# Railway Tracks - Habitat Conditions, Contamination, Floristic Settlement - A Review

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**Abstract**

Apart from roads, railways are one of the principal means of transportation. The specificity of rail transportation causes some environmental problems.

The study presents a review of the major environmental problems connected with railway transportation. The construction of railway tracks and properties of used materials, as well as the maintenance of railway infrastructure are responsible for the specific habitat condition with alkaline soil reaction and varying but rather high levels of nutrients, which favour plant encroachment and growth. The results of investigations described in this study show clearly that railway transportation causes typical organic and inorganic contamination. Among the most important railway pollutants are polycyclic aromatic hydrocarbons, heavy metals, and to some extent, polychlorinated biphenyls. The study also presents some information about the progress of floristic studies in operating and abandoned railway lines. In addition some trends in the transformation of the flora in abandoned railway areas are discussed: the retreat of alien species with a short life cycle, the encroachment of native perennial plants and an increase in the number of trees.

**Keywords:** Railway, Soil features, Contamination, PAHs, PCBs, Heavy metals, Plant encroachment

## 1. Introduction

Anthropopressure, in the broad sense of this word, has undergone changes over the centuries. However, since the beginning of 19th century, the Technological Revolution has started the era of modern industry, transportation and new sources of energy which seriously influenced the natural environment. Among these factors transportation must be a serious source of many disturbances due to specific technology which has two components: different types of conveyances and sometimes complicated infrastructure, transforming not only the habitat conditions but also the landscape.

Modern transportation includes many possibilities of movement of people and goods. Among them are two main types of transportation, i. e. road and rail. Since the Stockton and Darlington Railway was opened (1825) as the world's first publicly subscribed passenger railway, this type of transportation has started to develop rapidly. Currently the railway is one of the most principal means of transportation, although the political and economical changes which took place in many countries have led to the withdrawal of an increasing number of railway lines.

For several decades, whilst there has been considerable documentation of environmental threats and disturbances connected with road transport, there has been surprisingly a small number of reports describing environmental problems caused by railway transportation. Ever since it has become clear that the environmental impacts of the railways should not be underestimated, an increasing number of studies focused on railway has appeared.

The aim of the paper is to present a concise review describing the railway areas with respect to habitat conditions, soil contamination and plant encroachment.

## 2. Habitat Conditions

The railway route offers a variety of habitats which are very specific. Usually the biodiversity of a given fragment of any habitat including railway tracks is dependent upon a number of factors. Besides various types of contamination other factors also limit plant growth in railway areas. Railway tracks go through excavated sites that by consequence are shadowy, sheltered and more or less damp. Other stretches are on a high bank which is windy, cold, but sunny. In mountainous areas, the construction of railway tracks and infrastructure creates amounts of cut slopes and embankments. This is associated with changes in the soil characteristic which destroy natural soil profiles. Soil and bed of construction of railways in mountainous areas are more likely to suffer from soil erosion. Moreover, in such sites the transfer of nutrients and pollutants through storm water runoff is important. The mechanical composition of track ballast which is usually crushed stones or different sort of gravel (sand-gravel aggregate) in the tracks used with smaller intensity, also caused specific conditions.

Soil acidity and the levels of main plant nutrients (N, P, Ca, Mg) are the most important factors influencing plant growth in railway tracks. The chemistry of railway track basement was unified during their building and exploitation. After some time only pH remains unchanged and similar. Other chemical features become more differentiated. Our investigations carried out at many different railway track sites in Poland confirmed this general conclusion. In all the investigated areas track soil exhibited considerable uniformity with respect to basement soil reaction (the pH varied from 7.37 to 8.00 in $H_2O$, and from 7.23 to 7.94 in KCl), whereas the acidity of the soil in the surrounding areas showed a high variability of pH (Galera *et al*., 2011). Our results of soil reaction are in accordance with the results obtained by Canadian investigators who collected soil samples at three inactive railway yards on the Island of Montreal (Murray *et al*., 2000). They determined in different areas mean soil pH varied from 7.2 to 8.3, depending on the area.

Total nitrogen in soil of inactive railway tracks on the Island of Montreal varied from 0.2 to 0.4% in the first investigated fragment, from 0.1 to 0.4% in the second and from 0.07 to 0.33% in the third one. In our investigations we found nitrogen content varied from 0.067 to 0.613%

Murray *et al*. (2000) suggested that in the abandoned railway areas decomposition of organic debris occurred, thereby liberating nutrient to be taken up by vegetation on the site.

## 3. Contamination

It was generally thought that rail transportation was much less harmful to the environment than road traffic. However, due to its specificity, railway causes some typical organic and inorganic contaminations (Malawska & Wiłkomirski, 1999, 2000, 2001a, 2001b), resulting mostly from the exhausted lubricate oils and condenser fluids, the transportation of oil derivatives, metal ores, fertilizers and different chemicals, as well as from the application of herbicides. The three most important types of pollutants are: polyaromatic hydrocarbons (PAHs), heavy metals and – to some extent – polychlorinated biphenyls (PCBs).

Polycyclic aromatic hydrocarbons (PAHs), also known as polyarenes are the class of organic chemicals consisting of two or more fused-benzene rings and constitute a significant group of pollutants in anthropogenic and natural environments. In various concentrations, they have been detected not only in polluted industrial and urbanized areas, but also in soil, water sediments and derivative rocks in environments of different anthropogenic pressure (Coleman *et al*., 1997; Wiłkomirski & Malawska, 2005; Malawska *et al*., 2006). Although a vast majority of PAHs is introduced into the environment from anthropogenic sources (Harvey, 1998; Howsam & Jones, 1998) also a relatively small amount of these compounds derive from natural sources (Simoneit, 1998; Wilcke, 2000; Wilcke *et al*., 2000; Malawska & Wiłkomirski, 2005). The concentration of anthropogenic PAHs in the environment is usually several times higher than that of PAHs of natural origin.

Isolation of some polyarenes from coal tar in the first half of the 19$^{th}$ century began a period of great interest in this compound group of compounds. Currently PAHs play an important role in environmental toxicology. They are of environmental concern not only because of their toxicity and carcinogenicity (IARC, 1983), but also because they are very resistant to decomposition (Oleszczuk & Baran, 2003, Tamamura *et al*., 2006). PAHs can be transported into plants mostly from atmospheric air (Alfani *et al*., 2005), although in smaller amount PAHs can be absorbed by root system (Vacha *et al*., 2010).

Generally, the main anthropogenic sources of PAHs are processes involving combustion of organic matter with restricted oxygen supply. However, in the case of railway tracks and railway infrastructure some other sources of polyarenes are more important. The main sources of PAHs in railway areas derive from substances used for rolling stock exploitation such as machine grease, fuel and transformer oils, as well as from substances used for impregnation of wooden structures, including railway ties. The most important and almost exclusively used agent for impregnation the outdoor wood structures (railway ties, poles for electrical power transmission, marine pilings, fences and stake for agriculture) is creosote. This agent is a complex mixture of over 200 compounds, predominantly polycyclic aromatic hydrocarbons, as well as phenolic and aromatic nitrogen and sulphur compounds, obtained by fractional distillation of crude coal tar. It can contain over 30 different PAHs with a possible total PAH content of 85% by weight (World Health Organization, 2004).

The problem of PAHs migration from creosote-treated railway ties into ballast was described comprehensively by Brooks (2004). According to his investigations emission of creosote-derived PAHs from newly treated railway ties in supporting ballast is the biggest during the summer of the first year. Creosote-treated ties are strongly heated during the summer because the black surface of the railway ties absorbs sunlight. Swedish investigators stated that creosote emissions from the usage of impregnated wooden railway ties were a potential source of carcinogenic compounds to the environment (Thierfelder & Sandström, 2008). They have stressed that laboratory studies focused on how heat capacity, water and other solvents interact in the processes of creosote evaporation and leakage.

Moret *et al*. (2007) found high concentrations of PAHs in soil samples as a consequence of leaching from old railway ties used to make a fence in a domestic garden and from disused railway ties stored in olive-grove placed in a rural area. They also evaluated the possibility of PAH transfer to the surrounding vegetation (olives). Very high amounts of light PAHs (up to 6360 g $kg^{-1}$) and relatively low level of heavy PAHs were found in the oil extracted from olives taken near the railway ties. Usually PAHs amounts (like other pollutants) decreased rapidly with increasing distance from the source of contamination.

In Japan, consumers are free to use creosote and creosote treated wood for agricultural purposes and the recycling of disused railway ties has recently become popular. This situation may cause impermissible health damage to people handling such products, and the government has scheduled a restriction of the use of creosotes containing elevated amounts of PAHs (Ikarashi *et al*., 2005).

Kohler & Künninger (2003) determined that during the service time of a railway tie of 20 to 30 years, roughly 5 kg of creosote were emitted. The PAH emissions fro wooden ties have an enormous influence on the two effect oriented impact categories *photochemical ozone creation* and *human toxicity.* For all the other impact categories, the PAH emissions are not relevant. Compared to other sources of PAH emissions of rail traffic, however, the impact of PAH emissions from creosoted ties is rather low.

The problem of PAHs contamination was investigated by us at the railway junction Iława Główna (Malawska & Wiłkomirski, 2001a, Wiłkomirski *et al*., 2011a). Geographically, the Iława Główna junction is situated about 200 km north of Warsaw, in the western part of the Masurian Lake Region. This area is not polluted, since no heave industry is concentrated there. The forest and lakes cover a high percentage of land. This is relevant since it is due to the junction having such a location that the influence of railway transportation on environmental pollution can be assessed more precisely. The railway junction covers an area of about 2 km$^2$ within which the following structures are situated: platforms, main tracks and the buildings of passenger railway station, a railway siding where freight trains wait for further way, a loading ramp in which goods are transferred from trains to lorries and a rolling tock cleaning bay (an unsecured railway track with no facilities preventing the leakage of washing substances). In soil samples collected in 1995 a relatively small level of PAHs was determined. In soil collected from the main track within the platform area the content of the 14 investigated PAHs was as follows: main track – 2249 g kg$^{-1}$, loading ramp 1097 g kg$^{-1}$, cleaning bay 910 g kg$^{-1}$ and railway siding 2178 g kg$^{-1}$. The content of the 14 investigated PAHs in the control level was 384 g kg$^{-1}$. This is not a very high level, but the investigation was carried out just a few years after general renovation of the railway junction. Thirteen years later we collected the soil from the same places and determined the content of 17 PAHs. The content was much higher reaching the values: 59508 g kg$^{-1}$ in siding, 17948 g kg$^{-1}$ in loading ramp, 49670 g kg$^{-1}$ in platform areas and 15376 g kg$^{-1}$ in cleaning bay. Even when we compare the content of only 14 PAHs (the same as in former investigation) the values are much higher reaching 55186 g/kg, 14307 g kg$^{-1}$, 38861 g kg$^{-1}$ and 7434 g kg$^{-1}$. The level of the 14 PAHs in the control area was nearly the same as in former investigation reaching 356 g kg$^{-1}$. This confirms that railway transport may be an important source of PAHs and is the threat to the natural environment. The very high level of contamination should be a signal for renovation including the change of ballast bed and railway wooden ties for concrete ones.

Our study carried out in north-eastern Poland proved the persistence of PAH contamination in railway areas. Ten railway tracks abandoned at least for 10 years were selected for our investigations. The PAHs concentration in the collected samples varied from 1.954 g kg$^{-1}$ to 17853 g kg$^{-1}$, whereas the PAHs concentration in all control areas did not exceed 1000 g kg$^{-1}$. A very spectacular example of the persistence of PAHs contamination is railway track in Straszewo abandoned since 1990. The current total PAHs concentration here is 13159 g kg$^{-1}$, whereas the control level of these compounds in the surrounding forest is 559 g kg$^{-1}$. In the investigated samples fluorene, pyrene, benzo[a]anthracene, chrysene, benzo[b]fluoranthene, benzo[k]fluoranthene, benzo[a]pyrene and benzo[e]pyrene were present in higher concentrations than other determined PAHs (Wiłkomirski *et al*., 2011b).

Heavy metals are amongst the most frequently found and intensively studied chemical substances that contaminate the environment. Many different definitions have been proposed - the most classic one is based on density. Some definitions are based on atomic number or atomic weight and the most recent definitions are based on toxicity, which allows us to include such elements as aluminum or arsenic into this group. In the last decade some papers describing detrimental effects of heavy metals to human health and the environment were published (Turkdogan *et al*., 2003; Kawata *et al*., 2007; Gheorgiu *et al*., 2007). It should be noted that among different sources of heavy metal contamination those arriving from transport system (including railway transportation) are one of the most important.

Heavy metal emission in railway areas derives from fuel combustion, construction material abrasion and cargo leakage, as well as from tracks, wheels, brakes and the overhead traction lines. Studies aimed at characterizing railway heavy metal pollution focused on ambient particle emissions (especially to the atmosphere) soil contamination and plant contamination. A series of investigations were carried out to study the airborne particle emission in the vicinity of a busy railway line in Zurich, Switzerland (Lorenzo *et al*., 2006; Bukowiecki *et al*., 2007; Gehrig *et al*., 2007). In this investigation five particle classes – "iron", "aluminum", "silicon", "calcium" and "sulphur" – were distinguished. The "iron" class particles were appointed to the wear of tracks, wheel and breaks. "Aluminum", "silicon" and "calcium" particles are of geological origin connected with stones, gravel and sand used for railway ballast bed. "Sulphur" class particles are of minor importance and are connected with vehicular exhausts. The average mass concentration of all the abrasion particles was roughly 1-2 g m$^{-3}$.

Chinese investigators (Liu *et al*., 2009) studied heavy metal concentration in soil within the vicinity of mountain railway in Sichuan. Cu, Mn, Cd and Zn concentrations were elevated in top soil in the railway surroundings, whilst Pb showed no significantly raised level. The investigators presented for these metals the enrichment factors compared to local background values. These factors (for Cu, Mn, Zn and Cd were 2.7, 3.4, 3.7 and 7.7, respectively) indicated moderate or significant enrichment of these metals in the soil closest to the railway. Heavy metal concentrations decreased with the distance from the track.

We investigated levels of 9 heavy metals (Pb, Cd, Cu, Zn, Hg, Fe, Co, Cr, Mo) in the soil from railway junction Iława Główna (Malawska & Wiłkomirski, 2001a). Since the heavy metal contamination level was much higher in the area of the cleaning bay and the railway siding, it seems justified to state that it is dangerous to transport goods that contain harmful substances and are water-soluble at the same time. On the other hand it was also dangerous if trains remain in one place for a long time, which allows for emissions of pollutants both from the carried loads and tractor factors. Our latest investigations (Wiłkomirski *et al*., 2011) indicated that in the siding area of the railway junction Iława Główna the highest level of lead, which exceeded the control level approximately 50-fold, was determined in the siding area. The whole area of the junction contains elevated concentration of zinc. The highest concentration of copper was detected in the platform area. We suggested that it was due to the intensive action of pantographs of high velocity trains on trolley wires.

Polychlorinated biphenyls (PCBs) are organic pollutants frequently found in the environment. PCBs became widely used as lubricants, fire-resistant dielectric fluids in transformers and capacitors and heat-transfer fluids up to the mid of 1970s. Due to their persistence and lipophilic properties, which lead to their bioaccumulation in living organisms, they became a serious threat to natural environments (Bracewell *et al*., 1993; Safe, 1984, 1989a, 1989b).

The full and efficient utilization of PCBs is very complicate and expensive. This has lead to a situation where PCBs are illegally disposed of in some developed countries through adding them to used oils and sale to poorer countries.

Our investigations indicated emission of PCBs by railway transportation. Highly- chlorinated PCBs are adsorbed on the surface of polluted soil which has high contents of organic substances (oil derivatives) and, therefore, they do not penetrate into the soil at a high rate. Highly-chlorinated PCBs migrate into unpolluted soil with low content of organic substances (areas adjacent to railway lines and junction) (Malawska & Wiłkomirski, 1999; Malawska & Wiłkomirski, 2001b).

## 4. Floristic settlement

Since the first railway lines were opened in Europe, rapidly developing railway transportation has become one of the major factors affecting the process of flora synanthropization. The first publications concerning the analysis of flora and plant cover of railway areas appeared in the middle of $19^{th}$ century (e.g. Luscher, 1887; Eggert, 1891; Lehman, 1895). The history of floristic investigations on railway areas was presented by Mühlenbach (1979). In most cases the investigations were carried out on railway areas in a broad sense (including tracks, platforms, stations, storehouse ramps, loading sidings, slopes of railway embankments, railway wastelands). In this review the analyses of flora and plant cover of railway areas of operating railway tracks, as well as of abandoned railway tracks were presented.

The railway has greatly influenced the structure of local ecosystems. The threats resulting from the fragmentation of natural and seminatural biotopes were observed in Europe (e.g. Tikka *et al*., 2000, Gontier *et al*., 2006, Westermann *et al*., 2011). Railway stations, which are the major trans-shipment points for goods, are usually located in big cities. They are recognized as “hot spots” for expansion of synanthropic plants (e.g. Meyer, 1931; Gilbert, 1989).

Dynamic tendencies in the flora of railway areas are manifested mostly in overregional linear migration of plants whose diaspores were transported with trains (Jehlik & Heyny, 1974; Kowarik & Tietz, 1986; Jehlik, 1981, 1986 and 1995; Brandes & Oppermann, 1995; Tikka *et al*., 2001; Hansen & Clevenger, 2005). The consequences of migrations along railways (Kopecky, 1971; Brandes & Oppermann, 1995), were presented in a few papers of German authors (e.g. Böhmer, 2001; Büscher *et al*., 2008) describing the further fate of species spreading along the railway).

Based on the observed migration of species along railway lines, it appears that these areas act as ecological corridors. Due to the construction of railway the edaphic conditions within the railway area differ from those of the surrounding area (Galera *et al*., 2009, Jandová *et al*., 2009). After 180 years, the railway still acts as an ecological corridor for species of plants with specific habitat demands. Therophytes have great importance as species tolerant to habitat variability, mechanical damage, extreme temperatures and chemical contamination.

The question about the existence of some highly specialized group of species associated only with railway areas was a consequence of investigations dealing with the role of railway as an ecological corridor and migration pathway.

In German publications the terms “Eisenbahnpflanzen” and “eisenbahntypische Arten” refer to species “typical of railway facilities“ whereas the terms “Bahnhofspflanzen” and “typische Bahnhofspflanzen” and their synonyms refer to plants “typical of railway stations” (Brandes, 1983, 1993, 2002; Rothert, 1915, Hohla, 1998; Hohla *et al*., 2000; Hohla *et al*., 2002; Büscher *et al*., 2008). The discussion about species typical of railway facilities was particularly animated in the 1940s and 60s. During the last several decades new transport technology has been introduced and as a result the railway flora is not so variable and interesting as 50 years ago and the problem of “railway specialists” became marginal.

In the past the following maintenance procedures were more frequently used in railway areas: weeding, mowing, burning and tree cutting (Suominen, 1969). The growth of plants and the structure of flora along railway tracks have been strongly influenced due to the extensive use of herbicides (e.g. Lyre, 1972; Kowarik & Tietz, 1986; Gilbert, 1989; Brandes & Oppermann, 1995; Brandes, 1993, 2005; Wittig, 2002; Hayakawa, 2007). Recently attempts have been made to apply alternative weed control methods (Brandes, 1993).

The flora which in the course of time was shaped in railway areas is characterized by the increased presence of alien species and plants with a short life cycle, which are typical of the of railway areas. In addition the presence of pioneer tree species, which are represented mostly by juvenile specimens and are not capable of further development, is characteristics of some railway tracks (Galera *et al*., 2011). The development of road transportation as well as political and economical changes in Central Europe caused the withdrawal of an increasing number of railway lines from exploitation (Galera *et al*., 2011). Plant colonization of abandoned railway tracks increases after their exploitation has ceased, although only a limited number of species are able to encroach and naturalize successfully. The species encroaching into abandoned railway lines include forest species, which constitute an important group of plants during the process of forest regeneration in man-made habitats (Galera *et al*., 2011).

Generally, the process of plant regeneration on abandoned railway tracks depends on the accessibility of the diaspores from the various surroundings. This factor is crucial during the first stages of species encroachment. In the case of ground flora species the gradual “preparation” of the habitat (shadow factor on the track) is more important. This “preparation” could be realized by trees appearing on the abandoned tracks or by “forest wall” shadowing the track. The decreasing rate of theropytes, especially species of alien origin, marks the stage of succession on abandoned tracks. The degree of advancement of the forest regeneration process on abandoned railway tracks is more strongly evidenced, not, as was commonly thought, by the return of tree species, but by the constant return of ground flora species (Galera *et al*., 2011).

## 5. Conclusions

The construction of railway tracks and the consequent operations of trains have relevant impacts on the environment. The biggest concern with trains and the environment is the amount of pollution they create. This paper demonstrates, based on literature survey, that emission of different pollutants creates real environmental problem. The essential substances released by railways to the environment in a diffuse way are heavy metals, different hydrocarbons (including PAHs), PCBs, and some herbicides. The emission of PAHs and other hydrocarbons is related to wooden ties and lubrication of vehicle mechanisms. These compounds deserve particular attention due to their acute and chronic toxicity, carcinogenic and mutagenic effects as well as their stability which delays their degradation. The other group of pollutants, i.e. heavy metals. Due to their chemical features, heavy metals can be transferred from soil to the other ecosystems components, such as underground water, peat or plant crops. Subsequently they can affect human health through the water supply and food web. Because it is still impossible to assess the fate of the emitted substances, it is essential to investigate the leaching risk of the most crucial pollutants at railway tracks and infrastructure. Generally, soil pollution on railroad land in many countries is a significant problem in terms of: recurrence of polluted sites, present or future legal obligations, and huge costs of modern scientific investigations and activities leading to remediation of affected areas.

The analyses of flora and plant cover of operating railway tracks and the directions of changes in the structure of the flora in abandoned railway areas are very interesting and important part of floristic investigations. The synanthropic flora of railway tracks, stations and the adjacent areas is strongly affected by the diversity of transported and transshipped loads of plant origin. Although the chemical features of basement soil in railway tracks are within limits that do no make plant growth difficult, the process of plant settlement proceeds differently, depending mostly on the accessibility of diasporas from the surrounding areas. Therophytes and alien species contribute significantly to the flora of active railway areas. Their role decline after the closure of the railway lines. The decreasing rate of therophytes, especially aliens, manifests a stage of succession on abandoned tracks. It is important that although plant colonization of abandoned railway tracks increases after their exploitation has ceased, only a limited number of species are able to encroach and naturalize successfully.

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