B. These plant clusters block the bottom of the ballast slope and lead to reduced drainage of the ballast bed. This explanation is totally different from the above mentioned one and seems to be more realistic. At least it looks as if it is the faster process and takes places first. Living plants growing from Area C into Area B may close the coarse pores more quickly than the organic remains of dying plants. This argumentation is supported by [31, 32, 33], because the sources and the kind of fine material in the ballast are different: it may consist of organic as well as of inorganic matter, the latter contributing the higher proportion [31, 32, 33]. Organic material originates from vegetation in general. This means it may come from plantsgrowing along the track itself or away from the track, blown in by wind or unsealed train containers [65].

4.1.2 Inorganic material

Inorganic substances originate from the crushing of ballast stones by train traffic, sub-soil material coming up from the ground, unsealed train containers or else they are blown in from the outside. The crushing of ballast stones by operating trains is well-known as an ordinary process [31, 32, 33].

4.1.3 Effects of fine material (organic or inorganic material)

Leaving the time factor aside, the basic effect of organic and inorganic material may well be virtually identical. The water remaining in the track is absorbed by the base layer, being either blocked by vegetationpatches or retained by organic or inorganic material. As a result, the stability/carrying capacity of this layer will be reduced, strongly depending on the water content. While trains are passing, the sub-layer material is “pumped up” into the ballast itself and the ballast bed breaks down. The conclusion of [89] from 1944: The conditions of ① in Figure 8 (see page 36) have to remain as long as possible. Hence it is obvious that vegetation control measures are needed to avoid this situation even if one does not know the time-scale for that specific process.

4.1.4 Changes in the design of track

A glance at how track is actually designed reveals that there have been several modifications since the middle of the 19th century. There are varying kinds of sub-layer whilst carrying capacity has been increased by using different materials and changing the design [39].

In the past, natural soil in more or less compacted form was used as a “sub-layer” for the most part. Nowadays special mixtures of mineral material are used in combination with binding agents or slab track to withstand the high train loads. Thus, the problem of weakening the sub-layer by reduced drainage still exists but the process may take more time than in the past. This argumentation is supported by [31, 32, 33, 40]. The process of “pumping up” fine material from the ground is mostly connected to lines without any highly compacted sub-layers.

4.1.5 Limit values

Railways are frequently asked whether there is a limit value for organic material in the ballast. The present study only cites findings from other studies. In [31, 32, 33] a limit of fine material is proposed that has to be exceeded before the ballast bed needs to be cleaned. If the particle size of < 22.4 mm reaches a level of ≥ 30 percentage (by weight) in the ballast, cleaning is recommended. This limit is set to avoid a reduction in the level of conductivity, elasticity and drainage and hence also to avoid frost defects. Besides these facts, corrections of track position are more difficult. No distinction is made between organic and inorganic materials. In [40] a critical level of contamination with fine material < 22.4 mm was estimated as being 50 %. The behaviour of ballast material did not change in a dramatic way below 50 %. At levels higher than 70 %, changes in ballast behaviour are evident.

In both studies mentioned above the water content was neglected. [40] points out that water is around all the time in a track and the findings may vary with different water content.

Variations in organic material are not investigated either. If and how this influences the above-mentioned track characteristics is not resolved as yet. So far no railway company or university has been able to specify a vegetationlimit that may be acceptable in this section of the track. On the other hand, it is not possible at the moment to adopt the idea, familiar in agriculture, of what are known as damage limitation values. Railways are dealing with the safety of human beings and not with reduced crop yields.

There are a lot of ways in which plants influence railway operations. Due to coverage and transpiration of vegetation in the track mentioned by [30, 106], humidity in areas A to C is higher. As a consequence the growing conditions for plants improve continuously. Besides this, high humidity leads to higher rates of rust. Additional reasons such as reduced visual access to track fastenings and a faster deterioration of wooden sleepers were mentioned as well. Nowadays, concrete sleepers are being used more and more instead of wooden sleepers. Thus, the point about high humidity between rails hastening the deterioration of wooden sleepers is not applicable for all lines. On the other hand, a free view of fastenings is still needed when inspecting the track. Modern railways use automatic inspection systems that demand a clear sighting of fastenings. On new lines there are installations for signal systems and cables for traffic control. If coverage of plants and/or humidity reaches a certain level these systems do not work properly. Additionally, problems with brakes in rail yards were cited, along with an increasing risk of fire, if vegetationgrows along the track above a certain limit. These examples may show that it is very difficult (so far impossible!) to define limit values linked to safety/track stability.

Even if one is not able to define such values it is very obvious that vegetation control along the track has to be treated as one of the most important maintenance tasks [30, 106] for various reasons as shown above. Summing up the knowledge about vegetation treatment, it should start at a very early growing stage of plants due to higher efficacy and lower costs. But besides this, vegetation on the embankment has to be taken into account with the same priority.

Besides these facts, railway companies have started to set up vegetation rating systems for quality reasons. Reports have been forthcoming on a number of approaches to vegetation classification [54, 91], leading to a standard rating system as a basis for track quality. But these values are not based on evaluated risk potential and will be scrutinised after some years of usage [54]. It seems to be impossible to get a direct relation between a certain plant coverage in the ballast and reduced stability [73, 108]. There are too many parameters influencing plant growth here. The contribution of plant material to fine ballast material is still an unanswered question.

4.2 Embankment

A closed vegetation surface on the embankment enhances structural stability and counters erosion [20, 23, 97, 101]. In addition some positive ecological side-effects are named as well. All railway companies stated the need for vegetation control measures on the embankment. Safety considerations such as old diseased trees, view of signals and threats to workers' safety from in-growing plants are cited as being the main reasons. These are of course the predominant reasons, but a lot more reasons should be taken into account too. The embankment is the space where most plant species found in the track area originate from. Besides plant species, the characteristics of an embankment have an important impact on growing conditions within the track area as well [18, 20, 21, 22, 23, 67, 79, 93, 95, 97, 101, 111].

4.2.1 Influence of embankment on the track area

This is demonstrated in studies by [67, 93]. It is mentioned that a synergetic effect between vegetation control measures on the embankment and the track area is evident. Mowing and mulching on the embankment (in the vicinity of the track - 1 to 2 m) reduces the vegetation burden on the track and prevents bushes and small trees growing there. If the latter do take root and grow, they will produce shaded areas in the track area. This leads to higher humidity and a more uniform temperature regime alongside the litter from fallen leaves. The result of continuous and regular mowing and mulching will be close grass vegetation after some years [79], leading to dryer conditions in the track area and reduced plant growth. Besides such standard vegetation control measures, it is important to maintain drainage systems as well. Though not a straightforward vegetation control measure, it nevertheless engenders dry soil conditions and worsens growing conditions. Given that these systems are mostly located between the embankment and the track, they function as additional barriers to plants.

4.2.2 Combination

If these conditions are combined with specific constructional methods along the track, this waterless situation will cause growing conditions for plants to decline dramatically (see also Part B). As a result, only a few slow-growing specialists will survive under these conditions in the track and problem vegetation is slow to become established on the embankment as well.

4.2.3 Problem Plants

When taking all these facts into account, it is not surprising that some so-called problem plants for the track such as brambles (Rubus sp.) can be treated more effectively with the aid of mechanical measures on the embankment (see Part B, Problem Plants). Brambles (Rubus sp.), for example, grow on the embankment and usually send runners into the track area. While the runners are treated by vegetation control measures along the track (mostly herbicides), the mother plant remains unaffected by this treatment. It will grow continuously, sending new runners. Thus, regular maintenance of the embankment area, e.g. mowing once a year, is needed. This engenders close grass vegetation and is the best protection against brambles, which are not able to get established in such closed vegetation surfaces. This is applicable to some of the other “problem plants” as well.

4.2.4 Application time

The time or period for applying measures on the embankment has to be chosen carefully, because it should depend on the species growing in the area. The best time during the year for treatment is the time before the dominant plant species finish flowering to avoid maturation and hence seeds flying into the track area.

The afore-mentioned regular maintenance tasks need to start as soon as engineering work has been concluded. It is absolutely necessary to start with measures such as mowing and mulching at an early stage to keep maintenance costs at a low level. Once the right time has been missed, the costs for establishing maintenance and cost friendly conditions along the track will rise dramatically. This is due to the need for using bigger machines and/or blocking the track while removing trees e. g. (see Part B).

4.3 Areas away from the track

Information on the need for vegetation control measures in **areas away from the track** is thin on the ground. The reason might be that not all railways companies are responsible for these areas even though the needs for vegetation control measures are the same as already mentioned above. In the neighbourhood areas there may be some risk potential concerning diseased trees, which may damage cars in parking areas and injure people. The right distance from electrical installations to guarantee the free sighting of traffic signals is yet another important reason for carrying out vegetation control measures in such areas too [2, 118]. Besides these reasons there is the possibility of surface layer destruction by plants leading to reduced carrying capacity and increasing risk of accidents.

But before deciding what kind of method should be used, it should be checked whether a given **vegetation control measure is really necessary**. Thus, the following points have to be clarified first:

- vegetation control merely on aesthetic grounds (areas not used any more, for example, that cause a station to look “tatty”)
- other reasons such as safety, reduced drainage, deterioration of surface layers leading to reduced carrying capacity ...

If the first reason is the main motivating force, one should examine whether a measure is really needed or not, because avoiding extra maintenance helps to reduce costs. If the second reason applies, one has to look at the type of surface in order to select the appropriate method(s).

Given that routes/sites can have differing surfaces and uses, it is necessary to define clearly what needs doing where. Speed of colonisation and growth potential differ from species to species, but plant parameters are likewise strongly dependent on surface type and the material used.

4.3.1 Soft-cover surface

Most problems on **soft-cover surfaces** (permeable surfaces) are likely to take the form of clogged-up drainage systems, rough surface layers, holes in the surface caused by plant roots or impeded sighting on account of tall growing plant species. In most cases, the functioning of routes and locations is affected (e. g. drainage or sighting), but damage to actual buildings is seldom incurred by plants [2].

Thus, before inspecting the surface itself, the drainage system should be examined. An efficient drainage system reduces plant growth as already discussed earlier as well as preventing damage by frost and hence reduced carrying capacity. The last point is strongly dependent on how the area is used. A high carrying capacity is needed in places where heavy goods and big trucks are operating, while for walking ways a lower standard might be acceptable [63].

Plant growth in permeable surfaces may destroy the surface and as a result the sub-layer with time, but this depends on the plant species. While trees develop a high potential to destroy the surface, loose plant runners can increase the risk of accidents. The latter can be easily removed by cutting around them, whilst tree roots create rough surfaces. Hence the risk of accidents (possible damage to goods stored) will increase alongside a further, economic aspect, namely a shorter service life on account of damage to the surfaces.

4.3.2 Hard-cover surface

Hard-cover surfaces involve paving slabs in various materials with joints made of a variety of filling materials. It is in these interstices that plant growth will commence first. The decision as to what kind of measure has to be carried out should be made as a function of the plants occurring (see also Part B).

Too much moss may have an important impact on safety (slippery when wet), but only if the ratio of joints is high, relative to the surface as a whole. On the other hand, vegetation may have the converse effect of stabilising the paving slabs as well. Incident tree seedlings may destroy the entire foundations if allowed to grow. This is due to their loosening the paving slabs with their root systems as these thicken. The loosened paving slabs pose an additional potential risk for pedestrians. [118].

A totally sealed area will be the best protection against plant growth, but the positive effect of draining joints is lost, leading to a high amount of surface drainage water. At some point in the future this may have economic repercussions (cost of water drainage).

In general the material used is important. Concrete structures will last the longest time without vegetation, because of their high pH values and hard surfaces. The asphalt surface very often used is a weaker material. In such an instance, the in-growing of plants is linked to the thickness and quality of the sub-layer. This is due to the fact that most of the plants observed in these areas come from the sub-ground and only a few will have started to germinate on the surface.

PART B: Optimising and Improving the Effectiveness of Different Vegetation Control Methods and Vegetation Management System

5 Vegetation Control Methods: Demands and Strategies

5.1 General requirements of railway companies in respect of vegetation control methods

A ”new” method has to fulfil certain demands if it is to have any chance of being used by large numbers of railway companies. Besides more general guidelines each railway company or country evaluates and prioritises these parameters in a different way. This is due to the weighting of parameters, as a result of which diverse strategies may arise. Thus, the tree diagram (see Subsection 5.4) is rather general in design so as to leave space for each railway company to set up schemes tailored to their own individual needs.

The vegetation control methods should: (list without any prioritisation by authors, company or area of application):

- **have high and long lasting effects**: After the application of the method only the desired plant coverage (no enhancement of growth) should be recorded. Besides this, there are other ways to estimate the efficiency of a method such as frequency of application. The longer the treatment of a method lasts, the less frequently it has to be applied.
- **meet the various demands on vegetation control** in the various areas (ballast bed to embankment) according to the description in Part A.
- **not hinder line traffic**: the faster a method takes effect, the less it is an obstacle to the running of trains. Furthermore, more line km per hour can be treated (leads to higher economic efficiency).
- **be flexible**: Traffic density is constantly increasing in many countries, even during the night time. Thus, it is necessary to avoid track occupation for maintenance reasons such as vegetation control. If there is an absolute need to apply a track-bound method on busy lines, it would be better to use rail-road vehicles, since these can be rapidly removed from the track if need be. All in all, though, the best solution is a non track-bound method. The more independent a method is of weather conditions or seasons, the easier it is to plan an activity.A method applicable on open line as well as in station areas allows a flexible and a more intensive use by the company.
- **have low cost**: Nowadays every company is having to cut costs. Thus, a method for vegetation control should cost as little as possible. The simpler a method to apply the less it costs (no time-consuming instructions, preparations, ...).
- **have a low impact on the environment**: Environmental policies in several countries will be more strict in the future, especially the regulations concerning the use of herbicides. New methods have also to be tested for environmental friendliness.
- **be adapted to local conditions:** Every method has its optimal working conditions due to different track areas as well as differing vegetation composition. This has to be taken into account before applying a method.
- **be accepted by users:** Everything new is examined critically. To enhance acceptancy by potential users, good information and education strategies based on dependable data are necessary.
- **be accepted by the public:** the points listed above are also valid for this point

- **not damage the track and all the other railway installations:** After the application of a method the track should be in the same state as before. Also after several times of application the track itself should not be affected.
- **be safe for users:** Every method used has to fulfil the safety regulations for working staff and the surroundings.

5.2 Importance of vegetation control by railways in figures

The total length of all railway tracks in Europe is shown in Table 7.

*Table 7: Length of Railway Tracks (**bold**) and Railway Lines (not bold) in some European countries, Data from 2000 [113]*

Country	Length in km	Railway companies	Country	Length in km	Railway companies
Albania	**447**	HSh	Italy	**22,281**	FS
Austria	**10,692**	ÖBB+GKE	Latvia	**3,819**	LDZ
Belarus	**424**	ZRS	Lithuania	**4,140**	LG
Belgium	**6,145**	SNCB/NNBS	Luxembourg	**618**	CFL
Bulgaria	**6,467**	BDZ	Macedonia	**699**	CFARYM
Croatia	**4,063**	HZ	Moldavia	**14**	CFM (E)
Czech Rep	**16,948**	CD	Norway	4,179	JBV
Denmark	**3,197**	DBS	Poland	**44,415**	PKP
Estonia	**1,811**	EVR	Portugal	**3,370**	Refer EPE
Finland	**8,680**	RHK	Romania	**22,214**	CNCF CFR SA
France	**49,103**	RFF	Slovakia	**7,310**	ZSR
Germany	**75,109**	DB AG	Slovenia	**2,102**	SZ
Great Britain	**58**	Eurotunnel	Spain	**1,521**	FGC + FEVE
Great Britain	17,400	RT	Spain	12,319	RENFE
Greece	**734**	CH	Sweden	**11,000**	BV
Holland	**6,432**	NS, RIB	Switzerland	**7,780**	SBB/CFF/FFS + BLS
Hungary	**274**	GySEV	Turkey	**10,933**	TCDD
Hungary	**37**	MAV	Ukraine	22,473	ZU
Ireland	1,919	CIE	Yugoslavia	4,059	JZ
TOTAL Railway tracks				***334,557***	
TOTAL Railway lines				***60,629***	

A total length of 400,000 km of track yields an area totalling about 2,560 km^2 in Areas A, B and C (track area) and between about 2,000 km^2 and 4,000 km^2 of embankments.

The annual budget (2002) for vegetation control in the track area and the maintenance of embankments together (excluding woodland) is around 69 million € (total of following companies: DB AG, SBB, SNCB, BS, BV, OeBB). They spend on average about 130 €/km (track kilometres) for vegetation control in the track area (Areas A, B, C) and about 390 €/km for maintenance of the embankment.

These figures indicate just how many line kilometres and square kilometres of embankments requiring maintenance and treatment there are throughout Europe. The budgets earmarked for this work show that they are not negligible from the point of view of the chemical industry and private companies dealing with vegetation control measures.

5.3 Overview of the various strategies and methods

Methods can be divided into two different strategies (see Figure 9): **Preventive methods** combat causes. They include all measures and methods which help to minimise the maintenance of vegetation control in the track area. The methods be included in the planning of new lines or re-constructions or else shortly after constructionhas been completed (e. g. regular mowing of embankments). The advantage is that, embedded in the construction process in this way, such measures may not cost as much and yet are very effective. Contrastingly, there are some **methods** that only **combat the symptoms**. These have to be applied repeatedly and can only be used in maintenance, whereas preventive methods can be applied in new-build or re-constructions and in maintenance as well.

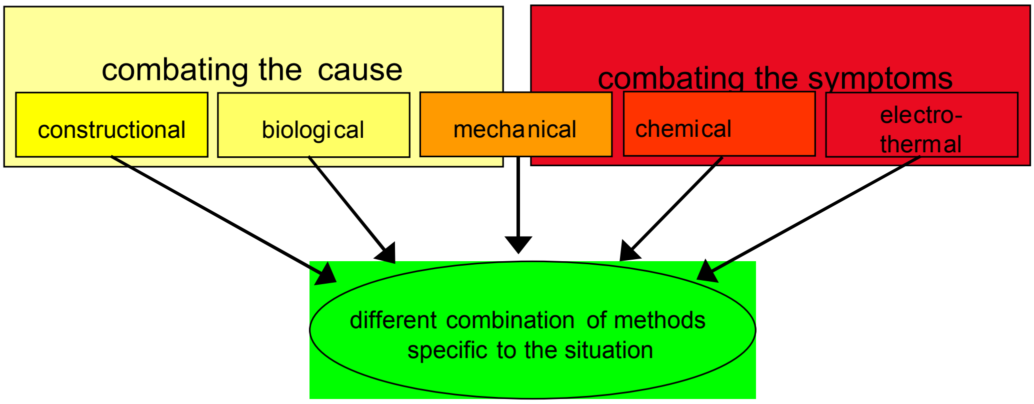


Figure 9: Overview of the various Methods of Vegetation Control

The explanation of the following methods can be found further on (see Section 7).

In responses to the survey [114], not all methods listed were predominantly used for vegetation control reasons and therefore were not cited as such (e. g. ballast cleaning/replacement). Since such methods have an influence on plant growth they are also mentioned as vegetation control methods in this report. Several of them are used frequently nowadays, but usually the effect on plants and therefore vegetation control is factored out. Why not include knowledge on vegetation control in the application of these methods? This aim has to be taken into account by more persons using such methods.

*Table 8: Currently known methods of vegetation control (these methods are either applied frequently by railways or tested in experiments) A more detailed overview of the various methods (*M XX*) can be found on page 73 forward, the methods are described in detail on page 156 forward.*

Methods combating the cause ***Prevention of unwanted plants along the track***						***Methods combating symptoms*** ***Elimination and suppression of unwanted plants***			
A) Constructional		**B) Biological**		**C) Mechanical**		**D) Chemical**		**E) Thermal/electrical**	
Lateral plant barriers/ Objects impeding plant incursion		M8	Greening	M13	Ballast cleaning	M18	Back-pack spraying	***Thermal***	
		M9	Selective embank-ment maintenance	M14	Ballast replacement	M19	Spraying train	M23	Burning
				M15	Mechanical weeding	M20	Rail-road vehicle	M24	Infrared devices
M1	Lateral plant barriers/ Objects impeding plant incursion in general	M10	Biological weed control	M16	Manual weeding	M21	Selective applica-tion by spraying train (e.g. weed eye)	M25	Hot steam
				M17	Brushing			M26	Hot water
		M11	Mowing					M27	Hot air
M2	Thin vertical plant barriers	M12	Mulching			M22	Weed wiping	M28	Freezing
		M33	Allelopathic plants					M34	Hot foam
M3	Plant-inhibiting design of the transition area (Area C)							***Electrical***	
								M29	Direct contact with electrical fields
M4	Porous concrete bars							M30	Microwaves
M5	Amount and kind of ballast material							M31	Laser
								M32	UV light
Plant barriers beneath the track									
M6	Plant barriers beneath the track in general								
M7	Slab track								

6 Comparison of Different Methods

6.1 Evaluation of Methods

Four factors have to be considered in parallel when evaluating methods:

- ***effect-related*** *factors*: What's the effect on plants? How long does this effect last?
- ***technical and operational*** *factors*: Is it possible to apply the method within the operational demands of the railway companies?
- ***economic*** *factors*: How much does this method cost (see also Subsection 6.2 Costs)
- ***ecological*** *factors*: In which way does this method have an impact on the environment?

These factors have already been explained in detail in Subsection 5, "Vegetation Control Methods: Demands and Strategies

General requirements of railway companies in respect of vegetation control methods". The evaluation has to be made step-by-step. Beside the examination of a method's impact on plants, possible impacts on the environment have to be checked as do economic and technical/operational aspects. The evaluation of different methods has to be conducted to reflect which methods can be applied in a given area. This means that very important requirements for methods are heavily weighted for evaluation purposes. The **findings** from an evaluation may **differ from railway to railway** depending on whether studies relate to railway organisational structures or to national regulations. For a better understanding of the findings, the steps carried out during the study have to be documented (reproducibility). Examples of the form such evaluations can assume are to be found in [50, 60, 86].

In this study the various methods are listed according to the factors described above (see Appendix 13.5). A detailed evaluation was not possible, since the findings from the UIC questionnaires [114] as well as publications and information of producers are not designed to be objective and directly comparable. Thus, a form of **classification reflecting the degree of practical use** was effected during data evaluation (see Table 9: Classification scheme for vegetation control methods based on their practical use by railway companies). Practical use includes most of the criteria described above. Besides this classification, the other data and factors mentioned above are also listed. Every reader should be able to make their own evaluation and place the emphasis on what is important for themselves (e. g. economy or environment). In addition everyone who is interested in more background information will be able to contact the railway company individually. Therefore, a reference list plus a list of contact persons is given in the Appendix.

Table 9: Classification scheme for vegetation control methods based on their practical use by railway companies

Classification	Description of method/measure
☺ I - Operational use	• used regularly by railways in maintenance, new-build or re-construction • available on the free market for buying or hiring
😐 II - Investigation/Study	• under investigation by railway companies or at an early stage of development • still not deployed for regular maintenance work • not available on the free market

☹	III - Not being pursued	• has already been investigated or used, not in use any more for practical reasons (technical, operational, ecological, economic) • not in use because of adverse study findings

6.2 Costs

Currently, a lot of railway companies are being transformed from state organisations into private companies. Hence operational costs are becoming more important as one criterion for choosing a specific method. At the same time only poor data on costs are available at the railway companies. Thus, the focus of the UIC survey [114] was on total costs and not on especially defined ones. The disadvantage of this procedure is that there is no way of knowing what the costs cited cover, so that they only provide a *weak* statistical basis for comparisons. It all depends on how companies conduct their costing.

Assumption: Personnel costs (salaries) and running costs (fuel, herbicides, spare material) were included by companies, but the level of salaries differs from country to country. Also differences in organisational structure lead to differing costs.

The exchange rates used in the survey [114] are listed in Table 11.

The points to be taken into consideration for an objective comparison are listed in Table 10. The actual comparison of costs for vegetation control methods is, amongst other things, dependent on the number of applications needed. Thus, a time schedule is important for reference purposes. There are two familiar and commonly-used means of describing costs:

- **annual costs:**, The duration of the effects of given methods on plants can be used as a costing basis (frequency of application). Total costs arising during the overall period are added up and divided by the number of years to arrive at comparable annual costs.

  Example: an constructional method might remain effective for 5 years, while a chemical method has to be applied twice a year for the same effect. If the constructional method costs five times as much as one single treatment of the chemical method, it is still the cheaper method.

- **Life Cycle Costs (LCC):** On the one hand, the life cycle of a machine or engineered entity should be taken into account, i.e. from construction to decommissioning. On the other, all costs incurred during this life cycle have to be taken into account too. It may be seen that this is a very complicated process. It is not applicable to all methods used by the railways at the moment, because of the gaps explained above.

- **External costs** are often left out when comparing methods. These are costs incurred indirectly once a method has been applied.

  Example: Following the operation of a spraying train in a given area, a resident complains that the herbicide used has wafted across and killed all the lettuces in their garden. The railway company is obliged to pay for the lost lettuces. This kind of cost is incurred by application of the method (e.g. spraying herbicides).

Table 10: Overview of cost factors (list is based on [86], but enlarged and changed)

	costs for...	***embraces ...***
Costs directly relating to methods	Investments	Research on new technologies or improvement of methods and machines
	Material	Machinery and equipment
	Operational costs	Fuel, water, spare pieces, herbicides,
	Personnel	Outlay on salaries
Railway internal costs	Administration	
	Occupation of line	Speed of method, installation, de-installation time, track-bound, non track-bound
External costs for the environment	Risk of toxic/harmful substances	Injuries, accidents and clean-up of contaminated sites, effect on other plants than those on railway installations
	Environmental pollution by substances/characteristics of methods	Exhaust emissions such as CO_2, NO_X and others noise
Other factors with bearing on costs	Flexibility	Weather, seasons of the year
	Plant coverage present	
	Length of line section to be treated	Several small or fewer large line sections
	Preventive method or method combating symptoms	
	Synergy effects	Combination (see Subsection 6.3) with: - other methods possible - methods in other track areas - other maintenance (not vegetation control) measures

Table 11: Exchange rates used in the Survey [114] (variable rates for June and Sept. 2001 [DKr., SKr.])

Currency	Exchange rate for 1 €	Currency	Exchange rate for 1 €
Belgium	40.3399	Austria	13.7603
Germany	1.95583	Portugal	200.482
Spain	166.386	Finland	5.94573
France	6.55957	Switzerland	1.5
Ireland	0.787564	Norway	7.5
Italy	1936.27	Sweden	9.44
Luxembourg	40.3399	Denmark	7.44
Netherlands	2.20371		

6.3 Combinations

The combined application of various methods is recommended by different railway companies (SBB, JBV) and found in literature [2, 67, 68, 93, 111]. JBV [68] for example recommends a combination of mowing and the use of herbicides to combat softwoods in the track area.

Different types of combinations may be possible e. g.:

a) combination of ***preventive methods*** and ***methods combating symptoms***:

   Example: *plant-inhibiting design of the transition area (Area C) with manual weeding to remove single plants*

b) combination of methods applied in ***the building of new line*** and ***maintenance methods***:
   When planning the building or renewal of lines, the issue of vegetation control has to be taken into account. This means using knowledge about both constructional methods and the spread of problem plants.

   Example: suitably positioned cable troughs in the transition area and annual mulching of the adjacent area.

c) combination of methods used in ***various track areas***:

   Example: *chemical vegetation control in the track area (Areas A, B and C) in combination with regular mowing/mulching on the embankment (Area D) to avoid in-growing plants and reduce seed transmission.*

d) combination of different methods for the ***same area:***
   This kind of combination is mostly used to combat problem plants (see Section 8).

   Example: some neophytes are first mown and subsequently treated with herbicides.

In the catalogue (see Appendix 13.5), there is also an item on combinations of methods.

6.4 Decision-Maker’s Tree Diagram

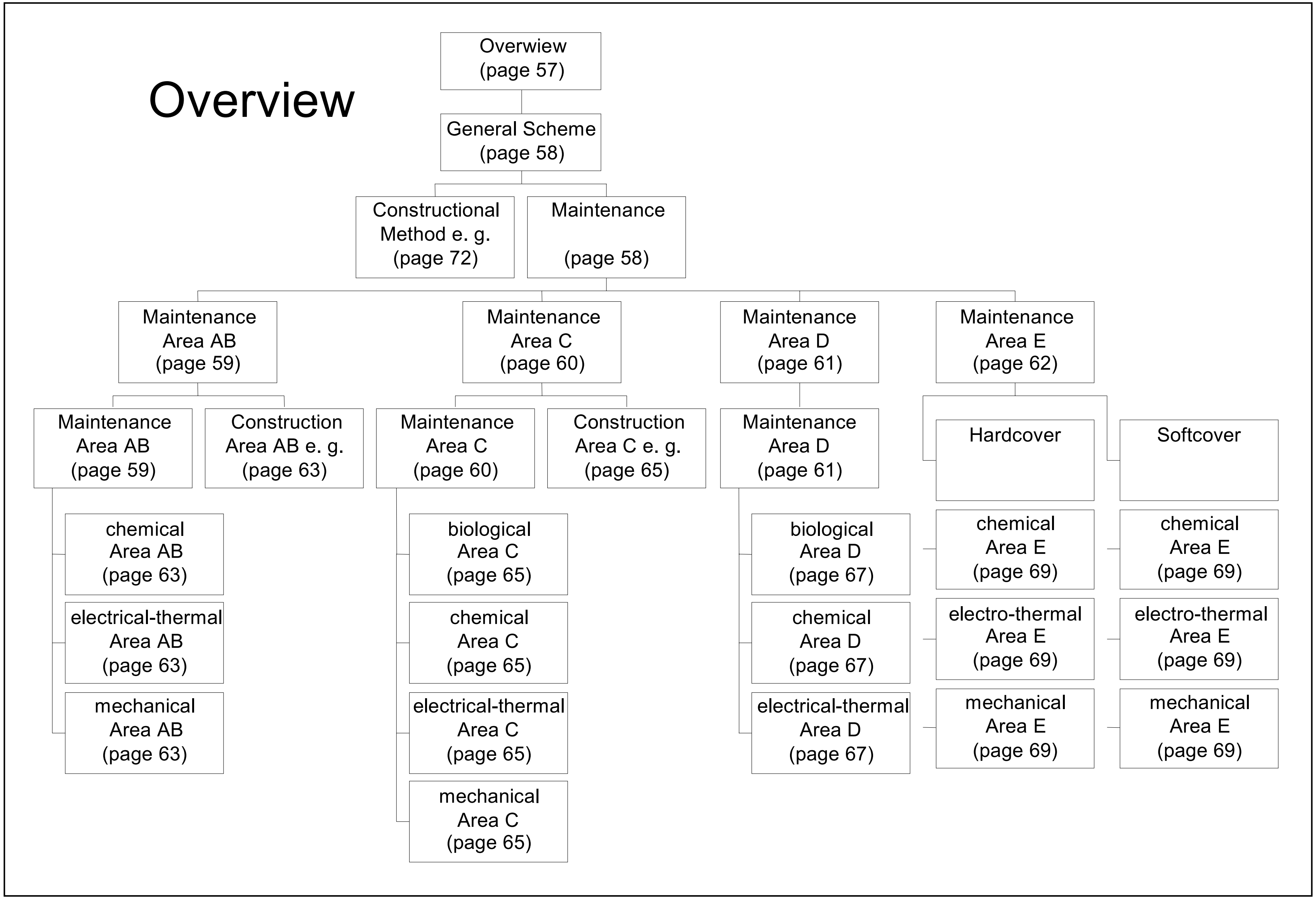
6.4.1 Introduction and Instruction

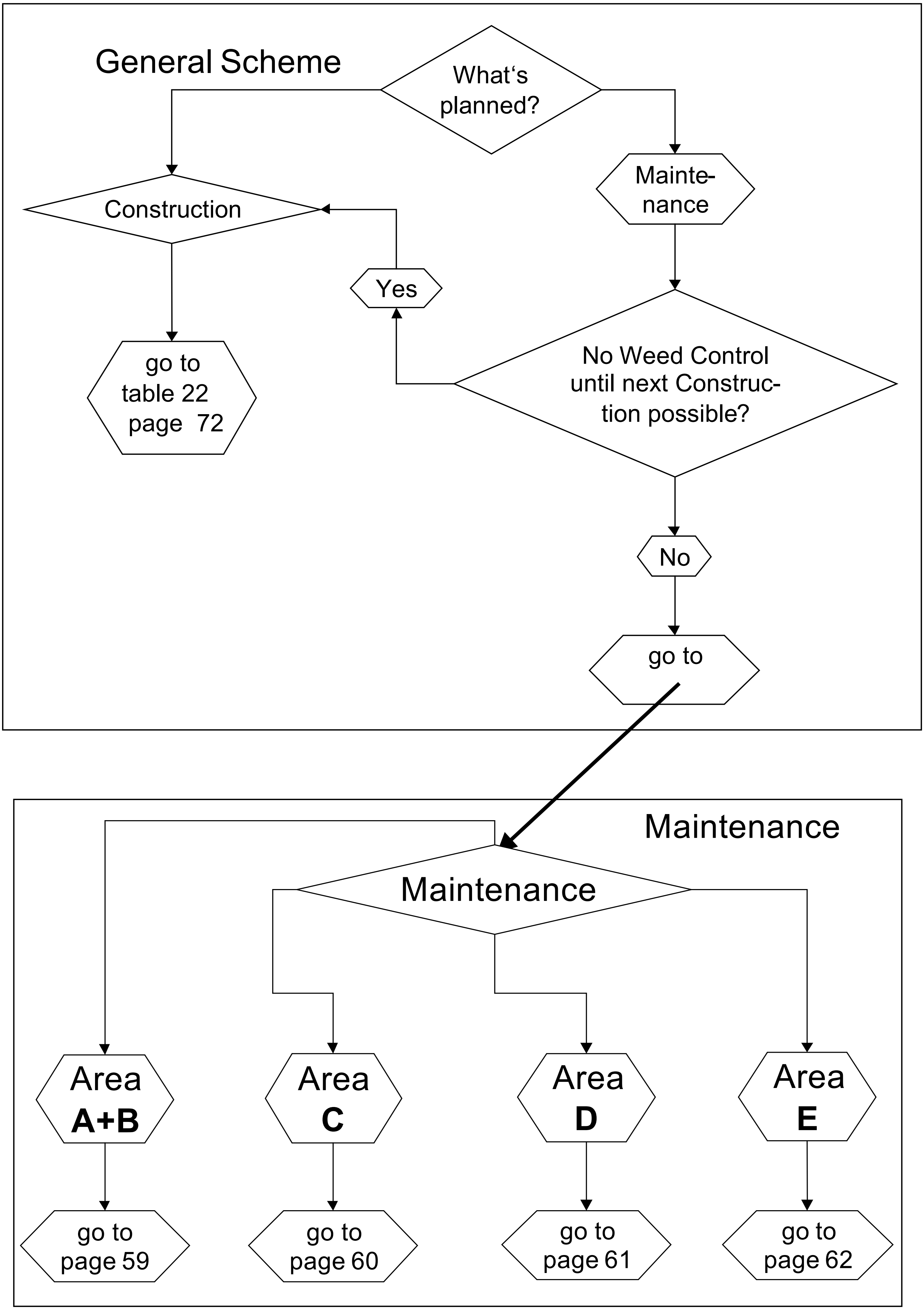
The tree diagram on the following pages should contribute to finding the appropriate method(s) for a given situation. It is rather general in design (see also Subsection 5). The findings constitute recommendations, since each country and railway company has different framing conditions. The diagram should give railway companies an idea of considerations to be taken into account, but it has to be adapted to their specific conditions. Accordingly, there may be more than the solutions given.

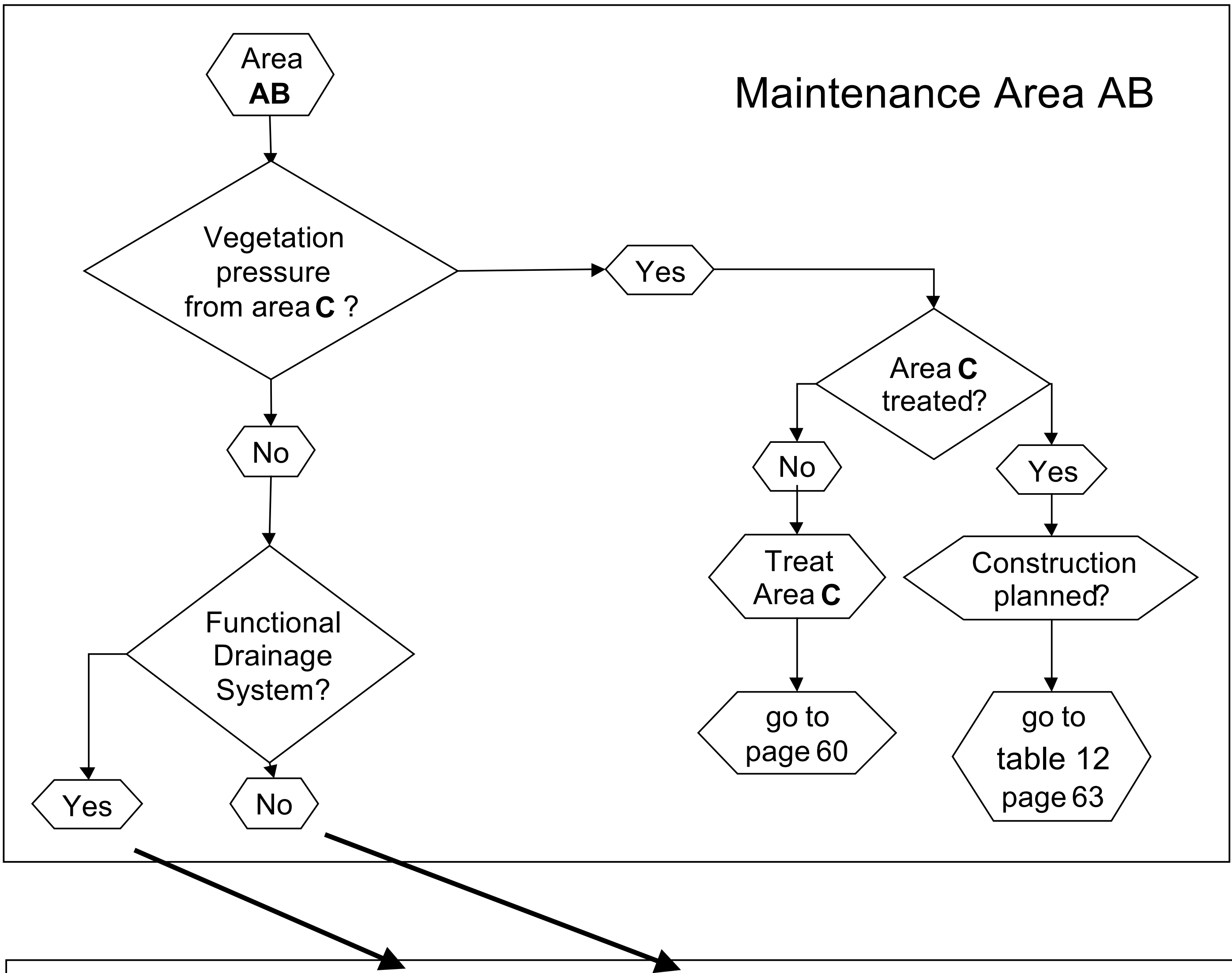
How to use the tree diagram? Once you have started on page 58 with the general diagram, you negotiate various paths and tables as indicated by the relevant “go-to” page details.

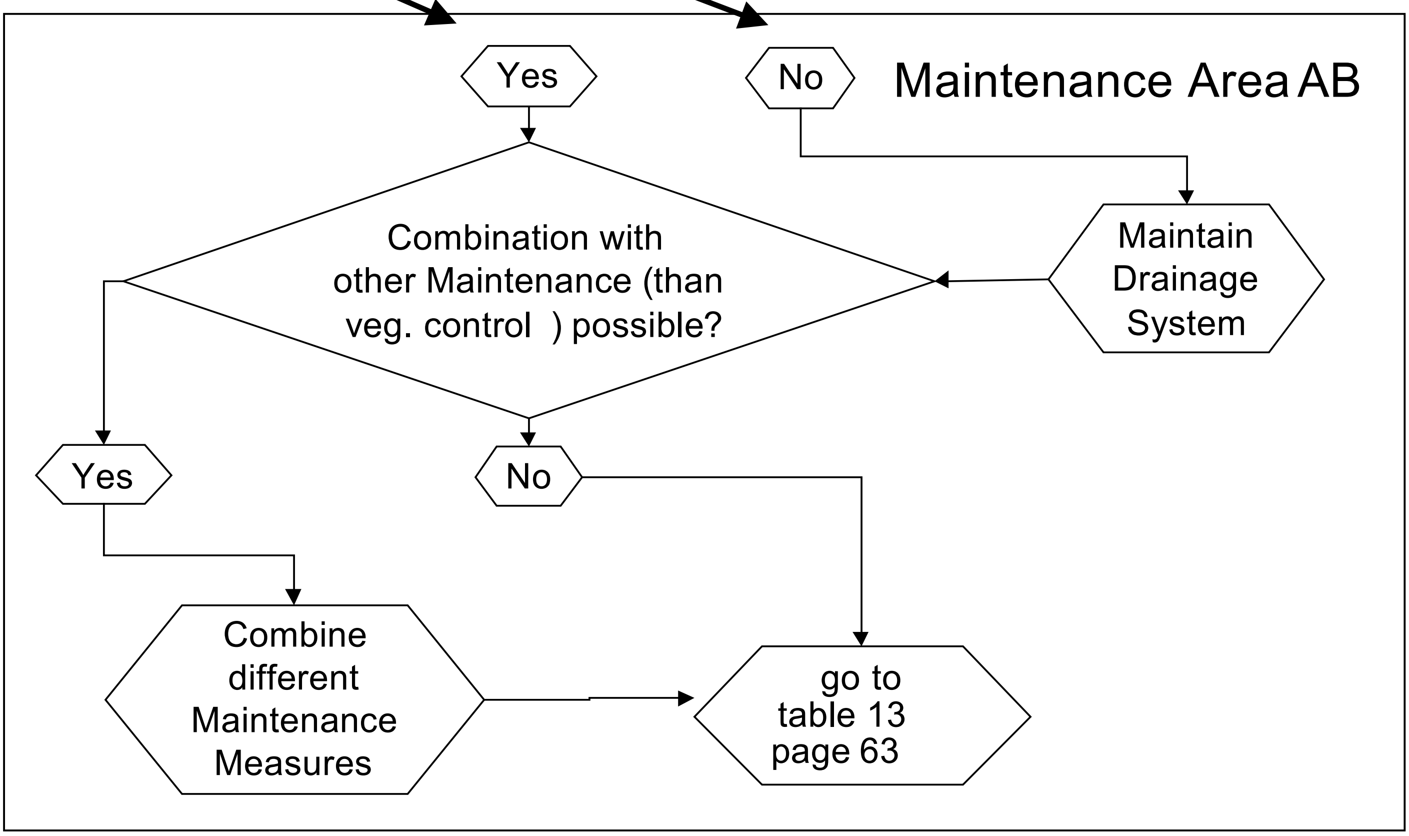
This tree diagram is also available as an electronic version (PowerPoint). Details on each method can be found in the catalogue sheets in Appendix 13.5.

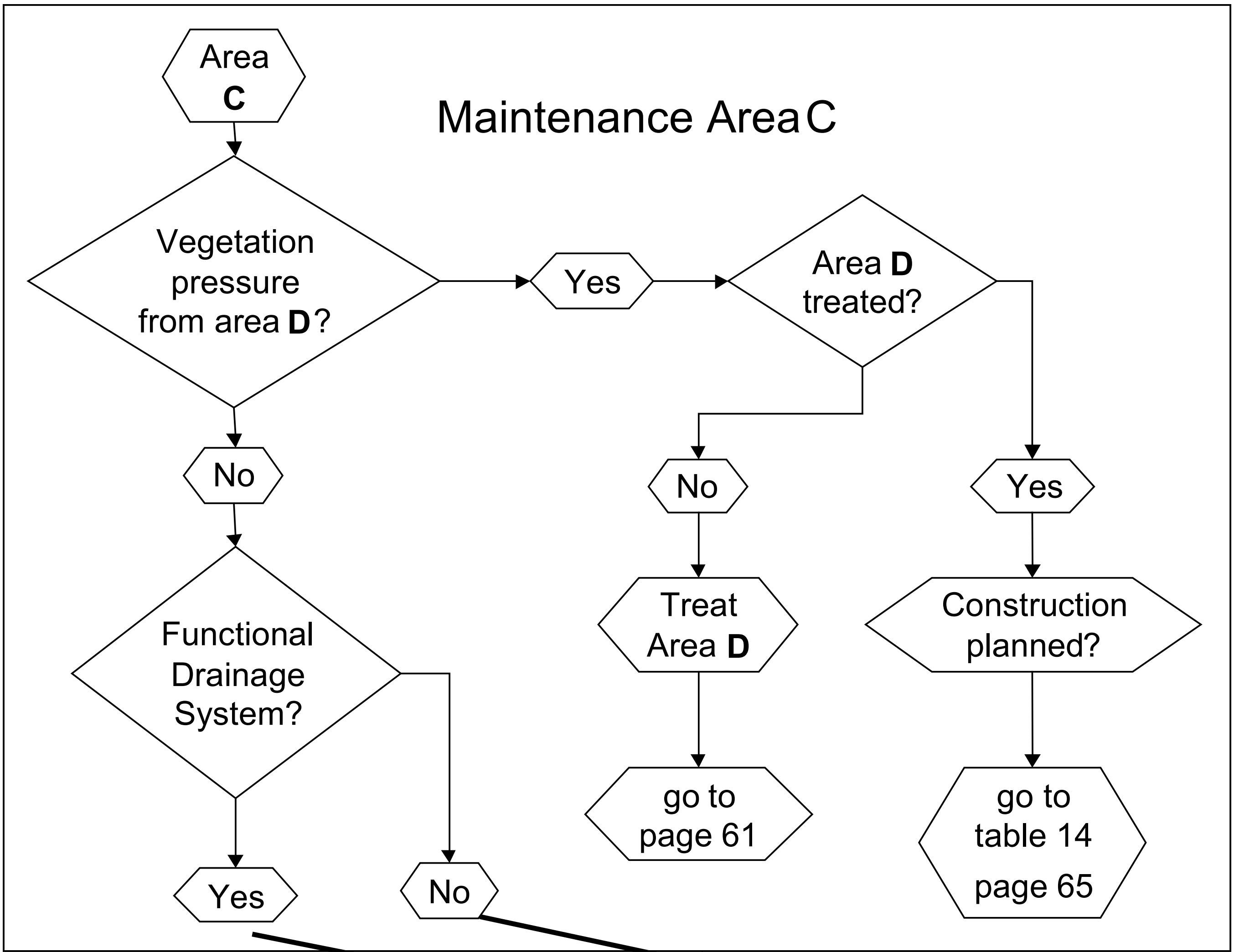
6.4.2 Tree Diagram

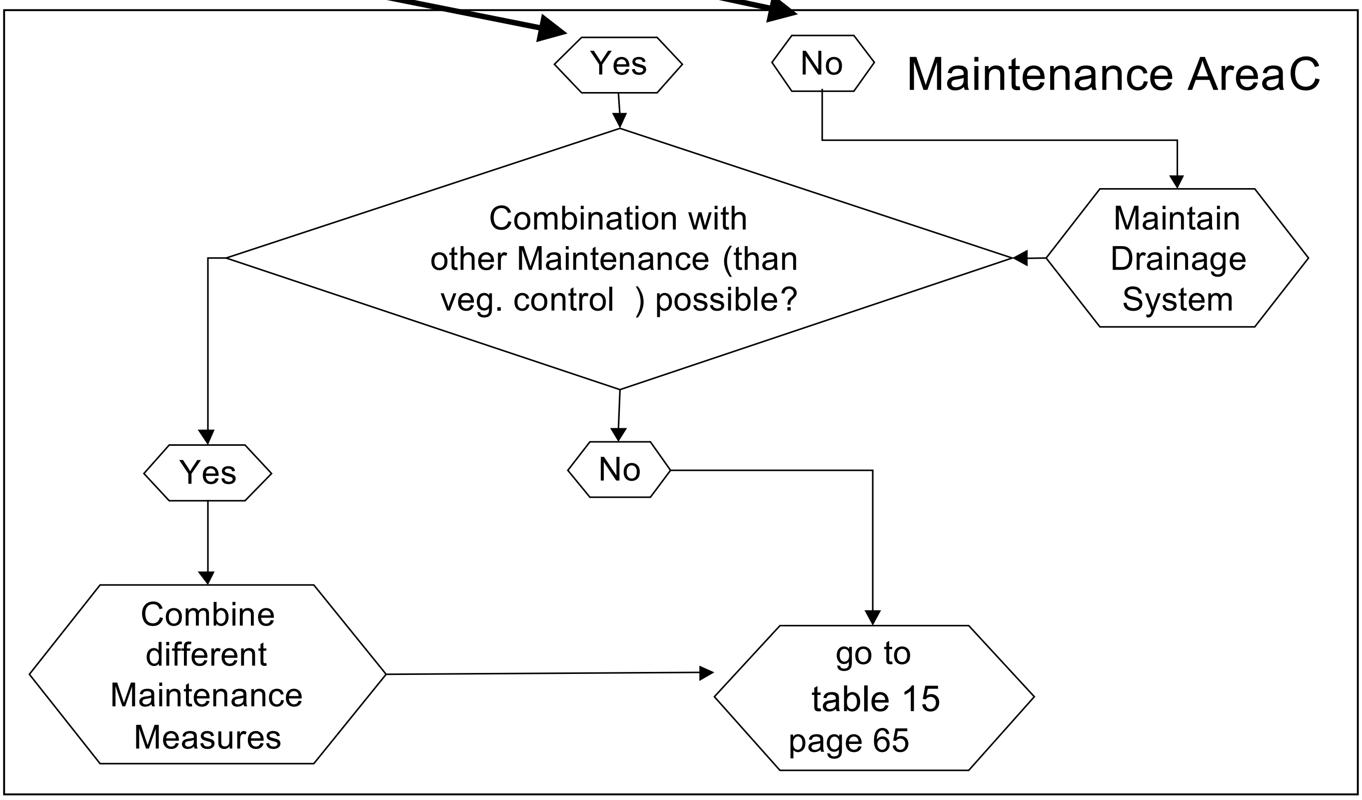


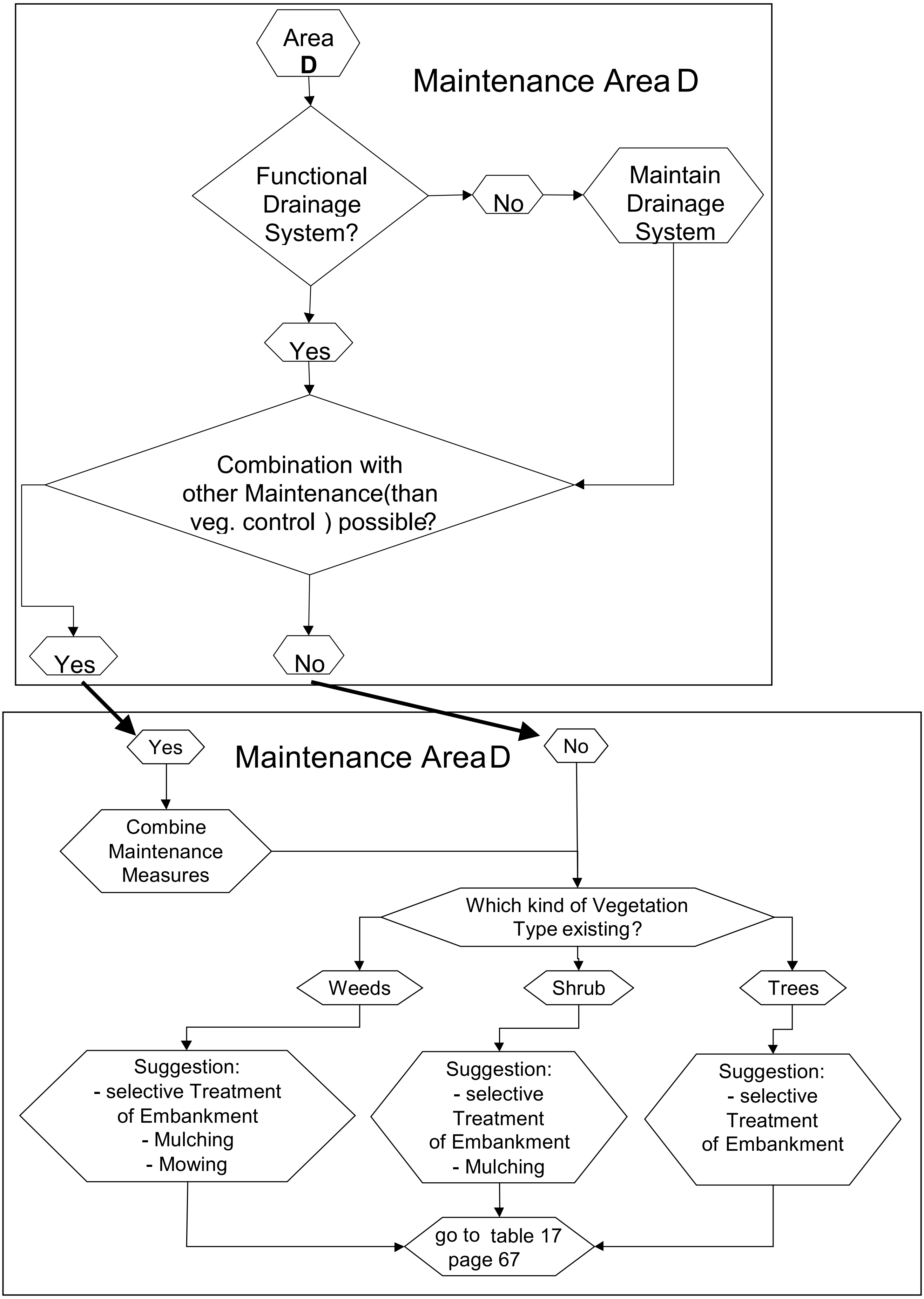

General Scheme
What‘s planned?
Construction
Mainte-nance
Yes
go to table 22 page 72
No Weed Control until next Construc-tion possible?
No
go to
Maintenance
Maintenance
Area A+B
Area C
Area D
Area E
go to page 59
go to page 60
go to page 61
go to page 62

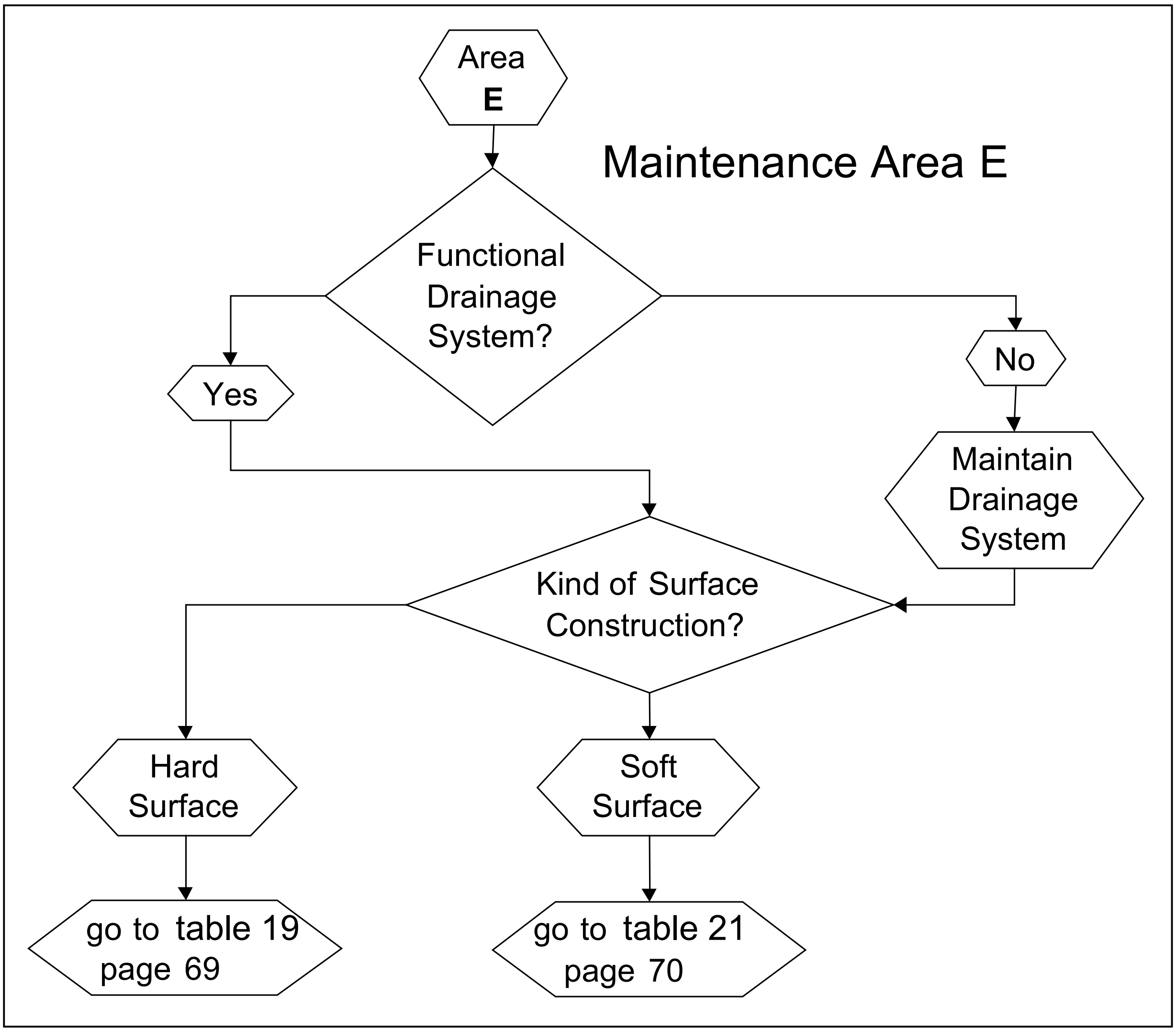

Maintenance Area AB
Area
AB
Vegetation
pressure
from area C ?
Yes
Area C
treated?
No
Yes
Treat
Area C
Construction
planned?
go to
page 60
go to
table 12
page 63
No
Functional
Drainage
System?
Yes
No


Yes
No
Maintenance Area AB
Combination with
other Maintenance (than
veg. control) possible?
Maintain
Drainage
System
Yes
No
Combine
different
Maintenance
Measures
go to
table 13
page 63


Area
C
Maintenance Area C
Vegetation
pressure
from area D?
Yes
Area D
treated?
No
Yes
No
Functional
Drainage
System?
Treat
Area D
Construction
planned?
go to
page 61
go to
table 14
page 65
Yes
No


Yes
No
Maintenance Area C
Combination with
other Maintenance (than
veg. control) possible?
Maintain
Drainage
System
Yes
No
Combine
different
Maintenance
Measures
go to
table 15
page 65


Area D
Maintenance Area D
Functional Drainage System?
No
Maintain Drainage System
Yes
Combination with other Maintenance(than veg. control) possible?
Yes
No
Yes
Maintenance Area D
No
Combine Maintenance Measures
Which kind of Vegetation Type existing?
Weeds
Shrub
Trees
Suggestion: - selective Treatment of Embankment - Mulching - Mowing
Suggestion: - selective Treatment of Embankment - Mulching
Suggestion: - selective Treatment of Embankment
go to table 17 page 67


Area
E
Maintenance Area E
Functional
Drainage
System?
Yes
No
Maintain
Drainage
System
Kind of Surface
Construction?
Hard
Surface
Soft
Surface
go to table 19
page 69
go to table 21
page 70

Measures for Area AB

☺ : Operational use (used regularly by railways, available on the free market)
😐 : Investigation/Study (under investigation, still not deployed for regular maintenance work)
☹ : Not being pursued (already been studied or used, not in use any more for practical reasons (technical, operational, ecological, economic)

Table 12: Constructional methods for Area AB

No.	*Method*	*Applied in Area*	*Combination with Method(s)*	*Effect on Plants*	*Assumption of Costs*	*Duration of Effect / Frequency of Application*	*Environmental Effects*
M5 😐	Amount and kind of ballast material	**A**, **B**	• M11, M12 • M13, M14 • M18 - M22 in Areas A, B, C	Slowly decaying material inhibits plant growth longer. Accumulation of nutrients slower	17.5 €/m^3, 27.5 €/t (BV) only little extra cost	30 to 50 years	no
M6 ☺	Plant barriers beneath the track in general	**A**, **B**, **C**, **E**	• M1 • M11, M12 • M13, M14	Hinders plants from growing up from below, additional benefit for drainage	14,000 €/km – 100,000 €/km	25 to 50 years	no
M7 ☺	Slab track	**A**, **B**	Any method in Area C	Plant barriers beneath the track hinder plants from growing up from below	1.4 to 2 times more expensive than traditional ballasted track (DB AG)	foreseeably up to 60 years	no

Table 13: Maintenance Measures for Area AB

No.	*Method*	*Applied in Area*	*Combination with Method(s)*	*Assumption of Costs*	*Operating Speed*	*Weather Conditions Period of Application*	*Duration of effect Frequency of Application*	*Environmental Effects*
M13 M14 ☺	Ballast cleaning and/or replacement	**A**, **B**, C	M6	5,100 €/km (MAV) – 350,000 €/km (SBB)	Up to 200m/h	Independent of weather	Up to 40 years	None (secondary effects of machines (CO_2,...)
M15 😐	Mechanical weeding	**A**, **B**, **C**	in Area D M11, M12	2,500 €/km (DB AG) – 18,000 €/km (BV) used on both sides of the track	Up to 5km/h 125 m^2/h – 3200m^2/h	Independent of weather, dependent on season		
M16 ☺	Manual weeding	**A**, **B**, **C**, **E**	in Area D M11, M12	315 €/km (BDZ) –4,000 €/km (RIB) used on both sides of the track 0.04 €/m^2 (MAV) – 2 €/m^2 (RIB)	9 m^2/h – 105 m^2/h	Independent of weather, dependent on season	Once a year up to 4 times a year	no
M17 😐	Brushing	**A**, B, **E**	in Area D M11; M12	0.1 €/m^2 (SBB) –0.4 €/m^2 (BV)	1-5km/h, 1,500 – 9,000m^2/h	Independent of weather, dependent on season	One to 4 times a year	None (secondary effects of machines (CO_2,...)

No.	*Method*	*Applied in Area*	*Combination with Method(s)*	*Assumption of Costs*	*Operating Speed*	*Weather Conditions Period of Application*	*Duration of effect Frequency of Application*	*Environmental Effects*
M18 ☺	Back-pack spraying	**A**, **B**, **C**, **D**, **E**	• M1-M6 • in Area D M11, M12	5 €/km (GySEV) – 850 €/km (DB AG) when used on both sides of the track	Up to 5 km/h 150 m^2/h – 4,750 m^2/h	Dependent on season, Dry and not windy during day time, depending on herbicide used	Depending on herbicide used Half a year up to 2 years	Depending on herbicide used, may have an effect on water and living organisms e.g. not for use in groundwater protection zones
M19 ☺	Spraying train	**A**, **B**, **C**, **D**		34 €/km (BS) to 260 €/km (DB AG) 0.01 €/m^2 (SNCF) – 2.5 €/m^2 (GySEV) when used on both sides of the track	Up to more than 40km/h 12,550m^2/h – 400,000 m^2/h	Dependent on season, Dry and not windy during day time, depending on herbicide used	Depending on herbicide used Half a year up to 2 years	
M20 ☺	Herbicide application with rail-road vehicle	**A**, **B**, **C**, D, E		196 €/km (SNCF) to 300 €/km (DB AG) 2 €/m^2 (GySEV) when used on both sides of the track	Up to 40 km/h 10,000m^2/h - 50,000 m^2/h	Dependent on season, Dry and not windy during day time, depending on herbicide used	Depending on herbicide used Half a year up to 2 years	
M21 😐	Selective application of the spraying train (e.g. " weed eye")	**A**, **B**, C, E		260 €/km (DB AG) when used on both sides of the track	Up to > 40km/h Up to 260,000m^2/h	Dependent on season, Dry and not windy during day time, depending on herbicide used	Depending on herbicide used Half a year up to 2 years	
M22 😐	Weed wiping	A, B, D		0.2 €/m^2 (BV)	Up to 10 km/h 8,000 m^2/h – 25,000 m^2/h	?	Depending on herbicide used Half a year up to 2 years	
M23 ☹	Flaming	A, B, D, **E**	• M1-M6 • in Area D M11,M12		6 km/h	Less effect when windy and humid		Very energy consuming
M24 ☹	Infrared devices	**A**, **B**, **E**		7,200 €/km (DB AG) when applied on both sides of the track	2km/h 800m^2 - 10,000m^2/h	Nice weather more effective	5 times a year	
M25 😐	Wet steaming	**A**, **B**, **C**, **E**	in Area D M11, M12	900 €/km (DB AG) – 2,000 €/km (SBB) 0.22 €/m^2 (DB AG) when applied on both sides of the track	1km/h, 3,500m^2/h	Not in rain to ensure safe visibility	Up to 3 – 4 times a year	Very energy and water consuming
M26 ☹	Hot water treatment	**A**, **B**, **C**		0.5 €/m^2 when applied on both sides of the track	Up to 6km realistic Up to 15,000 m^2/h	No rain, lower effect when raining	2 – 3 times a year	

Measures for Area C

☺ : Operational use (used regularly by railways, available on the free market)
😐 : Investigation/Study (under investigation, still not deployed for regular maintenance work)
☹ : Not being pursued (already been studied or used, not in use any more for practical reasons (technical, operational, ecological, economic)

Table 14: Constructional methods for Area C

No.	*Method*	*Applied in Area*	*Combination with Method(s)*	*Effect on Plants*	*Assumption of Costs*	*Duration of Effect / Frequency of Application*	*Environmental Effects*
M1 ☺	Lateral plant barriers/objects impeding plant incursion	**C**, **D**	• M11, M12 • M18 - M22 in Areas A, B, C	Hinders plants from growing into Area C and from there into Areas A and B	35,000€/km (JBV) – 500,000 €/km (SBB)	5 years and more	no
M3 😐	Plant-inhibiting design of the transition area	**C**, **D**	• M11, M12 • M18 - M22 in Areas A, B, C	Hinders plants from growing into Area C and from there into Areas A and B from the side of the surface	15,000 – 20,000 €/km (SBB)	5 years	no
M4 😐	Porous concrete barriers	**C**	M11, M12	Hinders plants from growing into Areas A and B; provides good drainage	100,000 – 200,000 €/km on one side (SBB)	More than 5 years	no
M6 ☺	Plant barriers beneath the track in general	**A**, **B**, **C**, **E**	• M1 • M11, M12 • M13, M14	Hinders plants from growing up from below, additional benefit for drainage	14,000 €/km – 100,000 €/km	25 to 50 years	no

Table 15: Maintenance Measures for Area C

No.	*Method*	*Applied in Area*	*Combination with Method(s)*	*Assumption of Costs*	*Operating Speed*	*Weather Conditions Period of Application*	*Duration of effect Frequency of Application*	*Environmental Effects*
M9 ☺	Selective embankment maintenance	C, **D**	M11	0.3 €/m^2 (SNCB) – 2 €/m^2 (SBB)	1km/h – 40 km/h; up to 3,000 m^2/h	Independent of weather	1 year in vicinity of track, irregularly as needed	No
M11 ☺	Mowing	C, **D**, E	• In Areas A to C M1-M7 • M16 • M18 - M22 • maintain drainage systems	0.15 €/m^2 (DB AG) - 1.2 €/m^2 (JR) when applied on one side of the track	Dependent on machine used: Up to 5 km/h, 0.5m^2/h (JZ) – 4,500m^2/h (QR)	Independent of weather Dependent on season	Every other year up to 4 times a year	None (secondary effects of machines (CO_2,...)

No.	*Method*	*Applied in Area*	*Combination with Method(s)*	*Assumption of Costs*	*Operating Speed*	*Weather Conditions Period of Application*	*Duration of effect Frequency of Application*	*Environmental Effects*
M12 ☺	Mulching	**C**, D	• In Areas A to C M1-M7 • M16 • M18 - M22 • maintain drainage systems	0.15 €/m^2 (DB AG) – 0.5 €/m^2 (MAV, GySEV) on one side of the track	Less than 1km/h – 5km/h 170 m^2/h – 1,000 m^2/h	Independent of weather Dependent on season	Once a year	Effect on small animals
M13 M14 ☺	Ballast cleaning and/or replacement	**A**, **B**, C	M6	5100 €/km (MAV) – 350,000 €/km (SBB)	Up to 200m/h	Independent of weather	Up to 40 years	None (secondary effects of machines (CO_2,...)
M15 😐	Mechanical weeding	**A**, **B**, **C**	in Area D M11, M12	2,500 €/km (DB AG) – 18,000 €/km (BV) used on both sides of the track	Up to 5km/h 125 m^2/h – 3,200m^2/h	Independent of weather Dependent on season		None (secondary effects of machines (CO_2,...)
M16 ☺	Manual weeding	**A**, **B**, **C**, **E**	in Area D M11, M12	315 €/km (BDZ) –4,000 €/km (RIB) used on both sides of the track 0.04 €/m^2 (MAV) – 2 €/m^2 (RIB)	9 m^2/h – 105 m^2/h	Independent of weather Dependent on season	Once a year up to 4 times a year	no
M18 ☺	Back-pack spraying	**A**, **B**, **C**, **D**, **E**	• M1-M6 • in Area D M11, M12	5 €/km (GySEV) – 850 €/km (DB AG) when used on both sides of the track	Up to 5 km/h 150 m^2/h – 4750 m^2/h	Dependent on season Dry and not windy during day time, depending on herbicide used	Depending on herbicide used Half a year up to 2 years	Depending on herbicide used, may have an effect on water and living organisms e.g. not for use in groundwater protection zones
M19 ☺	Spraying train	**A**, **B**, **C**, **D**	• M1-M6 • in Area D M11, M12	34 €/km (BS) to 260 €/km (DB AG) 0.01 €/m^2 (SNCF) – 2.5 €/m^2 (GySEV) when used on both sides of the track	Up to more than 40km/h 12,550m^2/h – 400,000 m^2/h		Depending on herbicide used Half a year up to 2 years	
M20 ☺	Herbicide application with rail-road vehicle	**A**, **B**, **C**, D, E	• M1-M6 • in Area D M11, M12	196 €/km (SNCF) to 300 €/km (DB AG) 2 €/m^2 (GySEV) when used on both sides of the track	Up to 40 km/h 10,000m^2/h - 50,000 m^2/h		Depending on herbicide used Half a year up to 2 years	
M21 😐	Selective application by the spraying train (e.g. " weed eye")	**A**, **B**, C, E	• M1-M6 • in Area D M11, M12	260 €/km (DB AG) when used on both sides of the track	Up to > 40km/h Up to 260,000m^2/h		Depending on herbicide used Half a year up to 2 years	

No.	Method	Applied in Area	Combination with Method(s)	Assumption of Costs	Operating Speed	Weather Conditions Period of Application	Duration of effect Frequency of Application	Environmental Effects
M25 ☹	Wet steaming	**A**, **B**, **C**, **E**	in Area D M11, M12	900 €/km (DB AG) – 2,000 €/km (SBB) 0.22 €/m^2 (DB AG) when applied on both sides of the track	1km/h, 3,500m^2/h	Not in rain to ensure safe visibility	Up to 3 – 4 times a year	Very energy and water consuming
M26 ☹	Hot water treatment	**A**, **B**, **C**		0.5 €/m^2 when applied on both sides of the track	Up to 6km realistic Up to 15,000 m^2/h	No rain, lower effect when raining	2 – 3 times a year	Very energy and water consuming

Measures for Area D

☺ : Operational use (used regularly by railways, available on the free market)

😐 : Investigation/Study (under investigation, still not deployed for regular maintenance work)

☹ : Not being pursued (already been studied or used, not in use any more for practical reasons (technical, operational, ecological, economic)

Table 16: Constructional methods for Area D

No.	Method	Applied in Area	Combination with Method(s)	Effect on Plants	Assumption of Costs	Duration of Effect / Frequency of Application	Environmental Effects
M1 ☺	Lateral plant barriers/objects impeding plant incursion	**C**, **D**	• M11, M12 • M18 - M22 in Areas A, B, C	Hinders plants from growing into Area C and from there into Areas A and B	35,000€/km (JBV) – 500,000 €/km (SBB)	5 years and more	no
M3 😐	Plant-inhibiting design of the transition area	**C**, **D**	• M11, M12 • M18 - M22 in Areas A, B, C	Hinders plants from growing into Area C and from there into Areas A and B from the side of the surface	15,000 – 20,000 €/km (SBB)	5 years	no

Table 17: Maintenance Measures for Area D

No.	Method	Applied in Area	Combination with Method(s)	Assumption of Costs	Operating Speed	Weather Conditions Period of Application	Duration of effect Frequency of Application	Environmental Effects
M8 ☺	Greening (with non in-growing plants)	**D**	• M11 • in Areas A-C M18 - M22	22,000 €/km (SNCF) 1.5 €/m^2 (GySEV, MAV) – 3.5 €/m^2 (SBB)		Not too dry or wet conditions Dependent on season	About 10 years	No
M9 ☺	Selective embankment maintenance	C, **D**	M11	0.3 €/m^2 (SNCB) – 2 €/m^2 (SBB)	1km/h – 40 km/h; up to 3,000 m^2/h	Independent of weather	1 year in vicinity of track, irregularly as needed	No

No.	*Method*	*Applied in Area*	*Combination with Method(s)*	*Assumption of Costs*	*Operating Speed*	*Weather Conditions Period of Application*	*Duration of effect Frequency of Application*	*Environmental Effects*
M11 ☺	Mowing	C, **D**, E	• In Areas A to C M1-M7 • M16 • M18 - M22 • maintain drainage systems	0.15 €/m² (DB AG) - 1.2 €/m² (JR) when applied on one side of the track	Dependent on machine used: Up to 5 km/h, 0.5m²/h (JZ) – 4,500m²/h (QR)	Independent of weather Dependent on season	Every other year up to 4 times a year	None (secondary effects of machines (CO_2,...)
M12 ☺	Mulching	C**, D**	• In Areas A to C M1-M7 • M16 • M18 - M22 • maintain drainage systems	0.15 €/m² (DB AG) – 0.5 €/m² (MAV, GySEV) on one side of the track	Less than 1km/h – 5km/h 170 m²/h – 1,000 m²/h	Independent of weather Dependent on season	Once a year	Effect on small animals
M18 ☺	Back-pack spraying	**A**, **B**, **C**, **D**, **E**	• M1-M6 • in Area D M11, M12	5 €/km (GySEV) – 850 €/km (DB AG) when used on both sides of the track	Up to 5 km/h 150 m²/h – 4750 m²/h	Dependent on season Dry and not windy during day time, depending on herbicide used	Depending on herbicide used Half a year up to 2 years	Depending on herbicide used, may have an effect on water and living organisms e.g. not for use in groundwater protection zones
M19 ☺	Spraying train	**A**, **B**, **C**, **D**, **E**	• M1-M6 • in Area D M11, M12	34 €/km (BS) to 260 €/km (DB AG) 0.01 €/m² (SNCF) – 2.5 €/m² (GySEV) when used on both sides of the track	Up to more than 40km/h 12,550m²/h – 400,000 m²/h		Depending on herbicide used Half a year up to 2 years	
M20 ☺	Herbicide application with rail-road vehicle	**A**, **B**, **C**, D, E	• M1-M6 • in Area D M11, M12	196 €/km (SNCF) to 300 €/km (DB AG) 2 €/m² (GySEV) when used on both sides of the track	Up to 40 km/h 10,000m2/h - 50,000 m2/h		Depending on herbicide used Half a year up to 2 years	
M22 😐	Weed wiping	A, B, D	• M1-M6 • in Area D M11, M12	0.2 €/m² (BV)	Up to 10 km/h 8,000 m²/h – 25,000 m²/h	?	Depending on herbicide used Half a year up to 2 years	
M23 ☹	Flaming	A, B, D, **E**	• M1-M6 • in Area D M11,M12		6 km/h	Less effect when windy and humid		Very energy consuming

Measures for Area E Hard Cover

☺ : Operational use (used regularly by railways, available on the free market)
😐 : Investigation/Study (under investigation, still not deployed for regular maintenance work)
☹ : Not being pursued (already been studied or used, not in use any more for practical reasons (technical, operational, ecological, economic)

Table 18: Constructional methods for Area E, Hard Cover

No.	*Method*	*Applied in Area*	*Combination with Method(s)*	*Effect on Plants*	*Assumption of Costs*	*Duration of Effect / Frequency of Application*	*Environmental Effects*
M6 ☺	Plant barriers beneath the track in general	**A**, **B**, **C**, **E**	• M1 • M11, M12 • M13, M14	Hinders plants from growing up from below, additional benefit for drainage	14,000 €/km – 100,000 €/km	25 to 50 years	no

Table 19: Maintenance Measures for Area E, Hard Cover

No.	*Method*	*Applied in Area*	*Combination with Method(s)*	*Assumption of Costs*	*Operating Speed*	*Weather Conditions Period of Application*	*Duration of effect Frequency of Application*	*Environmental Effects*
M16 ☺	Manual weeding	**A**, **B**, **C**, **E**	in Area D M11, M12	315 €/km (BDZ) –4,000 €/km (RIB) used on both sides of the track 0.04 €/m^2 (MAV) – 2 €/m^2 (RIB)	9 m^2/h – 105 m^2/h	Independent of weather, dependent on season	Once a year up to 4 times a year	no
M17 😐	Brushing	**A**, B, **E**	in Area D M11; M12	0.1 €/m^2 (SBB) –0.4 €/m^2 (BV)	1-5km/h, 1,500 – 9,000m^2/h	Independent of weather, dependent on season	One to 4 times a year	None (secondary effects of machines (CO_2,...)
M18 ☺	Back-pack spraying	**A**, **B**, **C**, **D**, **E**	• M1-M6 • in Area D M11, M12	5 €/km (GySEV) – 850 €/km (DB AG) when used on both sides of the track	Up to 5 km/h 150 m^2/h – 4750 m^2/h	Dependent on season Dry and not windy during day time, depending on herbicide used	Depending on herbicide used Half a year up to 2 years	Depending on herbicide used, may have an effect on water and living organisms e.g. not for use in groundwater protection zones
M20 ☺	Herbicide application with rail-road vehicle	**A**, **B**, **C**, D, E	• M1-M6 • in Area D M11, M12	196 €/km (SNCF) to 300 €/km (DB AG) 2 €/m^2 (GySEV) when used on both sides of the track	Up to 40 km/h 10,000m^2/h - 50,000 m^2/h		Depending on herbicide used Half a year up to 2 years	
M21 😐	Selective application by the spraying train (e.g. " weed eye")	**A**, **B**, C, E	• M1-M6 • in Area D M11, M12	260 €/km (DB AG) when used on both sides of the track	Up to > 40km/h Up to 260,000m^2/h		Depending on herbicide used Half a year up to 2 years	
M23 ☹	Flaming	A, B, D, **E**	• M1-M6 • in Area D M11,M12		6 km/h	Less effect when windy and humid		Very energy consuming

No.	Method	Applied in Area	Combination with Method(s)	Assumption of Costs	Operating Speed	Weather Conditions Period of Application	Duration of effect Frequency of Application	Environmental Effects
M24 ☹	Infrared devices	**A**, **B**, **E**		7,200 €/km (DB AG) when applied on both sides of the track	2km/h 800m^2 - 10,000m^2/h	Nice weather more effective	5 times a year	Very energy consuming
M25 😐	Wet steaming	**A**, **B**, **C**, **E**	in Area D M11, M12	900 €/km (DB AG) – 2,000 €/km (SBB), 0.22 €/m^2 (DB AG) when applied on both sides of the track	1km/h, 3,500m^2/h	Not in rain to ensure safe visibility	Up to 3 – 4 times a year	Very energy and water consuming

Measures for Area E Soft Cover

☺ : Operational use (used regularly by railways, available on the free market)
😐 : Investigation/Study (under investigation, still not deployed for regular maintenance work)
☹ : Not being pursued (already been studied or used, not in use any more for practical reasons (technical, operational, ecological, economic)

Table 20: Constructional methods for Area E, Soft Cover

No.	Method	Applied in Area	Combination with Method(s)	Effect on Plants	Assumption of Costs	Duration of Effect / Frequency of Application	Environmental Effects
M6 ☺	Plant barriers beneath the track in general	**A**, **B**, **C**, **E**	• M1 • M11, M12 • M13, M14	Hinders plants from growing up from below, additional benefit for drainage	14,000 €/km – 100,000 €/km	25 to 50 years	no

Table 21: Maintenance Measures for Area E, Soft Cover

No.	Method	Applied in Area	Combination with Method(s)	Assumption of Costs	Operating Speed	Weather Conditions Period of Application	Duration of effect Frequency of Application	Environmental Effects
M11 ☺	Mowing	C, **D**, E	• In Areas A to C M1-M7 • M16 • M18 - M22 • maintain drainage systems	0.15 €/m^2 (DB AG) - 1.2 €/m^2 (JR) when applied on one side of the track	Dependent on machine used: Up to 5 km/h, 0.5m^2/h (JZ) – 4,500m^2/h (QR)	Independent of weather Dependent on season	Every other year up to 4 times a year	None (secondary effects of machines (CO_2,...)
M16 ☺	Manual weeding	**A**, **B**, **C**, **E**	in Area D M11, M12	315 €/km (BDZ) –4,000 €/km (RIB) used on both sides of the track 0.04 €/m^2 (MAV) – 2 €/m^2 (RIB)	9 m^2/h – 105 m^2/h	Independent of weather, dependent on season	Once a year up to 4 times a year	no

No.	*Method*	*Applied in Area*	*Combination with Method(s)*	*Assumption of Costs*	*Operating Speed*	*Weather Conditions Period of Application*	*Duration of effect Frequency of Application*	*Environmental Effects*
M18 ☺	Back-pack spraying	**A**, **B**, **C**, **D**, **E**	• M1-M6 • in Area D M11, M12	5 €/km (GySEV) – 850 €/km (DB AG) when used on both sides of the track	Up to 5 km/h 150 m^2/h – 4750 m^2/h	Dependent on season Dry and not windy during day time, depending on herbicide used	Depending on herbicide used Half a year up to 2 years	Depending on herbicide used, may have an effect on water and living organisms e.g. not for use in groundwater protection zones
M20 ☺	Herbicide application with rail-road vehicle	**A**, **B**, **C**, D, E	• M1-M6 • in Area D M11, M12	196 €/km (SNCF) to 300 €/km (DB AG) 2 €/m^2 (GySEV) when used on both sides of the track	Up to 40 km/h 10,000m^2/h - 50,000 m^2/h		Depending on herbicide used Half a year up to 2 years	
M23 ☹	Flaming	A, B, D, **E**	• M1-M6 • in Area D M11,M12		6 km/h	Less effect when windy and humid		Very energy consuming
M24 ☹	Infrared devices	**A**, **B**, **E**		7200 €/km (DB AG) when applied on both sides of the track	2km/h 800m^2 - 10,000m^2/h	Nice weather more effective	5 times a year	Very energy consuming
M25 😐	Wet steaming	**A**, **B**, **C**, **E**	in Area D M11, M12	900 €/km (DB AG) – 2,000 €/km (SBB), 0.22 €/m^2 (DB AG) when applied on both sides of the track	1km/h, 3,500m^2/h	Not in rain to ensure safe visibility	Up to 3 – 4 times a year	Very energy and water consuming

6.5 Overview - all known Methods

Table 22: Overview of ConstructionalMethods

☺ : Operational use (used regularly by railways, available on the free market)
😐 : Investigation/Study (under investigation, still not deployed for regular maintenance work)
☹ : Not being pursued (already been studied or used, not in use any more for practical reasons (technical, operational, ecological, economic)

No.	*Method*	*Applied in Area*	*Combination with Method(s)*	*Effect on Plants*	*Assumption of Costs*	*Duration of Effect / Frequency of Application*	*Environmental Effects*
M1 ☺	Lateral plant barriers/objects impeding plant incursion	**C**, **D**	• M11, M12 • M18 - M22 in Areas A, B, C	Hinders plants from growing into Area C and from there into Areas A and B	35,000€/km (JBV) – 500,000 €/km (SBB)	5 years and more	no
M3 😐	Plant-inhibiting design of the transition area	**C**, **D**	• M11, M12 • M18 - M22 in Areas A, B, C	Hinders plants from growing into Area C and from there into Areas A and B from the side of the surface	15,000 – 20,000 €/km (SBB)	5 years	no
M4 😐	Porous concrete barriers	**C**	M11, M12	Hinders plants from growing into Areas A and B; provides good drainage	100,000 – 200,000 €/km on one side (SBB)	More than 5 years	no
M5 😐	Amount and kind of ballast material	**A**, **B**	• M11, M12 • M13, M14 • M18 - M22 in Areas A, B, C	Slowly decaying material inhibits plant growth longer. Accumulation of nutrients slower	17.5 €/m^3, 27.5 €/t (BV) only little extra costs	30 to 50 years	no
M6 ☺	Plant barriers beneath the track in general	**A**, **B**, **C**, **E**	• M1 • M11, M12 • M13, M14	Hinders plants from growing up from below, additional benefit for drainage	14,000 €/km – 100,000 €/km	25 to 50 years	no
M7 ☺	Slab track	**A**, **B**	Any method in Area C	plant barriers beneath the track hinder plants from growing up from below	1.4 to 2 times more expensive than traditional ballast construction than ballasted track (DB AG)	foreseeably up to 60 years	no

Table 23: Overview of Maintenance Methods

☺ : Operational use (used regularly by railways, available on the free market)
😐 : Investigation/Study (under investigation, still not deployed for regular maintenance work)
☹ : Not being pursued (already been studied or used, not in use any more for practical reasons (technical, operational, ecological, economic)

No.	*Method*	*Applied in Area*	*Combination with Method(s)*	*Assumption of Costs*	*Operating Speed*	*Weather Conditions Period of Application*	*Duration of effect Frequency of Application*	*Environmental Effects*
M8 ☺	Greening (with non in-growing plants)	**D**	• M11 • in Areas A-C M18 - M22	22,000 €/km (SNCF) 1.5 €/m^2 (GySEV, MAV) – 3.5 €/m^2 (SBB)		Not too dry or wet conditions Dependent on season	About 10 years	None
M9 ☺	Selective embankment maintenance	C, **D**	M11	0.3 €/m^2 (SNCB) – 2 €/m^2 (SBB)	1km/h – 40 km/h; up to 3,000 m^2/h	Independent of weather	1 year in vicinity of track, irregularly as needed	None
M11 ☺	Mowing	C, **D**, E	• In Areas A to C M1-M7 • M16 • M18 - M22 • maintain drainage systems	0.15 €/m^2 (DB AG) - 1.2 €/m^2 (JR) when applied on one side of the track	Dependent on machine used: Up to 5 km/h, 0.5m^2/h (JZ) – 4,500m^2/h (QR)	Independent of weather Dependent on season	Every other year up to 4 times a year	None (secondary effects of machines (CO_2,...)
M12 ☺	Mulching	**C**, D	• In Areas A to C M1-M7 • M16 • M18 - M22 • maintain drainage systems	0.15 €/m^2 (DB AG) – 0.5 €/m^2 (MAV, GySEV) on one side of the track	Less than 1km/h – 5km/h 170 m^2/h – 1,000 m^2/h	Independent of weather Dependent on season	Once a year	Effect on small animals
M13 M14 ☺	Ballast cleaning and/or replacement	**A**, **B**, C	M6	5,100 €/km (MAV) – 350,000 €/km (SBB)	Up to 200m/h	Independent of weather	Up to 40 years	None (secondary effects of machines (CO_2,...)
M15 😐	Mechanical weeding	**A**, **B**, **C**	in Area D M11, M12	2,500 €/km (DB AG) – 18,000 €/km (BV) used on both sides of the track	Up to 5km/h 125 m^2/h – 3,200m^2/h	Independent of weather Dependent on season		None (secondary effects of machines (CO_2,...)

No.	*Method*	*Applied in Area*	*Combination with Method(s)*	*Assumption of Costs*	*Operating Speed*	*Weather Conditions Period of Application*	*Duration of effect Frequency of Application*	*Environmental Effects*
M16 ☺	Manual weeding	**A**, **B**, **C**, **E**	in Area D M11, M12	315 €/km (BDZ) –4,000 €/km (RIB) used on both sides of the track 0.04 €/m^2 (MAV) – 2 €/m^2 (RIB)=	9 m^2/h – 105 m^2/h	Independent of weather Dependent on season	Once a year up to 4 times a year	no
M17 😐	Brushing	**A**, B, **E**	in Area D M11; M12	0.1 €/m^2 (SBB) –0.4 €/m^2 (BV)	1-5km/h, 1,500 – 9,000m^2/h	Independent of weather Dependent on season	One to 4 times a year	None (secondary effects of machines (CO_2,...)
M18 ☺	Back-pack spraying	**A**, **B**, **C**, **D**, **E**	• M1-M6 • in Area D M11, M12	5 €/km (GySEV) – 850 €/km (DB AG) when used on both sides of the track	Up to 5 km/h 150 m^2/h – 4,750 m^2/h	Dependent on season Dry and not windy during day time, depending on herbicide used	Depending on herbicide used Half a year up to 2 years	Depending on herbicide used, may have an effect on water and living organisms e.g. not for use in groundwater protection zones
M19 ☺	Spraying train	**A**, **B**, **C**, **D**, **E**	• M1-M6 • in Area D M11, M12	34 €/km (BS) to 260 €/km (DB AG) 0.01 €/m^2 (SNCF) – 2.5 €/m^2 (GySEV) when used on both sides of the track	Up to more than 40km/h 12,550m^2/h – 400,000 m^2/h		Depending on herbicide used Half a year up to 2 years	
M20 ☺	Herbicide application with rail-road vehicle	**A**, **B**, **C**, D, E	• M1-M6 • in Area D M11, M12	196 €/km (SNCF) to 300 €/km (DB AG) 2 €/m^2 (GySEV) when used on both sides of the track	Up to 40 km/h 10,000m2/h - 50,000 m2/h		Depending on herbicide used Half a year up to 2 years	
M21 😐	Selective application by the spraying train (e.g. “ weed eye”)	**A**, **B**, C, E	• M1-M6 • in Area D M11, M12	260 €/km (DB AG) when used on both sides of the track	Up to > 40km/h Up to 260,000m^2/h		Depending on herbicide used Half a year up to 2 years	
M22 😐	Weed wiping	A, B, D	• M1-M6 • in Area D M11, M12	0.2 €/m^2 (BV)	Up to 10 km/h 8,000 m^2/h – 25,000 m^2/h		Depending on herbicide used Half a year up to 2 years	
M23 ☹	Flaming	A, B, D, **E**	• M1-M6 • in Area D M11,M12		6 km/h	Less effect when windy and humid		Very energy consuming
M24 ☹	Infrared devices	**A**, **B**, **E**		7200 €/km (DB AG) when applied on both sides of the track	2km/h 800m^2 - 10,000m^2/h	Nice weather more effective	5 times a year	Very energy consuming
M25 😐	Wet steaming	**A**, **B**, **C**, **E**	in Area D M11, M12	900 €/km (DB AG) – 2,000 €/km (SBB) 0.22 €/m^2 (DB AG) when applied on both sides of the track	1km/h, 3,500m^2/h	Not in rain to ensure safe visibility	Up to 3 – 4 times a year	Very energy and water consuming

No.	*Method*	*Applied in Area*	*Combination with Method(s)*	*Assumption of Costs*	*Operating Speed*	*Weather Conditions Period of Application*	*Duration of effect Frequency of Application*	*Environmental Effects*
M26 ☹	Hot water treatment	**A**, **B**, **C**		0.5 €/m^2 when applied on both sides of the track	Up to 6km realistic Up to 15,000 m^2/h	No rain, lower effect when raining	2 – 3 times a year	Very energy and water consuming
M27 ☹	Hot air		No satisfactory effect on plants or problems with application for railways, tested in experiments		0.6 to 0.7 km/h			
M28 ☹	Freezing							Energy demanding
M29 ☹	Direct electrical contact					Dry weather		Effects on human health
M30 ☹	Microwaves	A, B, C			< 1km/h			Very energy demanding
M31 ☹	Laser							
M32 ☹	UV light							
M33 ☹	Greening with allelopathic plants	D						
M34 ☹	Hot foam	E						

6.6 Synergy effects and recommended combinations

Every method has a variety of combination options, the most general of which are set out in Subsection 6.3. The most common, reasonable and effective combinations cited in questionnaires [114] are shown to be as follows.

- **Mowing/mulching combined with the use of herbicides along the track:** Regular mowing/mulching on the embankment (Area D) near the transition area (Area C) prevents maturation of plant seeds and fewer seeds fall into the track area. Fewer plants along the track means reduced amounts of herbicides. Mowing before the development of seeds has the best effect. Regular mowing also prevents the growth of plants with shoot runners such as brambles.
- **Mowing/mulching combined with constructional methods along the track or in the transition area:** Regular mowing/mulching on the embankment (Area D) near the transition area (Area C) prevents plants flowering and leads to reduced seeds input in the track area, whilst constructional methods hinder the germination of seeds. Mowing/mulching is needed before the development of seeds is completed. The growth of plants with shoot runners is also prevented by regular mowing/mulching.
- **Mowing/mulching combined with manual weeding along the track:** the same reasons as above.
- **Constructional methods (e. g. lateral plant barriers) combined with the use of herbicides along the track:** lateral plant barriers hinder plants from growing into the track from the side. They help to protect the track against in-growing plants, but not against plants dispersed by seeds. To combat those plants herbicides are used.
- **Combination of barriers beneath the track and ballast cleaning/replacement:** It is useful to clean/replace the ballast when constructing barriers beneath the track, since such barriers are targeted at preventing the in-growing of plants from the sub-ground but are not a sufficient means of tackling plants dispersed by seeds. For an environment that is truly hostile to plant growth, the ballast should be clean (for reasoning, see also Part A).
- **Regular maintenance of drainage systems combined with mowing/mulching**: An efficiently functioning drainage system promotes dry conditions locally. These are reinforced by an absence of trees and shrubs in the area close to the track, brought about by regular mowing/mulching activities.

7 Details of the Various Vegetation Control Methods

The various vegetation control methods can be divided into five categories as set out in Figure 9 on page 52 and Table 8 on page 53. Each category is explained below. An overview of the various methods is given on page 64, while the details of specific methods can be found in Appendix 13.5.

7.1 Constructional Methods

Constructional methods are *designed to reduce the amount of water present* in the track area. They have been shown to have the best preventive effect against plantgrowth [101]. At the same time they can also *protect* the track area against *lateral plant incursions* as well as *plant incursions from sub-track layers*. Such methods can be used when building or relaying track. They can be applied beneath the track or in the transition area (Area C).

However, owing to the costliness of such methods and the disruption to operations they entail, it is always useful to factor vegetation control aspects in when planning other engineering works for operational reasons [101] (see also tree diagram “Constructionplanned” and “Combination with maintenance [other than vegetation control] possible”). In this context it might be useful to combine more than one engineering task. For example: whilst cleaning or replacing ballast, the pathway/walkway (transition area, Area C) could be renewed too.

Constructional methods can be divided into two sub-categories:

(a) Lateral plant barriers/objects impeding plant incursion

These barriers hinder plants (e. g. brambles [*Rubus sp.*]) from growing into the track from the side (e. g. transition area [Area C]).

Examples: *suitably positioned cable troughs, plant-inhibiting design of the transition area, porous concrete barriers*

(b) Plant barriers beneath the track:

These barriers hinder plants from growing up from sub-soil layers into the track area. As an additional benefit, these barriers promote good drainage of the track.

Examples: *sheets placed beneath the transition area, slab track construction*

7.2 Biological Methods

Biological methods treat plants without removing them totally. They include the sowing or planting of non-interfering species, selective embankment maintenance and regular mowing, mulching or grazing. Biological measures are used by most railways to manage and control the embankment, while a few companies treat the transition band in the same manner as well. Hence, only plants that do not interfere with railway operations and maintenance can grow in these areas. All of these works require adequately trained specialists to be effective [101].

7.3 Mechanical Methods

Mechanical methods remove unwanted plants from the track area. Thus, these measures are of the sort that attack the symptoms [101].

Two of the methods described (replacing and cleaning ballast) are mainly used to clean the ballast to guarantee track stability, while having a positive side-effect for vegetation control as well. Thus, when using these two methods the concerns of vegetation control should be taken into consideration too. These two methods act to remove dirt and therefore they are preventive methods from the point of view of vegetation control.

Mechanical methods, which mostly remove the overground parts of plants only, have the following disadvantages in terms of their efficiency:

- insufficient removal of plant roots, plants “removed” can therefore grow again quickly
- the development of seeds can be promoted

Because of these reasons, mechanical methods should be used in combination with other methods (for combination see Subsection 6.3).

7.4 Chemical Methods

Chemical methods are used to eliminate unwanted vegetation. These methods have two constituents: the herbicide used and the application technique, the method itself.

7.4.1 Use of Herbicides

Herbicides are a sub-category of pesticides. They act to damage the bio-chemical systems of plants. They fall into several groups such as selective or totally effective herbicides, mobile or immobile herbicides, as well as different substance groups. A further common form of differentiation involves separation into leaf and soil herbicides with reference to the uptake path of such substances:

- **leaf herbicides** need at least a certain biomass to be taken up by plant leaves. After application of leaf herbicides the “dead plant” remains in the track area and will be destroyed by the common process of biological degradation.
- **soil herbicides** are taken up by the roots of plants and seedlings. These herbicides are longer lasting and remain unchanged in the soil for a longer period than leaf herbicides. They have a preventive component due to the fact that they stop the production of biomass at an early growing stage (seedling) and hence, unlike leaf herbicides, avoid any input of organic material into the track [96].

In this report and during the survey, attention focused on methods (i.e. not on the actual herbicide but on how it is applied), because each country has its own regulations for the authorisation and use of herbicides by railway companies. Thus, no detailed information on the various herbicides, their advantages or disadvantages is given. Table 24 only provides a short overview of the substances used by different railway companies, without any attempt at rating them.

Table 24: Overview of herbicides used by various railway companies 1998 [66]. (*) Some herbicides are mainly used to combat problem plants

Active substance	*Railway company using the herbicide*
2, 4 D	SNCB
Amitrol	RENFE; SNCB, SNCF
Clopyralid	SNCB
Dichlobenil	MAV, SNCB, FS (1998 [34])
Dimefuron	DB AG
Diuron	GySEV, MAV, RENFE, SNCB, SNCF, FS (1998 [34]), (*) RT [92]
Ethidimuron	SNCF
Fluoxypyr	SNCB, (*) JBV [114]
Glyphosate	BV [19], CD, CFL, CFR, DB AG, DNRA, FS, Kyushu Japan, LG, MAV, RENFE, SBB [100], SCNB, SNCF, FS (1998 [34]), BS [114]
Gluphosinat	(*) SZ [114]
Hexazianone	RENFE
Imazapyr	BV, CD, CFR, JBV, GySEV, LG, RENFE, (*) RT [92]
Linuron	MAV
MCPA	MAV, SNCB, (*) JBV [114]
Oxadiazon	RENFE
Picloram	RENFE, (*) RT [92]
Simazine	MAV, RENFE
Sulfosate	CD, RENFE
Sulfonyle urea (flazasulfurone)	(*) SNCB [109]
Tryclopyr	MAV, SNCB, (*) RT [92]

7.4.1.1 Evaluation of chemical methods

Evaluation of chemical methods embraces both the herbicide in use (since the effect or condition of application depend on the herbicide used) and its application (e.g. amount of herbicide applied).

The use of herbicides may lead to negative impacts on nature and the environment. Thus the relevant operatives must be experts and act responsibly when using herbicides. These are the reasons why the use of herbicides is governed by special instructions in most countries [98, 101]. Evaluation and registration of the various herbicides is simultaneously a political issue, since the legislation factor is decisive for the acceptance of a chemical method.

Besides this, the chemical industry is asked to develop herbicides meeting the requirements of railway companies and specific legislation in a given country. A proposal by SNCB [109] argues that an ideal herbicide should:

- comply with environmental legislation
- combat problem plants in a preventive way (germination-inhibitor herbicide preferred)
- have a wide effective range: it should be effective for six to nine months but not have a cumulative effect or be persistent
- have low mobility in soil and be only slightly water-soluble so it cannot be washed out of the soil
- be capable of application virtually regardless of weather conditions

- have low global costs (product + packing + application)
- be a liquid herbicide (because of devices used)
- not be dangerous to persons (classification as non-dangerous)

Unfortunately this miraculous product does not exist, because there are some conflicting aspects named, e.g. duration of effect and non-persistence. In addition, the likelihood of the chemical industry developing a special-purpose herbicide exactly in line with railway requirements is very low given the modest consumption of herbicides by railways in comparison with agriculture. Furthermore, an overall decline in product numbers can be discerned due to the demands for registration of herbicides in respect of the higher quality level designed to protect the environment [109].

7.4.1.2 Application techniques for herbicides

Herbicides can be applied using various devices. These measures are described in the catalogue sheets (see Appendix 13.5). Nowadays there is the tendency to apply as little herbicides as possible. Several methods have been devised for this purpose: back-pack spraying or using a sensor-system for selective application are two examples. These systems make sure that only areas where plants are present are treated.

Operating conditions for the application of herbicides (e.g. weather, period and frequency of application) and effect on plants (duration of effects, treatable/untreatable plants, problem plants, plant age/growth stage) depend on the herbicide used and, as mentioned above, are not focused upon here [50, 98].

7.4.1.3 Further studies on chemical vegetation control

No distinction was made between herbicides used and methods applied for the purposes of the survey. The various chemical methods should therefore be compared very carefully, especially regarding effects arising from the method itself rather than from the substance used! A comparative study of the various chemical methods with the same herbicide under comparable conditions was not made and is recommended for further investigation.

7.5 Thermal/electrical Methods

Electrical or thermal methods destroy unwanted vegetation by acting electrically or thermally (high or low temperatures) on plant cells.

7.5.1 Thermal Methods

Thermal methods have the following effects on plants [61]:

- destroy proteins at temperatures higher than 42°C.
- cells expand and burst due to rapid rise in temperature.
- the skin of leaves changes or even peels off.

The main problem with thermal methods is the loss of energy when transmitting the heat to the plants. This can arise in the apparatus itself (poorly insulated tubes) or at the point of application, i.e. soil surface, ballast bed or transition area [61].

7.5.1.1 Evaluation of thermal methods

As things stand, the following conclusions can be drawn for thermal methods [61]:

- Unsatisfactory effect of thermal methods on woody plant species.
- Roots are not destroyed as a rule and new shoots can grow after a short time, plant growth is merely delayed [72, 114].
- Hence short-term effects in general, which leads to frequent application (several times a year).
- Only satisfactory if optimal application time is used [26, 46, 47], therefore not flexible in use.
- Risk of creating undesired plant-species composition by selection if this method is applied very frequently in isolation. Root growing species in particular can regenerate more quickly and become established.
- Very bad energy efficiency (a high amount of energy is invested for little effect compared to other methods) [42, 72, 76, 114].
- High cost [61, 114] of buying and maintaining the machinery used.
- For some methods, stringent provisions in respect of workers' safety have to be complied with alongside railway-related requirements.
- High production of CO_2 when using the method [26].
- Risk of fire from using infra-red devices [76, 114].
- Thermal methods are rather slow. If the operating speed is raised without changing the design, their effectiveness decreases [61].

7.5.2 Electrical Methods

Subjecting plants to an electrical current causes water in the plant cells to be heated up from inside, which in turn causes the cells to burst.

7.5.2.1 Evaluation of electrical methods

Research to date allows the following conclusions for electrical methods to be drawn [61]:

- Stringent demands on safety have to be followed [61]. Safety can be divided into safety for staff and the safe operation of trains [75].
- Electrical methods are very slow.
- An electrical current always takes the course of least resistance. This leads to the method malfunctioning at times (small fires were observed in dry grasses) [72].

8 Problem Plants

8.1 Definition

Problem plants are plants that have to be treated by adopting a special strategy.

8.2 Cause of Problem Plants

The emergence of *problem plants* has various reasons:

- **Vegetation control methods may stimulate the abundance of a certain plant species**. The method eliminates all plant species present with the exception of very few or even just one species that do not respond to the method applied. As a consequence of lower competition, the surviving plant species has/have more favourable conditions and can grow more easily. *For example: horsetail (Equisetum sp.) cannot be eliminated using the herbicide Glyphosate. Since Glyphosate kills nearly every other plant species present, horsetail has less competition in that area and can therefore propagate more easily. The result after several years of treatment with Glyphosate in isolation in a certain area is a floor covered with horsetail. (see also Table 25)*
- Some problem plants cannot be combated with the methods usually applied, because they are imported plants with a habit of spreading quickly (so-called **invasive neophytes**, e. g. Japanese knotweed [*Reynnoutria* japonica]). Some of these plants may cause safety problems (giant hogweed [*Heracleum mantegazzianum*], for instance, causes health problems for working staff) or else problems for train operations (see also Table 26: Reasons for combating).
- **neglecting maintenance of embankments and drainage** can stimulate the growth of various plants including problem plants. Thus, it is important to view all track areas as one interacting system. Forms of treatment have to be adapted to the plants occurring (see also Part A).

Whether a plant is a problem plant or not also depends on where it appears in the track area (from the ballast bed [Area A] to the embankment [Area D] or away from the track area [Area E]). Some plants are tolerated or even welcomed in one area - the embankment (Area D), for instance - whilst the same species might cause problems in another area such as the ballast shoulder (Area B), the latter determining that they are problem plants.

On the other hand there are “non-treatable plants”. This means plants that are not covered by the method applied; lateral plant barriers, for instance, are not effective against seed-dispersing plants but only against plants growing in from the side.

An overview of the reasoning for problem plants can be found in Table 25.

Table 25: Effectiveness of individual vegetation control methods for various plant types

Plant category	Lateral plant barriers	Plant barriers beneath the track	Mowing/ mulching/ grazing	Cleaning/ replacement of ballast	Manual/ mechanical weeding	Chemical methods	Thermal methods
Seed plants	o	o	o	x	x	x[1)]	x
Plants with shoot runners	x	o	x	o	x	x[1)]	o
Plants with sub-ground shoot runners/root runners	o	o	o	x	<	x[1)]	<

x = effective
o = more or less effective
< = less effective
[1)] Effect depends on kind of herbicide

Table 26: Reasons for combating problem plants

Invasive neophytes	***Reason for combating them***
Giant hogweed *(Heracleum mantegazzianum)*	Causes skin irritation, rashes and blistering [52, 92] Nature conservation: displacement of native plants [92]
Japanese knotweed *(Reynnoutria japonica)*	Increasingly colonises embankment, danger of erosion during winter-time because of lack of other vegetation (SNCB [109]) Nature conservation: displacement of native plants [92]
Golden rod *(Solidago canadensis)*	Nature conservation: displacement of native plants
Narrow-leaved ragwort *(Senecio inaequidens)*	Nature conservation: displacement of native plants [92]
Himalayan balsam *(Impatiens glandulifera)*	Nature conservation: displacement of native plants [92]
Other plants	***Reason for combating them***
Common ragwort *(Senecio jacobaea)*	Dangerous to livestock (plant poisoning) [92]
Thistle (*Cirsium arvense*)	Has to be treated by law (dangerous for agriculture, loss of yield) [92]
Broad-leaved dock (*Rumex obtusifolius)*	Has to be treated by law (dangerous for agriculture, loss of yield) [92]

8.3 Methods/strategies for combating problem plants

The best strategy for combating problem plants is to prevent them growing. Thus, the colonisation strategies of plants have to be known, and these are described in Part A.

Most of the plants found in the track area spread by seeds. Many of them are perennials and difficult to control from the second year onwards (e. g. thistle [*Cirsium arvense*]). For this reason alone, measures that avoid plant growth (e. g. minimise their supplies of water and nutrients) should be given particular consideration [101]. Problem plants cannot be combated with one single method alone. A combination of different methods is needed (strategy).

As Railtrack recommends [92]: Non-chemical methods should always be considered as the first choice. Only if non-chemical control measures have been evaluated and proved to be impracticable, should chemical methods be considered. Non-chemical vegetation control methods are recommended for small infestations, chemical ones for large infestations. Once an area is free of invasive plants, wanted species (slow growing, native plant species) should be planted to reduce the risk of re-colonisation [92].

Methods/strategies against problem plants used by and familiar to different railway companies are given in Table 27. They are listed without any attempt at evaluation. For practical purposes, some railways (e. g. RT, DB AG, SBB) have been/will be putting together information leaflets on problem plants. Especially when planning to treat invasive neophytes, co-ordination with nature conservation groups and their strategies is necessary.

Table 27: Short overview of problem plants and possible forms of treating them

Plant species	Latin name	Area	Non-chemical treatment	Chemical treatment
Reeds	*Phragmites sp.*	A,B	Good drainage (constructional methods) (SBB [10])	Use of various herbicides [114]: Repetitive use of MCPA or Triclopyr (SNCB [109])
		C	Regular mowing in June/July (SBB [10, 98]) complete removal through structural remediation (drainage) (SBB) lateral plant barriers (SBB)	use of various herbicides [114]: - use of Glyphosate after mowing (SBB) - repetitive use of MCPA or Triclopyr (SNCB [109]
		D	regular mowing (RIB [114]) in June/July (SBB [98])	use of various herbicides [114]: repetitive use of MCPA or Triclopyr (SNCB [109])
		E	preventive methods (drainage, dense grass cover, structures) [2] regular mowing (twice a year only weakens but does not suppress reeds [2]	chemical treatment for joints and gullies most effective [2]
		No effective method against reeds known (JBV, SNCB) [114]		

Plant species	Latin name	Area	Non-chemical treatment	Chemical treatment
Brambles	*Rubus sp.*	A,B		Use of various herbicides [114]
		C	mowing (RIB [2, 114], SNCB [109]) before august up to 3 times a year (SBB [98]) or once in autumn (SBB [10])	After mowing treatment with Glyphosate in autumn (SBB [2]) sow grass in the following growing season [2] Use of various herbicides [114]
		D	mowing (RIB [114], SNCB) before august (SBB [98])	Use of various herbicides [114] After mowing treatment with Glyphosate in autumn (SBB [2]) sow grass in the following growing season [2]
		No effective method against brambles known (SNCB) [114]		
Herb Robert	*Geranium robertianum*[3]	A,B	manual weeding in spring (but is time consuming) (SBB [10])	use of Glyphosate in spring before development of seeds, second treatment in autumn recommended (SBB [98])
		C, D	No problem plant in these areas	
		No effective method against cranesbill known (RIB) [114]		
Horsetail	*Equisetum sp.)*	A,B	ballast cleaning (SBB) manual weeding several times a year (SBB) structural remediation (deep drainage and asphalt layers) (SBB) avoid soil-moisture and raw soils (SBB [10])	use of the following among other herbicides/substances: - Imazapyr (BV [114]) - Glufosinat (SZ [114]) - Imazapyr (BV [115], RENFE, BV) - Tryclopyr (SNCB) Avoid Glyphosate (SBB)
		C	structural remediation (deep drainage and asphalt layers) (SBB [10]) stimulate growth of competitive vegetation (grasses) through regular mowing (SBB [98])	
		D	structural remediation (deep drainage) in addition (SBB) stimulate competitive vegetation (grasses) through regular mowing (SBB [2, 10, 98])	

[3] This may be Geranium purpureum, which likes warm places to grow. Needs to be checked.

Plant species	Latin name	Area	Non-chemical treatment	Chemical treatment
		E	Preventive constructional methods: no open joints and gullies [2]	
		No effective method against horsetail known (JBV, RIB, SZ, SNCB) [114]		
Japanese knotweed	*Reynnoutria japonica*	A,B	No methods known yet	No methods known yet
	Fallopia japonica	C	No methods known yet	No methods known yet
	Polygonum cuspidatum	D	Use of Glyphosate combined with mowing (SBB) Manual weeding (RT [92]) → do no flail (RT [92])	use of the following herbicides/substances several times a year: - Glyphosate (SBB combined with mowing, (RT [92]) - Imazapyr (RT [92]) - Tryclopyr 4 (RT [92], SNCB [109]) - Picloram (RT [92])
		No effective method against reeds known (RIB, SNCB) [114], SBB		
Giant Hogweed	*Heracleum mantegazzianum*	A,B		use of the following among other herbicides/substances: - Tryclopyr (SNCB) - Glyphosate (BV, JBV [114], SNCB, RT [92]) - herbicide containing Fluoxypyr or MCPA (JBV [114]) → only Glyphosate recommended (RT [92])
		D	Cut the roots early in spring [52, 92], JBV Regular mowing before development of seeds [52, 2]	
Sedges	*Carex sp.*	A, B	mowing in autumn or winter combined with use of Glyphosate in spring (SBB [98])	use of various herbicides [114], (SBB [98])
Bindweed	*Convol-vulus arvensis*	C	weeding in spring (SBB [10])	Use of the following herbicides/substances: - Tryclopyr (SNCB) - Glyphosate (SBB [98])
		E	preventive methods (dense grass cover, constructions) [2], mechanical or thermal methods ineffectual [2]	

Plant species	Latin name	Area	Non-chemical treatment	Chemical treatment
Thistle	*Cirsium arvense*	C		use of the following herbicides/substances: - Glyphosate (SNCB) - Tryclopyr (SNCB) - Picloram (RENFE)
Old man's beard	*Clematis*	A, B	manual weeding (pull or dig out) (SBB [98])	use of Glyphosate in autumn (SBB [98])
		C	manual weeding (pull or dig out) (SBB [98]) regular mowing up to 2-3 times a year (near D) (SBB [98])	
		D	Regular mowing up to 2-3 times a year (near C) (SBB [98])	
Common Ragwort	*Senecio jacobaea*	C	Manual weeding: must be removed before it seeds (RT [92], SBB [10]): pull in spring or dig out (RT [92]) → do no cut (RT [92])	use of the following herbicides/substances: - Glyphosate (RT [92]) - Diuron (RT [92]) - Picloram (RT [92]) - sulfonyl urea (SNCB [109])
Himalayan Balsam	*Impatiens glandulifera*		cutting down to ground level before end of June (RT [92])	use of the following herbicides/substances: - Glyphosate (RT [92])

8.4 Gaps in methods/strategies for combating problem plants

Since the use of herbicides is restricted in some countries, new solutions for combating problem plants are needed. Solutions are still needed for the following three plants species mentionned: BV [114] has examined a number of strategies for combating horsetail (*Equisetum sp.*) with herbicides. While several universities are carrying out research on Japanese knotgrass or knotweed (*Reynnoutria japonica/Fallopia japonica)*, no work is being done on the cranesbill (*Geranium sp.*).

9 Conclusions

9.1 Methods used

The survey shows clearly that chemical methods are the ones most used by the railway companies. Non-chemical measures are used in a supplementary way and/or on a few line kilometres.

The reasons are as follows:

- ***Chemical methods*** are still the most effective and cheapest maintenance methods (but no internalisation of external effects so far).
- Some countries have compelled their railways to abandon the use of herbicides in certain areas such as groundwater protection zones. It is mentioned by most of the railway companies that the tendency towards establishing such zones is increasing and the use of herbicides will be restricted in the future. Thus, in these areas companies are being forced to use non-chemical methods. Hence a lot of research was and is still being carried out by some railway companies, the main ones being DB AG, BV, JBV, BS and SBB, to develop new and improve existing non-chemical methods.
- Unfortunately ***non-chemical maintenance methods for the track area*** (Areas A to C, ballast to transition area) tested have not so far yielded satisfactory results. Either they are too expensive, not efficient enough, cannot be applied for operational reasons or they are not environmentally compatible. More research in this field is needed to produce new ideas for new systems for possible use on the railways.
  - A lot of experience with *mulching and mowing* (two non-chemical maintenance methods used predominantly on the embankment - Area D) has been acquired by several railway companies. It is mentioned that mulching and mowing are very effective when used regularly on the embankment as a means of reducing the amount of vegetation encroaching upon the track area.
  - *Commonly applied maintenance methods* also have an influence on vegetation control even though they are not primarily used for vegetation control. Two such methods are the cleaning and replacement of ballast. These have a strong impact on plant life along the track by removing any fine material (see Part A). Such methods should be *investigated* with this in mind in the future as well.
- ***Non-chemical methods for construction*** (new-build or relaying) may be more effective than maintenance methods. Their positive effect for vegetation control is shown in several cases. These preventive measures have to be taken into consideration when building new or re-constructionold lines.

Besides developing non-chemical methods for herbicide-free areas, efforts are also necessary to reduce the total amount of active substances (herbicide). Hence, there is a need to improve application techniques and search for more environmentally friendly substances.

9.2 Need for vegetation control strategies rather than individual vegetation control methods

The application of one single method, when used very frequently, leads to the development of a one-sided vegetation community. This can lead to the appearance of so-called problem plants. Past experience shows that there will never be one single means of solving the heterogeneous problems of vegetation control. Rather, a well-balanced combination of various vegetation control methods is necessary. Such a combination will productively harness the specific characteristics of each method. Thus, what is needed is a vegetation control strategy.

This strategy should be applied before (problem) plants emerge. It should focus on preventive measures and methods combating symptoms. These may be constructional methods, which means taking vegetation control measures into account when planning re-construction or new-build work. The ***regular application*** of maintenance methods (at least once a year) such as biological methods (mowing and mulching) may have the same effect as preventive measures. Even the best methods are doomed to fail if maintenance is neglected and therefore a situation develops that calls for remediation rather than straightforward maintenance. In such cases, remediation of a certain area should be considered as a means of re-establishing the initial state.

Furthermore, this strategy should include all areas (areas D to A, from the embankment to the ballast bed). This point is well described in Part A: the vegetation growing in one area has a direct effect on areas linked to each other. Thus, the vegetation control method used in one area has an influence on the other areas.

9.3 Vegetation Management System

A Vegetation Management System has to include a tool for choosing the appropriate method or combination thereof for a specific set of conditions. It takes all track and trackside areas (Areas A to D) into account. Thus, an overview of practicable methods, combinations and their time of application is needed as well.

The first step in setting up a management system is to record the amount and kind of vegetation present, and to check if other maintenance is needed as well and whether it might be carried out at the same time as vegetation control measures. The management system should help to choose the appropriate method or combination thereof for a specific situation. In the tree diagram ideas are given as to how to handle the various methods in combination with each other having regard to the local situation. It is a rough structure that has to be adapted to the specific factors governing each railway company such as legislation, organisational structures, methods available etc.

Some railway companies already have experience or are now starting to set up such systems. SBB for example is establishing a database for vegetation control that will be connected to a Geographic Information System (GIS) in the future. DB AG is also setting up a computer-based system to increase the efficiency of vegetation control measures (in and away from the track) including the infrastructure besides environmental demands.

9.4 Exchange of Information and Knowledge within and between Railway Companies

Experience reveals that little theoretical knowledge is being transferred to the practical sphere as yet. If all knowledge gained had been put to practical effect, fewer problems would have occurred than are evident today. Thus an exchange in both directions (top down and bottom up) is needed. Besides interchanges of knowledge, education is another important tool with which to distribute existing knowledge. Focus needs to centre on operatives as well as on the management level responsible for maintenance budgets.

The work on this UIC Vegetation Control Project has demonstrated that it is very important for the various railways to exchange know-how on vegetation control issues. Recently, many railway companies have been conducting experiments without knowing that the same experiments are being run by other companies or have, indeed, already been completed. If knowledge is shared between railways, the amount each of them spends on such studies can be reduced. This can be done as follows:

- A first step towards spreading knowledge was taken with the seminar (see Part C) and with this report.
- Furthermore the UIC could help by putting education material together and revising the existing UIC vegetation control leaflet No. 732 (1992). It should be a technical leaflet which also recommends constructional methods.
- In addition, a permanent reference group should be established to discuss vegetation control issues at the UIC besides regularly updating a literature/information database produced for the purposes of this project.

PART C: Seminar

10 Conclusions of the Seminar 29th und 30th of Nov. 2001

The need for vegetation control

There is need for vegetation control and it has to be seen as an integrated part of track maintenance. A number of methods (constructional, chemical, biological, etc.) already exist to control the vegetation within and along railway tracks, but with different levels of practicability.

Treatment approach

The prevailing approach in vegetation control is to start the efforts from the tracks (area A and B) towards the embankments, which is comparable to corrective maintenance. The new approach is different: Vegetation control should rather be preventive and start from the outer embankments (area D) and towards the rail. A well maintained area D would assure less vegetation pressure towards area A and B. Non-chemical methods are primarely used as preventive measures. This aims to reduce the use of chemicals.

Management systems

Management systems of Vegetation Control must support the planning, controlling, documentation, and improving of applied measures. The life cycle approach and comprehensive view on track maintenance (including safety, constructions/upgrading) is essential to achieve a satisfying level of Vegetation Control. Therefore life cycle comparison of technical, operational, cost and environmental aspects of the available methods is needed. Data and methods for such a comparison is missing at present.

Standardisation and guideline

The seminar recommends that a UIC technical leaflet funded by Infrastructure Commission based on the project findings to be elaborated in 2002. Recommendations for constructional measures should also be incorporated into the leaflet.

Networking

The railways should maintain and develop their specific knowledge and experience within the field of vegetation control. The railways will benefit from international networking in this area, thus an informal network hosted by UIC should be set up.

There is a need for better integration of the seminar findings in the agenda of the Commission Infrastructure. Railways should involve all relevant stakeholders (authorities, suppliers, neighbours, etc.).

Expectations to legislation

More pressure towards reducing the use of herbicides is put towards the railways, but all companies are using them presently. The following activities are recommended to avoid a general prohibition of herbicides:

- Railways should actively contribute with their knowledge and experience towards authorities (lobbying)
- Railways should communicate professionally in this area based on the project findings and commonly agreed principles (adapted treatments related to the present vegetation situation within and along the track)
- There is additional need for regional and local differentiation due to operational, climate, vegetation, and water resource conditions

11 Summaries of Presentations

11.1 Michael Below, Deutsche Bahn AG

Aim and Process of the Project

The use of chemicals for vegetation control in railway installations over many years showed that it only has a short time effect on the weed cover present. Additionally the actual application leads to a changes in the plant community present. More and more plants grow, which are unwanted. Furthermore the detection of some herbicides and their degradation products in ground and surface water was taken up by non governmental organisations in some European countries (e.g. Germany) to postulate a general stop of herbicide use in railway facilities. These reasons described above and the increasing pressure to cut costs for vegetation control motivated several railway companies to start different activities to reduce the amount of herbicides used.

In this background, the UIC Working Group Environment organised several conferences on weed control. After several discussions and meetings the UIC-project on weed control was started in 2000 and ended in 2001. The following points were focussed within four subprojects of this project:

- Subproject 1: Need of weed control (Possibilities to accept a certain amount of weed in relation to different track categories).
- Subproject 2: Recommendations for the application of non-chemical methods in “herbicide free areas” where either the use of herbicides is restricted or herbicides don’t have an effect.
- Subproject 3: Description of basics for a vegetation management system.

- Subproject 4: Communication of the results via a final seminar and a report.

The results are based on an inquiry, a literature study and the knowledge of railway experts.

The inquiry was separated into three steps. In the first step a general questionnaire was sent to 49 UIC railway companies. While the more specified questionnaires of step two the number of railways answered reduced down to 12 (Subproject 1) and 21 (Subproject 2) respectively. The third step was used to clear some misunderstandings and/or unanswered questions.

The inquiry showed that the use of herbicides on railway lines is ruled by governmental regulations. In some European countries the application of herbicides is limited to e. g.:

- only one active substance like Glyphosate
- the amount of active substance used per area or track length
- an increase of "herbicide free areas"

Most of the railways expect a more strict regulation in the near future. This and the controversial effects of chemicals itself lead to investigations of non-chemical methods and selective use of herbicides. In Europe about 131 € per track kilometer are spent for weed control maintenance and about 392 € per track kilometer for the maintenance of the embankment. Europe's railways have in total about 3'040 km^2 of track area and between 2'370 and 4'740 km^2 of embankments.

Need of weed control

The question about the need of weed control is linked to the development of plants and has to be viewed under two aspects. One is the differentiation into **track and embankment** areas the other one the **short and long term effects**.

In general plants tend to colonise all vegetation free areas and have developed different mechanisms adapted to different growing conditions. The basic needs of plants are light, nutrition and water. These growing factors have to be available for plants in a different amount, depending on the plant species. There are a few possibilities to cut these growing factors down or at least to manage them in that way to control growth.

The plant growth in the **embankment** is more or less influenced by the natural soil and climatic conditions. Therefore only very few possibilities are existing to manage the basic needs of vegetation. Embankments are usually covered by plants. This vegetation coverage is wished by the railway companies to avoid erosion e. g.. But there is also a need to keep the growth of plants within certain limits, and therefore to cut down shrubs and trees, if sight of signals is reduced or the safety of workers is not more guaranteed e. g.. The development of vegetation takes place on the short as well as on the long term time scale, but the earlier the control of weed is carried out in these areas the cheaper it is. For instance carrying out mowing or mulching continuously and regularly leads to a desired grass vegetation. This reduces the vegetation burden into the track area and minimises the need of weed control measures there. In the **area between the track and the embankment** a good functioning / well maintained drainage system like ditches (not a common weed control measure!) will keep the track area as a dry place. Hence only a few slow growing plants will survive, if they are well adapted to these conditions. These and lateral weed barriers like well placed cable pits protect the track from in-growing plants from the embankment. They lead to a reduced vegetation burden within the track itself and therefore weed control activities in the track area might be reduced.

The **track area** itself is a technical construction using specified materials which have to full fill the different demands of railway companies. Therefore the occurring of weed has different effects. On the **short term time scale** the safety of workers and the sights on low signals e. g. have to be guaranteed in the walkways. This can be supported by controlling the shrubs and trees in the embankment to turn off in-growing plants. Furthermore cutting shading trees lead to intensive radiation of the track area itself by sunlight. This leads to high temperatures, dry conditions and hence a minimised plant growth. An additional effect to increase the temperatures may be initiated, when using dark material in the walkways, which was shown in experiments. Almost no weed can be allowed in the gravel bed on the short term time scale, when leading to increasing risk of fire and disturbance of brake systems or hindering the inspection of the rails.

Beside these short term effects of weed **long term effects** are shown as well. The development of vegetation in the track is different in the walkway and in the gravel bed. The best growing conditions for vegetation are existing in the walkways, where plant growth starts usually first. When the vegetation reaches the base of the gravel slope, it closes the coarse gravel pores. This may lead to reduced drainage of the gravel bed. In consequence the moisture content increases and sub-layers under the ballast may start to weaken.

The gravel bed is usually a dry and hot place. Hence it is hard for plants to survive under this conditions. The crushing of gravel stones as a result of the traffic leads to an increase of the fine material. In follow the moisture content starts to increase, the growing conditions improve and the possibility of weakening the sub-layers is arising.

In both cases a reduced carrying load linked with a pumping up of fine material from the sub-layers into the gravel will be observed. This leads to further weed growth as well, because of improving growing conditions. Because these effects will occur beside other disturbances in the track, it can not be clearly separated from each other. Even so the railway companies have to guarantee a stable track and a constant carry load based on a stable base layer by a good drainage of the track.

The railway companies have different reasons and demands for weed control depending on their infrastructure. Due to the existing gaps about the direct link between weed coverage and stability on the long term scale no railway company is able to set up limit values for weed based on an objective data base. The issue is too complex because too many influences effecting each other have to be taken into account. Even so some railways started to establish quality standards concerning weed coverage, but not based on an objective data base.

On the short term there is need to avoid disturbance of rail traffic by weed as already described above. Hence weed control measures are needed. The possible methods in the different track areas and the recommended combination of possible methods used is shown further on.

Methods for weed control and proposed combinations

An overview on different methods known at the moment is reported. Different characteristics for each of the 34 methods (technical data, weed control area and operation conditions, costs and environmental effects) are listed in a catalogue.

The inquiry showed that the chemical methods are the most used ones by the railway companies. Non-chemical measures are used in a supplementary way or where the use of chemicals is prohibited. The reason: no satisfying non-chemical maintenance methods for the track area (ballast and walkway) are known today. Most of the methods tested did not lead to satisfactory results. They are either too slow (hindering railway traffic), have not the desired effect on plants or are too expensive. One exception may be the constructional measures, which also belong to the non-chemical methods. Their positive effect for weed control is shown in several cases. These preventive measures have to be taken into consideration, when building new or reconstructing old lines. The efficiency of constructional methods can be improved by applying maintenance measures in addition like mulching in the embankment. High efficiency of the methods is only guaranteed, if applied at the right time (time of year / day, plant age e. g.).

It is mentioned by most of the railway companies that the tendency establishing “herbicide free areas” like water protection zones is increasing and the use of chemicals will be more restricted in the near future. Therefore the **development of new** and the **improvement of existing methods is very important**. The improvement should include the methods, whether they are non-chemical or chemical ones itself. Beside the improvement of methods itself there is need of research for new herbicides meeting the actual demands of railways like being more environmental friendly. Also commonly applied maintenance methods have an influence on weed control even they are not used primary for weed control. Those methods should be investigated for that purpose in the future as well (e. g. ballast cleaning and exchange of ballast).

The application of one single method, when used very frequently leads to the development of a one sided vegetation community, which can include so called problem plants. Therefore a well balanced **combination of different weed control methods** is obviously necessary. The emphasis should be laid on preventive methods like constructional ones, which means taking weed control measures into account when planning re- or new constructions. The **regularly application of maintenance methods** e. g. mowing at least once a year have a preventive effect too. Furthermore a vegetation control strategy should include all areas, from the embankment to the ballast bed, since the weed control method used in one area has an influence on the other areas as well.

Basics for vegetation management system

The basis for the Vegetation Management System should include an overview on the methods available, their time of application and proposed combination. The first step in setting up a management system is to record the amount and kind of vegetation present, and to check if other maintenance is needed as well and whether it might be carried out at the same time as weed control measures. The management system should help to choose the appropriate method or method combination for a specific situation. Therefore a **decision scheme** was developed on a more general base, which is also available in an electronic version. For the daily use it has to be adapted to special demands of a certain railway company like legislation, organisation structure, methods available. Some railway companies already have experience or start building up such systems.

Exchange of experience

The experience shows that much of the theoretical knowledge is not transferred to the practice or management yet. This can be suspended as follows:

- The managers **responsible for the maintenance budgets should give the vegetation control the required importance**. Neglected vegetation control has sooner or later an effect on the track (e. g. reduced sights on signals or nature risks by broken trees in storms, track availability). The sanitation of these undesired effects needs much more money than regular maintenance.
- An **exchange of theoretical knowledge and practical experience** is important, which can be done by an intensive training program of staff in charge with weed control. But on the other hand they should have the possibility to communicate their practical experience as well. Also the education of the management board responsible for the budgets needed for an accurate weed control is important.
- The UIC can help to give information needed for such education. This report is the first step.

The UIC Project "Weed Control" showed that an exchange of the experiences in vegetation control issues between the different railways is needed. This helps the single railway to cut costs for investigations. Therefore a permanent contact group at the UIC should be established in the future. Their task is to discuss weed control issues and exchange information regularly beside a continuously update of a literature / information database, which was set up within this project as well.

11.2 Ulrick Winge, BS

UIC weed control Seminar Importance of weed control.
How legislation influences weed control measures.

By Ulrik Winge, Divisional director, Planning Division, Banestyrelsen, The infrastructure manager of Danish State rail network

Demands on the environmental performance of the infrastructure maintenance done by the railways have risen during the last decade and is still rising. Both Governments and environmental groups demand that railway companies behave responsibly when carrying out maintenance tasks and their most of all when using chemicals for weed control.

During the same period many railway companies have been forced to reduce expenses for maintenance. When expenses for maintenance are reduced, the need for chemical weed control will rise. With unlimited resources for maintenance there will be no need for chemical weed control.

Maintenance of the areas owned by railway companies is necessary with or without chemicals for many different reasons: Track stability is necessary in order to avoid derail, safety for workers must be evident, signals must be visible , weed control must prevent fires happening, public safety must be ensured, plants must be nursed, and neighbours opinions must be taken into consideration. These are all conditions that railway companies have to be aware of.

Insufficient maintenance of the track due to a high amount of fine materials and humus in the ballast, fine material on the ballast shoulder, ditch filled up with plants, or vegetation on the ballast shoulder reduce the track stability and create good conditions for the growing of weed. For this reason weed control by non-chemical or chemical methods is necessary, not only on the track area but also in the surroundings.

Chemical compounds consist of two main groups: 1) leaf herbicides where Roundup, based on Glyphosat, is most often used, and 2) soil herbicides, where many different products are regularly used.

Soil herbicides and leaf herbicides have different advantages. Soil herbicides are efficient already in the seed stage, and have a long term effect. Leaf herbicides are only efficient, if the plant is growing and have no long term effects. A few plants, which are quite common, cannot be treated with leaf herbicides, for instance horsetail.

The advantages of using leaf herbicides based on Glyphosat are to be found in the environmental effects, where RoundUp is relative harmless or at least the most harmless chemical to avoid groundwater pollution, which could in turn destroy ground water resources.

The Danish experiment of outfacing the use of chemicals has been going on since 1986. In light of the political trend we have voluntary agreed to outface the most problematic chemicals – today we only use Glyphosat. With a new spraying train system WeedEye SpotSpray we expect to reduce consumption with 50 % from 2003. We are aware that it may be necessary in the future to launch a campaign against problem plants, but using other chemicals than Glyphosat. During all this time we have co-operation with the Government Environmental Department to secure that the chemical we use is the best, when the use of chemicals is necessary.

My conclusions on weed control for the next 10 years is that weed control measures will entail a wide range of measures, where both chemical and non-chemical measures have to be used. We in the railway companies have to strengthen our knowledge of the expense and effects of different weed control measures. We have to enter into a constructive dialogue with our Governments and politicians to find a solution where the demand for weed control can balance the expenses of maintaining the railway system.

11.3 Herbert Miersch, DB Netz AG

Weed Control is important
DB Netz AG experiences

Starting with a brief description of the transformation of the former two German state railways into DB AG, the paper will outline the position of DB Netz AG in the new organisation structure and the scale of weed control activities based on the size and situation of the network.

Weed control methods will be outlined in this context as well as how DB Netz AG has responded to these developments. The leading research work and investigations carried out in the field will be summarised.

Following the restrictions placed on of the use of herbicides as a result of stronger environmental requirements, research in the field of weed control mainly focused on identifying new maintenance technologies and herbicide-free trackside methods.
The results achieved will be presented briefly. Current practical examples of weed development will be given.

The conclusion from the past 10 years is that, drawing on its own experience, DB Netz AG can prove convincingly that weed control is vital and must be carried out regularly and effectively.

The talk will end with an outline of recently-developed maintenance strategies for weed control.

This strategy is centred around an approach based on an objective appraisal of the actual situation, with all methods and procedures that have a bearing on weed control being considered for use to the extent or in the combination the case demands ("integrated weed control").

This also includes trackside chemical weed control governed by strict regulations and involving the use of modern environmentally-compatible herbicides.

11.4 Helmut Kuppelwieser, SBB and Herbert Miersch, DB Netz AG

Constructional weed control methods on SBB AG and DB AG

The UIC Weed Control project shows that a range of constructional methods can be used to control vegetation. The international railway community has so far had very little experience with measures of this type. On the Swiss Federal Railways (SBB) and German Railways (DB AG), some of these methods have already been used successfully for some years. Others have recently been undergoing tests to assess their performance in practice. This paper looks at the experience and knowledge gathered by SBB and DB in connection with the following constructional methods:

- Lateral plant barriers ("M1" in the classification used for the UIC project)
- Growth-inhibiting transition zone (M3)
- Porous concrete bars (M4)
- Plant barriers beneath the track (M6)

The individual methods are desribed in detail, their benefits and drawbacks explained and their optimum field of application identified. The paper ends with an indication of potential synergies with other railway functions (e.g. construction of track drainage systems) and the costs of applying the methods in question.

Lateral plant barriers between the ballast and the embankment prevent plant incursions into the track zone from the verge and the embankment. There is a wide range of different types, from expensive versions for new lines to cheaper alternatives for track sections that are being upgraded or rehabilitated. The same variety of forms exists for the growth-inhibiting applications in the transition zone between ballast and embankment, ranging from specially selected gravel with sheeting placed beneath the gravel layer through to special mats that serve at the same time as a walkway. Porous concrete bars are track drainage components that are specially optimised for vegetation control. Similarly, plant barriers installed beneath the track, like the bitumen seal, are an excellent means of keeping plant growth in, though their main function is to help drain the track formation.

SBB and DB experience shows that constructional measures are effective in preventing plant growth. The most effective measures are those that ensure the trackbed is well drained (like bitumen seals under the track). Constructional measures that serve exclusively to control vegetation are generally not cost-effective. If however their prime function is elsewhere, providing drainage for example, they can be optimised for vegetation control purposes at little extra cost. Constructional measures are most effective when combined with other approaches, particularly biological (such as mowing).

11.5 Jan Skoog, BV

Trackside clearing by Jan Skoog, Environmental Coordinator, Strategic Department, Swedish National Rail Administration

Introduction

Chemical vegetation control is the primary method of vegetation control on the Swedish railways. The method is at present well accepted as the only practical alternative for vegetation control within the railway tracks. Each year about 2 000 kilometers of railway tracks are treated primarily with RoundUp.

The use of herbicides within the trackside areas isn't as obvious. Concerns for groundwater protection and public opinion has led to the decision not to use chemicals where other possible alternatives are available.

It is also important to keep the area alongside the tracks clear of vegetation. A clear view towards signals and railway crossings is very important for safety reasons. Within this area vegetation control are usually done by spraying herbicides or manual clearing of bushes and small trees. The longterm effects of manual clearing are not satisfactory. The need for vegetation control in this area is a lot greater than the measures have been over the last few years. The Railway Inspectorate which is the authority responsible for the safety of railway traffic have made complaints regarding this.

The trackside clearing method

Trackside clearing is a mechanical method to remove unwanted vegetation from alongside the railway tracks. The method was developed during 1998 and was originally designed to remove excess material from the track and recreating its normal profile. It soon also proved to be a very efficient method for vegetation control

With a specially designed work train, the vegetation between the edge of the ballast and the trench is removed. The train consists of a traction vehicle, a machine that removes the vegetation and a number of wagons for the removed materials.

The interesting part of the train is the special “trackside clearing machine”. This machine is equipped with a rotating digging arm on each side that can be moved both vertically and horizontally. There are two operators who each control one side. They have camera monitors at their assistance to give the digging arms the right altitude in order to provide for an exact depth for the procedure. Inside the digging arm there are shovels attached to a chain according to the same principle as the track on a caterpillar.

The machine works with a width of 80 cm on each side and the arms reach 4,5 meters from the center of the track. The train works at a speed of approximately one kilometer per hour which is equivalent to a capacity of about 1600 m^2/h. The equipment is able to handle vegetation that is a couple of meters high and with dimensions around one decimeter.

The removed materials are transported through a conveer onto a number of loading wagons. (There is a rolling hoop at the bottom of the wagon that transports the materials backwards.)

Experiences

The method has been used only this past year, mostly for removing excess material and adjusting the normal profile of the track but it has also been used for vegetation control at 4 or 5 different places, on a total distance of 100 km. The method has worked entirely without disruptions.

The method has a longterm positive effect, mainly for three reasons:

First of all the entire vegetation is removed, including the roots. When clearing with a saw trees and bushes are usually cut above the growth zone which facilitates the regrowth.

Second; by removing parts of the upper layers of soil a large part of the seed bank is removed as well.

Third; the method improves the tracks' capacity to drain water which also makes regrowth more difficult.

The method thereby prevents regrowth for a longer period of time than the ordinary methods.

Chemical vegetation control can be used in this area, bushes that are sprayed dies and dehydrates and thereby becomes a fire hazard. It doesn´t give a nice appearance with brown and dead trees alongside the tracks which doesn't enhance the image of the railway as an environmentally friendly transport mode.

Conclusion

The method will be used by the Swedish rail administration predominately for recreating the normal profile of the track along with track renewal. Vegetation control will become an integrated part of these actions, but we also expect the method to be used for vegetation control in areas were chemical vegetation control cannot be used.

There are plans to try the equipment in Denmark and the Netherlands and eventually additional equipment will be developed.

For more information please contact Roland Bång at the Industrial division of the Swedish Rail Administration: roland.bang@banverket.se

11.6 Fernande Gächter, SBB

Is there a future for Hot Steam? Fernande Gächter, SBB Environment Centre, Switzerland

How it works

The hot steam method, or, based on existing technical equipment, better described as the wet steam method, is an electro-thermal method. Thermal methods destroy undesired plant growth by emitting high temperatures which induce negative effects on the plants. The effect of the heat leads to a denaturation of proteins (at T > 42°C), causing the plant cells to expand and burst through very rapid temperature increases, and the outer skin of leaves to change or peel off.

In the wet steam method, the water-saturated steam acts as a thermal conductor in which the steam is visible.

Time of treatment

As the wet steam method acts directly on plants, the plants must be in existence. The best time in the vegetation period to apply wet steam treatment depends on the species of plant in the section earmarked for treatment. A further factor is governed by the climate which also has an impact on plant growth. The times of treatment are therefore in spring and autumn (Switzerland). The treatment is less effective in the rain and the cold than in dry warm weather.

Frequency of treatment

The equipment used today does not have a deep effect and only destroys the outer surface of plants (leaves, stalks and blooms). Deeply rooted plants mostly re-grow after treatment and therefore must be treated as a rule more than once a year. The frequency of treatment is contingent on the species and also on the quantity of the plants in the areas earmarked for treatment.

Problem plants

Due to the above-mentioned characteristics, the plant spectrum may mutate to deep-rooted plants during the course of the year, as has been shown in experiments in Canada. Whether hot steam methods are effective in the long term against horsetail cannot be clearly stated from the Swiss studies carried out. If hot steam treatment on an area of horsetail is stopped, the plants will re-grow.

Working speed

If the effect of the steam lasts for a sufficiently long period, then plants can be killed off. For this to be possible though, equipment must be adapted or the working speed reduced. The current working speed practised is a maximum of 2 km/h. What is more, the steam apparatus used is rail-bound vehicles which require a track possession to be deployed. The vehicles used in Germany are road/rail vehicles, which, provided a suitable area of single track can be found, can be deployed on the track considerably faster than the other rail-bound vehicles. When shorter distances are involved, the latter can only be moved slowly (at a max. of 30km/h) and on the rails to the next location where they are to be used.

Economic aspects

Swiss investigations have revealed that steam treatment is only economically viable when applied to large areas lying close together. Only in this way can the equipment be used in optimum fashion. In Switzerland wet steam was tested on water protection zones which were often at least one hundred metres in length and lying a few kms apart from each other. The costs of this type of operation amounted to approximately 2 – 5.5 Euro per metre covered (depreciation and track possession not included in the equation).

Currently only prototypes of wet steam apparatus exist which all have a number of shortcomings. Priority should be given to developing a new type before applying this method in large areas.

Environment

The drawbacks of hot steam treatment are the massive consumption of energy and water required to produce wet steam. The method however can be used in groundwater protection zones.

In a nutshell

In a nutshell, we can state that the current equipment used presents considerable shortcomings. It is awkward to use, slow, consumes large amounts of energy and water and is expensive. The method must be used at least twice a year at given periods. The long-term effect on plants is to cause the plant species to mutate to deep-rooted plants. As this is not a chemical method, it can be used in groundwater protection zones.

If these shortcomings do not pose a problem for a section of track, then the wet steam method can definitely be considered for use. Nonetheless, the method does not appear to be suited for use throughout the network.

11.7 Gilbert Riboulet, SNCF

Development prospects for chemical weed control at SNCF - video-based weed detection and traceability of the treatment used by Gilbert Riboulet, SNCF-Infrastructure – Methods Production Division, Maintenance Development Department, Paris

The SNCF weed control operations are mainly carried out by spraying trains which spread average doses of herbicide along the entire route being treated. These average doses, which are calculated by SNCF on the basis of tests, are often ill-suited to dealing with the actual quantity of vegetation at a given site.

To address more effectively weed control and environmental compliance imperatives and with due regard for developments in terms of the herbicides suitable for use in non-agricultural zones and corresponding dosages, SNCF is crafting a prototype system which will tailor the herbicide treatment used to the type and quantity of vegetation.

This system will also make it possible to trace the treatment products used, keep a record of vegetation growth and adjust treatment in line with herbicide restrictions in protected zones.

11.8 Mads Bergendorff, UIC

EU Legislation Update on non-agricultural use of pesticides – November 2001

Currently DG Energy and Transport do not have very many details on the use of pesticides on railway tracks, they would therefore be very interested in the outcome of this UIC seminar.

The use of pesticides is controlled in the Directive 91/414/EEC and probably will be also in the future Directive for Community action in the field of water policy (exists only as a draft).

The Directive 91/414/EEC establishes that only active substances that have undergone a very thorough evaluation process and have then be included in Annex I of the Directive can be approved by the Member States in plant protection products to be used on their territory. All information regarding this Directive on the Commission's web-site at the following address: http://europa.eu.int/comm/food/fs/ph_ps/pro/index_en.htm. A very comprehensive description of the approval process also on this web-site in the form of a report to the Council and the European Parliament.

The issue of herbicide use on railway tracks is currently not included in the Directives regarding the interoperability of trans-European networks (96/48 and 01/16), which so far in the environment protection area deal only with emission of fumes and gases that are harmful and dangerous to the environment. The use of pesticides is probably considered a matter of subsidiarity to be dealt with by the Member States individually. For further information contact Anders Lundstrom (anders.lundstrom@cec.eu.int) at DG Energy and Transport.

In its proposal for a 6th Environmental Action Programme, the Commission has proposed to develop a so-called thematic strategy on the sustainable use of pesticides. The document and related information can be found at the following address: http://europa.eu.int/comm/food/fs/ph_ps/pro/index_en.htm

DG Energy and Transport is currently preparing a document for public consultation on potential measures that could become a part of this thematic strategy. The use of pesticides on non-agricultural land (like railways) will definitely be an issue among many others. Benilde Bujarrabal (Benilde.bujarrabal-fernandez@cec.eu.int) at DG Energy and Transport is working on the document, she could keep UIC and the railways informed on how and when the document will be released and how you could participate in the consultation.

OECD is organising a “Workshop on the Economics of Pesticide Risk Reduction” in Copenhagen November 29th – 30th (http://www.oecd.org →Events →Environment →Chemical Safety →Pesticides & Biocides). Contact at the OECD for this event is Ms Libby Harrison (e-mail: Libby.Harrison@oecd.org).

Source and contact person:

Klaus Berend (Klaus.Berend@cec.eu.int), European Commission, DG Energy and Transport

11.9 Michael Below, Deutsche Bahn AG

Computer-based Management System by Michael Below, DB AG

In developing a computer-based weed control management system, DB AG is seeking to:

- ensure efficient use of the resources deployed to combat weed growth, through targeted applications,
- appraise weed control as a maintenance procedure (critical for the environment),
- increase transparency and thereby secure greater acceptance of chemical weed control methods amongst authorities, political circles and the general public.

The weed control management circuit comprises the following steps:

(1) Snapshot of current situation
(2) Analysis of current situation
(3) Definition of measures
(4) Planning for introduction of measures
(5) Implementation of measures
(6) Quality monitoring
(7) Taking delivery
(8) Documentation

This sequence of processes and the range of different factors to be considered is highly complex, particularly for chemical vegetation control. Our aim is to simplify procedures through the introduction of a computer-based management system.

(1) The first link in the process chain is an objective appraisal of vegetation growth at the selected site. The findings obtained form the basis for decisions taken on step (2). Development of the commuter-based management system will initially focus on the track area as it is easiest to survey weed growth here. During the second phase, the scope of the system is to be extended to cover surrounding areas, thus encompassing all the zones in and around the track of relevance to weed control.
To ensure uniform weed detection, data-capture tables are provided. They must be suitable for recording the extent of growth in the track area either manually or by computer.
Work is in hand to develop a video-based method of ascertaining weed growth on tracks, with subsequent computer-based analysis. This system is currently capable of expressing vegetation growth in percentage terms for five distinct track zones. Information on weed growth along a specific line is then entered into a database.

(2) The data collected in step (1) is then compared against an appraisal table (selection criterion: extent of weed growth). The system selects lines or line sections for which weed control measures are required. The actual measures taken are determined during step (3).

(3) To define the weed control measures to be adopted, the computer program analyses the lines or line sections identified, drawing on further details relating to, say, environmental or infrastructure factors. The output of this process is a table of recommended measures for a given line or line section. The computer algorithm has an open structure and can therefore be adjusted to new requirements at any time.

(4) The work carried out during phase (3) simplifies the actual planning of measures, since recommendations already exist as to which methods are suitable for a specific line or line section. During the planning phase, account is taken of factors such as train timetables and climatic imperatives, to ensure that week control measures are applied effectively and at the right point in the operating schedule.

(5) DB AG outsources the actual execution of measures to outside firms. As is noted under point (6), DB is responsible for vetting the quality of the work done.

(6) DB AG assesses the quality of the work carried out by subcontractors while measures are actually being implemented. It does so by checking the firm's work against the quality criteria laid down in the contract. The findings are also recorded.

(7) Once measures have been fully implemented, DB AG signs for the work done by the subcontractor and logs the data produced as part of step (8).

(8) Concluding reports describing when and where which measures were carried out are stored in a database. In this way, it is possible to monitor weed growth on each line and compile a comprehensive record of measures implemented.

This process is set in a motion once a year, giving a chronological account of variations in weed growth and the action taken. It is therefore possible to identify the most effective response in line with the weed presence noted. This data can then be drawn on when considering new approaches and can also serve to run additional analyses – assessing the effect weeds have on track, for example – by pooling the findings with track-related data from other systems.

11.10 Beatriz Quevedo Puente, RENFE

Vegetation control system

Introduction and background:

In October 1997, Renfe obtained its first environmental certificate, according to the standard UNE-EN ISO 14001:1996, for two container terminals and a goods traffic route between them.

Continuing with this line of work, in July 1998 the Infrastructure Maintenance Business Unit established some Agreements with the Environment Management for the development of an Environmental Management System relating to track weeding activities, one of the most important environmental tasks of the Business Unit. For this purpose, an Environmental Diagnosis was carried out, which began in September 1998 and ended in April 1999. This study aimed to identify the different aspects deriving from the weeding activities. The aim of this evaluation was to analyse and check the level of compliance with the (European, national, regional and local) environmental legislation and fulfilment of the requirements of the above-mentioned standard. The weeding activities cause a series of environmental impacts on the environment which need to be identified, evaluated and controlled and, insofar as possible, prevented and minimised, covering all the types of incident, such as atmospheric emissions, wastewater dumping, generation of waste, accidents and incidents, etc...

In October 2001, the Infrastructure Maintenance Business Unit, on the basis of the previously established Agreements, decided to make an Environmental Diagnosis for all its activities in order to find out the environmental problems involved.

Consequently, the opportunity is being taken to update the previous Environmental Diagnosis of weeding activities.

The aim is to develop and subsequently introduce an Environmental Management System for all the activities carried out by the Business Unit and for all the environmental aspects involved.

Brief description of the activity:

Renfe uses two methods to carry out the weeding activity: the chemical and the manual, both methods being non-structural.

CHEMICAL METHOD:

The chemical method of controlling vegetation involves using herbicide trains equipped with spraying systems which allow the chemical treatment to be given to all the elements which comprise the field of application.

This method is applied by a subcontracted company. Although this company is therefore responsible for carrying out this activity, it must comply with the conditions and instructions established in the contract.

The activity is divided into two annual campaigns, one in the spring and the other in the autumn. In the spring campaign, all the A1, A2 and B lines, as well as some of the C tracks, are sprayed (according to RENFE's internal classification based on the traffic they cater for). In the autumn campaign, some of the A1, A2 and B lines are resprayed, as are the C lines which were not treated during the spring campaign (the autumn campaign is subject to the availability of budgetary funds).

There are two modes of treatment: double tracks are sprayed at a distance of 6 metres, whereas single tracks are sprayed at a distance of 7 metres.

The personnel who perform these tasks belong to the company which is awarded the contract, although in each one of the trains there is a representative of the Infrastructure Maintenance Business Unit who controls and facilitates the performance of the activity.

All the personnel of the subcontracted company are qualified and trained to use weed killers.

The subcontractor uses three trains for carrying out the weeding activity throughout the country (approximately 14,000 Km of railway lines).

The resources are as follows:

1. Herbicide production centre (factory plus laboratory).
2. One herbicide product storage centre.
3. One or various water storage centres.
4. Accompanying wagon.

The traction is provided mainly by diesel machines, although an electric machine sometimes has to be used. Shunting tractors are used for movements at stations.

The Herbicide Trains allow the spray treatment to be carried out at speeds of around 50 Km/h, although the advantage of these trains is that their travelling speed does not affect the effectiveness of the treatment, given that whatever the speed may be (from 0 to 80 Km/h), the amount of herbicide applied per surface unit is constant and, if necessary, can even be varied according to the density of vegetation in the areas to be treated. The automatic quantity determination system ensures that the amounts of herbicide applied remain constant, regardless of the speed at which the train is moving.

This characteristic is what allows the Herbicide Train to adapt to any situation, whether it be main lines at speeds of 50 Km/h and above (up to 80 Km/h) or secondary lines at stations and marshalling yards at walking pace.

Moreover, the special distribution of the spraying nozzles ensures that the risk of affecting agricultural crops near the line is no greater, at high speeds, than that which exists with any type of manual spraying equipment.

Another important characteristic is the possibility of applying three different herbicide solutions at the same time according to the various types of vegetation on the cross-sectional profile of the line, as well as that applying special herbicide solutions to specific areas or sections of the line.

In short, the Herbicide Trains offer optimum performances relating to the elimination of unwanted vegetation which grows on railway infrastructures, with a very favourable quality/price ratio for the railway company which uses them.

The treatments which the Herbicide Trains are able to provide on railway infrastructures are as follows:

- General maintenance spraying

- Spraying at railway stations
- Special treatments for bushes, reeds and hardy species
- Treatments with hoses

The main active herbicide materials used by the company responsible for the contract and for the control of weeds in railway installations are: Aminotriazol, Glifosato, Imazipir, Oxadiazón, Picloram, Simazina y Sulfosato, within the group of translocation or systemic herbicides.

Diurón is also used as a residual herbicide and Hexacinona is used a selective herbicide on alfalfa and forest crops.

In each one of the herbicide trains, a Renfe supervisor controls the activities of the subcontracted company and collaborates with the company's personnel. While the activity is being carried out, this supervisor sits in the train and informs the subcontractor's personnel of variations in the vegetation or the proximity of rivers, roads, fields of crops or inhabited areas.

The subcontractor is developing a system with television cameras which monitor the line from the herbicide production centre.

RENFE also employs an Expert Responsible for the Contract, who supervises the fulfilment of the latter and certifies the correct performance of the spraying activity.

In order to control the effectiveness of the sprayings, this Expert relies on specialised personnel who inspect the treated sections and check the correct execution of the weeding. The subcontractor also participates in these verification tasks.

MANUAL METHOD:

The proliferation of vegetation occasionally creates problems on certain stretches of line and also in installations (installations at stations, substations, etc.) which, due to their specific characteristics, cannot be treated with the herbicide train. In these cases, it is necessary to apply the product manually.

Both Renfe's personnel and the subcontractors' employees take charge of this operation. The treatment is manual, given that the employee carries a backpack loaded with the appropriate herbicide and applies it to the corresponding surface.

DESCRIPTION OF THE ENVIRONMENTAL MANAGEMENT SYSTEM:

The documentation of the Environmental Management System comprises a Manual, seven General Procedures and four Specific Procedures. The Infrastructure Maintenance Business Unit has introduced a Quality Management System and in order to simplify and not duplicate the documentation, some of the Quality System procedures will be adopted, such as: Control of the Documentation, Control of Records, Non-Conformance and Corrective Actions, Establishing Objectives and Goals and Evaluation of the System.

The seven general procedures of the Environmental Management System are:

- **Procedure for the identification and evaluation of environmental aspects.** This procedure describes the methodology which the Infrastructure Maintenance Business Unit uses to identify, evaluate and record the environmental aspects which derive from the performance of its services and activities. The activities, processes and services of the Infrastructure Maintenance Business Unit give rise to certain environmental aspects under normal and abnormal conditions which need to be identified. Once they have been identified, the aspects must be evaluated, in order to put them in hierarchical order and determine, according to their relative importance, whether or not they are significant. The record of the aspects is a fundamental reference document for establishing the environmental objectives and programmes.
- **Procedure for the identification and recording of legal requirements, customer requirements and environmental agreements and their verification.** This procedure assigns the functions and responsibilities for identifying, accessing and updating the legal requirements and other requirements which apply to the environmental aspects of the Infrastructure Maintenance Business Unit. This procedure refers to the European, national, regional and local legal requirements, customer requirements and agreements with public authorities, suppliers, contractors, the code of good practices or any non-regulatory guidelines of behaviour signed by the Business Unit.
- **Procedure for establishing the environmental training requirements.** This procedure establishes the criteria relating to the specific environmental training of the Infrastructure Maintenance Business Unit personnel, as well as the management of the records corresponding to their development. The training and awareness raising of the personnel are mainly based on filling any gaps in their knowledge of the existing legislation, the system implemented or the Specific Procedures which apply to it.
- **Procedure for dealing with external communications.** This procedure regulates the channels established for receiving, documenting, evaluating and responding to important communications from external interested parties, official entities or the general public. It also establishes the way to provide external interested parties or the general public environmental information punctually, accurately and clearly.
- **Procedure for dealing with internal communications.** The object of this procedure is to increase the level of understanding, collaboration and involvement of the personnel in environmental management, as well as to maintain a fluid communication between the different levels of the Infrastructure Maintenance Business Unit, in relation to environmental aspects. It establishes two types of communication:
    - Bottom-Up: from the employees to the Management
    - Top-Down: from the Management to the employees
- **Procedure for establishing environmental requirement and specifications applicable to suppliers and contractors.** This procedure establishes the environmental requirements and specifications to be included in the contracts which the Infrastructure Maintenance Business Unit establishes with suppliers and subcontractors. These requirements and specifications aim to ensure that the

environmental impact of the companies that work for Renfe and/or use Renfe's installations is minimal or non-existent, and that these companies take responsibility for their actions whenever this is not the case.

- **Emergency plan.** The emergency plan lays down the general guidelines to be followed in the event of an accident or in emergency situations and in order to prevent environmental impacts which might derive from the activities of the Infrastructure Maintenance Business Unit.

The four specific procedures of the Environmental Management System are:

∗ **Procedure for the evaluation of environmental aspects relating to the chemical weeding of the line activity.** This establishes the methodology used by the Infrastructure Maintenance Business Unit for evaluating and recording the environmental aspects which derive from the Chemical Weeding of the Line activity. Two types of criteria are established for the evaluation of environmental aspects, one qualitative and the other quantitative. The joint analysis of these criteria determines whether or not the aspect is significant.

∗ **Procedure for noise control.** The object of the procedure is the prevention and surveillance of possible situations of noise pollution caused by the different activities of the Infrastructure Maintenance Business Unit in order to ensure that the environment is suitably protected against exposure to excessive noise. This procedure includes the definitions of the terminology used, the identification of potential noise pollution activities, the description of procedural responsibilities and the measurement methodology.

∗ **Procedure for the control of water consumption.** This procedure describes the system for guaranteeing that the water is supplied at certain previously defined intervals. These intervals ensure that these consumptions are no more than strictly necessary according to the activity or the applicable environmental objectives. The procedure indicates that once all the significant consumptions of the activities included within the scope of the System have been identified, the indicators and the intervals of values corresponding to each one of those established will be defined, between which the consumptions must be maintained.

∗ **Waste management procedure.** This procedure describes the system for controlling and managing the waste generated by the activities of the Infrastructure Maintenance Business Unit. The procedure includes the systematic course of action to be followed, according to the existing legislation and depending on whether urban waste (or waste which can be assimilated to urban waste) or dangerous waste is generated.

IMPLEMENTATION OF THE ENVIRONMENTAL MANAGEMENT SYSTEM:

The Environmental Management System for line weeding activities is currently in the process of being implemented. The system is managed by a Specialist Chemical Line Weeding Technical Committee, which includes representatives of the six Management Centres into which the Infrastructure Maintenance Business Unit is divided.

Once the system has been fully implemented, the Internal Audit will take place, prior to the Certification audit, which AENOR (Certifying Entity) is expected to carry out on 15th and 16th November 2001.

CONCLUSIONS:

The objective of controlling vegetation on the line is mainly focused on the prevention of risks relating to railway operation (work accidents on lines, prevention of fires, etc.), the improvement of visibility (track, signalling, level crossings, etc.) and the ecological maintenance of the infrastructure of the railway line, preventing the vegetation from being able to modify its characteristics (permeability of the ballast, levelling, catenary,...).

Although the Infrastructure Maintenance Business Unit owns the activity and is therefore responsible for it, it is largely carried out by subcontracted companies. With regard to the correct environmental management on the part of Infrastructure Maintenance Business Unit, it is therefore very important for the contracts to clearly establish the minimums which must be fulfilled in this management. 80 % of the weeding activity is carried out by a single company which is also in the process of being certified in accordance with the standard UNE-EN ISO 14001:1996.

The Objectives and Goals set by the Infrastructure Maintenance Business Unit must include environmental prescriptions in keeping with the environmental aspects identified. Here are some of the most important points included in the Environmental Programme:

With respect to water consumption, an attempt will be made to establish a rational and appropriate use, and an analysis will be carried out in order to achieve a reduction in consumption by controlling the amount of water used.

In the same way, the consumption of fuels and electricity should be evaluated in order to be able to quantify minimisation and saving objectives.

As regards the management of waste, the latter must be perfectly characterised and identified in order to ensure compliance with the legislation.

The criteria for selecting weed-killing and phytosanitary products must consider the extent to which they are environment-friendly.

In the same way, the Programme recommends the assessment of criteria and procedures which ensure that the amounts of product used do not pose a potential danger to the environment. Therefore, written procedures should be established in order to state the conditions of application of these products.

Homogeneous follow-up reports would facilitate the definition of suitable products, doses and mixtures, by being able to draw conclusions from previous campaigns.

11.11 Markus Ammann, SBB AG

IVEG, a flexible tool for weed control

Objective and background

The maintenance of embankments is a key component of rail operating safety. It also has a decisive impact on the growth and composition of vegetation in track areas (especially problem types) and therefore acts as a preventive measure for weed control.

In the middle of the 90s, SBB drew up land registers in different regions detailing embankments, trees and/or wooded areas. Today there are close on twelve such registers, roughly half of which are regularly used by the maintenance services. In 2000, it was decided to amalgamate the existing registers into a uniform system IVEG (=Information Vegetation).

Project

The current IVEG project focuses on trackside embankment and forestry areas requiring supervision and maintenance for operating safety.

The aim is to ensure that data inputting, description and monitoring is carried out in uniform fashion so that maintenance planning in embankment and wooded areas can be carried out more efficiently.

At the same time, an effective auditing tool can be created.

The existing registers are largely available in electronic databases although the larger registers were supplemented with hand-drawn diagrams. All data related to the area (i.e. objects, attributes and plans) is now due to be inputted digitally so that in future it can be compiled, saved, restructured, analysed and outlined more easily and reliably.

In the design phase, the steps and processes as well as the project structure and organisation were defined and the layout of the register laid down as far as is possible.

The project is now due to be implemented in several phases. Firstly all areas not yet included must be captured, with estimates as to the quantity ranging from 50,000 to 100,000 areas. This data-capturing exercise should be completed at the end of 2002. At the same time, there are plans to develop a uniform database which can incorporate and supersede all current databases. A test version should be available as early as the end of 2001.

Lastly, the planning data will be digitised and merged with the object data in a GIS. The plan is to carry this out in the next years.

Funding and deadline

One major stumbling block for the project was securing a clear commitment on funding. The budget for 2001 allowed initial work to be launched, in particular the costly object-capturing exercise. The same budget also covered the development of the database. The first tests revealed that the integration of the object data and the plans was feasible and could be funded and that corresponding benefit could be guaranteed. The planned budget for the coming years (2002 and onwards) includes costs for development of the GIS as well as the digitisation of plans. Following some delay caused by uncertainty surrounding authority and decision-making procedures, problematic IT integration and funding which had not been secured, the deadline was postponed on various occasions. As a result, the current expectation is that production work on IVEG can get under way during the course of 2002 even if the register is not fully completed for another few years.

Prospects

The IVEG project has gained a broad level of acceptability within SBB despite the fact that it is not yet in operation. The system is designed in such a way that it is open for further applications in the field of vegetation and environmental management. Various ideas could take shape, such as the incorporation of the protected woodland and natural hazards register as well as the water protection register, the incorporation of different inventories on protected areas and biotopes, and last but by no means least information on weed control in the track area.

We are convinced that with GIS IVEG we will possess a modern, flexible tool that can be adapted to the future requirements of all facets of weed control.

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APPENDIX

13 Appendix

13.1 Addresses

Interlocutors at the railway companies

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Railtrack PLC Peter Rutt Euston Square, NW 1 2 EE London, England Tel. ++ 44 20 75 57 8439 Fax ++ 44 20 75 57 9050 email: ruttp.railtrack@ems.rail.co.uk	**Slovenian Railways (SZ)** Blagomir Cerne Kolodvorska Ul. 11, 1506 Ljubljana, Slovenia Tel. ++ 386 (61) 2 91 41 99 Fax ++ 386 (61) 2 91 48 13 email: miro.cerne@slo-zeleznice.si
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Appendix 1 - Addresses

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Appendix 1 - Addresses

Peter Zuber (retired) please contact his successor Franco Schiavi UIC, Representing UIC Group "Expert Tracks" Expert at Technical Dept. 16 rue Jean Rey, 75015 Paris France Tel:+ 33 1 44 49 20 67, Fax: + 33 1 44 49 20 69 email: schiavi@uic.asso.fr

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SBB AG **Bahn-Umweltcenter** **Fernande Gächter** Parkterrasse 14, 3000 Berne 65, Switzerland Tel. ++ 41 5 12 20 57 43 Fax ++ 41 5 12 20 44 75 email: fernande.gaechter@sbb.ch	

13.2 Procedures, Questionnaires and Findings

Procedure, Findings and Questionnaire for Step 1

Once the steering group had approved the questionnaire (see below) it was sent to 49 railway companies on 29th May 2000. The aim of this more general questionnaire was to find out which railway companies are engaged in the various fields together with the persons involved as well as to acquire initial information about

- environmental regulations covering chemical vegetation control
- general knowledge about the “need for vegetation control measures”
- measures currently and recently adopted/investigated
- new developments in vegetation control measures

A total of 31 questionnaires were answered and used for the study.

A more specific “need for vegetation control” section was answered by 26 railway companies with at least 14 railways declaring they had experience with this objective.

These 14 companies were selected for Step 2 of Subproject 1.

Appendix 2 – Procedures, Questionnaires and Findings Step 1

Date:
Railway company:
Person to be contacted:
Address :
Tel.
Fax
e-mail:

Questionnaire

Note: This questionnaire is also available in an electronic version (Word file) from fernande.gaechter@sbb.ch

1. What does the legislation in your country prescribe regarding vegetation control and permitted herbicides? (more than one answer possible)

☐ only Glyphosate is allowed

☐ restrictions for ☐ certain herbicides or substances

☐ dosage of herbicides

☐ other restrictions, please name........................

☐ no restrictions

☐ other observations ....

2. Do you think your legislation will be tightened up further in future?

☐ yes, when ....

☐ no

☐ I do not know

3. What are your internal regulations regarding the amount of weed you allow within the track? (more than one answer possible)

☐ no vegetation allowed within the track

☐ a certain amount of vegetation within the track is allowed

☐ no specific regulations

☐ observations ....

4. Describe problems with your internal regulations or your legislation (more than one answer possible).

☐ no clear rules on how much vegetation is allowed in the track area

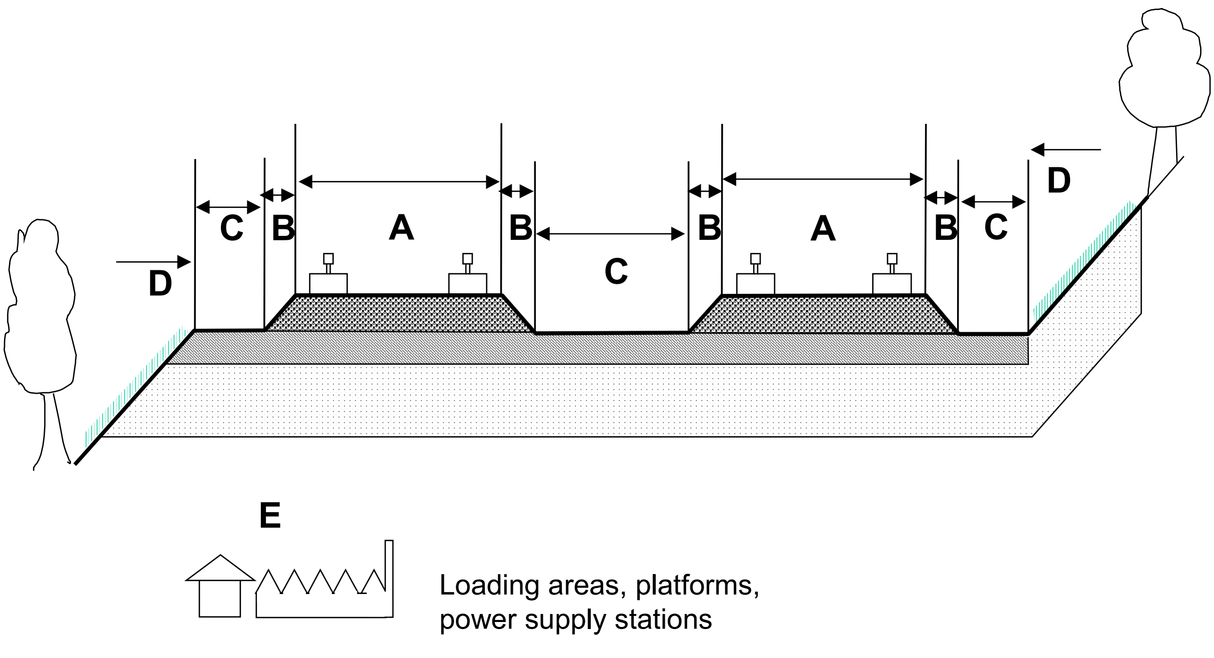
☐ problems complying with environmental legislation

☐ others ....

5. In which areas of your track system (A to E) do you carry out vegetation control methods?

Please mark with (1) for chemical treatment or (2) for other treatment within the specific areas marked on the following sketch

Application Areas of Weed Control Methods - schematic drawing



6. What kind of vegetation control methods were/are used or studied (laboratories, experiments) by your railway company or exist as ideas so far? (more than one answer possible)

Appendix 2 – Procedures, Questionnaires and Findings Step 1

You will find the description of the various methods in the Section entitled ”Definition of Areas of Application and Methods”. The numbers in this list correspond to the numbers in the definitions.

☐ A) Engineering

- ☐ 1 lateral vegetation barriers/objects impeding plant incursions in general
- ☐ 2 thin vertical vegetation barriers
- ☐ 3 plant-inhibiting design of the transition area (Area C, see sketch)
- ☐ 4 porous concrete bars
- ☐ 5 amount and kind of ballast material
- ☐ 6 vegetation barriers beneath the track in general
- ☐ 7 slab track
- ☐ other - please describe ....

☐ B) Biological

- ☐ 8 greening
- ☐ 9 selective embankment maintenance
- ☐ 10 biological vegetation control
- ☐ 11 mowing
- ☐ 12 mulching
- ☐ other - please describe ....

☐ C) Mechanical

- ☐ 13 ballast cleaning
- ☐ 14 replacement of ballast
- ☐ 15 mechanical weeding
- ☐ 16 manual weeding
- ☐ 17 brushing
- ☐ other - please describe ....

☐ D) Chemical

- ☐ 18 back-pack spraying
- ☐ 19 spraying train
- ☐ 20 rail-road vehicles
- ☐ 21 selective application of herbicides (e.g. weed eye)
- ☐ 22 weed wiping
- ☐ other - please describe ....

☐ E) Thermal/electrical

- ☐ 23 burning
- ☐ 24 infrared devices
- ☐ 25 hot steam
- ☐ 26 hot water
- ☐ 27 hot air
- ☐ 28 freezing
- ☐ 29 direct contact with electrical fields
- ☐ 30 microwaves
- ☐ 31 laser
- ☐ 32 UV light

☐ other - please describe ....

7. Does your railway company have experience in one or several of the following fields regarding vegetation control? (more than one answer possible)

☐ necessity of vegetation control (How much vegetation is acceptable within the track?)

☐ optimising and improving the effectiveness of alternative vegetation control methods

☐ vegetation management systems

☐ other ....

8. Do you know of any vegetation control methods applied in other industrial spheres (e.g. agriculture) which might be adapted to railway conditions?

☐ no

☐ if yes, which one and in which sphere

please name ....

You have reached the end of this questionnaire. Thank you for your support. Please send this questionnaire in the envelope enclosed to:

SBB AG, Berne
BahnUmwelt-Center
Frau Fernande Gächter
Parkterrasse 14
CH-3000 Berne 65
Switzerland

Fax. ++41-(0)512-20 44 75
E-mail: fernande.gaechter@sbb.ch

Appendix 2 - Procedure, Findings and Questionnaire of Step 2

Procedure, Findings and Questionnaire of Step 2

Need for vegetation control

Once the questionnaire (see below) had been approved by the steering group, it was sent to 18 railway companies on 24th July 2000. Questionnaires relating to vegetation control measures were sent out at the same time (see below). 18 instead of 14 railway companies were selected for the purpose of clarifying a number of misunderstandings arising from Step 1. The data evaluation itself is based on 12 questionnaires. The findings may be summarised as follows:

The varying intensity of vegetation control treatment seemed to be more or less a result of practical considerations such as the frequency or period of operation of vegetation control measures, their cost and the question of organisation.

Nine railway companies conduct vegetation control by track category, while only 3 do not. Reasons for the latter are the differentiation between open track and station track/ marshalling yards and, in many cases, the period of time since the last constructional measure.

The explanation given for the division into track categories cited potential risks in respect of safety/stability factors. The same importance was drawn to the period/frequency of application. Other points were made concerning the use of different vegetation control measures and maintenance costs.

Reasons cited by all railways for the need for vegetation control are track stability track (main reason) along with safety considerations with regard to staff. Besides these points, guaranteed view of signals, avoiding interference with train running (e. g. braking problems), prevention of fire and flashover at the catenary were ticked as well.

An increase in maintenance costs is anticipated by 50 % of companies if vegetation control is neglected. The other railways stated that they are already noticing an increase.

Most railway companies (10) have no experience in neglecting vegetation control, while only two railways stated that they own track that is not subject to vegetation control measures.

Seven companies indicated that limit values for plant coverage along the track are in place. It was mentioned by six railways that these limits are based on practical experience, while only two named theoretical models for estimating these values. The planning-to-investigate-this-question box was ticked by three companies.

VegetationControl Methods and Combinations

The questionnaire on vegetation control methods (see below) was adapted to each method. It was sent out to 31 railway companies on 24th July 2000. The number of questionnaires sent out differed from method to method. The questionnaire on spraying trains for example was sent out 25 times, others only once or twice.

Findings from the questionnaires are included in the catalogue sheets (see Appendix 13.5).

Appendix 2 - Procedure, Findings and Questionnaire of Step 2

Date: 24.07.2000
Railway Company: «Bahngesellschaft»
Contact person: «Vorname» «Name»
Address: «StraßeNr», «PLZ» «Ort», «Land»
Tel.: «Tel»
Fax: «Fax»
email: «Email»

Questions about the need for vegetation control measures

Note: This questionnaire is also available in an electronic version (Word file) from fernande.gaechter@sbb.ch

1. Do you treat the defined application areas* with varying intensity ? (*see Definitions and Descriptions in the Appendix)

☐ if yes, why? (several answers are possible!)

☐ use of various measures of vegetation control

☐ differing period/frequency of application

☐ economic aspects

☐ shared responsibilities for application areas

☐ other– please name ....

☐ no

2. Do you use a system of track categories when adopting vegetation control measures?

☐ yes ➔ go to question 3

☐ no ➔ go to question 5

3. How do you categorise the track for vegetation control purposes? (several answers are possible!)

☐ open track versus stations/marshalling yards

☐ passenger/cargo transport track

☐ maximum possible speed

☐ length of time since last constructional measure

☐ age of track

☐ other – please name ....

4. How do you explain the division into track categories? (several answers are possible!)

☐ classification in line with potential risk

☐ use of different vegetation control measures

☐ period/frequency of application

☐ economic aspects

☐ other – please name ....

5. Please name reasons explaining the need for vegetation control measures from the point of view of your company. (Several answers are possible!)

☐ safety of workers e.g. walking along or within the track

☐ prevention of fire

☐ guaranteed view of signals

☐ avoid interference with train operation (e. g. braking problems)

☐ flashover at the catenary

☐ guaranteed track stability

☐ measures useful for third parties (e.g. vector for plant diseases, poisonous plant, other effects on areas not belonging to railways)

☐ other – please name ....

6. If vegetation control is neglected does your railway company expect an additional increase in general maintenance expenses over time?

☐ yes, we have already observed this tendency

☐ yes, we do expect an increase

☐ no, we do not expect an increase

7. Is there any track which your company does not subject to vegetation control measures?

☐ yes

☐ no ➔ go to question 9

8. What has been your company’s experience with such untreated track?

☐ life-cycle of the track is reduced

☐ greater costs incurred for repair measures

☐ no effect on the life-cycle of the track

☐ I do not know

9. Do you have internal railway regulations covering the adoption of vegetation control measures?

☐ yes

☐ no ➔ go to question 12

10. What is covered by your regulations for vegetation control?

☐ specific measures/ application techniques for specific areas

☐ frequency/period of treatment

☐ areas to treat

☐ other – please name ....

11. Why did your company issue internal regulations for vegetation control (more than one answer possible)?

☐ to comply with legislation

☐ to define clear rules for contractors who carry out vegetation control

☐ to define clear rules for our own workers who carry out vegetation control

☐ others, please describe ....

12. Do you have limit values in respect of the allowed plant coverage within the track?

☐ yes

☐ no ➔ go to question 14

13. How did your company estimate these limit values?

☐ special studies within selected track

☐ theoretical models

☐ practical experience

☐ other – please name ....

14. Does or did your company ever run research projects on “Problems caused by vegetation growth along the track”?

☐ if yes, are these studies

☐ planned

☐ still running, expected to be completed in ....

☐ already concluded

☐ no

15. Do you think that vegetation control is accorded the proper priority within your company ?

☐ no

☐ yes ➔ go to question 17

16. Please name reasons for the “low priority” vegetation control is accorded. (more than one answer possible)

☐ financial restrictions

☐ lack of information about the consequences of plant growth in railway areas

☐ results of measures/methods used not as desired

☐ environmental regulations meet the minimum standard

☐ other, please name ....

You have reached the end of this questionnaire. Thank you for your support. Please send this questionnaire in the envelope enclosed to:

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CH-3000 Berne 65
Switzerland

Fax. ++41-(0)512-20 44 75
E-mail: fernande.gaechter@sbb.ch

Please use the space below for any observations and comments you may have.

Date: 24.07.2000
Railway Company: «Bahngesellschaft»
Contact person: «Vorname» «Name»
Address: «StraßeNr», «PLZ» «Ort», «Land»
Tel.: «Tel»
Fax: «Fax»
email: «Email»

Questions about methods and procedures

Note: This questionnaire is also available in an electronic version (Word file) from fernande.gaechter@sbb.ch

Short description of method/procedure:

Please complete or change the description of the method/procedure

....

....

....

....

....

....

Appendix 2 - Procedure, Findings and Questionnaire of Step 2

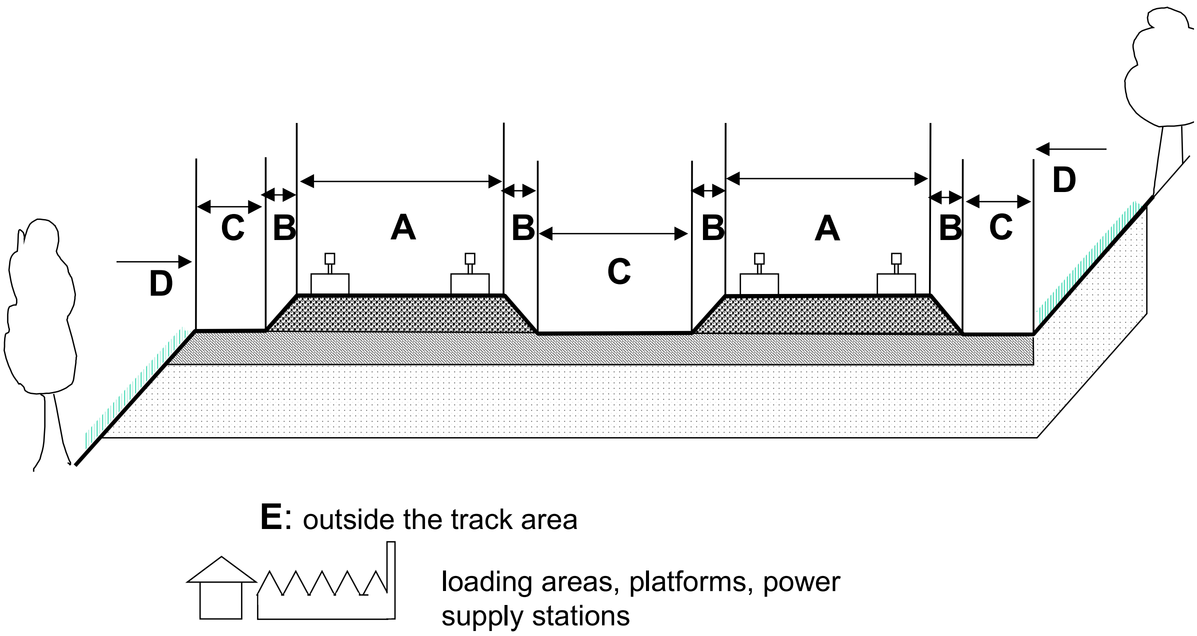
Please provide a sketch of your method or enclose a Figure if available

Appendix 2 - Procedure, Findings and Questionnaire of Step 2

Area of application

Where do you apply the method/procedure? –please mark the area of application on this sketch

Application Areas of Weed Control Methods - schematic drawing



2. How long have you been using this method/procedure?

☐ regular use for ..... years

☐ used on an experimental basis for ..... years

☐ not used any longer

☐ not used

☐ experimental stages planned for this method/procedure

☐ we are not cognisant with method/procedure ➔ go to question 20

3. How many line-kilometres[4] do you treat with this method?

☐ < 5 km

☐ 5 – 10 km

☐ 10 – 25 km

☐ 25 – 50 km

☐ 50 – 100 km

☐ > 100 km

4. Are there plants that cannot be adequately dealt with using this method/procedure?

☐ if yes, which plant(s)

☐ horsetail *(Equisetum sp.)*

☐ brambles *(Rubus sp.)*

☐ reeds *(Phragmites sp.)*

☐ Japanese knotgrass *(Reynnoutria japonica)*

☐ cranesbill, herb robert *(Geranium sp.)*

☐ others, please name..

☐ no

5. For which type of plant and at what stage of plant growth does this method/procedure show no or insufficient effects (more than one answer possible)?

☐ herb

☐ seedling

☐ young plant

☐ adult plant

☐ shrub or tree

☐ seedling

☐ young plant

☐ adult plant

[4] line kilometre: distance between two places regardless of number of tracks

6. As part of which activity do you use this method/procedure? (more than one answer possible)

☐ construction of new railway lines

☐ renewal/re-construction(replacement of ballast, sleepers, track)

☐ maintenance

☐ others – please specify ....

7. To apply this method where does the track have to be located?

☐ on a bank

☐ on the flat

☐ in a cutting

☐ can be used everywhere

☐ others – please specify................................

Point of time and period of treatment

8. What is the average frequency for the application of this treatment ?

☐ less than every 2 years

☐ every 2 years

☐ once a year

☐ twice a year

☐ two to four times a year

☐ more than four times a year

☐ irregularly, as required

9. How long is the average life cycle of this measure if it is adopted ....

☐ when lines are built: .... years

☐ when lines are relaid (replacement of ballast, sleepers, track): .... years

☐ other– please specify...................... years

Conditions for use

10. During what season do you use this method/procedure ? (more than one answer possible)

☐ spring

☐ summer

☐ fall/autumn

☐ winter

☐ immaterial

11. Do you use this method/procedure in combination with any other methods/procedures?

☐ if yes, with which one (please name) ....

☐ no → go to question 13

12. Why do you use this combination of methods? (more than one answer possible) This combination is

☐ imperative, to obtain the desired effect

☐ desirable, to obtain a better effect

☐ economically appropriate, to lower the total costs of vegetation control

☐ others – please note: ....

13. Does application of this method/procedure necessitate a temporary interruption of train services?

☐ yes ☐ total track possession (all tracks)

☐ partial track possession (only one track if more than one exists)

☐ restricted train services possible (temporary speed restriction)

☐ method/procedure used when trains not running

☐ only

☐ partly

☐ no

Technical conditions

14. Does application of this method/procedure require track-bound vehicles only?

☐ yes

☐ no

☐ application from track as well as from outside the track possible

15. What is the average operating speed for this method/procedure? (values in track-kilometres[5])

☐ < 1 km/h

☐ 1 – 5 km/h

☐ 5 – 10 km/h

☐ 10 –20 km/h

☐ 20 – 40 km/h

---

[5] track kilometre: distance between two places on one track

☐ > 40 km/h

16. Please state the area that can be treated in one hour (exclusive of time for installation and de-installation of machines and component parts) ....m^2/h.

How much time is needed for the installation and de-installation of machines and component parts for one application?

approximately .... h per session

Costs

18. Please state the total costs when applying the method/procedure (give in €)[6]?

☐ if only adopted on one side of the track

.... € per km track

€ per m^2 ....

☐ if adopted on both sides of the track

.... € per km track

€ per m^2 ....

Effects on the environment

19. Which of the following may be affected by the application of this method? (more than one answer possible)

☐ air

☐ water

☐ soil

☐ animals

☐ plants, other than target plants

☐ human health

---

[6] Adapt to country to which questionnaires are being sent

Currency	**Exchange Rate**	**Currency**	**Exchange Rate**
	for 1 € =		for 1 € =
Belgium	40.3399	Luxembourg	40.3399
Germany	1.95583	Netherlands	2.20371
Spain	166.386	Austria	13.7603
France	6.55957	Portugal	200.482
Ireland	0.787564	Finland	5.94573
Italy	1936.27		

20. You have reached the end of this questionnaire. Thank you for your support. Please send this questionnaire in the envelope enclosed to:

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BahnUmwelt-Center
Frau Fernande Gächter
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CH-3000 Berne 65
Switzerland
Fax. ++41-(0)512-20 44 75
E-mail: fernande.gaechter@sbb.ch

Please use the space below for any observations and comments you may have.

Appendix 2 - Procedure, Findings and Questionnaire of Step 3

Procedure, Findings and Questionnaire of Step 3

In a third step, 20 railway companies received a letter or an email containing specific questions relating to problems or misunderstandings arising from the previous steps either as regards the need for vegetation control or the vegetation control methods themselves. 16 companies responded to these questions. This information has likewise been worked into the report.

13.3 Plants

Type of propagation [114, 98]

Botanical Name	***Main type of propagation***
Amaranth *(*Amaranthus retroflexus*)*	Seeds
Ash *(Fraxinus excelsior)*	Seeds
Bindweed (Convolvulus arvensis)	Over-ground runners
Birch (*Betula species)*	Seeds
Blackberry (*Rubus sp.)*	Over-ground runners
Broad-leaved dock (*Rumex obtusifolius*)	Seeds
Cinquefoil *(Potentilla repens)*	Over-ground runners/seeds
Cranesbill (*Geranium robertianum, Geranium purpureum)*	Seeds
Dandelion *(Traxacum* off.*)*	Seeds
False acacia *(Robinia pseudoacacia)*	Seeds
Giant hogweed *(Heracleum mantegazzianum)*	Seeds
Golden rod *(Solidago canadensis)*	Seeds
Grasses *(Graminae)*	Seeds
Horsetail *(Equisetum arvense)*	Underground runners
Horseweed *(Erigeron canadensis)*	Seeds
Ivy *(Hedera helix)*	Over-ground runners
Japanese knotgrass *(Reynnoutria japonica)*	Underground runners/over-ground runners
Ladies bedstraw *(Galium verum)*	Seeds
Lilac *(Buddleia davidii)*	Seeds
Melilot *(Melilotus alba)*	Seeds
Northern bedstraw *(Galium boreale)*	Seeds
Old man’s beard *(Clematis vitalba)*	Over-ground runners/seeds
Quack grass *(Agropyron repens)*	Underground runners/seeds
Ragwort *(Senecio jacobaea)*	Seeds
Rape *(Brassica napus)*	Seeds
Reeds *(Phragmites sp.)*	Underground runners/over-ground runners
Sedges *(Carex sp.)*	Underground runners
St. John’s wort *(Hypericum perforatum)*	Seeds
Thistle *(Cirsium arvense)*	Seeds
Waybread *(Plantago major)*	Seeds
Willow *(Salix sp.)*	Seeds
Yarrow *(Achillea millefolium)*	Seeds

Appendix 3 - Plants - List of Plant Names

List of Plant Names

Plants names			
Latin	English	French	German
Achillea millefolium	Yarrow	Achillée	Gemeine Schafgarbe
Agropyron repens	Quack grass	Chiendent rampant	Gemeine Quecke
Amaranthus retroflexus	Amaranth	Vulpin	Gekrümmter Fuchsschwanz
Betula species	Birch	Bouleau	Birken
Brassica napus	Rape	Colza	Raps
Buddleia davidii	Lilac	Lilas	Flieder
Carex sp.	Sedges	Laîches	Seggen
Cirsium arvense	Thistle	Chardon	Distel
Clematis vitalba	Old man's beard	Clématite vigne blanche	Waldrebe
Convolvulus arvensis	Bindweed	Liseron	Winde
Equisetum arvense	Horsetail	Prèle	Schachtelhalm
Erigeron canadensis	Horseweed, Canadian fleabane	Vergerette du Canada	Kanadisches Berufkraut
Fraxinus excelsior	Ash	Frêne	Esche
Galium boreale	Northern bedstraw	Gaillet boréal	Nördliches Labkraut
Galium verum	Ladies bedstraw	Gaillet vrai	Echtes Labkraut
Geranium sp.	Cranesbill	Géranium	Storchschnabel
Graminae	Grasses	Graminées	Gräser
Hedera helix	Ivy	Lierre	Efeu
Heracleum mantegazzianum	Giant hogweed	Acanthe gigantesque	Riesenbärenklau
Hypericum perforatum	St. John's wort	Millepertuis	Johanniskraut
Impatiens glandulifera	Himalayan balsam	Impatiente glanduleuse	Drüsiges Springkraut
Melilotus alba	White melilot	Mélilot	Weißer Steinklee
Phragmites sp.	Reeds	Roseau	Schilf
Plantago major	Waybread	Plantain	Wegerich
Potentilla repens	Cinquefoil	Quintefeuille	Fingerkraut
Reynnoutria japonica	Japanese knotgrass, Japanese knotweed	Renouée de Japon	Japanischer Staudenknöterich
Robinia pseudoacacia	False acacia	Acacia	Robinie
Rubus sp.	Brambles, Blackberry	Mûre sauvage	Brombeeren
Rumex obtusifolius	Broad-leaved dock	Rumex à feuilles obtuses	Stumpfblättriger Ampfer
Salix sp.	Willow	Saule	Weide
Senecio inaequidens	Narrow-leaved	Séneçon sud-africain	Südafrik. Greiskraut

Appendix 3 - Plants - List of Plant Names

Plants names			
Latin	English	French	German
	Ragwort		
Senecio jacobaea	Common Ragwort	Senecon de Jacob	Jakobs-Greiskraut
Solidago canadensis	Golden rod	Solidage du Canada	Goldrute
Traxacum officinale	Dandelion	Pissenlit	Löwenzahn

13.4 Experience of Railway Companies

The following table gives an overview of railway companies with experience of the various methods. Some railway companies use the methods listed below without classifying them as vegetation control methods. The primary reason for adopting these methods is not vegetation control.

Note: The table also includes measures used by railway companies predominantly for maintenance reasons that incidentally have an effect on plants as well.

No.	*Method*	*Railway Company with Experience on Method*
M1	Lateral plant barriers/objects impeding plant incursion	JBV, SBB, FS
M2	Thin vertical barriers	no data sheets, included in M1
M3	Plant-inhibiting design of the transition area (Area C)	DB AG, SBB
M4	Porous concrete barriers	SBB
M5	Amount and kind of ballast material	BV, RIB, SBB
M6	Plant barriers beneath the track in general	BV, RIB, MAV, GySEV, SNCB, SBB
M7	Slab track	DB AG
M8	Greening (with non in-growing plants)	SNCF, RIB, BV, MAV, GySEV, SBB
M9	Selective embankment maintenance	SNCB, RIB, JBV, RT, QR, SBB
M10	Biological weed control	no data sheets
M11	Mowing	JZ, SNCB, DB AG; MAV, GySEV, ZSR, JR, QR, LDZ, RIB, SNCF, SBB, BS
M12	Mulching	DB AG, LDZ, MAV, GySEV, SBB
M33	Greening with allelopathic plants	DB AG
M13	and M14 Ballast cleaning and replacement	Ballast cleaning: CNCF, DB AG, RT, MAV, GySEV, BV, LDZ, RIB SBB, BS Replacement of ballast: LDZ, DB AG , SBB
M15	Mechanical weeding	DB AG, BV, RIB, CNCF SBB, BS
M16	Manual weeding	DB AG, BV, LDZ, LG, BDZ, RIB, JZ, SZ, MAV, GySEV, CNCF, SBB
M17	Brushing	BV, SBB
M18	Back-pack spraying	JZ, SNCB, DB AG, RT, LG, GySEV, BDZ, ZSR, QR, RIB, SBB, BS
M19	Spraying train	CNCF CFR SA; CD; SZ; JZ; SNCB/NNBS; DB AG; RT, BS; BV; LG; GySEV AG, BDZ; ZSR; JBV; LDZ; SNCF
M20	Rail-road vehicle	SNCB, DB AG, GySEV, JR, QR, SNCF
M21	Selective application by spraying train (e. g. ”weed eye”)	DB AG, BS, GySEV[1)], CH[1)], BDZ[1)]
M22	Weed wiping	BV, QR
M23	Flaming	SBB, BV, BS

M24	Infrared devices	DB AG, SBB
M25	Wet steaming	DB AG, BV, JZ, SBB, BS, CP
M26	Hot water treatment	BV, SBB
M27	Hot air	BV
M28	Freezing	BV, DB AG
M34	Hot foam	None, only experiments by University of Hohenheim, Bremen airport
M29	Direct electrical contact	SBB
M30	Microwaves	DB AG, SBB
M31	Laser	BS
M32	UV light	BV
[1] Possibly, the questionnaire was not fully understood in the first step, because no further information was received on these systems		

13.5 Details of the Various Vegetation Control Methods

The following Subsection catalogues all vegetation control methods currently known. These methods are listed regardless of whether they are used or not. The actual knowledge of each method is described in detail on a separate catalogue sheet. The catalogue structure and the detailed explanation of the various points is shown below. The catalogue sheets are sorted according to the category and numbering as in Table 8 on Page 53. The category itself is explained in Section 7.

13.5.1 Catalogue Sheets: Introduction

The data in the following catalogue sheets are based on a UIC survey [114] and the study of literature available mostly in German, English and French (see Literature on Page 92). Data are not interpreted in any way.

Some railway companies use the methods listed below without classifying them as vegetation control methods. The primary reason for their being adopted does not relate to vegetation control.

Category	Engineering, mechanical, biological, chemical or thermal/electrical method as described in the Section entitled "Overview of the various methods".
Name of method	
Description	Also contains variations on method, e.g. the use of different devices. Descriptions are general and do not give account to whether manufacturers actually produce given devices.
Effect of method on plants	Describes the aim of this method, i.e. to combat symptoms or prevent the growth of unwanted plant species. Methods may, for example, cut, burn or freeze existing plants or else prohibit their growth by removing nutrients or water from the site.
Drawings and/or pictures	To explain details of certain methods a picture or a drawing is helpful. This can be found in Appendix **14**.
Main application (vegetation control or vegetation control as a side-effect)	Some methods are not used for vegetation control reasons only, but their use has a positive side-effect on vegetation control. It might have an even bigger effect on vegetation if this fact is taken into consideration when using or developing this method.
Railway companies which have experience with this method	This information will give railway companies the chance to get in touch with others if specific problems exist in respect of specific vegetation control methods. It may help solutions to be found or ideas exchanged.
Experience of railway companies	Degree of experience based on line-km treated. To give a rough idea, line-km information is divided into categories. "Used on more than 100km" normally means a lot of experience.
1. Technical data	
Track-bound/non track-bound	Whether a method is conducted from the track or from outside the track has an influence on the occupation of a line and therefore on costs.

Appendix 5 - Details of the Various Vegetation Control Methods

Operating speed (km/h)	This point is mentioned for methods always covering the same area or having a fixed treatment range The faster the better. The slower the method, the more expensive it is (especially if track-bound) and the greater the outlay on personnel, which in turn has an effect on costs.
Installation and de-installation time per session	The higher the installation time the higher the operating costs (especially if the method is track-bound). It includes the working time needed to get the machine ready for operation and to close it down after work (de-installation).
2. Vegetation controlVegetation control areas	
Defined areas A to E	The various track areas have differing demands in respect of plant treatment. Thus, some methods suit some areas better than others. Methods are usually developed for specific problems in specific areas. A sketch clarifying the areas can be found in → Part A of the Report In some cases (where only one kind of device exists) use of a device is dependent on a given lie of the track (e. g. on a bank, in a inciscion or only on the flat). Not all devices can be used everywhere. This point gives information about the needs for development of the device in question.
Station areas or open line	There are different visual and operational demands for station areas than for open line. Hence the devices used for stations and open line may vary.
Used in areas where chemical vegetation control is prohibited, e. g. groundwater protection zones	Some methods are not allowed in certain areas of railway infrastructure, for environmental or other reasons (e. g. no herbicides in groundwater protection zones, no use in stations).
3. Vegetation controlVegetation control conditions	
Application in combination with other methods useful/necessary	Appropriate combinations of methods can lead to longer-lasting effects against plants or reduce costs. The most common and promising combinations as defined under Subsection 6.3 are marked in *italics.*
Period of application during the year/day	Some methods of vegetation control need to be adopted at a certain time to be most effective. They may depend on climatic conditions (cold, hot) or the stage of development of the vegetation (season).
Weather conditions	Some methods need specific weather conditions to produce a satisfactory effect (e. g. no rain). The less dependent on weather conditions a method is, the better, since this makes planning easier.
Treatable growth stage	This information also has an effect on the frequency of application of this method. For example: The method is only very effective on seedlings, therefore this method should only be applied while plants are young.
Treatable plants – problem plants → see also Subsection 4.2.3 and Section 8	Problem plants (= not treatable with the method described) usually need a special treatment focusing on the aim to kill or reduce the problem plant species in certain areas. An overview of plant names in English, French, German and Latin can be found in Appendix 3.
Duration of effects	The longer a constructional method remains effective, the better its life cycle costs.

Appendix 5 - Details of the Various Vegetation Control Methods

Frequency of application	Shows how often a method is applied. The greater the frequency, the greater the cost over a given period of time.
Impact on services (temporary/ permanent track possession)	As mentioned above, this point relates to whether a method is performed from the track or from outside the track and hence to whether a (temporary) halting of traffic is needed.
4. Costs	
see also Subsection 6.2	
per km (one or both sides)	This point is mentioned if the method has a fixed range of treatment.
per m^2	This point is mentioned if the method involves a variable breadth of treatment and thus variable coverage.
Internal costs	Costs incurred/paid for own railway company workers. May still be incurred if work is carried out by an external company. Only few companies have as yet begun putting new control mechanisms in place for costs. Thus, these data are not available yet.
Division into machine, personnel costs etc.	To permit better comparison of costs in different countries, it is worthwhile breaking total costs down in their constituent parts, e.g. those relating to, respectively, the machine itself, wages and supplies. Only few companies have as yet begun putting new control mechanisms in place for costs. Thus, these data are not available yet.
Life Cycle Costs (LCC)	Total cost of a machine from production to decommissioning. If divided by the expected life span of the machine, they are more readily comparable with, for instance, constructional methods (see annual costs). Only few companies have as yet begun putting new control mechanisms in place for costs. Thus, these data are not available yet.
Costs when combined with another method	Some methods are used less frequently when combined. This has an effect on costs.
Annual costs	Costs for using the method over a year. The initial costs for construction have to be divided by the expected lifespan of the method.
5. Environmental effects	
Chemical methods: There was no distinction made between the herbicides used and the methods of applying the herbicides. Thus, the environmental effects mentioned by railways may also refer to the effects of herbicides and not just of the methods adopted.	
Known toxic effects	Details of known toxic effects on humans and other creatures
Safety of staff	The safety of staff may be a reason for not adopting this method.
Others	Other environmental impacts are mentioned, e. g. noise, vibration,...
6. Observations	
Observations on advantages and negative effects and other details entered here.	

Appendix 5 - ConstructionalMethods - M1 Lateral plant barriers/objects impeding plant incursion

13.5.2 ConstructionalMethods

M1 Lateral plant barriers/objects impeding plant incursion

Category	Engineering
Name of method	**Lateral plant barriers/objects impeding plant incursion**
Description	Plant incursion can be avoided by means of: - suitably positioned cable troughs (JBV [114], SBB [55], FS [34]) - concrete bars (SBB) (Ribbert system) [83] - concrete step blocks (SBB [11], FS [34]) - well built and maintained parts of the transition areas (SBB) [13, 78], see also M3 - porous concrete barriers (SBB) see M4 - different materials in the transition area (DB AG [114], SBB) see M3.
Effect of method on plants	Method of prevention; hinders plants from growing into the transition area and from there into the ballast area from the side of the surface
Drawings and/or pictures	See Appendix **14**
Main application (vegetation control or vegetation control as a side-effect)	Main application: concrete step blocks instead of cable troughs. Side-effect: well built and maintained parts of the transition areas (when constructing pathways), suitably positioned cable troughs, rehabilitation of pathways (concrete bars)
Railway companies which have experience with this method	JBV [114], SBB, FS [34]
Experience of railway companies	Regularly used for 3 to 5 years (JBV [114]) used on experimental basis for 8 years (SBB) and regular used (suitably positioned cable troughs) for over 10 years (SBB) used on 25 to 50km (JBV [114]), used on over 100 km (SBB)
1. Technical data	
Operating speed, track-bound/non track-bound,..	This is an constructional method, hence these data are not applicable
2. Vegetation control areas	
Defined areas A to E	Transition area (C) (JBV [114], SBB), used both for banks and cuttings [114]
Station areas or open line	on open line
3. Vegetation control conditions	
Application in combination with other methods useful/necessary	*Mowing and mulching on the embankment*, design of transition area, barriers beneath track to obtain desired effect (SBB), *with herbicides* to obtain a better effect (JBV [114])
Period of application during the year/day	built all year round except in winter time (JBV [114])
Treatable plants – problem plants	Not enough experience yet (JBV) [114] Hinders plants from growing into the ballast on the surface (SBB) [10, 78], step blocks: problem of willows growing into

	drainage elements, can be solved technically (SBB [11])
Duration of effects	Average life-cycle to last more than 5 years (SBB) average life cycle estimated to be about 10 years after new-build and re-construction for thin vertical barriers [114]
Impact on services (temporary/ permanent track possession)	Constructed during periods free of traffic only ([SBB], train operation is restricted [temporary speed restriction]) (JBV [114], SBB)
4. Costs [7]	
per km (one or both sides)	35,000 €/km on both sides for cable troughs (JBV [114]) but no extra cost for vegetation control, concrete bars (Ribbert system): 133,000-145,000 €/km (lookouts and gravel excluded) (SBB, 1992 [83]), concrete step blocks 350,000 €/km (SBB, 1990 [27]), for lateral plant barriers in general 200,000 - 500,000 €/km (SBB [101])
5. Environmental effects	
Known toxic effects	None
6. Observations	
When building lateral plant barriers good drainage should still be possible [101].	

M2 Thin vertical plant barriers

Thin vertical plant barriers can also be understood as lateral plant barriers/objects impeding plant incursion. Thus, this method is integrated into M1 “Lateral plant barriers”.

[7] Excludes internal costs, cf. points made in Subsection 6.2

Appendix 5 - ConstructionalMethods - M3 Plant-Inhibiting Design of the Transition Area (Area C)

M3 Plant-inhibiting design of the transition area (Area C)

Category	Engineering
Name of method	**Plant-inhibiting design of the transition area (Area C)**
Description	Transition area (Area C) near the ballast shoulder (Area B) is designed with a highly compacted top layer consisting of fine material such as gravel. It has a smooth surface and inhibits plant growth. Drainage is still guaranteed. In the sub-layers a drainage layer is constructed using foils or geo-textiles. (e.g. plant barriers beneath the track M6, porous concrete barriers M4) *Materials* with more extreme growth-resistant properties can be used for construction in transition area (pathways) (Area C): - chippings of recycled glass (SBB) [101] - gravel made of calcium-free silicate (SBB) [101] - pathways (transition areas) made of ballast (SBB) [101] Investigations by DB AG [6] with different materials and constructions in Area C (pathways); requirements: drainage and walking stability - macadam layer with and without Preventol (growth inhibitor); thickness of approx. 5 and 10 cm - lysit layer, white gravel material 2 to 5 and 5 to 8 mm in size; thickness approx. 5 cm - basalt/granite layer, dark gravel material 2 to 5 and 5 to 8 mm in size; thickness approx. 5 cm - layers of *Schmelzkammergranulat* (a glass material from charcoal incineration) in combination with root-inhibiting fleece; thickness 5 cm beneath and 15 cm above the fleece without root-inhibiting fleece approx. 20 cm thick with polyethylene foil; thickness 5 cm beneath and 15 cm above the foil - layers of original covering material above a polyethylene foil (1 mm thick); thickness of original material 3 to 5 cm above the foil - Regupol (recycled rubber material with pores for drainage) type 6510 and 1008 FH; thickness 8 and 10 mm *Properties*: smooth surface that slopes down towards the outside [101] Porous concrete barrier (SBB) see M4, and plant barriers beneath the track in general (see M6) can also be used. Adjacent to the transition area, a plant-inhibiting design of the embankment (SBB) [11] has an additional effect (see also Biological Methods M8 Greening (with non in-growing plants)).
Effect of method on plants	Method of prevention, hinders plants from growing into the transition area and spreading into the ballast area A 200-300mm layer of *gravel* does not stop perennial plants (BV [114])

Appendix 5 - ConstructionalMethods - M3 Plant-Inhibiting Design of the Transition Area (Area C)

Drawings and/or pictures	See Appendix **14**
Main application (vegetation control or vegetation control as a side-effect)	Side-effect when constructing or renewing pathways
Railway companies which have experience with this method	DB AG [114], SBB [82]
Experience of railway companies	Used as an experiment for 3 years on less than 5km (DB AG [114]), chippings of recycled glass (SBB [82]) used in experiments [101], plant-inhibiting design of the embankment (SBB) used in experiments for 10 years (SBB) [11]
1. Technical data	
Operating speed, track-bound/non track-bound,..	This is an constructional method, hence these data are not applicable
2. Vegetation control areas	
Defined areas A to E	Used in the transition area (C) (DB AG [114]; SBB [11]) and on pathways (DB AG [114]), used on the embankment (Area D) (plant-inhibiting design (SBB [11]), suitable both for banks and cuttings [114]
Station areas or open line	Mainly built on open line (DB AG [114], SBB [11]) and in rail yards (DB AG [114])
Used in areas where chemical vegetation control is prohibited, e. g. groundwater protection zones	Yes, can be built in water-conservation zones depending on the material used (e. g. groundwater protection law for recycled materials in Switzerland)
3. Vegetation control conditions	
Application in combination with other methods useful/necessary	Ballast cleaning or changing to obtain a better effect (SBB [82]), *mowing of the adjacent embankment* to prevent the in-growing of above-soil runners of plants such as brambles. When mowing or mulching the embankment, avoid leaving plant detritus in the transition area (SBB [82]) Combination with *herbicides in the ballast area* (ballast bed and ballast shoulder) to obtain a better effect (DB AG [114], SBB [56]),
Period of application during the year/day	Can be built all year round except in winter time (DB AG [114])
Treatable plants – problem plants	Horsetail can grow through some of the materials used in the transition area (DB AG [114]) SBB: horsetail, reeds, Japanese knotgrass can grow through materials such as ballast, glass sand [80], not effective against plants growing up from below [101].
Duration of effects	Average life-cycle estimated to be five years regardless of whether new-build or relaid (DB [114])
Impact on services (temporary/ permanent track possession)	Constructed during periods free of traffic only, train operation is restricted (temporary speed restriction) (DB AG [114]), as normal construction section with temporary speed restriction

	or during periods free of traffic only (SBB)
4. Costs [8]	
per km (one or both sides)	Design of the transition area: 15,000-20,000 €/km on both sides (SBB) [101]
5. Environmental effects	
Known toxic effects	None
6. Observations	
It is important to conduct constructional methods carefully. When renewing the transition area a renewal of the ballast bed is also useful. If the ballast bed is still contaminated, this dirt can be washed out into the transition area. Especially the overlaid parts of foils have to be constructed carefully Smooth surface that slopes down towards the outside (additional advantage that almost no organic matter can settle on it) [101] *Glass chippings* have the disadvantage of not being pleasant to walk on, they are not effective against plants growing up from below. *Pathways (transition areas) made of ballast*: not recommended, because too much effort is needed for maintenance (manual weeding, mowing is not possible) [101], if ballast used, it has to be clean and a cover with finer gravel is recommended, drainage should still be possible (SBB) *Schmelzkammergranulat*: disadvantage of not being pleasant to walk on [87] All materials and constructions are still under investigation (at DB AG), hence it is not possible to draw final conclusions. A more general finding: the greater the exposure to sunlight, the better the results in respect of absence of plants. All materials seem to be penetrated by horsetail.	

[8] Exclusive of internal costs, cf. points made in Subsection 6.2

Appendix 5 - ConstructionalMethods - M4 Porous Concrete Barriers

M4 Porous concrete barriers

Category	Engineering
Name of method	**Porous concrete barriers**
Description	Drainage system located alongside the track in a ditch, ditch filled with round gravel and special drainage material, it combines construction of pathways and vertical plant barrier to avoid plant growth, retention of stones by means of steel netting has roughly the same function.
Effect of method on plants	Method of prevention, hinders plants from growing into the ballast area from the side via sub-soil, provides good drainage and therefore a bad habitat for plants, some materials are not effective against in-growing plants from below (e.g. reeds or horsetail)
Drawings and/or pictures	See Appendix **14**
Main application (vegetation control or vegetation control as a side-effect)	Drainage to the side and stability of the ballast bed [77, 99]. Is used mainly in re-constructions
Railway companies which have experience with this method	SBB
Experience of railway companies	Since 1991 (SBB [80])
1. Technical data	
Operating speed, track-bound/non track-bound,..	This is an constructional method, hence these data are not applicable
2. Vegetation control areas	
Defined areas A to E	Transition area (C) adjacent to the ballast shoulder (Area B) (SBB), suitable both for banks and cuttings, can also be used to raise the pathway (SBB)
Station areas or open line	Open line (SBB)
Used in areas where chemical vegetation control is prohibited, e. g. groundwater protection zones	Yes, possible
3. Vegetation control conditions	
Application in combination with other methods useful/necessary	*Mowing* of the adjacent area SBB [77, 99])
Weather conditions	Good weather conditions preferred, not applied in hot or rainy weather because slabs may work loose [77]
Treatable plants – problem plants	If adjacent transition area is not maintained regularly and close to the outer edge of the barrier, plants growing on the surface (such as horsetail or brambles) are able to reach the ballast area, careful execution of construction without any residual dirt (soil) is important as well [56]
Duration of effects	efficient barrier against in-growing plants for more than 5 years (no more data analysed yet) [56]
4. Costs[9]	
per km (one or both sides)	100,000 – 200,000 €/km on one side (1995), for construction only [77]

[9] Exclusive of internal costs, cf. points made in Subsection 6.2

	80,000 €/km (1991) material, work included, without cost for closing of track [55]
5. Environmental effects	
Known toxic effects	None
6. Observations	
First step, construction of porous concrete barriers, then cleaning of ballast or relaying, edges of porous concrete barriers should be at the same level as the adjacent transition area in order to be able to mow properly, mowing helps to keep plant incursions on the surface down [56] After construction, a quick greening of the soil is necessary to achieve the vegetation desired. [77, 99] Maintenance: ensure coarse pores remain free of dirt. [55]. To this end, several covering layers might be an option. Additional advantage of this constructional method: enhanced stability (SBB)	

Appendix 5 - ConstructionalMethods - M5 Amount and Kind of Ballast Material

M5 Amount and Kind of Ballast Material

Category	Engineering
Name of method	**Amount and kind of ballast material**
Description	The amount of ballast and the quality of the material (e.g. not contaminated, free of lime) have an influence on plant growth. Quality regulations for ballast material exist at different companies (see M13/14 ballast replacement/ cleaning), but only some enhance the correlation between ballast quality and the speed of colonisation by plants. This method is also related to the methods of ballast cleaning and replacement, see also M13/M14 *Quality criteria for ballast:* - ballast needs a certain granular gradation to guarantee high compaction density (SBB [90]) - ballast quality has a preventive influence on germinating plants. It should be clean, have a geological homogeneity and a certain hardness. Good damping to minimise vibration is also recommended (JBV [51]) - Ballast quality: free from earth, free from pieces of plants and other contamination (BV [114]) *Amount of ballast:* The thickness of the ballast layer must be at least 30cm to stop seeds from growing through.(BV [114]) A ballast layer of 25-30 cm usually helps against the plants growing from below (JBV [68]). Vegetation control requirements do not have any influence on criteria for the quality of ballast (RIB [114])
Effect of method on plants	Method of prevention. Material which does not decay quickly inhibits plant growth for a longer time. Thus, the accumulation of fine material is slower, only material brought in from outside the track has any effect. Non-indigenous stones in a specific area can also have a plant-inhibiting effect (the plants are not adapted to these nutrients).
Drawings and/or pictures	See Appendix **14**
Main application (vegetation control or vegetation control as a side-effect)	Side-effect when building or renewing track (cleaning and replacing ballast) see also Method M13/24 ballast cleaning/replacement
Railway companies which have experience with this method	BV, RIB [114]
Experience of railway companies	Used regularly for 30 years on over 100 km (RIB [114]), on experimental sites for 2 years on less than 5km (BV) [114]
1. Technical data	
Operating speed, track-bound/non track-bound,..	This is an constructional method, hence these data are not applicable
2. Vegetation control areas	
Defined areas A to E	Choice of ballast material for ballast bed (A) and the ballast shoulder (B).
3. Vegetation control conditions	

Appendix 5 - ConstructionalMethods - M5 Amount and Kind of Ballast Material

Application in combination with other methods useful/necessary	Membranes beneath the ballast to obtain a better effect (RIB [114]) *ballast cleaning, replacement* (SBB)
Treatable plants – problem plants	Seed-dispersing plants should grow more slowly (BV [114]), not effective against plants growing into the ballast from below (BV, RIB [114], SBB), not effective against brambles (RIB) [114]
Duration of effects	Average life cycle estimated to last about twice as long (50 years) on newly built railway lines (RIB [114]). With re-constructions the life cycle is also twice as long (but only 30 years) (RIB [114]). These are conclusions from common practice, which shows that ballast of a good quality is very serviceable (RIB [114]).
***4. Costs*[10]**	
per m^3	17.5 €/m^3 or 27.5 €/t ballast material, ready for use (BV) [114]
5. Environmental effects	
Known toxic effects	None [114]
6. Observations	
The influence of the careful choice of ballast material should always be taken into consideration whether a new line is constructed or maintenance only is carried out (RIB; BV [114] SBB) Larger stone sizes would make it more difficult for annual plant species to grow on the track area. Perennial plants could grow in from the sides into the track area [71]. On high speed lines the load on the line is much bigger, therefore this has also to be taken into account when looking at the duration of effects as part of choosing the right material.	

[10] Exclusive of internal costs, cf. points made in Subsection 6.2

Appendix 5 - ConstructionalMethods - M6 Plant barriers beneath the track in general

M6 Plantbarriers beneath the track in general

Category	Engineering
Name of method	**Plantbarriers beneath the track in general**
Description	Hinder plants from growing up from below. As an additional benefit, these barriers promote drainage. A sub-ballast layer (beneath Areas A and B) can minimise plant incursion. *Material used*: - layer of bitumen (min. 5 cm) and concrete (min. 15 cm) (SNCB: [114]), bitumen layer (HMT), 10 cm (SBB [104, 117]), - sheets: spun bound polypropylene fabric sheets (BV [41]), geomembrane (PP) 1mm thick (BV [114]), polyethene foils (BV [42]), woven slit film (BV [114]) insertion of sheet in the transition area (Area C); sheets must be reinforced, not rot, withstand storms and resist the roots of horsetail, reeds and Japanese knotgrass (e.g. roofing sheets; matting is not suitable, as plants can grow through it) (SBB [101]) different kind of foils (DB AG [114]) - geotextiles (MAV, GySEV [114]), geotextiles to prevent fine material being pumped into the ballast from underlying ground (BV [42], DB AG [114]) needle punched non-woven geotextile (BV [114]) - thin but strong film/filter cloth (called Geolon) beneath is used to separate the ballast from the substratum (sand/clay). This cloth even functions as a plant barrier (RIB [114]) - tests with flow coats used as covers on the surface (BS: [42]) - slab track is also a form of barrier beneath the track see M7 - other kind of materials which can be specifically used in the transition area see: M3 plant-inhibiting design of the transition area
Effect of method on plants	Method of prevention (drainage and barrier) hinders plants from growing up from below, additional benefit for drainage. *Sheets*: only compact material (sheets) gives full protection against plants growing through [42] *Geomembranes*: needle punched non-woven geotextiles (e.g. Top Tex) are sensitive to plant penetration, other geomembranes are completely immune to plant penetration, plant barriers avoid plant development, due to the lack of water during dry periods. [114] *Bitumen layer*: no data on influence of humus accumulation and fertility of ballast (SNCB [114])
Drawings and/or pictures	See Appendix **14**
Main application (vegetation control or vegetation control as a side-effect)	Side-effect when constructing high speed track (SNCB [114]) Measure to enhance the loading capacity of the track (RIB [114]), standard on newly built lines (SBB [80])
Railway companies which have experience with this method	BV [114, 107], RIB, MAV, GySEV, SNCB, DB AG [114], SBB [80, 81]

Appendix 5 - ConstructionalMethods - M6 Plant barriers beneath the track in general

Experience of railway companies	Regularly used for 20 to 40 years on over 100 km (RIB, MAV, GySEV [114]), used in experiments for 4 years on less than 5 km (BV [114]) not used for the specific reason of vegetation control, but fitted on 10 to 25 km (SNCB [114]), HMT regularly used since 1994 (SBB), sheets in the transition area in 1996 as an experiment on 500 m (SBB [81]). No studies concerning the use for vegetation control of Geolon (RIB [114])
1. Technical data	
Operating speed, track-bound/non track-bound,..	This is an constructional method, hence these data are not applicable
2. Vegetation control areas	
Defined areas A to E	Used beneath the ballast bed (Area A), ballast shoulder (Area B) and beneath the transition area (Area C). (BV, SNCB, DB AG, RIB [114] SBB) away from the track area (E) (MAV, GySEV [114]) Used in new-build schemes (BV, SNCB, MAV, GySEV, RIB [114], SBB) and in the re-constructions of railway lines (BV, MAV, GySEV, RIB [114], SBB) Re-engineering: sheets in the transition area (SBB) New-build work: HMT (SBB) Used both for banks and cuttings [114]
Station areas or open line	Open line and stations
Used in areas excluded of chemical vegetation control e. g. groundwater protection zones	Protects the environment against the washing-out of hazardous substances in groundwater protection zones, if drainage is incorporated, depending on the material used, the groundwater may be affected (regulations on the use of recycled material in Germany [DB AG], Switzerland [SBB])
3. Vegetation control conditions	
Application in combination with other methods useful/necessary	*Ballast cleaning* for economic reasons (BV [114]), constructing a plant barrier can be usefully combined with track re-constructions to cut costs (reduced disruption of traffic)[114], plant-inhibiting design of the embankment/transition area and *lateral plant barriers* (concrete step blocks, suitably positioned cable troughs) to obtain the desired effect. (SBB [80]).
Period of application during the year/day	can be constructed all year round (RIB, BV, SNCB) constructed only in spring and summer (GySEV, MAV [114])
Treatable plants – problem plants	Plants propagating from the side above the ground are not treatable with this method. Horsetail, reeds and brambles are plants which can grow despite plant barriers beneath the track (RIB, GySEV, MAV [114]), problems with cranesbill (RIB [114]), no problems (BV [114]). Effectiveness depends on the material used (e.g. bituminous layer thick enough), how the material is fitted beneath the track (e.g. non-porous, good clean ballast on the shoulder when fitting foils in the transition area), combined with other methods (regular mowing, lateral plant barriers) (SBB) [80, 104] Geotextiles are no good at preventing plant growth (GySEV,

	MAV [114])
Duration of effects	Average life cycle of plant barriers beneath the track are estimated to be about 25 years. (RIB: 50 years for new-build, SNCB: 100 years for new-build [114]), 30 to 50 years (BV [42])
Impact on services (temporary/ permanent track possession)	Total track possession (MAV, GySEV [114]) and a partial track possession is needed (MAV, GySEV, SNCB [114]), constructed during periods free of traffic (SNCB [114]).
4. Costs[11]	
per km (one or both sides)	70,000 €/km (BV [114]), 72,000 €/km (SNCB [114]) on one side. (and half on both sides) [114] HMT: 14,000-55,000 €/km (SBB), insertion of sheets 65,000-100,000€/km[12] (SBB [101])
per m^2	12.5 €/m^2 (BV), 20 €/ m^2 (and half on both sides) [114]
5. Environmental effects	
Known toxic effects	None [114]
6. Observations	
When laying the ***sheets***, attention should be paid to ensure that water runs off the sides of the ballast bed and that the sheet is pulled roughly 50 cm beneath the ballast (in Area B). It must also slope sufficiently downwards and outwards, which means that the pathway (transition area, C) surface must be provisionally renovated. The sheet must also be secured against wind using gravel or a similar material [101]. Sheets should be resistant to root growth, degradation and weather influences.	

[11] Exclusive of internal costs, cf. points made in Subsection 6.2

[12] Costs of an experiment

M7 Slab track

Category	Engineering
Name of method	**Slab track**
Description	Instead of using ballast the track-bed is built with concrete. This method is a new system for -re-constructing railway lines.
Effect of method on plants	Method of prevention, plant barriers beneath the track hinder plants from growing up from sub-soil.
Drawings and/or pictures	See Appendix **14**
Main application (vegetation control or vegetation control as a side-effect)	Side-effect when constructing high speed track[13] (DB AG [114]), slab track is a measure for the enhancement of loading capacity. A special type of slab track is favoured because of noise and vibration reduction (SBB)
Railway companies which have experience with this method	DB AG [114]
Experience of railway companies	Regularly used for 9 years, in experiments for 28 years, on over 100km (DB AG) [114].
1. Technical data	
Operating speed, track-bound/non track-bound,..	This is an constructional method, hence these data are not applicable
2. Vegetation control areas	
Defined areas A to E	Used in areas A (ballast bed) and B (ballast shoulder) (DB AG) [114], used both for banks and cuttings (DB AG [114])
Station areas or open line	Open line
Used in areas where chemical vegetation control is prohibited, e. g. groundwater protection zones	Yes, possible
3. Vegetation control conditions	
Application in combination with other methods useful/necessary	Should be used in combination with vegetation control in the transition area to obtain the desired effect (DB AG) [114].
Period of application during the year/day	can be build all year round except in winter (DB AG) [114]
Treatable plants – problem plants	No plants have so far been observed to grow into slab track (DB AG) [114]
Duration of effects	Average life cycle is estimated to be about 60 years for new-build schemes (DB AG) [114].
Impact on services (temporary/ permanent track possession)	Total track possession needed. Built during periods free of traffic (DB AG) [114].
4. Costs[14]	
per km (one or both sides)	In the present state of evaluation, 1.4 to 2 times more expensive than traditional ballast designs (DB AG) [114].
5. Environmental effects	
Known toxic effects	None [114]
6. Observations	
Can only be used for initial building of lines (SBB)	

[13] The main reason for using slab track concerns the superstructure
[14] Exclusive of internal costs, cf. points made in Subsection 6.2

Appendix 5 - Biological Methods - M8 Greening (with non in-growing Plansts)

13.5.3 Biological Methods

M8 Greening (with non in-growing plants)

Category	Biological
Name of method	**Greening (with non in-growing plants)**
Description	Plants with a strong competitive disposition, adapted to the local situation, covering the soil and without runners are promoted or specifically sown when new railways are built or old ones relaid. Grasses promise to be the most interesting plants in this respect. This method should reduce the tendency of other plants to grow from the embankment (Area D) and transition areas (Area C) into the ballast (Areas B and A). Greening is often used in combination with structural biology to stabilise embankments. Choice of seeds adapted to local conditions and future maintenance (SBB [56]), in the 2 m adjoining the ballast shoulder competitive plants are sown immediately after construction. *Aim*: prevent the growth of brambles and horsetail. Further away at > 2 m, less competitive plants can also be sown (wild flowers), regular maintenance is important when plants are developing (SBB [77])
Effect of method on plants	Method of prevention, competitive behaviour of sown plants used to suppress problem plants.
Drawings and/or pictures	See Appendix **14**
Main application (vegetation control or vegetation control as a side-effect)	Main application (instead of spontaneous greening)
Railway companies which have experience with this method	SNCF, SN, BV, MAV, GySEV [114], SBB [77, 56]
Experience of railway companies	Used regularly for 10 years (RIB), 20 years (SNCF) and 100 (GySEV, MAV) years on 50 to 100km (RIB) and on over 100 km (GySEV, MAV, SNCF), used on an experimental basis for 3 years on less than 5 km (BV) [114].
1. Technical data	
Operating speed, track-bound/non track-bound,..	This is an constructional method, hence these data are not applicable
2. Vegetation control areas	
Defined areas A to E	On the embankment (Area D) [114] used everywhere (SNCF, BV, RIB [114], SBB) used on cuttings and banks[15]. (MAV, GySEV) [114]
Station areas or open line	Open line
Used in areas where chemical vegetation control is prohibited, e. g. groundwater protection zones	Yes, possible
3. Vegetation control conditions	
Application in combination with other methods useful/necessary	Geo-textiles (MAV, GySEV [114]), *mowing* to cut back problem plants and strengthen competitors (SBB) [56],

[15] To stabilise slopes

	mechanical and *chemical methods* (SNCF [114]) to obtain the effect desired [114]
Period of application during the year/day tested	Used in autumn (SNCF, SN, BV, MAV, GySEV [114]), used in spring (MAV, GySEV, SNCF [114]) used in summer (RIB [114]).
Period of application during the year/day recommended	Optimum period spring, but shortly after completion of works (new-build and re-engineering) whatever (SBB) [56]
Weather conditions	Do not use if conditions too dry or wet (if too dry, seeds are not able to germinate; if too wet, seeds may be washed away) (SBB [12])
Treatable plants – problem plants	Problem plants: horsetail and reeds (SNCF, SN, BV, MAV, GySEV [114]), brambles (SNCF, MAV; GySEV [114]) not effective against plants for which conditions are conducive to growth (SNCF [114]); If unwanted plants appear in significant quantities after germination, a first cut has to be performed to eliminate these; to suppress the growth of problem plants permanently, regular mowing of the embankment is needed (SBB [56])
Duration of effects	The average life cycle of greening is estimated to last about 10 years for new-build schemes (RIB) [114]
Impact on services (temporary/ permanent track possession)	Depending on the method used
4. Costs [16]	
per km (one or both sides)	22,000 €/km (SNCF)[114].
per m^2	1.5 €/m^2 whether on one or both sides of the line (GySEV, MAV) and 0.44 €/m^2 (SNCF) [114], 3.5 €/m^2 (SBB)
5. Environmental effects	
Known toxic effects	None [114]
6. Observations	
Spontaneous greening (no sowing after engineering) has some disadvantages: Problem plants already present on the embankment do not have any competition, seeds flying in from outside (wind) can easily germinate without competition, bare embankments (without vegetation) are more susceptible to erosion [77], embankments that are liable to erosion and subsidence should also be greened quickly.	

[16] Exclusive of internal costs, cf. points made in Subsection 6.2

Appendix 5 - Biological Methods - M9 Selective Embankment Maintenance

M9 Selective embankment maintenance

Category	Biological
Name of method	**Selective embankment maintenance**
Description	Specific plant species are removed (e.g. certain trees or neophytes[17] are selectively cut): pruning of trees in winter (SNCB) [114] devices used: - maintenance of embankment with 2-way vehicles every year in vicinity of track (SNCB) [114] - chain saw (JBV) [114] - vegetation cutter (JBV) [114] - mowing and pruning (RIB [114]) removal of undesirable plants and plant groups by selective weeding by hand, mowing or pruning. (SBB) [101] Pruning trees, mulching and removing undesirable plants in winter time (DB AG) Control and co-ordination of the various methods with the aid of a cadastre or register (SBB) only in urban areas: pruning, shrub planting, promoting turf-grass (QR [114])
Effect of method on plants	Method of prevention, promotes desired vegetation, eliminates undesired vegetation
Drawings and/or pictures	See Appendix **14**
Main application (vegetation control or vegetation control as a side-effect)	Main application
Railway companies which have experience with this method	SNCB, RIB, JBV, RT, QR [114] SBB [101], BS [114] but used for other reasons than vegetation control, DB AG
Experience of railway companies	Regularly used for 5 years (RT), 10 years (RIB), 45 years (JBV) 100 years (QR) on over 100 km, experiments planned (SNCB) [114].
1. Technical data	
Track-bound/non track-bound	Both with track-bound vehicles and from outside the track (RT, RIB, JBV, SNCB), only from outside the track (QR) [114].
Operating speed (km/h)	Less than 1km/h (SNCB, JBV, RIB), 1-5 km/h (SNCB, QR, RIB), between 20 and 40 km/h (RT), [114].
Area covered in m^2/h	2,000 m^2/h(QR) 2,500 m^2/h (RIB) 3,000 m^2/h (JBV) [114].
Installation and de-installation time per session	5 minutes (JBV), 1 hour (RIB) [114].
2. Vegetation control areas	
Defined areas A to E	Used on the embankment (Area D) (DB AG, SNCB, RIB, JBV, RT, QR [114], SBB) and in the transition area (C). (RT [114]) used both for banks and cuttings [114].
Station areas or open line	Open line

[17] Neophytes: new plant species formerly not common in a given region or country, Having no enemies, it spreads rapidly

Used in areas where chemical vegetation control is prohibited, e. g. groundwater protection zones	Yes
3. Vegetation control conditions	
Application in combination with other methods useful/necessary	*Mowing* (QR), selective treatment with herbicides (JBV) to obtain a better effect and for economic reasons. Not in combination (SNCB, RIB) [114].
Period of application during the year/day tested	All year round (RIB, RT), spring (JBV, QR), summer (QR), autumn (JBV; QR), winter (JBV) [114], tree pruning in winter (SNCB) [114], mowing in summer (SNCB) [114] mulching and pruning of brush/trees only in winter time, because of laws to protect breeding birds (DB AG)
Period of application during the year/day recommended	All year round, giving consideration to fauna living in trees and bushes (SBB)
Weather conditions	Not dependent on weather
Treatable plants – problem plants	Problem plants: horsetail (SNCB, RT, JBV [114]), Japanese knotgrass (RIB, SNCB, [114] SBB), reeds (RIB [114]), common ragwort (RT [114]), giant hogweed (JBV [114], SBB).
Treatable growth stage	Not effective against seedlings (herbs and shrubs) (RT, RIB) and young herbs (RT) [114].
Frequency of application	Irregularly as needed (DB AG, RIB, SNCB, JBV, RT), every other year (QR), every year in vicinity of track, concept of embankment maintenance (SNCB) [114].
Impact on services (temporary/ permanent track possession)	No disruption to traffic (QR, RIB), used partly during periods free of traffic. (RT, SNCB) [114].
4. Costs[18]	
per m^2	1 €/m² + 50 € per tree on average: 0.3 € /m² wooded embankments. (SNCB [114]). 0.65 € per m^2 when applied on both sides of the line (JBV) [114]. 0.7 – 2 €/m^2 (SBB, 1999 [101])
5. Environmental effects	
Known toxic effects	None [114].
Others	Effect on animals [114]. Other effects noise, air pollution [114].
6. Observations	
None	

M10 Biological Weed Control

Biological vegetation control involves attacking plants with the aid of insects, fungi or nematodes. This method is tested for the selective eradication of certain unwanted plant species (e.g. certain neophytes in nature conservation areas [49].). Vegetation control at railways usually includes the combating of all plant species of a plant community growing on railway land. Since biological vegetation control methods are effective against one specific plant species only, they

[18] Exclusive of internal costs, cf. points made in Subsection 6.2

are not effective against several plant species together. Fgvvurthermore most of the plants found on railway installations also grow in the adjacent area. Since neither insects, fungi nor nematodes can be territorially confined, they can easily spill over onto adjacent areas and damage plants, including such as may be considered desirable there.

Thus, biological vegetation control is not an ideal method for general application on railway lands.

Appendix 5 - Biological Methods - M11 Mowing

M11 Mowing

Category	Biological
Name of method	**Mowing**
Description	Mowing involves cutting the grass and, ideally, removing it from the site. devices used are: - rotary mower (LDZ [114], DB AG, SBB) - scythe, cannot treat different plant species (JZ [114]) - Rasant (MAV, GySEV [114]) - self propelled rotary mower (SNCF [114], SBB [101]) - motor scythe, motor mower (SNCB [114], DB AG, SBB) - rotary mower with suction device, grazing by sheep (rarely) (SBB [101]) - knife-mowers (various types), clapper (RIB [114]) - tractor, slasher with 1.2 to 2m cut width, smaller tractors for smaller areas (QR [114]) - hand-scythe (ZSR [114], SBB [101]) - tractors for mowing along the track (Area D) DB AG *aim* of mowing along the track: to prevent growth or emergence of in-growing plant species (SNCB [114])
Effect of method on plants	Method of prevention, promotes desired vegetation, used to grow vegetation that can compete with problem plants. Frequent mowing is only withstood by competitive strong plants.
Drawings and/or pictures	See Appendix **14**
Main application (vegetation control or vegetation control as a side-effect)	Main application
Railway companies which have experience with this method	JZ, SNCB, DB AG; MAV, GySEV, ZSR, JR, QR, LDZ, RIB, SNCF [114], BS but used for other reasons than vegetation control [114], SBB
Experience of railway companies	Regularly used for 3 years (RIB[19]), 8 years: LDZ[19], 9 years: DB AG, 13 years (JR new organisation), 30 years (QR), 100 years (MAV, GySEV) no details of length of use furnished (JZ, SNC , ZSR, SNCF, SBB), on over 100 km [114].
1. Technical data	
Track-bound/non track-bound	Both with track-bound vehicles and from outside the track (SNCB, SNCF, JZ, DB AG, MAV; GySEV, RIB [114], SBB), applied from outside the track only (LDZ, QR, ZSR [114]) use of track-bound vehicles only (JR [114])
Operating speed (km/h)	Less than 1 km/h (LDZ, JR, ZSR, DB AG), 1 to 5 km/h (JZ, SNCB, QR, RIB, SNCF, MAV, GySEV) [114].
Area covered in m^2/h	0.5 m^2/h (JZ), 40 m^2/h (JR), 100 m^2/h (MAV, GySEV) 170 m^2/h (LDZ), 400 m^2/h (DB AG), 750 m^2/h (SNCF, SNCB), 1,800 m^2/h (RIB), 4,500m^2/h (QR) [114] depending on the machines used 600 – 1,000 m^2/h (SBB [84])
Installation time per session	10 min (ZSR), ½ h (QR, RIB), 1 h (SNCF) [114]

[19] Experience with specific method of mowing, not mowing in general

(installation and de-installation of machines and component parts)	
2. Vegetation control areas	
Defined areas A to E	Embankment (Area D) (JZ, SNCB, DB AG; MAV, GySEV, ZSR, JR, QR, LDZ, RIB, SNCF [114], SBB) in the transition area (Area C) (JZ, DB AG, ZSR, JR, LDZ, RIB [114] SBB), away from the track area (Area E) (SNCB, DB AG, QR, JR [114]); is used both for banks and cuttings [114]
Station areas or open line	Open line; possibly in stations too, with modifications (by hand)
Used in areas where chemical vegetation control is prohibited, e. g. groundwater protection zones	Yes, possible
3. Vegetation control conditions	
Application in combination with other methods useful/necessary	Not combined (JZ, MAV, DB AG, GySEV, QR, RIB [114]); combined with *constructional methods and back-pack spraying* in the adjacent areas A, B and C (SBB), *use of herbicides* to obtain a better effect and for economic reasons. (ZSR, JR, SNCF [114]), only small amount of herbicide as needed used on the embankment (ZSR [114]), no use of herbicide on the embankment (JR [114]), manual weeding, regular maintenance of drainage systems in Areas A, B, C [Part A of report]
Period of application during the year tested	Summer (JZ, SNCB, DB AG, MAV, GySEV [114]), summer and autumn (JR, ZSR, QR, ZSR [114]) mowing in spring (ZSR, JR; LDZ [114].) pruning shrubs and trees in winter (SNCB [114])
Weather conditions	Independent of weather
Treatable plants – problem plants	All plants can be treated sufficiently (DB, ZSR, JR [114]), not effective against: brambles (SNCB, MAV; GySEV, RIB [114]), horsetail and reeds (MAV, GySEV, RIB [114]), Japanese knotgrass (SNCB, RIB [114], SBB)
Treatable growth stage	Not effective against seedlings of herbs and shrubs (JZ, SNCB, ZSR [114]) and adult shrubs/trees (ZSR, MAV, GySEV, DB AG [114])
Frequency of application	Once a year (JZ, SNCB, DB AG, MAV, GySEV [114], SBB), twice a year (JR [114]), two to four times a year (ZSR, QR [114]), less than every other year (SNCF [114])
Impact on services (temporary/ permanent track possession)	No disruption to traffic (LDZ, RIB, QR, JR, ZSR, MAV; GySEV, DB AG, JZ [114]), partial track possession needed (SNCB, SNCF) [114]. Whether traffic is disrupted depends on the machine used for mowing (DB AG) [114] during periods free of traffic only when using track-bound vehicles (SBB) or no disruption when using non track-dependent vehicles (SBB)
4. Costs[20]	
per km (one or both sides)	0.16 €/km (JZ) [114]

[20] Exclusive of internal costs, cf. points made in Subsection 6.2

per m^2	0.15 €/ m^2 (DB AG), 0.3 €/ m^2 (MAV; GySEV, SNCF [114]), 0.8 €/ m^2 (SNCB [114]) and 1.2 €/ m^2 (JR [114]), 0.15-0.5 €/m^2 (SBB) [101, 84] when applied on one side only between 0.07 €/ m^2 (LDZ [114]), 0.6 €/ m^2 (RIB; SNCF [114]), 0.75 €/ m^2 (SNCB [114]) when applied on both sides of the line [114]
5. Environmental effects	
Known toxic effects	None [114]
Safety of staff	Machines
Others	Effect on animals and desired plants (JZ, SNCB, LDZ, QR [114]) Effects on air, water and soil (RIB [114]) and human health (RIB, ZSR, SNCB, JZ [114])
6. Observations	
Problems with mice on embankments may arise if cuttings are not removed (SBB [116]), Removal of cuttings necessary especially on steep embankments or above walls, where there is a risk of cuttings falling into the track area or clogging drainage systems (SBB). *Hand scythe*: Purely manual work, noiseless, but with low surface area coverage [101]. *Motor scythe*: Best used to tackle obstacles and for mowing areas that are difficult to access or not suited to larger equipment [101]. *Motor mower*: Used mostly on smaller or sloping areas and to protect valuable plant growth [101]. *Rotary mower with suction device*: to protect animal life in the bank, this procedure is not recommended in the low-intensity maintenance zone [101].	

Appendix 5 - Biological Methods - M12 Mulching

M 12 Mulching

Category	biological
Name of method	**Mulching**
Description	The fine cut grass and shrub material remains in the area. Devices used: - rotary mower (LDZ [114], SBB[101]), - Mercedes Unimog (MAV, GySEV [114]) - rotary-mower with attachment for blowing cuttings out onto the embankment or a suction device (SBB) [101] - self-propelled rotary mower (SBB) [101]
Effect of method on plants	Method of prevention, promotes desired vegetation, mulching is used to develop vegetation that can compete with plants growing from the embankment into the track areas. Frequent mulching is only withstood by strong, competitive plants.
Drawings and/or pictures	See Appendix **14**
Main application (vegetation control or vegetation control as a side-effect)	Application as vegetation control measure on the embankment to reduce the vegetation burden
Railway companies which have experience with this method	DB AG, LDZ, MAV, GySEV [114] SBB [101] BS but used for other reasons than vegetation control [114],
Experience of railway companies	Regularly used for 8 years (LDZ [114]), 20 years (DB AG) on over 100 km (DB AG [114], SBB), used in experiments for 2 years on 10 to 25 km (MAV; GySEV [114]), study of various methods for mulching planned (SBB)
1. Technical data	
Track-bound/non track-bound	Applied both with track-bound vehicles and from outside the track, (DB AG, MAV, GySEV [114], SBB) only applied from outside the track. (LDZ) [114] used both for banks and cuttings [114]
Operating speed (km/h)	Less than 1 km/h (DB AG, LDZ) from 1 to 5 km/h (MAV, GySEV) [114]
Area covered in m^2/h	170 m^2/h (LDZ), 250 m^2/h (MAV, GySEV), 400 m^2/h(DB AG [114]), 500 – 1,000 m^2/h (SBB [84])
Installation and de-installation time per session	No data available [114]
2. Vegetation control areas	
Defined areas A to E	Used on the embankment (Area D) (DB AG, MAV, LDZ [114], SBB) and in the transition area (Area C). (DB AG [114], SBB)
Station areas or open line	Open line (SBB)
Used in areas where chemical vegetation control is prohibited, e. g. groundwater protection zones	Yes, possible
3. Vegetation control conditions	
Application in combination with other methods useful/necessary	Not combined (DB AG) [114] Combination with *constructional methods and back-pack spraying* in adjacent areas A, B and C (SBB), *use of herbicides* (MAV [114]), use of herbicide only selectively in experiments on the embankment (MAV [114]) to obtain the

	desired effect. manual weeding, regular maintenance of drainage systems in Areas A, B, C [Part A of report]
Period of application during the year/day	During the growing season (before July) in winter time to protect breeding birds when using machines on bushes/shrubs (DB AG), all year round (MAV, GySEV) [114]
Weather conditions	Independent of weather
Treatable plants – problem plants	Deals adequately with all plants (DB AG, MAV, GySEV [114]), not effective against Japanese knotweed (SBB)
Treatable growth stage	not effective against adult shrubs and trees (DB AG) [114]
Frequency of application	Irregularly as needed (DB AG, MAV; GySEV [114]), once a year regularly in the transition area recommended (DB AG [114], SBB)
Impact on services (temporary/ permanent track possession)	No disruption to traffic due to its being carried out during periods free of traffic (MAV, GySEV, [114] SBB) or when restricted train running is still possible (DB AG) [114]
4. Costs[21]	
per m^2	0.15 €/m^2 (DB AG), 0.5 €/m^2 (MAV, GySEV), applied on one side only [114]; applied on both sides of the line: 0.07 € per m^2 (LDZ) [114], 0.15-1.6 €/m^2 (SBB, 1999) [101, 84]
5. Environmental effects	
Known toxic effects	None [114]
Safety of staff	Machines
Others	Effect on animals (DB AG, LDZ) [114], effect on animals (SBB)
6. Observations	
Rotary mower with suction device: to protect animal life on the embankment, this procedure is not recommended in the low-intensity maintenance zone [101]. Effect of mulching as stated in [67]: Problem plants can be repulsed with regular mulching (even horsetail and reeds) Plant coverage in the transition area, on the ballast shoulder and in the ballast diminishes or at least stagnates - compared to areas where mulching has not been applied (no maintenance measures adopted at all) Strong, competitive plants become established in regularly mulched areas (grasses etc.)	

[21] Exclusive of internal costs, cf. points made in Subsection 6.2

Appendix 5 - Biological Methods - M33 Greening with Allelopathic Plants

M 33 Greening with Allelopathic Plants

Category	Biological
Name of method	**Greening with allelopathic plants**
Description	Allelopathic plants are sown in vicinity of track, secreting substances to inhibit/reduce the growth of other plants in their neighbourhood
Effect of method on plants	Biological methods promote desired vegetation or make it possible to sow this vegetation. Method of prevention (drainage and barrier)
Main application (vegetation control or vegetation control as a side-effect)	Main application
Railway companies using this method	DB AG [114]
Experience of railway companies	Used in experiments for 2 years on less than 5 km of newly-built railway lines (DB AG [114]).
1. Technical data	
No data available	
2. Vegetation control areas	
Defined areas A to E	Used on the embankment (D) (DB AG [114]) used both for banks and cuttings (DB AG [114])
Used in areas where chemical vegetation control is prohibited, e. g. groundwater protection zones	Yes, can be used in groundwater protection zones.
3. Vegetation control conditions	
Application in combination with other methods useful/necessary	Not used in combination with any other method (DB AG [114])
Period of application during the year/day	Allelopathic plants are sown or planted in spring (DB AG [114])
Treatable growth stage	Influence on some problem plants not known in detail, no data available on the life cycle of this method. (DB AG [114])
Impact on services (temporary/ permanent track possession)	No halting of train services needed (DB AG [114])
4. Costs	
No data available	
5. Environmental effects	
Known toxic effects	None (DB AG [114])
Others	No adverse impacts on the environment cited (DB AG [114].
6. Observations	
Experiments at Max Plank Institute did not deliver satisfactory results [114]	

Appendix 5 - Mechanical Methods - M13 and M14 Ballast Cleaning and Exchange of Ballast

13.5.4 Mechanical Methods

M 13 and M14 Ballast cleaning and replacement of ballast

Category	Mechanical
Name of method	**Ballast cleaning and replacement of ballast**
Description	**Ballast cleaning** Ballast cleaning machines remove the ballast and clean it mechanically, cleaned ballast and additional new material (if needed) is redistributed along the track *Quality criteria for ballast*: - see ”Kind and Amount of Ballast Material M5” *Criteria for ballast after ballast cleaning*: - based on particle size: determined by size of holes in sieve (SBB), sizes: 31.5 - 63 mm (CNCF [114]), content of sand (gravel size <0,5): less than 1% [31, 32], gravel size: 32/50 (size of holes in sieve) (MAV, GySEV [114]); fraction 0-11.2: max 2% weight; 11.2 - 22.4: max 4% weight; 22.4-31.5: max 10% weight (BV [114]), ballast pieces > 20 mm; attained by fraction division (RIB [114]) - Other criteria: should be clean - meaning free of animals or plant detritus or oil constituents. (CNCF [114]), no criteria on the amount of organic material defined (BV [42]), no major criteria (SBB), *Ballast cleaning*: - high-performance machine (DB AG) [114] experiments investigating the effect of ballast cleaning for vegetation control, traditional machine sieve clogged with plant material, plant detritus not removed to a sufficient extent from ballast material - ballast cleaning machines: RM-80 /OT-400, RM-76, RM-78 (CNCF/LDZ [114]) - existing material is taken out and screened. Useful material is reutilised.(BV) [42] - excavation of ballast with a sucking machine, no excavation beneath the sleepers, cleaning on an external site with a dry clean method, re-building of ballast [36] - ballast cleaning is not used for vegetation control purposes (RIB) [114] - Also used for local contamination, minimum length 150m (BV) [114] *aim of ballast cleaning:* - to restore the track-bed to an as-new condition. Specific views on: homogeneity, elasticity of the track-bed, and drainage aspects (CNCF) [114] - sieves on cleaning machine should guarantee the removal of plant material from the ballast (SBB) **Replacement of ballast** Old ballast exchanged for new ballast.

Appendix 5 - Mechanical Methods - M13 and M14 Ballast Cleaning and Exchange of Ballast

	Ballast cleaning or else cleaning plus partial replacement is increasingly being given preference over total replacement of ballast (DB AG [114], SBB) Excavation with a digging machine fitted with a special shovel or using vacuum technique (BV) [42]
Effect of method on plants	Method of prevention as well as of combating symptoms; unwanted plants and their basis for growth (fine material containing water and nutrients) are removed
Drawings and/or pictures	See Appendix **14**
Main application (vegetation control or vegetation control as a side-effect)	Side-effect
Railway companies which have experience with this method	Ballast cleaning: CNCF, DB AG, RT, MAV, GySEV, BV, LDZ, RIB [114], BS but used for other reasons than vegetation control [114], SBB Replacement of ballast: LDZ, DB AG [114], SBB
Experience of railway companies	Regularly used for 7.5 (BV [114]), 8 (LDZ [114]), 30 (MAV, GySEV [114]) and 50 (RT [114]) years, on 10-25 km (MAV, GySEV [114]), on 50 to 100 km (RIB) or on over 100 km (CNCF CFR, DB AG; RT, LDZ, BV [114]). used in experiments for 1 year with the focus on ballast cleaning for vegetation control reasons (DB AG) [114] Not used for vegetation control reasons (RIB, CH [114]), ballast replacement used for technical reasons (stability) (RIB [114])
1. Technical data	
Track-bound/non track-bound	Use of track-bound vehicles (CNCF, DB AG, RT, MAV, GySEV, BV, LDZ) [114], SBB
Operating speed (m/h)	100 (LDZ), 125 (MAV, GySEV), 150 (BV), 180 (RIB), 200 (DB AG) m per hour. [114]
Installation and de-installation time per session	1h (LDZ, GySEV, MAV), 2h (DB AG, BV), 8h (RIB) [114]
2. Vegetation control areas	
Defined areas A to E	Used in the ballast bed (Area A) and on the ballast shoulder (Area B) (CNCF, DB AG, RT, MAV, BV, LDZ, RIB [114], SBB), in the transition area (Area C).(CNCF, RT) [114] used both for banks and cuttings [114]
Station areas or open line	Open line and stations
Used in areas where chemical vegetation control is prohibited, e. g. groundwater protection zones	Yes, ideal for groundwater protection zones, no effect on groundwater, used in some areas where herbicides are banned for the last 5-10 years BV [114]
3. Vegetation control conditions	
Application in combination with other methods useful/necessary	Not combined (RIB, LDZ, DB AG, CNCF) [114], *barriers beneath the track* to obtain a better effect (MAV, GySEV, BV). When constructing plant barriers beneath the track it is better to clean the ballast at the same time (BV) [114], herbicides to obtain the desired effect (RT), trackside clearing to prevent detritus from bushes and other vegetation

	getting stuck in sieves to avoid manual cleaning (BV [114])
Period of application during the year/day tested	Spring to autumn (LDZ, BV, MAV, GySEV, DB AG), in winter (RT), all year round (RIB) [114]
Period of application during the year/day recommended	no data
Weather conditions	Independent of weather better efficiency when conducted in dry weather (SBB [80]
Treatable plants – problem plants	Sufficient treatment of plants (RT, MAV, GySEV, BV, RIB) [114], not effective against brambles (LDZ, DB AG), reeds (DB AG) and horsetail (DB AG) [114], only effective against seed dispersing plants (BV) [41]
Treatable growth stage	Not effective against adult shrubs and trees (DB AG) [114]
Duration of effects	2.5 (MAV, GySEV) 25 years (RIB) on newly built lines, 2.5 (MAV, GySEV), 3 (LDZ), 15 (RIB), 35 years (DB AG) in re-constructions [114], 10-20 years (BV) [114], 20 to 40 years if the adjacent transition area and the embankment are built and maintained well (SBB) [101]
Frequency of application	Less than every 10 years (DB AG, MAV, GySEV [114]), every 10 to 20 years (RT, BV, LDZ [114]), for economic reasons only every 10th year (LDZ, GySEV, MAV) every 20 to 30 years (RIB), more than every 5th year (CNCF) [114] every 20 to 40 years depending on the condition of the sleepers (SBB) used in re-constructions (RIB, LDZ, RT, DB AG, MAV, GySEV), and in maintenance only (BV, RIB; CNCF) [114] replacement of ballast depending on the quality of the ballast, regularly cleaned ballast has a life cycle of 40 to 80 years, with increasing use of concrete sleepers the replacement of ballast might be more frequent (SBB).
Impact on services (temporary/ permanent track possession)	Total track possession required (RIB, MAV, GySEV, Railtrack, CNCF), partial track possession required (RIB, BV, CNCF, DB AG; MAV, GySEV, LDZ) [114], conducted during periods free of traffic only (RIB, RT [114], SBB)
4. Costs[22]	
per km (one or both sides)	5,100 €/km (MAV, GySEV), 41,000 €/km (BV), 100,000 €/km (DB), 182,000 € per km (LDZ total track overall [23] [114], Prices also depend on the condition of the track (CNCF) [114], 200,000-335,000 €/km (SBB), [101] 95,000 €/km (ballast cleaning machine + filling + tamping (CH) [114])
5. Environmental effects	
Known toxic effects	None [114]
Safety of staff	Machines
Others	Effect on air (DB AG, RT, LDZ), effects on water, soil,

[22] Exclusive of internal costs, cf. points made in Subsection 6.2

[23] Total costs for renewal of track using ballast cleaning

	human health (RIB, DB AG) effect on plants other than those wanted (RIB) [114].
6. Observations	
Ballast cleaning: may remove thin-walled and large seeds, virtually no seeds remain in cleaned ballast, the cleaned ballast however remains as substrate for seeds flying in from outside [36] depends on weather conditions: in moist weather more soil substances stick to ballast stones; the cleaner the stones the greater their contribution to vegetation control [36] no protection against in-flying seeds [38] In most cases it is enough to change the top ballast layer down to 0.2 – 0.5 m [42] When cleaning or replacing ballast, it is also necessary to renew the inspection walkway (transition area) so as to ensure the renewed track-bed drains well (avoiding the creation of "tubes") (SBB)	

Appendix 5 - Mechanical Methods - M16 Manual Weeding

M 15 Mechanical Weeding

Category	Mechanical
Name of method	**Mechanical weeding**
Description	Performed by special machines, used to remove plants altogether or at least sever them above the soil surface, *WESPE* (DB AG, RIB [114]): the presence of plant indicates that the ballast is soiled, WESPE is used to remove plants in toto; besides this, fine material will be sucked in as well and cleans the ballast close to the surface (DB AG), vegetation cleaning is a side-effect of the WESPE technique (RIB [114]) when used only to remove dirt *trackside clearing*: mechanical method to remove unwanted plants and bushes in the trackside area, removed with an adjustable arm mounted on a track-bound vehicle, removed vegetation and soil is collected in wagons (BV [114]) *Camulino* removes a thin layer of soil surface inclusive plants by mechanically peeling off the surface (SBB [101])
Effect of method on plants	Method of combating symptoms, unwanted plants are removed from areas.
Drawings and/or pictures	See Appendix **14**
Main application (vegetation control or vegetation control as a side-effect)	Main application (DB AG) is a side-effect of the WESPE technique (RIB [114])
Railway companies which have experience with this method	DB AG, BV, RIB, CNCF [114], SBB [101], BS but used for other reasons than vegetation control [114],
Experience of railway companies	Occasionally used[24] (CNCF [114]), regularly used for about 1year (BV [114]), 3 years (DB AG [114]), experimentally for 4 years (DB AG[114]) on 25 to 50 km (DB AG, BV [114]). Experiments planned (SBB)
1. Technical data	
Track-bound/non track-bound	Track-bound vehicles (DB AG, BV[114], SBB), both track-bound vehicles and vehicles operating from outside the track (RIB) [114]
Operating speed (km/h)	1 to 2 km per day (SBB [101]) less than 1 km per hour (DB AG), 1 to 5 km/h (RIB, BV) [114]
Area covered in m^2/h	125 m^2/h (RIB), 2880 m^2/h (DB AG), 3200 m^2/h (BV) per hour [114]
Installation and de-installation time per session	½ h (DB AG, RIB). 2 min (BV) [114]
2. Vegetation control areas	
Defined areas A to E	Used in the ballast bed (Area A) (RIB [114]) on the ballast shoulder (Area B) (DB AG, BV [114]) and in the transition area (Area C) (DB AG, BV[114], SBB) Used both for banks and cuttings [114]
Used in areas where chemical vegetation control is prohibited, e. g. groundwater protection zones	Yes, planned for use in groundwater protection zones (SBB)

[24] Increasingly being replaced by manual weeding or use of herbicides (CNCF [114])

3. Vegetation control conditions	
Application in combination with other methods useful/necessary	*Mulching* or *mowing* of the transition area (Area C) and adjacent areas to obtain a better effect (DB AG [114]), mowing on the embankment (Area D) for economic reasons and to get a better effect will be tested (SBB) application of herbicides to obtain the effect desired (RIB [114]), not combined (BV [114])
Period of application during the year/day tested	In summer or autumn (DB AG, RIB [114]), less than every other year, all year round (experimental stage) (BV) [114], used mainly as a maintenance measure (DB AG; BV, RIB) [114]
Period of application during the year/day recommended	Experimental stage, no recommendations yet
Weather conditions	Independent of weather, but more effective if applied during dry summer weather (SBB [101])
Treatable plants – problem plants	Insufficient effect on horsetail, Japanese knotgrass and narrow-leaved ragwort (RIB), assumption: able to treat every plant (BV), not enough experience (DB AG) [114]
Treatable growth stage	Is not effective against adult herbs (DB AG [114]) and young and adult shrubs/trees (DB AG, BV [114])
Frequency of application	Once a year (DB AG [114]), irregularly as needed (RIB) [114],
Impact on services (temporary/ permanent track possession)	Partial track possession needed (DB AG, BV [114]). applied during periods free of traffic only (RIB [114], SBB)
4. Costs[25]	
per km (one or both sides)	2,000 €/km (RIB [114]), 1,000 €/km. (2001, SBB) when used on one side of the track only, 2,475 €/km (DB), 4,000 €/km (RIB), 18,000 €/km (BV) when used on both sides of the track [114]
per m^2	2 €/m^2 when used on one side of the track only (RIB) [114] 0.51 €/m^2 (DB) 2 €/m^2 (RIB), 9 €/m^2 (BV) €/m^2 when used on both sides of the track [114]
5. Environmental effects	
Known toxic effects	None [114]
Safety of staff	Machines
Others	Effects on human health (noise emissions) (DB AG) [114]
6. Observations	
Mulching intensifies the effect of weeding, because shrubs and tall plants reduce the effectiveness of the machine used, deep roots are removed more effectively with weeding than with other non-chemical methods (DB AG) [114] The Camulino can defer structural renewal of the verge by several years; avoid material removed, which is rich in humus, being left lying on the walkway or the ballast, method can only be used on gravel verges (SBB) [101]	

[25] Exclusive of internal costs, cf. points made in Subsection 6.2

Appendix 5 - Mechanical Methods - M16 Manual Weeding

M 16 Manual Weeding

Category	Mechanical
Name of method	**Manual weeding**
Description	Plants are removed by hand. Hence the vegetation is removed totally or only in parts depending on the plant species. Used for major plant coverage of ballast, may loosen ballast and enable deep roots to be twisted out (DB AG) [114], severs plants (SBB) [13], eradicates plants with roots (SBB) [13]
Effect of method on plants	Method of combating symptoms, unwanted plants are removed from areas.
Drawings and/or pictures	See Appendix **14**
Main application (vegetation control or vegetation control as a side-effect)	Main application
Railway companies which have experience with this method	DB AG, BV, LDZ, LG, BDZ, RIB, JZ, SZ, MAV, GySEV, CNCF [114], SBB,
Experience of railway companies	Regularly used (SZ, JZ, BDZ, LDZ [114] SBB) for about 4 years (DB AG), 9 years (LG), 15 years (CNCF) 25 years (RIB) [114], experimentally for 2 years (DB AG [114]), not used any longer (GySEV, MAV [114]), not used for safety reasons (BV [114]). Used on less than 5 km (MAV, GySEV), 5 –10 km (DB AG, LG, RIB), 10 – 25 km (LDZ), on over 100 km[26] (SZ, CNCF) [114], between 25 and 60 km (SBB).
1. Technical data	
Operating speed (km/h)	Less than 1 km/h (DB AG, LDZ, LG, BDZ, RIB, SZ, MAV, GySEV, CNCF [114] SBB), 1-5km/h (JZ [114]); depends on density of plants (JZ [114], SBB), the substrate plants are growing in (sand, gravel, ballast) (SBB) and the plant species (JZ) [114].
Area covered in m^2/h	9 m^2/h (BV) [42], 15 m^2/h (BDZ [114]), 26 m^2/h (LDZ [114]), 50 m^2/h (MAV, GySEV, RIB [114]), 109 m^2/h (DB AG [114]). 30 – 33 m^2/h per operative (SBB) [101].
2. Vegetation control areas	
Defined areas A to E	Ballast bed (Area A) (CNCF, JZ, DB AG, LDZ [114] SBB), ballast shoulder (Area B) (CNCF, JZ, DB AG, LDZ, BDZ [114] SBB), transition area (Area C) (JZ, MAV, GySEV, BDZ, RIB [114], SBB)
Station areas or open line	Open line and stations
Used in areas where chemical vegetation control is prohibited, e. g. groundwater protection zones	Yes, used mainly in groundwater protection zones (DB AG, SBB)
3. Vegetation control conditions	
Application in combination with other methods useful/necessary	Not combined (JZ, LDZ, RIB, MAV, GySEV [114]) combined with *mowing* to obtain the effect desired (DB AG [114], SBB) and *mulching* to obtain a better effect and, for economic reasons (SZ [114]), with the use of herbicides (SZ, CNCF, LG, BDZ [114] SBB)
Period of application during the year/day tested	Used mostly for maintenance reasons (CNCF, JZ, MAV, GySEV, DB AG, BDZ [114]) used in renewal measures (RIB, LDZ, JZ, SZ [114]). Applied in summer (CNF, JZ, DB AG, MAV, GySEV, LG, LDZ, RIB

[26] To cut operating expenses in less accessible zones (CNCF [114])

	[114]), in spring (CNCF, JZ, LG, BDZ, LDZ [114]) or in autumn (JZ, LG, RIB [114]). regardless of season (SZ [114]), time of application depends on the species present (SBB)
Weather conditions	Independent of weather, but greater efficacy given dry weather conditions (DB AG)
Treatable plants – problem plants	Sufficiently effective against all plants (LDZ, GySEV, MAV, LG, DB AG, CNCF [114], SBB) not effective against: horsetail (SZ, BDZ, RIB), brambles (BDZ), reeds (JZ), Japanese knotgrass (RIB), narrow-leaved ragwort (RIB) and other plant species [114]
Treatable growth stage	Effective against adult herbs and young herbs and shrubs/trees (CNCF, SZ, JZ, BDZ [114]) against adult shrubs/trees (CNCF, DB AG, LG, RIB [114] SBB). no effect against seedlings of herbs and shrubs/trees (BCZ, JZ, SZ, CNCF [114])
Frequency of application	Irregularly as needed (SZ, JZ, MAV, GySEV, BDZ, RIB [114], SBB), once a year (LG, DB AG [114], SBB [101]), twice a year (LG, LDZ [114]) two to four times a year (CNCF [114]).
Impact on services (temporary/ permanent track possession)	No halting of train operating services needed (DB AG, LDZ, BDZ, RIB, JZ, SZ, MAV, GySEV, CNCF [114] SBB). carried out during periods free of traffic only (LG, SZ [114], SBB)
4. Costs[27]	
per km (one or both sides)	2,000 € (RIB [114]) per km when used on one side of the track only, approx. 2,000 €/km (up to 11,000 Euro./km) depending on density and species (SBB [13]), 315 €/km (BDZ [114]), 1186 €/km (DB AG [114]), 4,000 €/km (RIB) when used on both sides of the track, 2,700-3,400€/km (SBB) [101]
per m^2	0.04 €/m^2 (MAV, GySEV [114]) 0.4 €/m^2 (DB AG [114]) 0.05 €/m^2 (BDZ, LDZ [114]) 2 €/m^2 (RIB [114]), 2.1 €/m^2 (BV, 1994 [42])
5. Environmental effects	
Known toxic effects	None [114]
Others	Effects on soil (SZ). no adverse impact on environment (DB AG, LDZ, LG, BDZ, RIB, JZ, MAV, GySEV, CNCF [114] SBB
6. Observations	
Recommended as supplement to biological and constructional methods (SBB [97])	

[27] Exclusive of internal costs, cf. points made in Subsection 6.2

Appendix 5 - Mechanical Methods - M17 Brushing

M 17 Brushing

Category	Mechanical
Name of method	**Brushing**
Description	Plants above the soil surface are brushed away.
Effect of method on plants	Method of combating symptoms, unwanted plants are removed from areas.
Drawings and/or pictures	See Appendix **14**
Main application (vegetation control or vegetation control as a side-effect)	Main application
Railway companies which have experience with this method	BV [114], SBB [103]
Experience of railway companies	Used experimentally for 3 years on less than 5 km (BV [114]), at experimental stage (SBB)
1. Technical data	
Track-bound/non track-bound	Non track-bound (BV[114], SBB)
Operating speed (km/h)	Between 1 and 5 km per hour (BV [114]), approx. 2km/h (SBB [103])
Area covered in m^2/h	Around 9,000 m^2/h (BV [114]), around 1,500 m^2/h depending on the vegetation (SBB [103])
Installation and de-installation time per session	About 5 – 10 min (SBB [103]), about 10 min (BV [114])
2. Vegetation control areas	
Defined areas A to E	Used in the ballast bed (Area A) and on the ballast shoulder (Area B) (BV [114]), on platforms (Area E) (SBB), used both for banks and cuttings (BV [114])
Used in areas where chemical vegetation control is prohibited, e. g. groundwater protection zones	Yes, possible
3. Vegetation control conditions	
Application in combination with other methods useful/necessary	Not combined with any other method (BV [114], SBB [103]) combined with other methods possible (SBB [103]) *mowing and mulching* on the embankment Area D [Part A of report]
Period of application during the year/day tested	Four times a year during spring and summer for maintenance reasons only (BV [114]), independent of season or time of day (SBB[28] [103])
Weather conditions	Independent of weather (BV [114]), dry weather preferred (SBB [103])
Treatable plants – problem plants	Seems to have sufficient effect on various problem plants (BV [114]) woody plants more than 1 year old are difficult to treat (SBB [103])
Treatable growth stage	not suitable for adult herbs, shrubs/trees. (BV [114], SBB [103]),
Frequency of application	Four times a year (BV [114]) once or twice a year (SBB [103])

[28] Estimations no scientific tests conducted

Appendix 5 - Mechanical Methods - M17 Brushing

Impact on services (temporary/ permanent track possession)	Partial track possession needed, carried out during periods free of traffic only (BV [114]) no track possession needed (SBB [103])
4. Costs[29]	
per m^2	0.4 €/m^2 when used on one side of the track only (BV [114]), 0.1 EUro/m^2 (SBB, 2001 [103])
Division into machine, personnel costs etc.	Machine itself costs € 3,000 plus adaptations for railway use, use of machine (fuel,…) costs 0.01 €/m^2, personnel costs are 0.07€/m^2 (approx. 95 €/h) (SBB, 2001 [103])
Life Cycle Costs (LCC)	A machine can be used for 10 to 15 years (SBB [103])
5. Environmental effects	
Known toxic effects	None (BV [114] SBB)
Others	No adverse environmental impact cited (BV [114])
6. Observations	
Has little effect on root-growing plants, best effect when using a brush made of steel, the pressure towards the ground should not be too great, otherwise plant is cut off, whereas it should be ripped out of the ground; best effects when soil is moist; once brushed loose, plants should be removed from the track to protect ballast from decaying detritus (BV [42])	

[29] Exclusive of internal costs, cf. points made in Subsection 6.2

13.5.5 Chemical Methods

M 18 Back-pack Spraying

Category	Chemical
Name of method	**Back-pack spraying**
Description	Herbicides are sprayed directly onto the plants by back-pack sprayers. Constant spray pressure of 2 bars and an average walking speed of approx. 1 m/s, about 50 litres of fluid needed per hectare (SBB [101])
Effect of method on plants	Method of combating symptoms, herbicides are used to destroy unwanted vegetation. Effect depends on herbicide used.
Drawings and/or pictures	See Appendix **14**
Main application (vegetation control or vegetation control as a side-effect)	Main application
Railway companies which have experience with this method	JZ, SNCB, DB AG, RT, LG, GySEV, BDZ, ZSR, QR, , BS [114], SBB [101]
Experience of railway companies	Regularly used for about 6 years (LG), 10 years (SNCB, DB AG, RT), 15 years (ZSR), 25 years (RIB), 30 years (QR), 50 years (GySEV) on over 100 km (RIB, LG, RT, SBB), 50-100 km (BDZ), 25-50 km (JZ, ZSR), 10 to 25 km (GySEV, QR) less than 5 km (DB AG) [114]
1. Technical data	
Track-bound/non track-bound	Non track-bound
Operating speed (km/h)	Less than 1 km/h (SNCB, LG), 1 to 5 km/h (DB AG, RT, GySEV, BDZ, ZSR, QR, RIB [114] SBB), 10- 20 km/h (JZ) [114] also dependent on the plant cover present (SBB)
Area covered in m^2/h	150m^2/h(JZ [114]), 1,000 m^2/h (GySEV, QR [114])
Installation and de-installation time per session	5 minutes (QR [114]), ½ h (GySEV, BDZ, ZSR [114]), RIB [114])
2. Vegetation control areas	
Defined areas A to E	Used in transition area (Area C) (JZ, DB AG, RT, RIB, QR [114], SBB), on the ballast shoulder (Area B) (JZ, DB AG, RT, RIB [114], SBB)), in the ballast bed (Area A) (JZ, DB AG, RT [114], SBB) on the embankment (Area D) (QR [114]), away from the track area (Area E) (SNCB, QR, GySEV) [114] Used both for banks and cuttings (JZ, SNCB, DB AG, RT, LG, GySEV, BDZ, ZSR, QR, RIB [114], SBB)
Station areas or open line	Less accessible parts of track, stations and their surroundings (SNCB [114]) not on open line (GySEV [114]) open line and stations (SBB)
Used in areas where chemical vegetation control is prohibited, e. g. groundwater protection zones	Herbicides might pollute groundwater depending on the herbicide used. No chemical used in groundwater protection zones (SBB, DB AG)

Appendix 5 - Chemical Methods - M18 Back-pack Spraying

3. Vegetation control conditions	
Application in combination with other methods useful/necessary	Combined with *mowing* (SNCB, ZSR [114]), mowing and mulching in area (C) and (D) (SBB), spraying train (RT, LG, BDZ [114]), selective spraying (RIB [114]), rail-road vehicle (DB AG [114]) to obtain a better effect (SNCB, ZSR [114]), for economic reasons (LG, BDZ, RIB [114]) or to obtain the effect desired (RT [114] SBB) Not combined (GySEV JZ [114]), constructional methods
Period of application during the year/day *and frequency of application*	Depending on the herbicide used
Weather conditions	Depending on the herbicide used
Treatable plants – problem plants	Depending on the herbicide used
Treatable growth stage	Depending on the herbicide used
Frequency of application	Depending on the herbicide used
Impact on services (temporary/ permanent track possession)	No temporary track possession needed (RIB, ZSR, BDZ, GySEV, RT, SNCB [114], SBB). used during periods free of traffic only (DB AG, LG[114])
4. Costs[30]	
per km (one or both sides)	2.5 €/km (GySEV [114]), 480 €/km (JZ [114]) when used on one side of the track only. 5 €/km (GySEV [114]), 147 €/km (BDZ [114]) when used on both sides of the track 135 €/km (1996, SBB) [101]
per m^2	0.02 €/m^2 (BDZ [114]) when used on both sides of the track, 0.08 €/m^2 when used on one side of the track only (JZ [114])
5. Environmental effects	
Known toxic effects	Depends on the herbicide used (DB AG)
Safety of staff	A lookout has to accompany back-pack sprayers (SBB)
Other impacts on	Depending on the herbicide used
6. Observations	
None	

[30] Exclusive of internal costs, cf. points made in Subsection 6.2

Appendix 5 - Chemical Methods - M19 Spraying Train

M 19 Spraying Train

Category	Chemical
Name of method	**Spraying train**
Description	Herbicides are sprayed by motor operated spraying devices mounted on a special train. The spraying solution is mixed permanently. Spraying devices mounted on a train or a gang car, spraying devices either manually operated or controlled electronically, basic method (CD [114]). Injection-procedure: solution of water and herbicide mixed shortly before it enters the nozzle (DB AG [114]) Different types of equipment depending on track categories: for open track, fast-spraying train leased from BV; for stations, mobile track-bound equipment, which is slower (JBV [114]) Experiments with new equipment are planned (pictures of various types with short description available) (JBV [114]) SNCB hires spraying train from SNCF [114]
Effect of method on plants	Method of combating symptoms. Chemical methods are used to destroy unwanted vegetation. Effect depends on herbicide used.
Drawings and/or pictures	See Appendix **14**
Main application (vegetation control or vegetation control as a side-effect)	Main application
Railway companies which have experience with this method	CNCF CFR SA; CD; SZ; JZ; SNCB/NNBS; DB AG; RT, BS; BV; LG; GySEV AG, BDZ; ZSR; JBV; LDZ; SNCF [114]
Experience of railway companies	Regularly used for 4 years (SZ), 6 years (LG, LDZ), 10 years (CD), 15 years (CNCF CFR SA), 20 years (SNCB), 25 years (DB AG), 30 years (ZSR), 40 years (GySEV), 45 years (BS; JBV, JZ), 50 years (RT,SNCF), 60 years (BV) on over 100 km (CNCF CFR SA; CD; SZ; JZ; SNCB/NNBS; DB AG; RT, BS; BV; LG; GySEV AG, BDZ; ZSR; JBV; LDZ; SNCF) [114]
1. Technical data	
Operating speed (km/h)	1 to 5 km/h (CD), 5 to 10 km/h (CD, GySEV, ZSR), 10 to 20 km/h (ZSR, SZ, CNCF CFR), 20 to 40 km per hour (CNCF CFR SA; JZ, BS; BV; LG, BDZ; JBV; LDZ;); over 40km/h (SNCB, DB AG, RT, SNCF) [114]
Area covered in m^2/h	12,550 m^2/h(CD), 40,000 m^2/h (GySEV), 55,000 m^2/h (ZSR), 75,000 (BS), 100,000 m^2/h(BV, LG, SZ, JZ), 150,000 m^2/h (CNCF CFR), 175,000 m^2/h (JBV), 200,000 m^2/h (BCZ), 256,000 m^2/h(LDZ), 280,000 m^2/h (DB AG; SNCF), 400,000 m^2/h (SNCB) [114]
Installation and de-installation time per session	½ h (LDZ, SNCF), 1h (BV, DB AG, SNCB), 1.75h (ZSR), 2.5h (GySEV), 3h (CNCF CFR), 7h (BDZ), 15h (JZ), 18 h (SZ), 150 h (JBV, this also includes testing of equipment). [114]
2. Vegetation control areas	

Appendix 5 - Chemical Methods - M19 Spraying Train

Defined areas A to E	Most companies use it in the ballast bed (Area A) and on the ballast shoulder (Area B) (CNCF CFR, CD, JZ, DB AG, RT, BS, GySEV, BDZ, ZSR, JBV, LDZSNCF). Some also in the transition area (Area C) (JZ, DB AG, RT, BS, GySEV, BDZ, ZSR, JBV, LDZ, SNCF), on the embankment (Area D) and away from the track area (Area E) (JBV, but spraying only such as needed [selective spraying]) [114] Used both for banks and cuttings (CNCF CFR, SZ, SNCB, DB AG, RT, BS, BV, LG, GySEV, BDZ, ZSR, JBV, LDZ,SNCF), on banks or on the flat (CD) [114]
Used in areas where chemical vegetation control is prohibited, e. g. groundwater protection zones	Depending on type used, herbicides may pollute groundwater No chemical used in groundwater protection zones (DB AG)
3. Vegetation control conditions	
Application in combination with other methods useful/necessary	Not combined (CNCF CFR, JZ, SNCB, BV, GySEV, JBV, LDZ, SNCF). Combined with *mowing* or *mulching* (DB AG, SZ, CD), other chemical methods: back-pack spraying (LG, BDZ, BS, RT, DB AG) is imperative to obtain the desired effect (RT, BS) [114], ballast cleaning (BDZ), manual weeding (BDZ, LG, SZ). [114] Combined to obtain a better effect (CD, SZ, DB AG, LG, BDZ, ZSR), for economic reasons (ZSR, LG, SZ), for maintenance reasons (DB AG),
Period of application during the year/day	Depending on the herbicide used
Treatable plants – problem plants	Depending on the herbicide used
Treatable growth stage	Depending on the herbicide used
Frequency of application	Depending on the herbicide used
Impact on services (temporary/ permanent track possession)	Used only during periods free of traffic (CNCF CFR, BV, GySEV, ZSR, BDZ, JBV, SNCF) used partly during periods free of traffic (BS, JZ, SZ, CD), partial track possession needed (JZ, ZSR) [114]
4. Costs[31]	
per km (one or both sides)	50 €/km (SNCF), 60 €/km (ZSR), 90 €/km(SNCB), 175 €/km (BDZ), 480 €/km (JZ)) when it is applied only on one side. applied on both sides of the line: 50 €/km (SCNF), 75 €/km (LG), 90 €/km (SNCB), 100 €/km (ZSR), 134 €/km (BS), 140 €/km(LDZ), 185 €/km(JBV), 250 €/km (BDZ), 260 €/km (DB AG), 3 to 16 €/km (CD) [114]
per m^2	0.01 €/m^2 (SNCF), 0.02 €/m^2 (SNCB), 0.05 €/m^2 (BDZ), 0.06 €/m^2 (BV), 0.08 €/m^2 (JZ), 0.12 €/m^2 (ZSR), 2.5 €/m^2 (GySEV) when it is applied on one side only [114] applied on both sides of the 0.01 €/m^2 (SNCF), 0.02 €/m^2 (LDZ, SNCB), 0.03 €/m^2 (JBV), 0.04 €/m^2 (BDZ), 0.2 €/m^2 (ZSR), 2.5 €/m^2 (GySEV) [114]
5. Environmental effects	

[31] Exclusive of internal costs, cf. points made in Subsection 6.2

Known toxic effects	Depends on the herbicide used
Safety of staff	Machines
Other adverse impacts on	Water (CD, SNCB, RT, BS, BV, GySEV, BDZ, ZSR), soil (SNCF; LDZ, JBV; BDZ, GySEV, LG, BV, RT, SNCB, JZ, SZ), animals (CD, JZRT, BS, BV, GySEV, ZSR, LDZ), plants (other than those wanted) (CD, SZ, JZ, SNCB, RT, BV, GySEV, BCZ, JBV), human health (CD, JZ, RT, BS, BV, LG, GySEV, ZSR, JBV), air (RT, BS, GySEV, JBV) [114]
6. Observations	
None	

Appendix 5 - Chemical Methods - M20 Rail-Road Vehicle

M 20 Rail-Road Vehicle

Category	Chemical
Name of method	**Rail-road vehicle**
Description	Herbicides are sprayed onto the plants by using motor operated spraying devices mounted on a road vehicle which can run on track too. The spraying solution is mixed in advance (SNCB [114]) used to be more flexible; self driving device on the road to the place of application, while operating it runs along the rails, spraying solution is permanently mixed. (DB AG [114])
Effect of method on plants	Method of combating symptoms, Chemical methods are used to destroy unwanted vegetation. Effect depends on herbicide used.
Drawings and/or pictures	See Appendix **14**
Main application (vegetation control or vegetation control as a side-effect)	Main application
Railway companies which have experience with this method	SNCB, DB AG, GySEV, JR, QR, SNCF, BS [114]
Experience of railway companies	Regularly used for 3 years (SNCF), 10 years (GySEV), 20 years (SNCB, JR, QR), 25 years (DB AG), 45 years (BS) on over 100 km (SNCB, SNCF, DB AG, QR, J, BS) on 5 to 10 km (GySEV) [114]
1. Technical data	
Track-bound/non track-bound	Track-bound and non track-bound (= rail-road vehicle)
Operating speed (km/h)	1 to 5 km/h (SNCB, GySEV, JR, SNCF), 20 km/h (DB AG, BS), 40 km/h (DB AG, QR) [114]
Area covered in m^2/h	10,000 m^2/h (GySEV), 20,000 m^2/h (SNCF), 75,000 m^2/h (BS), 50,000 m^2/h (QR), 100,000 m^2/h (DB AG) [114]
Installation and de-installation time per session	5 min(QR), 1/2h (JR, SNCF), 1h (DB AG), 2h (GySEV, SNCB) [114]
2. Vegetation control areas	
Defined areas A to E	Ballast bed (Area A), ballast shoulder (Area B) and in the transition area (Area C) (SNCF; QR, JR, DB AG, GySEV, BS), embankment (Area D) and away from the track area (Area E) (SNCF), used both for banks and cuttings (SNCF, SNCB; QR; JR, GySEV, DB AG, BS) [114]
Station areas or open line	Station track and everywhere where the spraying train cannot be used (DB AG) [114]
Used in areas where chemical vegetation control is prohibited, e. g. groundwater protection zones	Depending on type used, herbicides may pollute groundwater (DB AG [114]) No chemical used in groundwater protection zones (DB AG)
3. Vegetation control conditions	
Application in combination with other methods useful/necessary	Not combined (SNCB, GySEV, QR), combined with *mowing* (JR, SNCF) and back-pack spraying (DB AG, BS) combined to obtain a better effect (JR), for economic (SNCF) or operational reasons (DB AG) [114]
Period of application during the year/day	Depending on the herbicide used
Weather conditions	Depending on the herbicide used

Appendix 5 - Chemical Methods - M20 Rail-Road Vehicle

Treatable plants – problem plants	Depending on the herbicide used
Treatable growth stage	Depending on the herbicide used
Frequency of application	Depending on the herbicide used
Impact on services (temporary/ permanent track possession)	No temporary track possession needed (DB AG, JR), only used during periods free of traffic (GySEV), total halting of train operations needed (SNCF), partial halting of train operations needed (SNCB, BS) [114]
4. Costs[32]	
per km (one or both sides)	196 €/km (SNCF) when it is applied only on one side. applied on both sides of the line: 134 €/km (BS), 196 €/km (SNCF), 300 €/km (DB AG) [114]
per m^2	0.03 €/m^2 (SNCF, SNCB), 2 €/m^2 (GySEV) when applied on one side When applied on both sides of the line: 2 €/m^2 (GySEV) [114]
5. Environmental effects	
Known toxic effects	Depends on herbicide used [114]
Safety of staff	Machines
Others: effect on	Water (SNCB, JR, QR, SNCF, BS), soil and plants (other than those wanted) (SNCB, JR, QR), air (QR) [114]
6. Observations	
None	

[32] Exclusive of internal costs, cf. points made in Subsection 6.2

Appendix 5 - Chemical Methods - M21 Selective Application by Spraying Train (e. g. „Weed Eye“

M 21 Selective Application by Spraying Train (e. g. “Weed Eye”)

Category	Chemical
Name of method	**Selective application by spraying train (e. g. “weed eye”)**
Description	A computer-controlled sensor gauges vegetation cover within the track, herbicides are only sprayed if plants are detected. plant detecting system uses infrared-sensors, sketch available (DB AG [114]) Spot spraying instead of spraying of whole track, volume of pesticides reduced by about 50 %,sketch available, video (digital camera) is used (BS [114])
Effect of method on plants	Method of combating symptoms, herbicides used to destroy unwanted vegetation. Effect depends on herbicide used.
Drawings and/or pictures	See Appendix **14**
Main application (vegetation control or vegetation control as a side-effect)	Main application
Railway companies which have experience with this method	DB AG, BS, SNCF [114], GySEV, CH, BDZ [114][33)]
Experience of railway companies	Regularly used for 2 to 5 years (DB AG, GySEV), used in experiments for 1 to 2 years (DB AG, BS), not used any longer (BDZ). used regularly and in experiments on over 100 km (DB AG), used regularly on 5 – 10km (GySEV), on over 100km (CH), experiments on less than 5km (BS) at development stage (SNCF) [114]
1. Technical data	
Track-bound/non track-bound	Track-bound
Operating speed (km/h)	1-5 km/h (GySEV), 10-20 km/h (CH), 20 km/h (DB, BS, BDZ), > 40 km/h (DB AG) [114]
Output in m^2/h	10,000 m^2 /h(GySEV), 90,000m^2 /h (CH), 200,000m^2/h (BDZ), 260,000 m^2/h (DB) [114].
Installation and de-installation time per session	1h (DB AG), 2.5h (GySEV), 7h (BDZ), 8h (CH) needed [114]
2. Vegetation control areas	
Defined areas A to E	Ballast bed (Area A) (DB AG, BS, GySEV, CH), ballast shoulder (Area B) and transition area (Area C) (BS, GySEV, CH). away from the track area (Area E) (BS), embankment area (Area D) (CH [114]). used both for banks and cuttings (DB AG, BS, GySEV, BDZ [114])
Used in areas where chemical vegetation control is prohibited, e. g. groundwater protection zones	Depending on type used, herbicides may pollute groundwater (DB AG [114]) No chemical used in groundwater protection zones (DB AG)
3. Vegetation control conditions	

[33)] Possible that the questionnaire was not understood completely, no further information on the systems received

Appendix 5 - Chemical Methods - M21 Selective Application by Spraying Train (e. g. „Weed Eye“

Application in combination with other methods useful/necessary	Not combined (GySEV, BS) [114] Combined with other herbicide application methods (back-pack spraying, rail-road vehicles, spraying train) to obtain a better effect and for operational reasons (BDZ, DB AG) [114]
Period of application during the year/day tested	Depending on the herbicide used
Weather conditions	Depending on the herbicide used
Treatable plants – problem plants	Depending on the herbicide used
Treatable growth stage	Depending on the herbicide used
Frequency of application	Depending on the herbicide used
Impact on services (temporary/ permanent track possession)	No temporary track possession needed (DB AG) used during periods free of traffic only (CH, GySEV, BS) [114]
4. Costs [34]	
per km (one or both sides)	About 260 €/km (DB AG) (when applied on both sides of the line) [114]
per m^2	1.5 €/m^2 (GySEV) [114]
5. Environmental effects	
Known toxic effects	Depends on herbicide used [114]
Safety of staff	Machines
Other adverse impacts on	Water (GySEV, BDZ), soil (CH, GySEV, BDZ) air (CH, GySEV) humans (CH, GySEV), plant (other than those wanted) (CH, GySEV), animals (GySEV) [114]
6. Observations	
None	

[34] Exclusive of internal costs, cf. points made in Subsection 6.2

Appendix 5 - Chemical Methods - M22 Weed Wiping

M 22 Weed wiping

Category	Chemical
Name of method	**Weed wiping**
Description	Herbicide is transferred to plants by direct contact between the plants and strips of cloth saturated with the herbicide.
Effect of method on plants	Method of combating symptoms, herbicides are used to destroy unwanted vegetation. Effect depends on herbicide used.
Drawings and/or pictures	See Appendix **14**
Main application (vegetation control or vegetation control as a side-effect)	Main application
Railway companies which have experience with this method	BV, QR [114]
Experience of railway companies	Used on experimental basis for 3 (BV [114]) or 6 years (QR [114]) on less than 5 km (QR [114]). used for maintenance only (BV, QR [114])
1. Technical data	
Track-bound/non track-bound	Track-bound and non track-bound vehicles used (BV, QR [114])
Operating speed (km/h)	1 - 5 km/h (BV [114]), 5 - 10 km/h (QR [114])
Area covered in m^2/h	8,000 m^2 /h (QR [114]), 25,000 m^2 /h (BV [114])
Installation and de-installation time per session	10 min (BV [114]) and 30 min (QR [114])
2. Vegetation control areas	
Defined areas A to E	Ballast bed (Area A) and ballast shoulder (Area B) (BV [114]) embankment (Area D) (QR [114]). used both for banks and cuttings (BV, QR [114])
Used in areas where chemical vegetation control is prohibited, e. g. groundwater protection zones	Depending on type used, herbicides may pollute groundwater
3. Vegetation control conditions	
Application in combination with other methods useful/necessary	Not combined (BV [114]), combined with *mowing* to obtain the effect desired and for economic reasons (QR [114])
Period of application during the year/day	Depending on the herbicide used
Weather conditions	Depending on the herbicide used
Treatable plants – problem plants	Depending on the herbicide used
Treatable growth stage	Depending on the herbicide used
Frequency of application	Depending on the herbicide used
Impact on services (temporary/ permanent track possession)	No temporary track possession needed (QR [114]), partial track possession needed and used during periods free of traffic (BV [114])
4. Costs[35]	
per m^2	About 0.2 €/m^2 (BV [114])

[35] Exclusive of internal costs, cf. points made in Subsection 6.2

Appendix 5 - Chemical Methods - M22 Weed Wiping

5. Environmental effects	
Safety of staff	Machines
Others	Impacts on water, soil and animals (BV [114])
6. Observations	
None	

13.5.6 Thermal/Electrical Methods

M 23 Flaming

Category	Thermal/electrical method
Name of method	**Flaming**
Description	With flaming, plants are destroyed by both heat on the surface of plants and heat conducted inside the plant. No ash is produced (≠ burning) [61], gas burners generally used, Little difference to IR methods
Effect of method on plants	High temperatures destroy unwanted plants. Method of combating symptoms
Drawings and/or pictures	See Appendix **14**
Main application (vegetation control or vegetation control as a side-effect)	Main application
Railway companies which have experience with this method	SBB, BV [42], BS [114]
Experience of railway companies	Used in experiments (BS [114], BV [42], SBB [101])
1. Technical data	
Track-bound/non track-bound	Non track-bound
Operating speed (km/h)	6 km/h is the limit because of wind and turbulence [5]
Area covered in m^2/h	36 m^2/h (SBB [101])
2. Vegetation control areas	
Defined areas A to E	On ballast shoulder (Area B), in the transition area (Area C), away from the track area (Area E) (SBB), used both for banks and cuttings (SBB)
Station areas or open line	Open line (SBB), stations (BS [114])
Used in areas where chemical vegetation control is prohibited, e. g. groundwater protection zones	Also allowed in groundwater protection zones
3. Vegetation control conditions	
Application in combination with other methods useful/necessary	No combination tested or mentioned
Period of application during the year/day for optimal effect of method, recommended	From spring to autumn [5]
Weather conditions	Less effective when windy [42, 61] and humid [42].
Treatable plants – problem plants	Very tolerant plant species are: dandelions, horsetail (plants having storage capacity below ground)(BV [42]) Not effective against plant seeds in the ground (BV [5])
Treatable growth stage	Less effective against adult plants [61]
Frequency of application	Conducted at close intervals during spring and early summer, if renewed growth is low, less frequently (BV [5])
Impact on services (temporary/ permanent track possession)	No track possession needed (SBB)
4. Costs	
Not known	

5. Environmental effects	
Known toxic effects	None
6. Observations	
Heat at ground surface 700 – 1,000°C [5] Technical operating problems: gas bottles may ice up → bottles were put in warm water to prevent this (SBB [61]) Danger of damaging other rail infrastructure: During flame control wooden sleepers can start to glow (BV [42]), (BS [114]), risk of damaging cables (BS [114]) Flame control is appropriate given constant supervision, but not for rehabilitation of vegetation-filled areas [42]. The ground should be as flat as possible to achieve good results [5] No treatment recommended if there is any danger of grass burning (BV [5]) → Use not recommended (BS [114])	

Appendix 5 - Thermal/Electrical Methods - M24 Infrared Devices

M 24 Infrared devices

Category	Thermal/electrical
Name of method	**Infrared devices**
Description	Plants are subjected to infrared radiation (indirect flaming) [48] by using steel grids or plates.
Effect of method on plants	High temperatures destroy unwanted plants. Method of combating symptoms
Drawings and/or pictures	See Appendix **14**
Main application (vegetation control or vegetation control as a side-effect)	Main application
Railway companies which have experience with this method	DB AG, BS [114], SBB [76]
Experience of railway companies	Regularly used for 5 years on over 100 km but not used any longer. (DB AG [114]), used in experiments (SBB [76])
1. Technical data	
Track-bound/non track-bound	Track-bound vehicles (DB AG [114]), non track-bound (SBB [76])
Operating speed (km/h)	Approx. 2 km/h (DB AG [114]), approx. 1km/h (SBB [76])
Area covered in m^2/h	Approx. 10,000 m^2/h (DB AG [114]), approx. 800 m^2 (SBB [76])
Installation and de-installation time per session	About 1 hour was needed. (DB AG [114])
2. Vegetation control areas	
Defined areas A to E	Used in the ballast bed (Area A), on the ballast shoulder (Area B) (DB AG [114]) away from the track area (Area E) (SBB [76]), used both for banks and cuttings (DB AG [114])
Station areas or open line	Open line and stations
Used in areas where chemical vegetation control is prohibited, e. g. groundwater protection zones	Yes, possible
3. Vegetation control conditions	
Application in combination with other methods useful/necessary	Not combined (DB AG [114])
Period of application during the year/day tested	From spring to autumn (DB AG [114])
Weather conditions	Dry weather conditions yield the best effect [76]
Treatable plants – problem plants	Treatable: evergreen plant species [57] Not treatable: horsetail, reeds, brambles and all deep-rooting plants (DB AG [114]), little effect on dandelions [57, 94]
Treatable growth stage	Not effective against adult plants and young shrubs/trees (DB AG [114], [57]), treatment only effective at 3/5-leaf stage of plants [61]
Frequency of application	5 times a year (DB AG [114])
Impact on services (temporary/	Partial track possession was needed. (DB AG [114])

permanent track possession)	
4. Costs [36]	
per km (one or both sides)	7,186 €/km when applied on both sides of the line (DB AG [114])
per m^2	No data; owing to slow speed, high outlay on personnel (DB AG [114])
5. Environmental effects	
Known toxic effects	None (DB AG [114])
Safety of staff	Machines
Other adverse impacts on	Air (DB AG [114]) output of CO_2 (SBB [76]) animals, plants (other than those wanted) and human health (DB AG [114]), SBB [76])
6. Observations	
TIK [76, 114] IR-train developed in Germany: only plant constituents that are visible can be destroyed, roots remain in the ballast, plants adapt to new conditions, plant growth only delayed, not a preventive method, no long-lasting effects, too expensive (up to 26 times as costly as use of spraying train), negative ecological rating (CO_2, burning of wooden sleepers) use of 120 kg/h (propane gas) = 10g/m^2 [114] *"Puzzy Boy" and "Thermflex" hand operated machines tested (SBB* [76]*):* only suitable for small areas in nice weather, effect on plants not investigated (over several years), risk of burning unavoidable, the same side-effects as TIK [76], IR methods not favourable owing to overly high energy consumption, insufficient effect on plants, risk of burning [72], use of 6.4g/m^2 propane gas [76], energy consumption too high [72], slow heat conduction on plants [61] IR is less effective than flaming: reduced speed because of lower temperature (BV [5])	

[36] Exclusive of internal costs, cf. points made in Subsection 6.2

Appendix 5 - Thermal/Electrical Methods - M25 Wet Steaming

M 25 Wet Steaming

Category	Thermal/electrical
Name of method	**Wet steaming**
Description	Plants are treated with wet steam. Saturated steam and boiling fluids (not hot steam) are used. [61] with pre-heating of track for better effect (DB AG [114])
Effect of method on plants	Hot water as medium to conduct heat onto the plant surface [61], method of combating symptoms
Drawings and/or pictures	See Appendix **14**
Main application (vegetation control or vegetation control as a side-effect)	Main application
Railway companies which have experience with this method	DB AG [114], BV [114], JZ [114] SBB [35, 37], BS [114], CP
Experience of railway companies	Used in experiments for 2 years (DB AG, BV [114], SBB), used in experiments for 1 year (BS [114]) on about 5km (SBB) on 10 km (DB AG) on 300m (BS [114]), used in experiments for 10 years (pers. inf. CP), not used any longer (BV [114]), experiments planned (JZ [114])
1. Technical data	
Track-bound/non track-bound	Track-bound vehicles only (DB AG [114], SBB [35, 37], inf. from Canadian Pacific Rail), vehicle for road use (BS [114]) tested
Operating speed (km/h)	1 km/h[37] (DB AG [114], SBB [35, 37]) 1 km/h - 5 km/h (BV), speed of 25km/h was expected but not technically feasible, speed achieved 2km/h depending on plant cover (CP)
Area covered in m^2/h	3,360 m^2/h (DB AG), 3,750 m^2/h (SBB)
Installation and de-installation time per session	3/4 hours are needed (DB AG, SBB)
2. Vegetation control areas	
Defined areas A to E	Ballast bed (Area A), on the ballast shoulder (Area B) (DB AG, BV, SBB), in the transition area (Area C) (DB AG, BV), used both for banks and cuttings (DB AG, SBB)
Station areas or open line	Effect in stations not satisfactory, because of high platform walls (SBB) tested in stations (BS [114])
Used in areas where chemical vegetation control is prohibited, e. g. groundwater protection zones	Yes, can be used in groundwater protection zones
3. Vegetation control conditions	
Application in combination with other methods useful/necessary	Not combined with any other method (DB AG, BV), combined with *mowing/mulching* in transition area, embankment recommended (SBB)
Period of application during the year/day	Once a year (DB AG), two to four times a year (BV), twice a year (SBB), in spring and summer (SBB),

[37] Total operating speed per track km, because the machine has to move twice to cover the whole track width

	day time more effective than during night (SBB)
Weather conditions	Dry weather conditions yield best results, in rainy weather problems with visibility and therefore safety problems (SBB)
Treatable plants – problem plants	Can treat all plants (DB AG), long-term effects not yet investigated (DB AG, SBB), not effective against deep-rooting plants such as dandelions (SBB, DB AG), effect on other problem plants not clear yet (SBB) long-term effect: species composition shifted to species with lower growing habits (grasses) (CP)
Treatable growth stage	Not effective against adult plants (DB AG, SBB)
Frequency of application	Twice a year or more recommended (SBB) 3-4 times a year in Alaska [42], four times a season but 6 times a season recommended (BS [114]), 3-5 times a year necessary for adequate control (CP)
Impact on services (temporary/ permanent track possession)	Partial halting of train services needed (DB AG, BV, SBB) or applied during periods free of traffic (DB AG, BV, SBB, CP)
4. Costs[38]	
per km (one or both sides)	895 € /km when applied on both sides of the line (DB AG). 6,000 €/km[39] (2001, SBB), estimated 540 €/km (BS [114])
per m^2	0.22 € per m^2 when applied on both sides (DB AG)[39]
5. Environmental effects	
Known toxic effects	None (DB AG, BV, SBB)
Safety of staff	Machines
Others	Enormous consumption of energy and water (SBB, BV [42], inf. from Canadian Pacific Rail)
6. Observations	
Steam temperature 437°C (Alaskan Railroad Corporation) (1994) [42] [40], fast cooling of steam, hence large energy loss, penetration very low in compact stands [42] not considered to be applicable because of high energy consumption [42]: 2,700L of fuel per day and 27,000 L water per day used, heat of steam: 115°C with a pressure of 7 bar (CP), heat 100-110°C and pressure of 1 bar at the point of emission of the steam in the Austrian model (SBB [35, 37]) Only cost-effective if applied over long distances, which in most cases is not possible (frequency of trains running too great) (SBB)	

[38] Exclusive of internal costs, cf. points made in Subsection 6.2

[39] (Experimental stage, machine and personnel for operating same, exclusive of internal costs)

[40] probabely Fahrenheit meant: 437 F = 225 °C

Appendix 5 - Thermal/Electrical Methods - M26 Hot Water Treatment

M 26 Hot Water Treatment

Category	Thermal/electrical
Name of method	**Hot water treatment**
Description	Hot water as means of conducting heat onto plant surface [61]
Effect of method on plants	High temperature destroys unwanted plants. Method of combating symptoms. It is a maintenance method
Drawings and/or pictures	See Appendix **14**
Main application (vegetation control or vegetation control as a side-effect)	Main application
Railway companies which have experience with this method	BV[114, 42], SBB [81]
Experience of railway companies	Used in experiments for 3 years (BV) [114], lab and field experiments for 3 years in orchard [61], long-term studies on development and composition of various plant species at different operating speeds have yet to be conducted [61]
1. Technical data	
Track-bound/non track-bound	Track-bound vehicles only used (BV) [114]
Operating speed (km/h)	About 3 km/h (BV) [114], about 6 km/h [61] when adding wagons in a rake, an operating speed of about 20 km/h should be possible (assumption - not tested) [61] operating speed depends on weather conditions, slower in wet conditions [61]
Area covered in m^2/h	About 15,000 m^2/h (BV) [114], 500-1,000 m^2/h (SBB) [81]
Installation and de-installation time per session	About 1/4 hours are needed (BV) [114]
2. Vegetation control areas	
Defined areas A to E	Used in the ballast bed (Area A), on the ballast shoulder (Area B) and in the transition area (Area C) (BV) [114], used both for banks and cuttings. (BV) [114]
Used in areas where chemical vegetation control is prohibited, e. g. groundwater protection zones	Yes, may be used in vicinity of water and in groundwater protection zones [70]
3. Vegetation control conditions	
Application in combination with other methods useful/necessary	Not used in combinations (BV) [114]
Period of application during the year/day	Used two to four or more times a year depending on the amount of plants, used in spring and summer (BV) [114],
Period of application during the year/day for optimal effect of method, recommended	Has to be adapted to dominant plant species in area requiring treatment [61]
Weather conditions	More effective in sunny, warm and dry weather, during rainy weather a slower speed of application is recommended [61]
Treatable plants – problem plants	Insufficient effect on horsetail, but not enough data available (BV) [114], plants with storage facilities (e.g. dandelions) or deep-rooting plants are not easy to treat [61]
Treatable growth stage	Ineffective against adult plants and young shrubs/trees. (BV) [114], adult plants of woody species in particular are not easy to treat [61]

Duration of effects	Up to 6 weeks under favourable conditions (summer, high temperatures and sun) [61], 8 to 12 weeks with the apparatus from New Zealand [16]
Frequency of application	Two to three applications a year should lead to long lasting effects [61] (this is an estimation)
Impact on services (temporary/ permanent track possession)	partial stop of operating train services needed, applied during periods free of traffic only, (BV) [114]
4. Costs	
per m^2 [41]	about 0.5 €/m^2 when applied on one side of the line only (BV) [114]. 0.06 €/m^2 (1994 [4], 42]), 0.05 €/m^2 (New Zealand apparatus) [16]
5. Environmental effects	
Known toxic effects	None [114]
Safety of staff	Machines
Others	No adverse impact on environment cited (BV) [114], no impacts on humans or animals [61]
6. Observations	
Use of water Use of 1,400 L/h, 1.4 – 2.8 L/m^2 treatment [81, 16], 20,400 L/h, 1.8 L/m^2 [42], 0.8 – 1. L/m^2 (= 1,000 L/h) [61], use of water depending on height of plant 0.1 – 4.5 L/m^2 [4, 70] *Use of energy* 34 L/m^2 fuel used → energy consumption too high [81], fuel 0.01 – 0.015 L/m^2 [61], wet or higher plants need more energy [42] *Other observations* Water temperature has to be as close to boiling point as possible to get a good effect, grass needs more heat than other leaf plants, tests show that this method only delays growth, even when large amount of water is used [42]; long time needed to fill up water reservoir a drawback of the New Zealand apparatus [16], no effects in deeper soil layers (from 5 cm downwards no change in original temperature recorded) [16], to achieve a better overall effect, the energy content of the exhaust fumes is used as a pre-drying procedure before the hot water treatment takes place (higher temperatures produced) [61]	

[41] No indication as to what is included in costs; probably exclusive of internal costs (experimental stage, machine and personnel for operating same, exclusive of internal costs), cf. points made in Subsection 6.2.

Appendix 5 - Thermal/Electrical Methods - M27 Hot Air

M 27 Hot air

Category	Thermal/electrical
Name of method	**Hot air**
Description	Plants treated with hot air.
Effect of method on plants	High or low temperatures destroy unwanted plants. Method of combating symptoms
Main application (vegetation control or vegetation control as a side-effect)	Main application
Railway companies using this method	BV [42]
Experience of railway companies	Used in experiments (prototype for use on railways built) (BV) [42]
1. Technical data	
Track-bound/non track-bound	Track-bound vehicles (BV) [42]
Operating speed (km/h)	0.6-0.7km/h (BV) [42]
2. Vegetation control areas	
Used in areas where chemical vegetation control is prohibited, e. g. groundwater protection zones	Does not pollute groundwater.
3. Vegetation control conditions	
No data available	
4. Costs	
No data available	
5. Environmental effects	
No data available	
6. Observations	
Heat of hot air in pipe: 700 °C, equipment still being developed [42], the effect on plants was not wholly satisfactory [42], a hot-air circulation system (300-400°C) with high flow speed delivers good heat penetration into the body of plants; high operating speeds possible using a device 2 m long; this method can be improved by using water-saturated air (= hot steam) [26, 44]	

Appendix 5 - Thermal/Electrical Methods - M28 Freezing

M 28 Freezing

Category	Thermal/electrical
Name of method	**Freezing**
Description	Plants are treated with liquid nitrogen (-196°C) and carbon dioxide snow (-78°C).
Effect of method on plants	High or low temperatures destroy unwanted plants. Method of combating symptoms
Main application (vegetation control or vegetation control as a side-effect)	Main application
Railway companies using this method	BV [42], DB AG
Experience of railway companies	Used in experiments (not on railway lines) (BV) [42] (DB AG)
1. Technical data	
No data available	
2. Vegetation control areas	
No data available	
3. Vegetation control conditions	
No data available	
4. Costs	
No data available	
5. Environmental effects	
No data available	
6. Observations	
Immediate effect on perennial herbaceous plants, after some time plants start growing again. Grass was not affected immediately, woody plants only minimally affected, repeated applications needed [42] Very energy-consuming method, not believed to be practically applicable [42]	

Appendix 5 - Thermal/Electrical Methods - M34 Hot Foam

M 34 Hot foam

Category	Thermal/electrical
Name of method	**Hot foam**
Description	Plants are treated with hot foam to retain the heat for a longer period. The foam is created with an injector using hot water, pressurised air and an added detergent substance [61]
Effect of method on plants	High temperatures destroy unwanted plants. Method of combating symptoms
Drawings and/or pictures	See Appendix **14**
Main application (vegetation control or vegetation control as a side-effect)	Main application
Railway companies using this method	None, only experiments at Hohenheim University, Bremen airport [61]
Experience of railway companies	Used in experiments [61]
1. Technical data	
No data available	
2. Vegetation control areas	
No data available	
3. Vegetation control conditions	
No data available	
4. Costs	
No data available	
5. Environmental effects	
No data available	
6. Observations	
Measurements of temperature beneath the foam show a longer-lasting high temperature, probably yielding a more intense effect on plants [61], Effects on humans and animals have yet to be investigated, as have the operating speed achievable and the question as to whether it is possible to use the procedure on railway lines. Its effect is likely to be roughly equivalent to that of wet steam, the impact on the environment of the detergents used to make the foam have yet to be tested.	

Appendix 5 - Thermal/Electrical Methods - M29 Direct Electrical Contact

M 29 Direct Electrical Contact

Category	Thermal/electrical
Name of method	**Direct electrical contact**
Description	Plants are ”cooked” with an electric current
Effect of method on plants	The electrical effect damages plants. Method of combating symptoms, used as maintenance measure
Drawings and/or pictures	See Appendix **14**
Main application (vegetation control or vegetation control as a side-effect)	Main application
Railway companies which have experience with this method	SBB [17, 74]
Experience of railway companies	Used in experiments for 2 years, not used any longer (SBB)
1. Technical data	
No data available	
2. Vegetation control areas	
No data available	
3. Vegetation control conditions	
Weather conditions	Dry weather (SBB) [74]
4. Costs	
No data available	
5. Environmental effects	
Other impacts	On human health (SBB) [74]
6. Observations	
Safety problems: high voltage hazardous to operational safety: it is not permitted to use track as an earth [17, 74], risk of interference with signalling [42], one application of current is not enough, plants subsequently grow even more sturdily and quickly (same observation as with burning), more than one application required [74], current has little or no effect on plant species other than horsetail [74], only tall plants can be treated (otherwise contact with track) [42], other methods, e.g. constructional methods, preferred [74] Devices for applying direct electrical contact are very complicated to assemble, only a small area can be covered with one application (steel grids, rakes, poles,...) Alternating and direct current have an equal effect on plants [74]	

Appendix 5 - Thermal/Electrical Methods - M31 Laser

M 30 Microwaves

Category	Thermal/electrical
Name of method	**Microwaves**
Description	Plants are radiated with microwaves.
Effect of method on plants	The electrical effect damages plants. Heat radiation and high-frequency electro-magnetic waves have a thermal and a mechanical effect on plants (heating and destroying cell walls) [3, 53, 88] Method of combating symptoms. Maintenance method.
Main application (vegetation control or vegetation control as a side-effect)	Main application
Railway companies using this method	DB AG[114], SBB [35, 58, 72]
Experience of railway companies	Used in experiments for 1 year (basic research 1990-1992), not used any longer (DB AG) [114] experiments only (SBB) [28, 58]
1. Technical data	
Track-bound/non track-bound	Track-bound vehicles only were tested. (DB AG) [114]
Operating speed (km/h)	less than 1 km/h (DB AG) [114]
2. Vegetation control areas	
Defined areas A to E	Ballast bed (Area A), on the ballast shoulder (Area B) and in the transition area (Area C). (DB AG) [114]
3. Vegetation control conditions	
No data available	
4. Costs	
No data available	
5. Environmental effects	
Others	Impacts on air and human health (DB AG) [114]
6. Observations	
Effect on plants Killing of plants in closed system possible (DB AG [114]), deep effect is possible, depending on the operating speed, has an effect on seeds and pests but the costs for the method are too high, in agriculture it is only recommended for disinfection of soils [8] *Operational/technical problems:* microwaves also destroy plastics used in the track area (DB AG [114]), the adsorbent has to be too close to the ballast, no practicable means of handling (DB AG [114]), not suitable for track use [114] extremely slow 100 hours/hectare (SBB [28]) *Safety problems:* major problems with technical screening of radiation, from a safety point of view adoption would not be possible (SBB [58]), safety problems arise (BV [42]), potential danger for environment (SBB [72]), shielding against microwaves to costly (DB AG [114]) *Energy consumption:* Comparison of energy consumption by J. Ascard for various vegetation control methods: microwave uses the most energy per hectare [28], overly high energy consumption (SBB [72]), microwaves lead to energy losses due to heating of the ballast (BV [42])	

Appendix 5 - Thermal/Electrical Methods - M31 Laser

M 31 Laser

Category	Thermal/electrical
Name of method	**Laser**
Description	Plants are radiated with lasers.
Effect of method on plants	The electrical effect damages plants. Method of combating symptoms, tested for use as a maintenance method
Main application (vegetation control or vegetation control as a side-effect)	Main application
Railway companies using this method	BS [105]
Experience of railway companies	Experiments with lasers in a greenhouse (BS [105])
1. Technical data	
No data available	
2. Vegetation control areas	
No data available	
3. Vegetation control conditions	
Treatment up to which plant age/growth stadium	Not effective against seedlings, plants grow again (BS [105])
4. Costs	
No data available	
5. Environmental effects	
No data available	
6. Observations	
No satisfactory effect on plants (BS [105]) Lasers for cutting purposes only tested theoretically, no field experiments [69]	

M 32 UV Light

Category	Thermal/electrical
Name of method	**UV light**
Description	Plants are radiated with UV light.
Effect of method on plants	Radiation with UV waves destroys unwanted plants. Method of combating symptoms
Main application (vegetation control or vegetation control as a side-effect)	Main application
Railway companies using this method	BV [42]
Experience of railway companies	Used in experiments (not on railway lines) (BV) [42]
1. Technical data	
Operating speed (km/h)	24-72km/h posited but not tested (BV[42])
2. Vegetation control areas	
No data available	
3. Vegetation control conditions	
No data available	
4. Costs	
No data available	
5. Environmental effects	
No data available	
6. Observations	
Plants with large leaves are more sensitive to UV light than grass, in early stages vegetation more sensitive, leaves exposed to UV light will die within two days, UV light is absorbed and transformed into heat [42] High demands on safety devices to ensure healthy working environment, uncertainty about mutations that occur at certain wavelengths, vegetation control with short waves forms ozone [42]	

6 Illustrations of each method

6.1 Constructional Methods

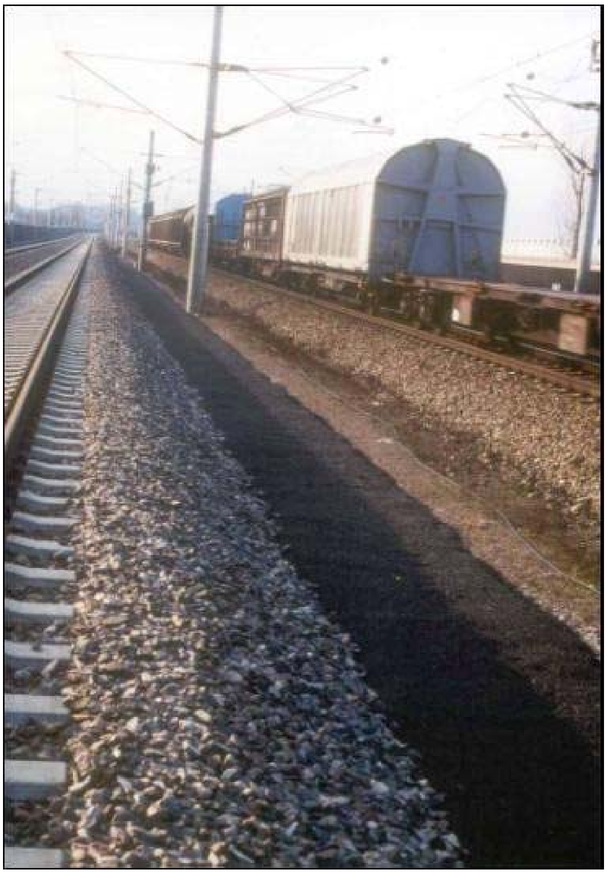
6.1.1 M 1 Lateral plant barriers/objects impeding plant incursion in general


Picture 1 and 2: Concrete border elements (left) and suitably positioned cable troughs (right)


Picture 3 and 4: Concrete step block support

Appendix 6 – Illustrations of each method

6.1.2 M 3 Plant-inhibiting design of the transition area (area C)



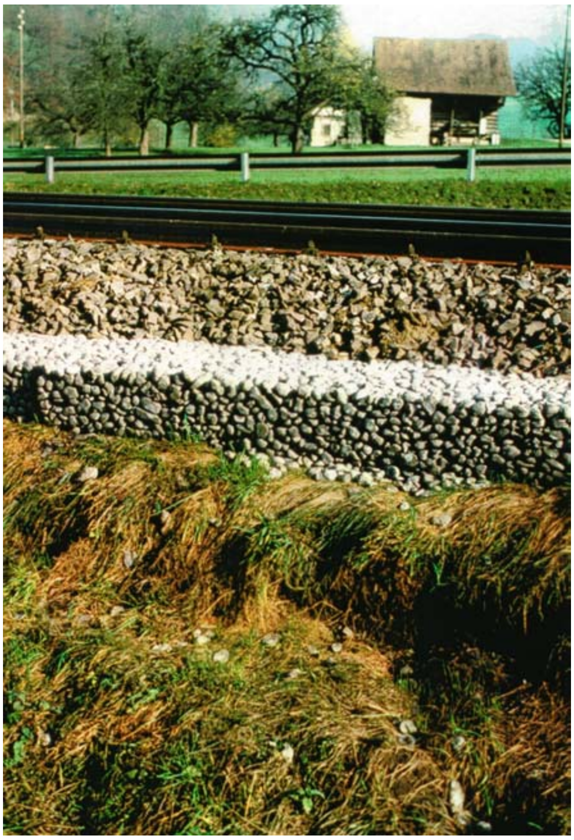
Picture 5 and 6: Schmelzkammergranulat (left) and Lysit (right)

Picture 7 and 8: basalt-granit (left) and macadam thikness 10cm (right)

Appendix 6 – Illustrations of each method

6.1.3 M 4 Porous concrete barriers

Picture 9 and 10: porous concrete barrier after building (left), five years after building, gap in the barrier (right)



Picture 11 and 12: porous concrete barrier (left), optimised surface (right)

6.1.4 M 5 Amount and kind of ballast material

Picture 13: non-lime gravel

6.1.5 M 6 Plantbarriers beneath the track in general

Picture 14 and 15: bituminous layer under the ballast

Appendix 6 – Illustrations of each method

Picture 16 and 17: PVC- foil and foil-covered transition area four month after construction

Picture 18 and 19: use of penetrable foils: penetrated by horse-tail

6.1.6 M 7 Slab track

Picture 20: slab track

6.2 Biological Methods

6.2.1 M 8 Greening

Picture 21: Greening with non ingrowing plants right after construction

6.2.2 M 11 Mowing

Picture 22 and 23: regular mowing by handmachines

Appendix 6 – Illustrations of each method

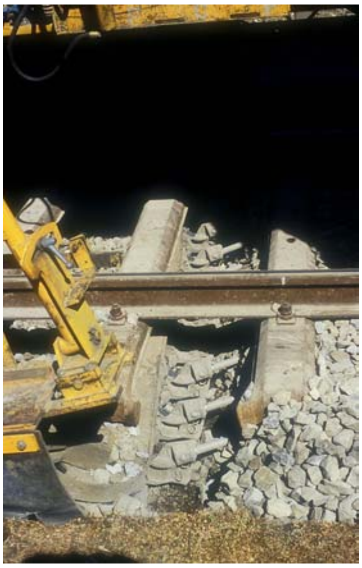
Picture 24: mowing with rail-road vehicle

6.2.3 M 12 Mulching

Picture 25: mulching: this machine blows the cut plants away from the transition area

6.3 Mechanical Methods

6.3.1 M 13 Ballast cleaning and M 14 Replacement of ballast



Picture 26, 27 and 28: replacement of ballast with PUSCAL (left), ballast cleaning (right)

6.3.2 M 15 Mechanical weeding

Picture 29 and 30: Mechanical weeding with WESPE (left) and with camulino (right)

Appendix 6 – Illustrations of each method

6.3.3 M 16 Manual weeding

Picture 31: manual weeding

6.3.4 M 17 Brushing

Picture 32: brushing

6.4 Chemical Methods

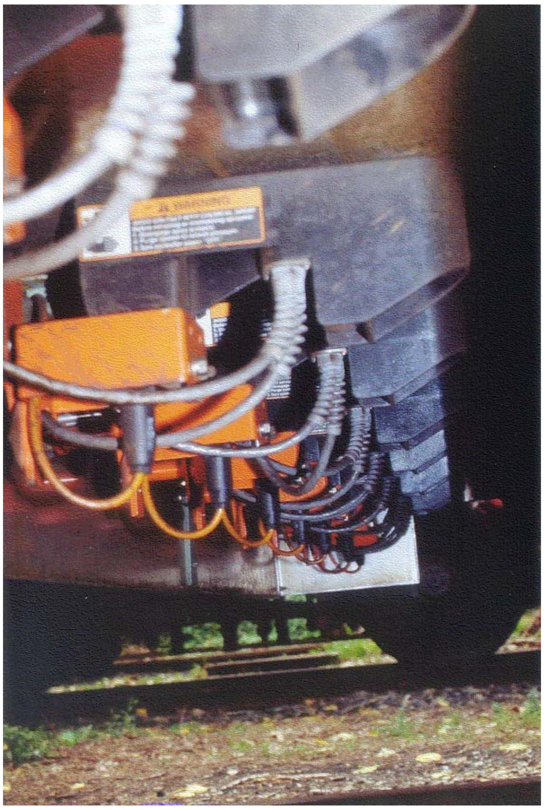
6.4.1 M 18 Back-pack spraying

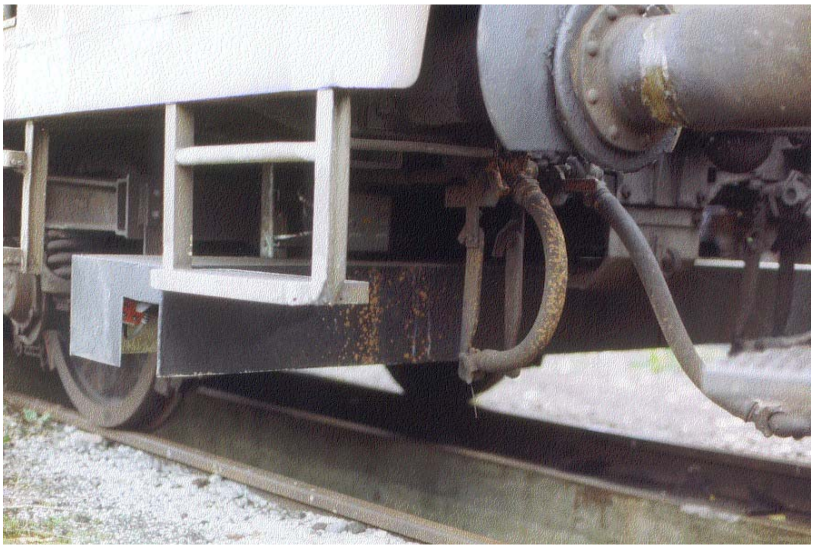
Picture 33 and 34: Spraying team (3 sprayer and one safety-guard)

6.4.2 M 19 Spraying train

Picture 35: Spraying train

6.4.3 M 21 Selective application by spraying train





Picture 36 and 37: position of cameras under the wagon

6.4.4 M 22 Weed wiping

Picture 38: weed wiping

6.5 Thermal/Electrical Methods

6.5.1 M 23 Flaming

Picture 39: flaming of transition area

6.5.2 M 24 Infrared devices

Picture 40 and 41: steel grids heated, only for use outside the track area

Appendix 6 – Illustrations of each method

6.5.3 M 25 Wet steaming

Picture 42 and 43: Wet steaming machine used in Germany: rail-road vehicle (left) and the one used in Switzerland and Austria: track-bound vehicle (right)

6.5.4 M 26 Hot water treatment

Picture 44: demonstration of hot water treatment

6.5.5 M 34 hot foam

Picture 45 and 46: experiments with hot foam

6.5.6 M 29 Direct electrical contact

Picture 47 and 48: experiments with direct electrical contact

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