Chapter 10
Ex-Ante Analysis of a Hypothetical International Road Construction Project in Poland

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Abstract This case study uses equivalency analysis to identify and quantify environmental damage, remediation benefits and compensatory liabilities for the construction of a hypothetical international road in northeastern Poland. Habitat equivalency analysis (HEA) was used as an evaluative approach to comparing the potential environmental damages associated with two alternatives. Application of HEA on an *ex-ante* basis enabled us to compare the cost effectiveness of the two alternatives considering their relative future environmental damages. Under a simple base case, environmental damages for the proposed Route G alternative were somewhat greater than for the Route N alternative. When we considered potential wide-scale ecosystem damages using a probabilistic approach, however, environmental damages for Route G were considerably greater than for Route N. When this probabilistic approach was expanded further to consider the relative scarcity of the extremely rare alkaline fen habitat that could be lost, the cost of necessary remediation increased considerably to over €11 billion. This case study is an illustration of how equivalency analysis can be used to implement the Habitats, Environmental Impact Assessment, and Strategic Environmental Assessment Directives.

Keywords Habitat equivalency analysis · Alkaline fen habitat
Habitats directive · Infrastructure construction · Poland

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10.1 Introduction

This case study assesses the potential environmental damages associated with the construction of a hypothetical international road project. We assume that the hypothetical road project would occur in northeastern Poland. The case study provides an illustration of equivalency analysis in an *ex ante* context (analysis before the damage occures).

For the Environmental Impact Assessment Directive (EIAD) and the Strategic Environmental Assessment Directive (SEAD) to apply, the road building project needs to be a public or private project that is likely to have significant effects on the environment[1] or a plan or program that is subject to preparation and/or adoption by an authority at national, regional, or local level or that is prepared by an authority for adoption, through a legislative procedure by Parliament or Government and is required by legislative, regulatory, or administrative provisions.[2] One or both of these characteristics are likely to apply to major road building projects. Therefore, the road building project in this case study is assumed to fall under the provisions of these Directives. It is also assumed that mitigation measures will be required. However, it is also assumed that the project will consider different routing possibilities to reduce the damage[3] (BBOP and UNEP 2010).

Similarly, an appropriate assessment under Article 6(3) of the Habitats Directive (HD) is required in relation to plans or projects likely to have a significant effect on Natura 2000 sites. If there are likely to be significant adverse effects, development is only allowed for imperative reasons of overriding public interest.[4] In such a case, compensatory measures are required. However, in relation to priority natural habitat types and/or priority species, imperative reasons of overriding public interest can only be those relating to human health or public safety, beneficial consequences of primary importance for the environment or, further to an opinion from the European Commission, to other imperative reasons of overriding public interest.[5]

For the purpose of this case study, it is assumed that the necessary reasons of overriding public interest exist and the European Commission's opinion has confirmed this in the case of priority habitats or species. Consequently, the case study assumes that the construction falls within the overall scope of applicable European Union Directives and that equivalency analyses may be applied on an *ex ante* basis.

Section 10.2 describes the project. Section 10.3 presents the initial evaluation of the impacts of the incident. Section 10.4 quantifies debits from environmental damage, while credits from remediation are quantified in Sect. 10.5. Scaling of

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[1]Article 1, EIAD.

[2]Article 2(a), SEAD.

[3]Mitigation hierarchy—used for Environmental Impact Assessments and biodiversity offsets—requires that projects first avoid, then minimise impacts, and restore and finally offset residual impacts.

[4]Article 6(4), HD.

[5]Ibid.

remediation to sufficiently offset damages is discussed in Sect. 10.6. The chapter ends with a brief discussion of conclusions (Sect. 10.7).

10.2   Description of the Incident

This case study involves the anticipated environmental damage associated with construction of a hypothetical international highway. Specifically, we address a situation in which a highway bypass is planned that would link two cities: City A and City B. Two alternative routes are proposed. Route G would involve construction of the road through pristine wetlands in a river valley. Two Natura 2000 sites (a Primeval Forest Special Protection Area (SPA) and potential Primeval Forest Special Area of Conservation (SAC)) lie within the path of Route G. Route G would include construction of an elevated causeway some 500 m in length above the wetlands and the river valley. The alternative route, N, would bypass the Natura 2000 sites and would be constructed within a pre-existing corridor containing electricity transmission lines.

Both routings would likely adversely affect the river valley. Route G, however, would affect important wetlands and Natura 2000 sites. Table 10.1 summarises key characteristics of the alternative construction routes.

10.3   Initial Evaluation of Affected Habitats and Species

10.3.1   Protected Areas

The hypothetical study are contains several legally protected habitats. These include a Primeval Forest SPA site, covering nearly 120,000 ha; a HD SAC site, covering more than 120,000 ha and proposed as a Site of Community Importance; and a Primeval Forest/Important Bird Area of European Union Importance, covering nearly 135,000 ha.

The Primeval Forest is an extensive complex of relatively dense, old-growth forest. It lies on a postglacial, sandy plateau that is 100–140 m above sea level, with relatively numerous preserved glacial basins and postglacial channels, which are

Table 10.1 International road construction—characteristic of Routes N and G

	Route N	Route G
Total road length (km)	41.25	41.35
Length of road within Natura 2000 sites (km)	1	12
Length of river valley at crossing (m)	130	500
Length of elevated bridge/causeway at river crossing (m)	150	517.34
Construction costs (million €)	260	240

filled by lakes and bogs. Water bodies totalling 5% of the site surface are especially numerous in the western, central, and northern part of the SPA, with a large lake complex east of City B.

The majority of the site ($\sim$85%) is forested, with a few open patches used for agriculture, mostly as grasslands. Coniferous forests, predominantly pine stands, prevail. There are also patches of well-preserved wet and swampy coniferous forests growing on bogs. However, the lowest, very wet, places in the river valleys and around the lakes are typified by riparian wetlands. In some places, dry forests and subboreal swampy birch forests are extant. The Primeval Forest is situated within the range of the continental climate, and many boreal and subboreal species are present.

10.3.2   Vegetation and Habitats

An extensive network of wetland habitats within the river valley is included within the Natura 2000 network as part of the SPA Primeval Forest under the Wild Birds Directive (WBD). These habitats also are included on the Shadow List of sites of Community Importance under the HD.

Twenty-four habitat types of community importance (including eight priority habitats) listed in Annex I of the HD cover approximately 17% (204 km^2) of the Primeval Forest. Extensive patches of bog woodland (Eurpoean Union Habitat Code 91D0*), mixed pine-birch stands, and other bog and fen habitats (codes 7110, 7140, 7150, 7210, 7230) highlight the importance of the site for listed habitats.

Most of the peatland area is covered by vegetation types included in Annex I of the HD. Approximately 100 ha (more than 15% of the valley) is occupied by alkaline fen (code 7230) with sedge-moss rich fen vegetation. Nearly 300 ha are covered by bog woodland (code *91D0), a priority vegetation type.

The extensive open sedge-moss fen communities are the most valuable habitat of the river valley. They have permanently high water levels and are largely free of invading willow or birch shrubs. The plant communities are dominated by sedges (*Carex rostrata*, *C. diandra*, *C. limosa*, *C. lasiocarpa*, *C. chordorrhiza*) and brown mosses (including *Drepanocladus* s.l., *Tomenthypnum nitens*, *Calliergon giganteum*, *Calliergonella cuspidata*, *Aulacomnium palustre,* and locally calcitolerant *Sphagnum* spp.). These communities belong to the mesotrophic small sedge-brown moss vegetation, with a high number of calcicole species from the *Caricion davallianae* assemblage.

The vegetation zones in the valley include aquatic plant communities close to the riverbed, reed beds, tall sedge communities, an extensive zone of sedge-moss fen communities of the *Scheuchzerio-Caricetea* class, bog woodland and pine-birch shrubs classified as the *Thelypteridi-Betuletum pubescentis* association, and spruce forests or peat or alder swamp forests close to the mineral slopes of the valley.

The sedge-moss communities, covering more than 100 ha, are the most valuable habitat of the river valley. They have permanent high water levels and, in most

parts, are free of encroaching willow or birch shrubs. They are dominated by small sedge communities with *Carex rostrata*, *C. diandra*, *C. limosa*, *C. lasiocarpa*, *C. chordorrhiza*, and 'brown mosses,' mostly *Drepanocladus* s.l., *Tomenthypnum nitens*, *Calliergon giganteum*, *Calliergonella cuspidata*, and *Aulacomnium palustre* with an addition of Sphagna at places.

10.3.3   Threatened Species

Several rare and threatened species occur within the study area. The rarest species of vascular plants occurring in the valley are: musk orchid (*Herminium monorchis*), three species protected by the HD (marsh saxifrage (*Saxifraga hirculus*), fen orchid (*Liparis loeselii*), lady's slipper orchid (*Cypripedium calceolus*)), dwarf birch (*Betula humilis*), Jacob's ladder (*Polemonium caeruleum*), adder's-mouth orchid (*Malaxis monophyllos*), slender cotton-grass (*Eriophorum gracile*), and cotton deergrass (*Baeothryon alpinum*). Among bryophytes, many are relict species, for example, *Paludella squarrosa*.

At the time of conducting this case study, the open fens of the river valley were a last resort for many plant species that are endangered in Poland and the rest of Europe. As many as 14 vascular plant species were included in *Poland's Red Data Book of Plants* (e.g., *Eriophorum gracile, Carex chordorrhiza, Baeothryon alpinum, Herminium monorchis*); 32 species of vascular plants, mosses, and liverworts were listed in the Polish 'red list' (e.g., *Meesia triquetra, Paludella squarrosa, Tomentypnum nitens*); and 75 species were under protection in the country. The valley was the only site in Poland where musk orchid *(Herminium monorchis)* occurs. It accommodated the most numerous and best-preserved Polish populations of two HD species: *Liparis loeselii* and *Saxifraga hirculus*. Considerably fewer protected plants occur in proximity to the planned Route N.

In the Primeval Forest SPA, at least 42 breeding bird species listed in Annex I of the WBD were found. In addition, 12 species found in the SPA were included in the list of threatened birds in *Poland's Red Data Book of Animals* (2001). For eight Annex I WBD species, the Primeval Forest was one of the 10 most important breeding sites in Poland, supporting >1% of their national populations. These species (referred to as key species) included black stork, honey buzzard, lesser spotted eagle, capercaillie, grey-headed woodpecker, white-backed woodpecker, three-toed woodpecker, and red-breasted flycatcher. Further, the site supported a large breeding population of crane (just below 1% of national total). In addition, the Primeval Forest provided breeding habitat for a number of rare raptor species including the short-toed eagle, black kite, red kite, and white-tailed eagle. As with vegetation, considerably more protected avian species occurred within proximity to Route G than Route N.

The Primeval Forest habitat is also home to the following five species of mammals listed in Annex II of the HD: wolf, lynx, otter, beaver, and pond bat. In addition, the local population of elk is of considerable importance. Together with

other neighboring natural forests, the Primeval Forest represents the largest continuous forest tract in northeast Poland and is of key importance in maintaining the largest viable metapopulations of lynx and wolf in the lowlands of Poland and Central Europe.

10.3.4 Landscape Values

In addition to being a unique mire ecosystem, the river valley offers landscape values. These landscape values derive from the unspoiled nature of the habitat associations, the low degree of human impacts within the overall watershed, the extensive forest buffer surrounding the wetland habitats, and the large number of rare and critical plant species that occur across the various habitat gradients.

10.3.5 Preliminary Identification of Potential Damages: Stressors

Construction of the road would involve a number of stressors that could damage species, habitats, and landscape values. Environmental damage could occur during both the construction and operation phases of the project. Examples of anticipated stressors during the construction phase include:

- Direct loss of habitat from construction;
- Disturbance of fauna due to human presence, equipment operations, noise, and light;
- Creation of barriers for animal movements—both for migration and normal dispersal movements;
- Temporary or permanent changes in hydrology (both groundwater and surface water);
- Vibrations from driving piles;
- Shading from platforms and bridges;
- Primary and secondary dust from excavation, traffic, and equipment;
- Air pollution;
- Sedimentation; and
- Altered patterns of water runoff and sediment yields in local drainage basins.

In addition to the above stressors, examples of anticipated stressors during road operations include:

- Disturbance from invasive roadside species;
- Facilitated spread of pathogens and diseases, as well as of exotic and pest species along roadways;

- Increased human access affecting wildlife, fire, and other disturbance to sensitive habitats and species;
- Vibrations caused by heavy traffic;
- Introduction of traffic or/and increase of traffic intensity and related pollution and risks;
- Salt and other ice-control chemicals;
- Pollution in road runoff;
- Noise and light; and
- Accidents with hazardous products.

10.3.6 Potential Impacts Associated with the Road

To evaluate potential adverse effects from the road project, we first considered the sensitivity and fragility of the unique river mire ecosystem. Specifically, it is important to understand that integrity of these peatland ecosystems relies on the interconnectivity of hydrological and vegetation processes. The composition of vegetation communities determines the type of peat that will be formed and the nature of its hydraulic properties. Site hydrology, in turn, determines which plants will grow, whether peat will be created, and decompositional processes. The peat structure and the physical relief determine how the water will flow and fluctuate. These close interrelationships imply that when any one of these components changes, the others will be affected as well.

The river mire in the study area is categorised as a sloping mire, where the water level forms an inclined plane and water flow is mainly horizontal. The laterally flowing water is retarded by vegetation and peat. Vegetation growth and peat accumulation actively cause a rise of the water table in the mire and often also in the catchment area.

The specific type of sloping mire found within the study area is known as a percolation mire. Percolation mires are found in areas where there is adequate water supply evenly distributed over the year. As a result, the water level in the mire is almost constant; dead plant material reaches the permanently waterlogged zone quickly and is subject to aerobic decay only for a short time. Consequently the peat remains weakly decomposed and highly permeable so that the water flows through a considerable part of the peat body. Because the only weakly decomposed peat also remains elastic, the mire surface can oscillate with changing water supply, leading to very constant water levels relative to the surface and very stable conditions for peat formation. With growing peat thickness, this mire oscillation capacity increases, and the mire becomes less susceptible to absolute water level fluctuations.

Percolation mires are normally fed by groundwater because in most climates only large catchment areas can guarantee the necessary large and continuous water supply. Groundwater-fed percolation mires contain a high diversity of strongly

specialised species that are not found in other habitats. These often rare and threatened peatland plants have special adaptations to deal with the extreme lack of phosphate that is made unavailable by groundwater-derived iron and calcium.

Along the river, a narrow zone is regularly flooded and, consequently, is more nutrient rich. Furthermore, rainwater 'lenses' that are extremely poor both in minerals and nutrients have developed locally in the center of the valley. The smooth and fine-scaled gradients between these three conditions (groundwater-, floodwater-, and rainwater-fed) lead to numerous intermediate situations and a high diversity of ecological niches.

Within the temperate zone of Europe, the study site is the best remaining example of a percolation mire. The river valley, furthermore, has excellent prospects for long-term conservation. The hydrogeological system bears no signs of anthropogenic disturbances. Human impact has been low not only in the valley but also in its catchment, which is largely forested and in low-intensity use. The surrounding forest forms a buffer zone that limits the influence of the nearby agricultural land.

The good hydraulic, hydrologic, and hydrogeochemical conditions of the river mire guarantee slow successional processes and stable habitat conditions that offer a unique chance to preserve endangered and protected habitats and species without active (and expensive) management.

However, fens are among the most sensitive ecosystems in Europe, susceptible to degradation through any interference of their local and regional hydrological regime. There has already been large-scale and severe degradation of fen systems in Poland and throughout Europe. Given the fragile hydrological equilibrium, road development could create irreversible damage to the fens of the river valley. Although mitigation measures may be effective in reducing the impact, they would not ensure preservation of the key functional aspects of this system.

10.3.7 Potential Impacts to Fauna

Road development may adversely affect resident and migratory fauna through a number of processes, including:

- Increased mortality from collisions with vehicles;
- Decreased densities in areas adjacent to the road as a result of increased disturbance (noise, visual and human disturbance, pollution), which reduce habitat quality;
- Loss of supporting habitat;
- Altered animal behaviour through changes in activity patterns, spatial behaviour, and increased stress; and
- Increased fragmentation of animal populations caused by the barrier effects of roads. Fragmentation can cause increased probability of extinction of local or isolated populations. Roads with heavy traffic can seriously impair animal movements (dispersal and migrations) and gene flow across both sides of the expressway.

10.3.8   Potential Habitat Impacts

Habitat impacts associated with road development may include:

- Considerable and far-reaching changes in freshwater habitats caused by substantially altered patterns of water runoff and sediment yields in local drainage basins, coupled with increased chemical pollution and light pollution;
- Direct habitat loss from construction; and
- Decreased habitat quality from construction and operation.

10.3.9   Potential Impacts: Landscape Fragmentation, Ecological Integrity, and Ecological Connectivity

The habitats affected are likely to directly serve as the dispersal corridor for large mammals such as wolf, lynx and elk. In a broader spatial context, this dispersal corridor is the main tract supporting the connectivity of continuous forest tracts of the South Baltic basin (Lithuania, Latvia, Belarus, Russia) and fragmented forests of Central Europe.

One of the main requirements for proper functioning of wolf and lynx populations is the maintenance of long-distance dispersal movements of individuals. If Route G is selected, the substantial increase in traffic volume on road sections placed in dispersal corridors is likely to seriously impair dispersal. Animals not only avoid busy roads but also suffer heavy mortality while crossing them. Limiting the dispersal possibilities would reduce the probability of animals colonising in new areas. Even more importantly, it could also cause the isolation of existing local populations that would then be exposed to higher risk of decline and extinction.

The prevention of dispersal may be a particularly important threat to the lynx population of northeastern Poland, which is almost entirely isolated from the bulk of the Baltic basin population. Road mortality is invariably identified as one of the most important sources of lynx mortality across Europe. Additionally, lynx numbers in Poland have been declining since 1989. Therefore, the lynx population of northeast Poland is particularly vulnerable and requires efficient conservation measures, including protection of dispersal routes.

10.3.10   Anticipated Temporal Extent of Damage

The construction period for both alternatives is estimated to be 24 months. Consequently, direct effects associated with construction (noise, dust, equipment) are anticipated to last for two years, with recovery assumed to occur within 1 year. Habitat losses caused by the road, once constructed, are anticipated to continue in perpetuity.

10.3.11   Primary Remediation Undertaken

For the purposes of this case study, we assume that no primary remediation will be undertaken as part of the project. Rather, we use equivalency analysis to determine the scale of the offsetting mitigation that would be required for the two road alternatives.

10.3.12   Preliminary Identification of Potentially Affected Services

The road construction project is likely to result in a range of ecological losses. Table 10.2 identifies potentially affected habitats, resources, and services within both the direct road path (approximately 60 m wide), which we refer to as the primary impact zone, and within 1 km on either side of the road, which is the secondary impact zone.

Table 10.2 International road construction—potentially affected habitats, resources, and services

Primary impact zone (60-m road width)	Secondary impact zone (2-km-wide buffer)
Permanent loss of protected plants, including loss of individuals and loss of supporting habitat	Temporary loss of avian breeding habitats
Permanent loss of avian breeding habitats	Temporary loss of avian feeding sites
Permanent loss of avian feeding sites	Temporary loss of mammalian habitat
Permanent loss of mammalian habitats	Temporary loss of amphibian habitat
Permanent loss of amphibian habitats	Temporary loss of reptile habitat
Permanent loss of reptile habitats	Temporary loss of fish habitat
Permanent loss of fish habitats	Temporary loss of insect habitat
Permanent loss of insect habitats	Temporary loss of habitat integrity and connectivity
Permanent fragmentation of habitats and landscapes	Temporary loss of greenhouse gas sink (sequestration) ability
Permanent change of hydrological regime along the road	Temporary loss of recreation usage
Loss of hydrological stability of fens	Temporary separation from arable fields
Decrease in the hydraulic conductivity of the substrate	
Permanent fragmentation of agricultural land	

10.3.13 Potential Social, Economic, and Transboundary Issues

For the purposes of this case study, we focus on the loss of ecological resources, specifically habitat services. Losses of social, economic, or recreation-related services are assumed to be modest. The case study area is sparsely populated, and the road project would not substantially affect social or economic values. No significant social, economic, or transboundary issues are anticipated for either road alternative.

10.4 Quantifying Debits from Environmental Damages

We used HEA to compare potential environmental damages from the two alternative routes including both primary and secondary impact zones as described above (see Table 10.2). Although the project would potentially affect a number of different habitat types, we simplified our HEA analysis by pooling similar types into five discrete habitat assemblages:

- For Forest Habitats, we evaluated three habitat groups: bog forests (inclusive of the bog woodland assemblage, habitat code 91D0), alluvial forests (inclusive of alluvial forests with *Alnus glutinosa* and *Fraxinius excelsior*, habitat code 91E0), and oak forests (inclusive of Galio-Carpinetum oak-hornbeam forests, habitat code 9170).
- For Wetland Habitats, we pooled individual habitat types into two general assemblages: alkaline fens (inclusive of alkaline fens and transition mires, codes 7230 and 7140) and common wetlands (e.g., habitat code 3260).

As discussed above, road construction could adversely affect a number of different ecological services. Consequently, a variety of ecological metrics could be used to describe debits (and credits). However, rather than apply individual metrics to different potential categories of loss, we employed an overall habitat-integrity metric to describe changes across a range of ecological services. This metric was based on the professional judgment of local scientists and experts. It describes an overall *gestalt* view of habitat integrity and considers impacts to local flora and fauna, potential hydrological impacts to wetland habitats, and habitat fragmentation/connectivity. Although semiqualitative multi-resource metrics that rely on professional judgment may not be ideal, particularly in *ex post* analyses, use of such metrics may be warranted in certain *ex ante* analyses for which quantitative data on environmental damage may not be available, particularly in situations in which alternatives are being considered and contrasted.

Finally, we employ habitat scalars in our HEA to provide for equivalency scaling between habitat assemblages. We also considered uncertainties in potential future outcomes in this *ex ante* case by performing a probabilistic analysis of alternative scenarios.

Habitat service losses were quantified for Routes N and G. For each route, ecological service losses were defined for all habitat assemblages for both primary and secondary impact zones. Tables 10.3 and 10.4 present the quantification of affected habitats within the primary and secondary impact zones and related service loss assumptions for Routes G and N, respectively.

As shown in the above tables, the number of hectares that would be impacted is significantly higher for Route G than for Route N. The greatest difference with respect to forest habitats occurs in bog forests. Specifically, the secondary impact zone for Route G includes 79 ha of bog forest, while secondary impact zone for Route N includes only 0.4 ha of bog forest. The greatest difference with respect to wetland habitat occurs in alkaline fens. Secondary impacts for Route G include 35 ha of alkaline fens, while no alkaline fen habitat is impacted for Route N.

Table 10.3 International road construction Route G—ecological service loss assumptions by habitat type and impact zone

Habitat type	Damaged area (ha)		Ecological service loss (%)		Duration of loss during construction (years)	Recovery period (years)	
	Primary	Secondary	Primary	Secondary		Primary	Secondary
Forest							
Bog	1	79	100	50	2	None	5
Alluvial	0	15	na	50	2	None	5
Oak	5	167	100	50	2	None	5
Wetland							
Alkaline fens	1	35	100	50	2	None	5
Common wetland	1	7	100	50	2	None	5

Table 10.4 International road construction Route N—ecological service loss assumptions by habitat type and impact zone

Habitat type	Damaged area (ha)		Ecological service loss (%)		Duration of loss during construction (years)	Recovery period (years)	
	Primary	Secondary	Primary	Secondary		Primary	Secondary
Forest							
Bog	0	0.4	na	50	2	na	5
Alluvial	0	5	na	50	2	na	5
Oak	4	139	100	50	2	None	5
Wetland							
Common wetland	0.1	8	100	50	2	None	5

Primary loss continues in perpetuity for all habitat types where a primary loss occurs
Secondary loss continues for seven years for all habitat types

Although the extent of habitats to be impacted differs for the two routes, the pattern of primary and secondary impact zone service losses are consistent for both alternatives. Service losses in the primary impact zone are assumed to begin with a loss of 100% at the time of construction and continue in perpetuity. In the secondary impact zone, initial losses are assumed to be 50%, which reflects an average of losses that vary with distance from the road. Specifically, it is assumed that losses are 100% immediately adjacent to the road and then decline linearly to zero at the edge of the secondary impact zone. This is equivalent to an average loss of 50% extending 1 km in either direction from the road. The initial 50% average loss is assumed to continue during the two-year construction period. Once construction ends, losses in the secondary impact zone decline to zero over a period of five years. Loss assumptions for the primary and secondary impact zones are illustrated graphically in Fig. 10.1.

Using the information in Tables 10.3 and 10.4, we calculated total debits associated with habitat damages for the two routes. We used 2008 as the base year, combined with a 3% discount rate, to calculate the present value of ecological service losses. Present value service losses were expressed in Discounted Service Hectare Years (DSHaYs). Table 10.5 presents an example of the debit calculations for the damages to the oak forest habitat in the primary impact zone for Route N. To calculate present value, the constant service loss of 4.0 ha in each year is multiplied by the discount factor in each year, which declines through time. The result is shown in the final column of Table 10.5. The sum from 2008 to perpetuity is 134 DSHaYs.

The terminal value represents combined discounted losses into perpetuity, starting in the year 2108. It is calculated by dividing annual losses by the annual discount rate, then multiplying by the discount factor for 2108 $((3.9/0.03) \times 0.05 = 6.6)$.

Similar calculations were undertaken for other habitat types. Tables 10.6 and 10.7 summarise the results of the total debit calculations for Routes G and N, respectively. Although the area affected in the primary impact zone is considerably smaller than the area affected in the secondary impact zone for each habitat and route, the difference in
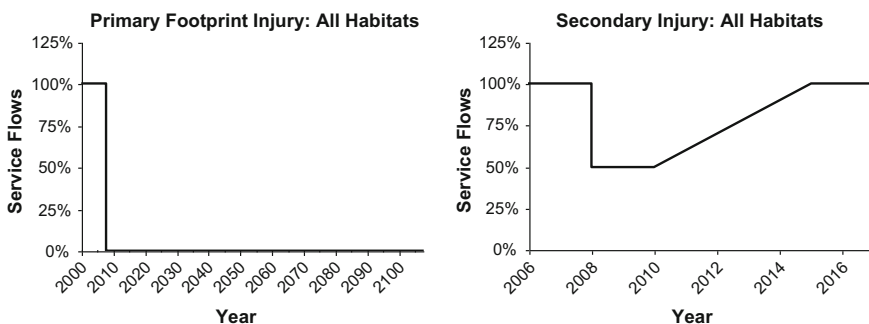

Fig. 10.1 Illustration of ecological service flows for primary and secondary impact zones of all habitats for Route G and Route N

Table 10.5 International road construction Route N—HEA calculations for 4 ha of oak forest in primary impact zone

Year	Annual ecological service loss (%)	Total annual service loss (ha)	Discount factor	Total annual discounted service loss (DSHaYs)
2008	100.0	3.9	1	4.0
2009	100.0	3.9	0.97	3.8
2010	100.0	3.9	0.94	3.7
2011	100.0	3.9	0.92	3.6
2012	100.0	3.9	0.89	3.5
2013	100.0	3.9	0.86	3.4
2014	100.0	3.9	0.84	3.3
2015	100.0	3.9	0.81	3.2
2016	100.0	3.9	0.79	3.1
⋮	⋮	⋮	⋮	⋮
2107	100.0	3.9	0.05	0.2
2108	100.0	3.9	0.05	0.2
2108+	100.0	3.9	0.05	6.6[a]
Total				134

Notes [a] The terminal value represents combined discounted losses into perpetuity, starting in the year 2108. It is calculated by dividing annual losses by the annual discount rate, then multiplying by the discount factor for 2108 ((3.9 / 0.03) × 0.05 = 6.6).
To shorten the table, some of the results were omitted and substituted by the ellipsis

Table 10.6 International road construction Route G—total DSHaYs of debit

Habitat	Impact zone		
	Primary	Secondary	Total
Forest			
Bog	28	150	178
Alluvial	0	28	28
Oak	188	317	505
Wetland			
Alkaline fens	26	66	92
Common wetland	18	13	31

Table 10.7 International road construction Route N—total DSHaYs of debit

Habitat	Impact zone		
	Primary	Secondary	Total
Forest			
Bog	0	1	1
Alluvial	0	10	10
Oak	134	264	398
Wetland			
Alkaline fens	0	0	0
Common wetland	3	15	18

calculated service losses between the two zones is less significant. This is because losses in the primary impact zone continue in perpetuity, which causes significant total losses through time even for relatively small areas of impact.

In order to combine losses across habitats, the relative value of different habitats was addressed using habitat scalars. Because remediation projects are available for bog forest and common wetlands, losses were converted to these habitat types. Specifically, all forest habitat losses were converted to bog forest losses, and all wetland losses were converted to common wetland losses. These calculations are shown in Tables 10.8 and 10.9.

As shown in Table 10.8, the habitat scalars used for bog forest, alluvial forest, and oak forest were 1.0, 0.5, and 0.33, respectively. This indicates that 2 ha of alluvial forest are equivalent to 1 ha of bog forest and that 3 ha of oak forest are equivalent to 1 ha of bog forest. As shown in Table 10.9, the habitat scalars for alkaline fens and common wetland are 15 and 1, respectively. This implies that 1 ha of alkaline fens is equivalent to 15 ha of common wetland. The habitat scalars were based on professional judgment related to the ecological functions of the different habitats, as well as the relative scarcity of the habitats.

Table 10.8 International road construction Route G—debits normalised to bog forest and common wetland

Habitat	Unadjusted DSHaYs	Habitat scalar	Normalised debit (DSHaYs)
Bog	178	1	178
Alluvial	28	0.5	14
Oak	505	0.33	168
Total bog forest equivalent			**360**
Alkaline fens	92	15	1,387
Common wetland	31	1	31
Total common wetland equivalent			**1,418**

Total equivalents are indicated in bold text

Table 10.9 International road construction Route N—debits normalised to bog forest and common wetlands

Habitat	Unadjusted DSHaYs	Habitat scalar	Normalised Debit (DSHaYs)
Bog	1	1	1
Alluvial	10	0.5	5
Oak	398	0.33	133
Total bog forest equivalent			**138**
Alkaline fens	0	15	0
Common wetland	18	1	18
Total common wetland equivalent			**18**

Total equivalents are indicated in bold text

To calculate debits normalised to bog forest and common wetland, we multiplied unadjusted DSHaYs for each habitat (as calculated in Tables 10.6 and 10.7) by the appropriate habitat scalar. The resulting normalised debits are shown in the last columns of Tables 10.8 and 10.9. The total forest loss for Route G is 360 DSHaYs when converted to normalised bog forest debits. The total adjusted forest loss for Route N is 138 bog forest DSHaYs. The total wetland loss for Route G is 1418 DSHaYs when normalised to common wetland debit. This was nearly 100 times greater than the 18 DSHaYs of normalised wetland loss for Route N.

10.5   Quantifying Credits from Remediation

Debits from damages to forest and wetland habitats are offset using remediation projects that restore bog forest and common wetland habitat types. Habitat credits for these remediation projects were calculated using the credit assumptions presented in Table 10.10. It was assumed that construction of an offsetting bog forest remediation project would be completed in 2010 and that it will take 100 years for the enhanced habitat to reach full maturity. Ecological services were assumed to increase linearly during that time, resulting in a final increase in ecological services of 75% in the year 2110. The present value of the increase in services is calculated using the same discounting methods applied to the habitat service debits. Specifically, a 3% discount rate is applied on an annual basis and annual discounted credits are summed over the 100-year life of the project. As shown in Table 10.10, total remediation credits for the bog forest project projected to be 6.7 DSHaYs per hectare of remediated habitat.

A similar set of assumptions was applied to determine credits for the remediation of common wetland, also shown in Table 10.10. The remediated wetland is

Table 10.10 International road construction—remediation credits for each hectare of remediated habitat

| Bog forest	
Assumed year of project completion	2010
Years to full service gain	100
Percent ecological service gain	75%
Final year of quantified benefits	2110
Remediation credits	6.7 DSHaYs per ha
Common wetland	
Assumed year of project completion	2010
Years to full service gain	20
Percent service gain	75%
Final year of quantified benefits	2110
Remediation credits	17.4 DSHaYs per ha
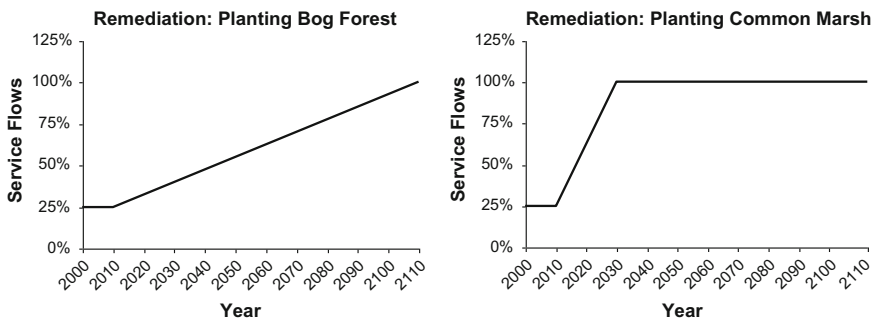
Fig. 10.2 Ecological service flows derived from forest bog and common marsh remediation projects

assumed to reach a full service increase of 75% in 20 years. Total credits for the wetland project are 17.4 DSHaYs per hectare. The service flows from the forest bog and common marsh remediation projects are illustrated in Fig. 10.2.

Remediation habitats are assumed to be constituted in year 1, and hence costs are not discounted. The numbers in the final column are based on the remediation scale that is not rounded up or down.

10.6 Scaling Complementary and Compensatory Remediation

Because outcomes are uncertain in this *ex ante* application of HEA, we present two alternative scaling scenarios. The first scenario, which we refer to as the 'base case', uses the information on debits and credits presented above to calculate the amount of remediation required to compensate for environmental damage. In the second scenario, we apply a probabilistic approach to evaluate potential damages associated with losses to highly scarce alkaline fen habitats.

10.6.1 Base Case

Our base case uses the results outlined above to calculate the amount of remediation required to offset expected losses. For Route G, the debit of 360 DSHaYs of bog forest habitat (Table 10.8) must be offset by per-unit remediation credits of 6.7 DSHaYs per hectare (Table 10.11). The required scale of the bog forest remediation project therefore is 54 ha (360/6.7 = 54). The debit of 1,418 DSHaYs of wetland habitat (Table 10.8) must be offset by the per unit remediation credits of 17.4 DSHaYs per hectare (Table 10.11). The required scale of the common wetland remediation project therefore is 81 ha (1,418/17.4 = 81). We assume, for

Table 10.11 International road construction—total remediation costs by habitat type

Habitat type	Debits (from Table 10.10) (DSHaYs)	Credits per Unit (from Table 10.10) (DSHaYs/ha)	Scale of required remediation (ha)	Remediation costs per unit (€/ha)	Total remediation costs (€)
Route G					
Bog forest	3606.7	6.7	54	10,000	537,313
Common wetland	1,418	17.4	81	10,000	814,943
Total Route G					**1,352,256**
Route N					
Bog forest	138	6.7	21	10,000	205,970
Common wetland	18	17.4	1	10,000	10,345
Total Route N					**216,315**

Total equivalents are indicated in bold text

illustrative purposes only,[6] a remediation cost of €10,000 per hectare for both habitat types. This results in a cost of €537,313 to offset forest damages and €814,943 to offset wetland damages. Thus, the total cost of remediation for Route G, under the base case analysis, would be €1,352,256.

For Route N, the debit of 138 DSHaYs of bog forest habitat must be offset by the per unit remediation credits of 6.7 DSHaYs per hectare. The required scale of the bog forest remediation project therefore is 21 ha (138/6.7). The debit of 18 DSHaYs of wetland habitat must be offset by the per unit remediation credits of 17.4 DSHaYs per hectare. The required scale of the common wetland remediation project therefore is 1 ha. Again, assuming an illustrative remediation cost of €10,000 per hectare, this results in a cost of €205,970 to offset forest damages and €10,000 to offset wetland damages. Thus, the total cost of remediation for Route N, under the base case analysis, is €216,315.

Under the base case analysis, the cost of remediation for Route G is €1,135,941 greater than the remediation cost for Route N. This means it would be cost effective to choose Route N over Route G, unless the construction costs for Route N are at least €1,135,941 greater than construction costs for Route G. While cost differential is an important factor for choosing between alternative routes, there are also other factors that would be taken into account that could change this selection calculus.

10.6.2   Alternative Case: Probabilistic Approach

Our alternative case analysis considers the potential wide-scale adverse impacts to the function and structure of the sensitive alkaline fens ecosystem. These broader

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[6]The remediation unit cost used here is purely illustrative. Actual remediation costs for bog forest or wetland remediation are likely to differ and would be dependent on site-specific factors.

scale impacts could occur if road construction in this sensitive habitat type affects overall integrity and function of the habitat unit. Such effects could extend beyond the actual footprint of the roadway. For example, if hydrological changes alter water flows, peat formation, and nutrient cycling, the entire fens could be damaged. Table 10.12 presents three probabilistic scenarios of supplemental ecological harm. All of these scenarios reflect possible ecological effects specific to the construction of Route G, which would pass directly through the alkaline fens habitat. Route N would not pass through the alkaline fens habitat and consequently is assumed to have no impact on the alkaline fens ecosystem.

The first scenario in Table 10.12 assumes that the fens continue to function but that biodiversity losses would extend throughout a broader habitat area (assumed to be 100 ha). Such biodiversity losses could occur from migration barriers or changes in the water table. The probability of this scenario is assumed to be 25%. The total area of affected alkaline fens habitat is 100 ha, with an estimated 40% decline in habitat quality associated with biodiversity impacts. It is assumed that losses do not occur immediately at the time of construction but increase from zero to 40% during a transition period of 30 years. Given the habitat scalar for alkaline fens of 15:1 relative to common marsh (Sect. 10.4) and using the calculations for discounting and normalised debits described above, the total debit from the potential loss of biodiversity is 3,466 DSHaYs. This total loss accounts for the 25% probability that this scenario will occur.

Table 10.12 International road construction—ecological harm scenarios

Alternative scenarios	Scenario probability	Affected area (ha)	Perpetuity ecological service loss relative to full-function alkaline fens	Transitional period (years)	Habitat scalar	Additional normalised debit (DSHaYs)
Remains as alkaline fens, with biodiversity loss	25%	100	40%	30	15	3,466
Becomes common wetland, with full function	25%	100	93%	30	15	8,087
Becomes common wetland, with 20% loss from reduced biodiversity	25%	100	95%	30	15	8,202
Total						19,754

The second scenario assumes that hydrological or other habitat function critical to sustaining alkaline fens are disrupted by the presence of the road in Route G. Because of these alterations in function, the 100 ha of alkaline fens habitat shift to become common marsh over a 30-year transition period. The common marsh is assumed, however, to be fully functioning. An assumed service loss of 93% is calculated based on the habitat scalar of 15:1 for alkaline fens relative to common marsh. The units of loss are then normalised to common marsh, again using the habitat scalar. After discounting, and after accounting for the 25% estimated probability of occurrence, total losses associated with this scenario are 8,087 DSHaYs.

The third scenario assumes ecological losses that would be associated with the transition of alkaline fens to a degraded common marsh (e.g., the common marsh is degraded relative to fully functioning common marsh because of reduced biodiversity). The service assumptions presented in the third scenario result in total ecological service losses of 8,202 DSHaYs. The ecological service flows associated with each of the three ecological risk scenarios are illustrated in Fig. 10.3.

In addition to the three scenarios presented in the table, we assume that there is a 25% probability that no supplemental adverse impacts will occur to the alkaline fens ecosystem. Expected value losses from the first three scenarios therefore represent the total expected losses from ecosystem impacts (i.e., summation of the individual probablistic outcomes). As shown in Table 10.12, the total expected value of debit therefore is 19,754 DSHaYs. Adding these losses to the base case results, total wetland losses associated with Route G would increase from 1,418 to 21,172 DSHaYs. The quantity of required wetland remediation therefore would increase from 81 ha (Sect. 10.6.1) to 1,216 ha. Under the alternative case therefore the total cost of remediation for Route G would be €12,700,000 (again, assuming unit costs of €10,000 for illustrative purposes).

These alternative assumptions regarding potential ecosystem impacts to alkaline fens do not affect the analysis for Route N. The cost of remediation for Route G damages would therefore be €12,500,000 greater than the remediation cost for Route N. This means it would be cost effective to choose Route N over Route G unless the construction costs for Route N are at least €12,500,000 greater than construction costs for Route G. As above, there are of course other factors to consider when choosing between routes.

Finally, we examined an alternative assumption regarding the habitat scalar for alkaline fens. The habitat scalar of 15 was based in part on the scarcity of sedge moss fens relative to total mire habitat in Poland. Alkaline fens is included within the category of sedge moss fens habitat, and sedge moss fens is one of many wetland habitats included within total mire habitat. The ratio of the area of sedge moss fens to total mire habitat is 15. By comparison, however, the area of alkaline fens, by itself, relative to total mire habitat is 1:13,222. If this scarcity ratio is used as the habitat scalar for converting alkaline fens to common marsh, the revised estimate of required wetland remediation would be 1,123,000 ha. The total cost of remediation for environmental damages associated with Route G could be as much as €11 billion.
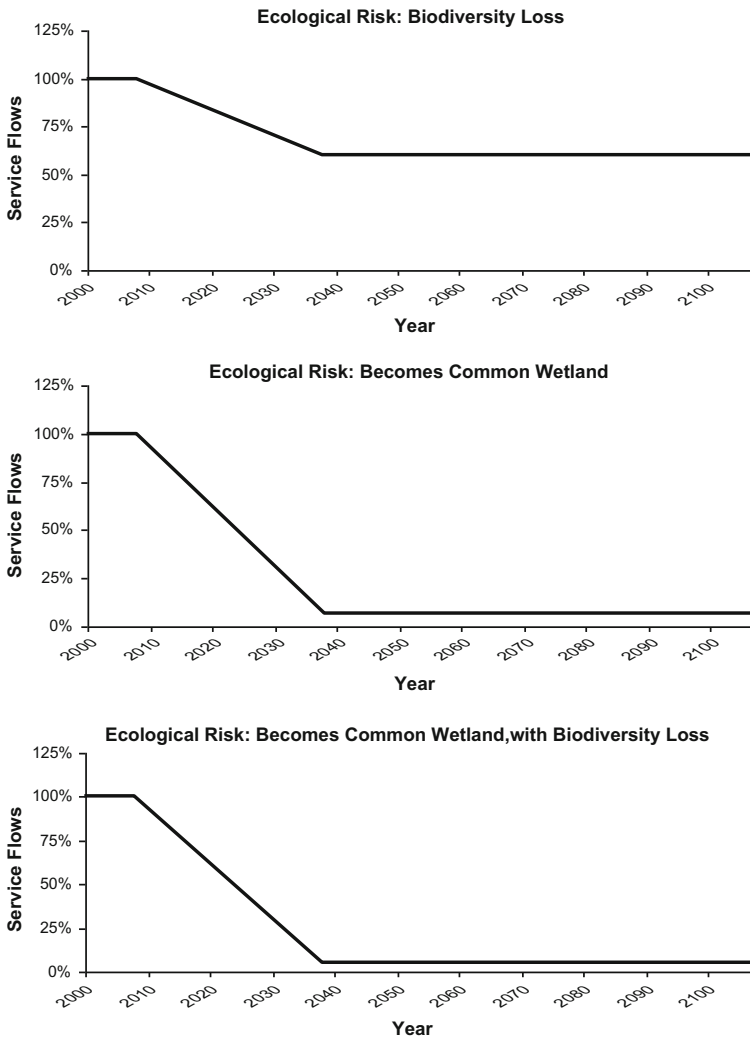
Fig. 10.3 Reductions in ecological service flows associated with disturbance of sensitive alkaline fen ecosystems

10.7   Conclusions

HEA was used to contrast the potential environmental damages associated with two alternative routes of a hypothetical international highway. Application of HEA on an *ex ante* basis enabled us to compare the cost effectiveness of the two alternatives, considering the environmental externalities associated with anticipated future environmental damage. Under a simple base case, environmental damages for Route G were somewhat greater than for Route N. When we considered potential

wide-scale ecosystem damages using a probabilistic approach, environmental damages for Route G were considerably greater than for Route N. When this probabilistic approach was expanded further to consider the relative scarcity of the extremely rare alkaline fen habitat that could be lost, environmental damages could increase to over €1 billion.

This case study illustrated how HEA could be applied in an *ex ante* case involving infrastructure development. Further, the case study illustrates application of habitat scalars in resource equivalency. Finally, the case study illustrates a probabilistic approach to estimating expected environmental damages in *ex ante* situations.

Reference

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