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Expert Perceptions of the Ecological Impacts of Road Construction in Natural Ecosystems: A Cross-Disciplinary Comparison

Oguz Kurdoglu, Saliha Unver, Emre Küçükbekir and Mahmut Muhammet Bayramoglu *

Department of Forest Engineering, Karadeniz Technical University, 61080 Trabzon, Türkiye; kurdoglu@ktu.edu.tr (O.K.); salihaunver@ktu.edu.tr (S.U.); ekucukbekir@ktu.edu.tr (E.K.)
* Correspondence: mahmud@ktu.edu.tr

Abstract

Expert assessments of the ecological impacts of road construction in natural ecosystems were examined through a cross-disciplinary comparative perspective. Data were collected from experts in civil engineering, urban and regional planning, forest engineering, and landscape architecture. Responses to the Ecological Impacts of Road Construction in Natural Ecosystems (EIRCNE) scale were analyzed using exploratory factor analysis and comparative statistical tests. Five hypotheses (H1–H5) were developed to examine disciplinary differences in expert evaluations. Results indicated broad agreement on the overall ecological impacts of road construction, although discipline-specific differences emerged in perceptions of direct ecological damage and construction priorities. Factor analysis confirmed a multidimensional structure of expert assessments (KMO = 0.810; χ^2 = 1665.219; df = 435; $p < 0.001$). Hypotheses concerning direct ecological damage (H2) and construction priorities (H5) were supported, whereas no significant disciplinary differences were detected for indirect effects or managerial processes (H3 and H4). These findings suggest that evaluating road planning and construction solely from a technical perspective may overlook important ecological dimensions. The study provides empirical evidence from Türkiye regarding how experts from different professional disciplines perceive and prioritize the ecological impacts of road construction and highlights the importance of incorporating diverse disciplinary perspectives into environmental decision-making processes.

Keywords: cross-disciplinary comparison; expert opinion analysis; ecological planning; environmental damage; infrastructure facilities; road construction; factor analysis

1. Introduction

Approximately 5% of the terrestrial biosphere remains largely free from human intervention, while the rest is exposed to varying degrees of anthropogenic pressure [1,2]. The acceleration of human impacts on natural ecosystems is often associated with the processes of production and spatial expansion that emerged after the Industrial Revolution [3–5]. In developing countries, the high dependence on natural resources has substantially increased the pressure on these ecosystems [6]. This has increased the demand for a certain level of road infrastructure to access areas where people seek to benefit from natural ecosystems [7,8]. Most existing roads worldwide pass through agricultural lands and natural ecosystems beyond the urban boundaries [9,10]. Accordingly, global assessments project that at least 25 million kilometers of new roads will be constructed worldwide by 2050 [11–13]. This development demonstrates that road infrastructure is not merely a

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means of access but also a key mechanism accelerating the spread of human impact into natural areas.

Roads in natural ecosystems are functional systems that, beyond transportation, enable production, conservation, maintenance, and monitoring activities to be conducted in the field [14,15]. Therefore, roads are an element that directly determines the capacity to intervene in areas within the management of natural ecosystems [16,17]. In particular, in areas with challenging topography, the continuity and functionality of the road network are critical to the feasibility of field practices [18,19]. However, roads are also considered interventions that directly affect ecosystem integrity and its components in the environments in which they are located [20–23]. Therefore, the planning and construction processes of roads should be addressed not only through technical criteria but also considering ecosystem characteristics and management objectives [24,25].

Most studies on the ecological impacts of roads have been limited to forest ecosystems [26]. However, natural terrestrial ecosystems are not limited to forests; wetlands, uplands, rangelands, and alpine meadows should also be considered within this scope [27,28]. Therefore, there is a need for assessment approaches that address different ecosystem types [29]. While the biophysical impacts of roads on ecosystems have been comprehensively examined in the existing literature [30], comparative studies on how different professional disciplines involved in the road planning and construction process assess these impacts are limited. However, it is known that the environmental impacts of various activities can be perceived differently by diverse expert groups and segments of society [31]. Therefore, it is thought that ecological impacts can differ not only through physical processes but also through discipline-specific assessment methods [32]. Considering the multidimensional structure of road planning and construction processes in natural ecosystems, in which different disciplines are involved, the inability to reveal these perceptual differences makes it difficult to assess ecological impacts holistically and may lead to certain impacts being prioritized over others in decision-making processes [33–35].

This study aimed to compare how experts from different professional disciplines involved in the planning, design, and construction phases of roads in natural ecosystems assess their ecological impacts.

1.1. Impacts of Roads on Natural Ecosystems

Natural ecosystems are complex systems in which biotic and abiotic components are shaped by natural processes, providing a wide range of ecosystem services [36,37]. Carbon sequestration, maintenance of air quality, regulation of the water cycle, soil stabilization, and mitigation of natural disasters are among the major services provided by ecosystems [38–40]. In particular, high-altitude and mountainous areas are considered priority ecosystems requiring protection owing to their topographic characteristics and ecological sensitivity [41–44]. In this context, infrastructure interventions such as road construction in these areas should be carefully evaluated in terms of their impact on ecosystem integrity [45].

Road construction in natural ecosystems has both direct and indirect effects on ecosystem components. Direct effects include changes in ecosystem dynamics [46,47], habitat loss [48], fragmentation [49–52], changes in biodiversity [53–59], damages to trees and saplings [60], impacts on wildlife [61–65], deterioration in soil properties and erosion processes [66,67], landslides [68,69], sediment transport and hydrological changes [70–73] and changes in water quality [74,75]. It is also known that heavy machinery used during road construction can exert direct pressure on many species, thereby affecting habitat use [76]. These effects weaken relationships among ecosystem components, leading to disruptions in the overall functioning of ecosystems. Indirect effects, on the other hand, include poaching, illegal logging, grazing, fire, land-use change, the spread of invasive species [77,78], microclimate change [66], and deforestation [12,79]. These effects often extend beyond direct impacts, influencing broader spatial areas and longer time frames, thereby increasing the overall pressure on the ecosystems.

In recent years, the road ecology approach has gained prominence, as studies aimed at identifying and mitigating the impacts of roads on ecosystems have increased [80]. This approach highlights the need to evaluate road projects not only in terms of technical performance but also within the context of ecological sustainability [81–85]. Understanding the cumulative impacts of road construction requires a holistic approach to spatial processes [86,87]. Furthermore, land-use policies and economic dynamics directly shape the ecological outcomes of road infrastructure [88,89]. Therefore, evaluating the ecological impacts of road construction solely based on physical processes is insufficient. It is also necessary to consider how relevant experts perceive and interpret these impacts.

1.2. Professional Disciplines Related to Road Construction

Road planning and construction in natural ecosystems exhibit multidisciplinary structure [90]. Different professional disciplines involved in these processes evaluate the same intervention in line with their own accumulated knowledge and professional priorities, which directly influences how ecological impacts are interpreted [91–94]. Therefore, it is important to determine how the accumulated knowledge of the professional disciplines involved in road planning and construction processes is reflected in ecological assessments.

Road planning and construction processes in natural ecosystems are multidimensional and require contributions from various disciplines, including civil engineering, urban and regional planning, forest engineering, and landscape architecture. Interdisciplinary and integrated approaches play an important role in developing environmentally sensitive infrastructure [95]. However, the multifaceted impacts of ecosystem-based interventions make the integrated assessment of these impacts more complex and necessitate multi-criteria evaluation approaches [96]. Therefore, because each discipline approaches road projects with different objectives and priorities, certain dimensions may become more prominent in the ecological impacts of roads.

The discipline of civil engineering focuses on technical criteria such as geometric design suitability, structural performance, cost-effectiveness, and safety in road projects [97,98]. From this perspective, elements such as drainage systems, slope stability, and cut-and-fill balance are technically critical; however, improper planning of these elements can increase the risk of flood and landslide and create additional pressure on the ecosystem [99]. Therefore, an engineering approach should be addressed within a framework that also considers environmental impacts [100].

Urban and regional planning considers roads as instruments that guide spatial development and focuses on the indirect effects of road construction. Processes such as land-use change, settlement pressure, and tourism development have been evaluated within this framework [101,102]. In this respect, the planning discipline enables the analysis of the long-term spatial consequences of road projects.

From the forest engineering perspective, roads are among the most fundamental infrastructure elements for implementing forestry activities [23,103]. The timely and successful execution of planned routine forestry activities depends on the adequacy of the regional road network [104,105]. Ankomah et al. [106] emphasized that the effective implementation of sustainable forest management is enabled by appropriately planned road networks. In other words, the forestry discipline adopts a perspective that seeks to balance production and conservation by considering road planning and ecosystem characteristics [107,108].

The discipline of landscape architecture focuses on design approaches that mitigate the environmental impacts of road-related interventions in natural ecosystems [16]. Ecological corridors, wildlife crossings, and vegetation strategies are among the most important tools in this context [109]. In addition, factors such as landscape character and visual integrity are also taken into account [110,111]. This approach plays an important complementary role, particularly in practices aimed at mitigating the negative ecological impacts.

The focal points of these disciplines demonstrate that assessments of the ecological impacts of road construction in natural ecosystems may vary not only in technical terms but also in terms of prioritization and interpretation. Therefore, revealing these disciplinary differences may contribute to the development of more balanced and feasible decisions in road planning and construction processes in natural ecosystems [112].

1.3. Research Questions and Hypotheses

The following research questions and their associated hypotheses guide this inquiry and provide a framework for the empirical analysis.

(RQ1) Do professionals from different disciplines assess the ecological impacts of roads in natural ecosystems in similar ways?

(RQ2) To what extent do professionals from different disciplines prioritize the different dimensions of ecological impacts?

The interdisciplinary nature of road planning and construction processes in natural ecosystems can lead experts involved in these processes to evaluate the same phenomenon based on their disciplinary knowledge and priorities. The assessment of ecological impacts is not limited to examining biophysical processes; how these processes are interpreted across different disciplines is also important. The literature emphasizes that discipline-specific differences in methods, scales, and expertise can influence the assessment of environmental impacts [31,32,113]. Therefore, it is necessary to examine how perceptions of the ecological impacts of road construction vary across different professional disciplines. Within this framework, the following hypotheses were tested:

H0. *Expert opinions on the ecological impacts of road construction in natural ecosystems do not differ significantly across professional disciplines.*

H1. *Expert opinions on the ecological impacts of road construction in natural ecosystems differ significantly across professional disciplines.*

The following sub-hypotheses were developed to test the research questions in greater detail:

H2. *Experts' assessments of the impacts of road construction on ecosystems differ significantly across professional disciplines.*

H3. *Experts' assessments of the long-term and indirect consequences of road construction differ significantly across professional disciplines.*

H4. *Experts' approaches to incorporating environmental considerations into decision-making processes for road projects differ significantly across professional disciplines.*

H5. *Experts' assessments of the consideration of ecological sensitivity in road planning and construction processes differ significantly across professional disciplines.*

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2. Materials and Methods

Assessing the ecological consequences of road construction in natural ecosystems requires incorporating perspectives from professionals across diverse fields. Accordingly, this study was designed based on assessments by experts in civil engineering, forestry, landscape architecture, and urban and regional planning.

2.1. Sample Design

The study sample consisted of experts from professional disciplines that contribute directly or indirectly to at least one of the planning, design, and construction stages of roads in natural ecosystems in Türkiye. In this context, the study population was defined not merely as individuals in the relevant professional disciplines but rather as a target group of experts with experience in road-related processes in natural ecosystems.

As of 2025, there are 198,748 professionals in Türkiye registered with the Union of Chambers of Turkish Engineers and Architects (UCTEA) in relevant disciplines, including 164,234 civil engineers, 19,751 forest engineers, 7144 landscape architects, and 7619 urban and regional planners [114]. However, rather than attempting to reach the entire population, this study focused on experts with experience in road planning, design, or construction processes in natural ecosystems. This approach enabled the selection of individuals with specific qualifications that aligned with the study's objectives.

Equation (1) was utilized to determine a general reference value for the sample size, based on a 95% confidence level and a 10% margin of error [115]:

$$n = \frac{N \cdot t^2 \cdot p \cdot q}{d^2 \cdot (N-1) + t^2 \cdot (p \cdot q)} \tag{1}$$

where t represents 1.96 for a 95% confidence level, p and q denote the probability of the event occurring and not occurring (0.5 each), and d signifies the acceptable margin of error (10%). In expert-based studies, the sample size is typically shaped by the accessibility of the target expert group, the accepted error level, and the study's methodological objectives [116,117].

While the initial calculations indicated a minimum requirement of 96 participants, the final sample was expanded to 120. This decision was informed by the literature, which emphasizes that larger sample sizes in expert-based studies bolster data diversity and the robustness of results [118,119]. Consequently, this expansion aimed to strengthen the study's representativeness and mitigate potential data attrition.

Purposive sampling was used as it allows the selection of individuals with specific expertise and experience. In this context, the primary criterion was that the participants had at least five years of professional experience in their respective fields. Additionally, to ensure that interdisciplinary comparisons could be made in a balanced and statistically meaningful manner, an equal number of participants (30 people) from each professional discipline were included in the sample.

2.2. Data Collection Instrument

The data collection instrument used in this study was a questionnaire developed to capture the assessments of experts involved in road planning, design, and construction processes in natural ecosystems. The data used were primary data collected from participants through an online survey. The Ecological Impacts of Road Construction in Natural Ecosystems (EIRCNE) scale, developed for this study, served as the primary measurement instrument. In this context, the EIRCNE scale aims to comprehensively assess various aspects of experts' perceptions of the ecological impacts of road construction in natural ecosystems.

The scale development process was conducted in multiple stages. In the first stage, a draft questionnaire comprising 58 items was prepared based on the literature and research objectives. To assess the content validity of the draft questionnaire, opinions were obtained from 20 experts across four professional disciplines using the method proposed by Lynn [120]. The experts were asked to evaluate each item in terms of content relevance, clarity, comprehensibility, and representativeness. The items were rated as "appropriate," "partially appropriate," or "inappropriate." Based on expert evaluations, the necessary qualitative revisions were made to the items, and content validity was strengthened through expert consensus. As a result of the evaluation process, statements with similar content were combined, and items that did not sufficiently represent the intended construct or conceptually overlapped with other items were revised. In addition, items with low clarity were reviewed, and 13 items were removed from the questionnaires. As a result of these revisions, the questionnaire was finalized as a 45-item instrument. The questionnaire consisted of three sections.

(i) Five questions designed to determine participants' demographic characteristics.
(ii) One multiple-choice and 3 open-ended questions aimed at eliciting experts' opinions in greater detail.
(iii) The 36-item EIRCNE scale.

Participants rated the items on a 5-point Likert-type scale, ranging from 1 (strongly disagree) to 5 (strongly agree). The complete scale is presented in Appendix A.

Data collection was carried out between 4 March and 28 March 2026, using an online questionnaire developed via Google Forms. Participants were provided with information about the study's purpose, and their participation was voluntary. The data collected was analyzed anonymously, and the participants' personal information was protected.

2.3. Statistical Analysis

Statistical analyses were performed using IBM SPSS Statistics (Version 22.0). For all inferential tests, the threshold for statistical significance was established at $p < 0.05$.

The dataset underwent a rigorous screening for missing values and univariate outliers to maintain structural integrity and ensure its suitability for statistical modelling [121]. Within this framework, missing data were addressed through listwise deletion, while outliers were identified and evaluated via z-score standardization.

In accordance with the criteria recommended in the literature, items with communality values below 0.40, low factor loadings, or cross-loadings across multiple factors were excluded from the analyses [122]. Cronbach's alpha was calculated to assess the internal consistency of the overall scale and the derived factors, and a minimum reliability threshold of 0.70 was adopted [123,124].

The demographic characteristics of the participants and the distribution of the responses to the scale items were summarized using frequencies (f), percentages (%), arithmetic means, and standard deviations.

Before performing between-group comparisons, the assumptions of normality and homogeneity of variance were tested to verify the suitability of parametric tests. The suitability of the data for normal distribution was examined using skewness and kurtosis values; values within ± 2.0 were considered acceptable for parametric analyses, in accordance with the criteria specified by George and Mallery [125] (Appendix B). Homogeneity of variance was checked using Levene's test.

Harman's Single-Factor Test was employed to examine the presence of Common Method Bias (CMB), a potential issue in studies utilizing single-source data collection. The assessment of common method variance revealed no evidence of significant bias, suggesting that it is unlikely to distort the observed relationships [126].

Differences in assessments of ecological impacts across the four professional disciplines were tested using a one-way analysis of variance (One-Way ANOVA).

Exploratory Factor Analysis (EFA) was conducted to assess the construct validity and underlying dimensional structure of the EIRCNE scale. The suitability of the dataset for factor analysis was evaluated using the Kaiser–Meyer–Olkin (KMO) measure of sampling adequacy and Bartlett's test of sphericity. Principal Component Analysis (PCA) was used as the extraction method within the EFA framework to identify the initial factor structure, and varimax orthogonal rotation was applied to improve factor interpretability. Components with eigenvalues greater than 1 were retained when determining the number of factors. Interdisciplinary comparisons were performed in two sequential stages. First, item-level ANOVA was conducted to examine whether expert responses differed across professional disciplines for individual EIRCNE items. Second, to minimize the risk of Type I error associated with multiple item-level testing and to provide a more parsimonious assessment, the primary comparisons were based on factor scores derived from the EFA. When ANOVA indicated a statistically significant difference among disciplines ($p < 0.05$), post hoc comparisons were performed to identify the groups responsible for the difference. Tukey's HSD test was used when the assumption of homogeneity of variance was met [127].

3. Results and Discussion

The empirical findings and hypotheses are evaluated here within the context of existing road ecology literature. The analysis integrates participants' demographic profiles, disciplinary assessments, and statistical evaluations of the EIRCNE scale to provide a comprehensive discussion.

3.1. Demographic Characteristics

An analysis of the participants' demographic characteristics revealed that 73 (60.83%) were male and 47 (39.17%) were female. According to the age distribution, 32.5% of the participants were 30–40 years old, 35.8% were 41–50, 22.5% were 51–60, and 9.2% were 61 years old or older. Regarding institutional affiliation, 35.0% of the participants worked in the private sector, 31.7% in the public sector, and 33.3% at universities. In terms of professional experience, 21.7% had 5–10 years of experience, 11.7% had 11–15 years, 11.7% had 16–20 years, and 55.0% had 21 years or more.

The distribution of participants' demographic characteristics by professional discipline is shown in Table 1.

Table 1. Frequency distributions of participants' demographic characteristics by occupational group.

Demographic Characteristics		Civil Engineer		Forest Engineer		Landscape Architect		Urban and Regional Planner	
		f	**t (%)**	**f**	**t (%)**	**f**	**t (%)**	**f**	**t (%)**
Gender	Male	23	76.7	26	86.7	9	30	15	50
	Female	7	23.3	4	13.3	21	70	15	50
Age (Years)	30–40	9	30	4	13.3	15	50	11	36.7
	41–50	11	36.7	13	43.3	9	30	10	33.3
	51–60	5	16.7	10	33.3	6	20	6	20
	60+	5	16.7	3	10	-	-	3	10
Institution	Private Sector	22	73.3	4	13.3	10	33.3	6	20
	Public Sector	5	16.7	15	50	5	16.7	13	43.3
	University	3	10	11	36.7	15	50	11	36.7

Table 1. *Cont.*

Demographic Characteristics		Civil Engineer		Forest Engineer		Landscape Architect		Urban and Regional Planner	
		f	t (%)	f	t (%)	f	t (%)	f	t (%)
Professional Experience (Years)	5–10	3	10	5	16.7	12	40	6	20
	11–15	3	10	2	6.7	4	13.3	5	16.7
	16–20	3	10	6	20	1	3.3	4	13.3
	21+	21	70	17	56.7	13	43.3	15	50

An examination of Table 1 revealed that the participants' demographic characteristics varied by professional discipline. In terms of gender distribution, the proportion of male participants was higher in civil engineering and forest engineering, whereas it was more balanced in landscape architecture and urban and regional planning. In terms of institutional distribution, civil engineers were predominantly represented in the private sector, whereas participants from the other three disciplines were more strongly represented in public and academic institutions. This may be attributable to legal regulations in Türkiye and differences in the employment capacities of relevant sectors.

A significant proportion of the sample (55%) had more than 20 years of professional experience, indicating that the study group consisted largely of experienced individuals. The fact that the assessments reflected the views of experts with field experience increases confidence in the credibility of the findings.

3.2. Relationship Between Professional Disciplines and Expert Opinions

Variation in participants' responses within the second section of the survey was analyzed across professional disciplines. Participants' knowledge levels regarding the ecological impacts of road construction in natural ecosystems were assessed using a 5-point Likert scale (none (1), insufficient (2), moderate (3), sufficient (4), and very good (5)), and the results are shown in Figure 1.

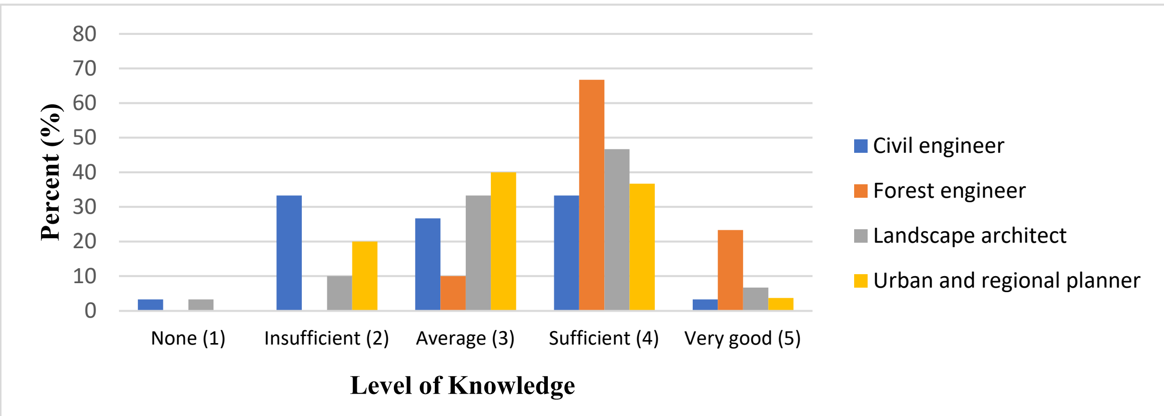

Figure 1. Distribution of experts' knowledge levels regarding the ecological impacts of road construction.

Figure 1 reveals that 90% of forest engineers, 80% of landscape architects, and 76.7% of urban and regional planners reported having a "moderate" or "sufficient" level of knowledge of the subject. In contrast, 36.6% of civil engineers described their level of knowledge as "insufficient." This finding indicated that self-assessed knowledge of ecological impacts varied across professional disciplines.

Expert prioritizations regarding the direct ecological impacts of road construction were evaluated based on the second question in the survey's second section. The 283 responses provided by all participants to the question "What are the three most important ecological impacts of road construction in natural ecosystems?" were classified into 10 categories through content analysis. When all participants were evaluated together, the most frequently cited impacts were fragmentation (19.08%), impacts on wildlife (17.3%), and pollution (16.6%). The distribution of the top three ecological impacts cited by professional discipline is presented in Table 2.

Table 2. Distribution of the most important negative ecological impacts by professional discipline.

Negative Ecological Impacts	Civil Engineer		Forest Engineer		Landscape Architect		Urban and Regional Planner	
	f	t (%)	f	t (%)	f	t (%)	f	t (%)
Pollution	10	15.38	-	-	14	18.42	18	25.71
Vegetation cover	9	13.84	-	-	-	-	-	-
Wildlife	15	23.07	11	15.27	12	15.78	11	15.71
Erosion and landslides	-	-	12	16.66	-	-	-	-
Fragmentation	-	-	11	15.27	23	30.26	14	20.00

An examination of Table 2 reveals trends in assessments across disciplines regarding the specific types of impact. Civil engineers tended to emphasize direct and observable impacts, such as vegetation loss, whereas forest engineers tended to focus on topographic processes such as erosion and landslides. In contrast, landscape architects and urban and regional planners tended to highlight fragmentation and its impact on wildlife. However, the ANOVA results indicated that these differences were not statistically significant ($F = 1.312$; $p = 0.274$). This suggested that the trends observed across disciplines do not constitute a statistically robust differentiation of the disciplines.

The prominence of fragmentation and its impacts on wildlife across all disciplines demonstrated that the ecological effects of roads are not limited to the immediate area of intervention but influence broader spatial and ecological processes [47,128]. However, the fact that certain types of impacts were reported more frequently than others suggests that directly observable impacts may become more prominent in the assessment process.

The 290 responses provided by participants to the question "Measures to reduce the ecological impacts of roads" were analyzed using content analysis and classified into 13 categories. The three measures considered the most important by the participants were damage-reducing planning (19.31%), wildlife crossings (17.93%), and avoiding road construction (13.79%) (Table 3).

Table 3. Distribution of the measures considered most important by professional discipline.

Proposed Measures	Civil Engineer		Forest Engineer		Landscape Architect		Urban and Regional Planner	
	f	t (%)	f	t (%)	f	t (%)	f	t (%)
Damage-reducing planning	18	25.00	13	16.45	14	19.44	11	16.41
Damage-reducing construction techniques	12	16.66	-	-	-	-	-	-
Avoiding road construction	-	-	12	15.18	-	-	-	-
Ecologically compatible structures	10	13.88	-	-	11	15.27	13	19.40
Wildlife crossings	-	-	12	15.18	21	29.16	15	22.38

Table 3 showed that different disciplines exhibited certain trends in their solution approaches. Civil engineers placed greater emphasis on damage-reducing construction techniques, landscape architects and urban and regional planners tended toward ecologically compatible design approaches, and forest engineers highlighted conservation-based measures. According to the ANOVA results, a statistically significant difference was found among professional disciplines in terms of proposed measures to reduce ecological impacts ($F = 4.073$; $p = 0.009$), supporting hypothesis H5. According to the Tukey post hoc test, the differentiation among the professional groups was mainly attributable to the lower mean scores of civil engineers. Civil engineers had the lowest mean score for measures aimed at reducing the ecological impacts of forest roads (Mean = 2.945). The mean score of this group was significantly lower, particularly compared with that of forest engineers (Mean = 5.055; mean difference = −2.110, $p = 0.006$). In contrast, no significant differences were found among forest engineers, landscape architects (Mean = 3.678), and urban and regional planners (Mean = 3.467) ($p > 0.05$). This result indicated that the differentiation in the variable was mainly driven by civil engineers' evaluation patterns. This suggested a difference between engineering-oriented and ecology- and planning-based approaches. This differentiation became clearer when evaluated within the framework of the mitigation hierarchy approach [129]. Civil engineers tended to emphasize solutions focused on "minimization," whereas other disciplines gave greater weight to "avoidance" and "compatibility"-based approaches, as suggested by Benítez-López et al. [130] and Van Dijck [131]. This indicated that interdisciplinary priorities were shaped not only by technical considerations but also by differences in approaches. A similar differentiation was observed in the assessment of stream rehabilitation practices (Figure 2).

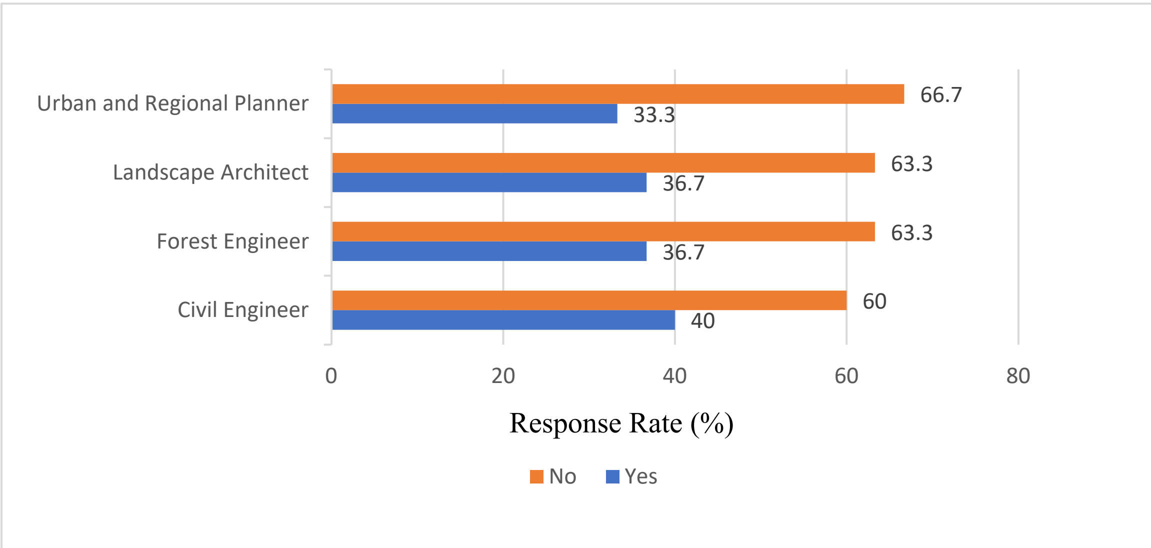

Figure 2. Distribution of the perceived necessity of stream rehabilitation practices by professional discipline.

As shown in Figure 2, 63.3% of the participants did not consider stream rehabilitation practices necessary. The ANOVA conducted in relation to professional experience showed that as the length of professional experience increased, the tendency to oppose stream rehabilitation practices also increased significantly ($F = 4.796$; $p = 0.003$). The results of Tukey's post hoc test indicated that this difference was mainly attributable to the differentiation between participants with 5–10 years of professional experience and those with 21 years or more of professional experience. Accordingly, the mean score of participants with 21 years or more of experience (Mean = 1.74) was significantly higher than that of participants with 5–10 years of experience (Mean = 1.35; mean difference = −0.396, $p = 0.002$). These results suggest that attitudes toward intervention-based practices may change as professional experience increases. However, explaining the difference solely in terms of professional experience may be limited. Other factors, such as field of professional expertise and working context, may also influence these assessments.

3.3. Evaluation of Findings Related to Professional Disciplines and the EIRCNE Scale

The empirical findings derived from the EIRCNE scale, employed to evaluate the ecological consequences of road construction in natural ecosystems, are detailed below. The 120 experts participating in the study evaluated the 36-item scale using a 5-point Likert-type rating. As a result of the reliability analysis assessing the scale's internal consistency, the Cronbach's alpha coefficient was 0.797, indicating acceptable reliability [132]. In addition, no substantial risk of Common Method Bias was detected in the dataset. The distribution of participants' responses to the scale items was examined through frequency analysis, and the results are presented in Table 4.

Table 4. Percentage Distribution of Responses to Likert-Scale Items.

Proposal No	Strongly Disagree (1)	Disagree (2)	Undecided (3)	Agree (4)	Strongly Agree (5)
S1	4.2	11.7	9.2	45	30
S2	2.5	6.7	20.8	35.8	34.2
S3	2.5	4.2	4.2	30	59.2
S4	4.2	7.5	25.8	32.5	30
S5	41.7	29.2	10	7.5	11.7
S6	20.8	19.2	15	27.5	17.5
S7	4.2	1.7	6.7	32.5	55
S8	61.7	18.3	6.7	4.2	9.2
S9	65.8	23.3	5	3.3	2.5
S10	0.8	2.5	-	14.2	82.2
S11	2.5	4.2	5.8	25.8	61.7
S12	2.5	5.8	14.2	30	47.5
S13	48.3	29.2	7.5	9.2	5.8
S14	5	8.3	37.5	28.3	20.8
S15	53.3	30	7.5	5.8	3.3
S16	5	7.5	40	25	22.5
S17	4.2	2.5	15	33.3	45
S18	71.7	15.8	4.2	2.5	5.8
S19	6.7	7.5	5.8	23.3	56.7
S20	59.2	18.3	15.8	3.3	3.3
S21	1.7	0.8	5	32.5	60
S22	-	1.7	6.7	24.2	67.5
S23	14.2	18.3	20	15.8	31.7
S24	0.8	1.7	4.2	22.5	70.8
S25	14.2	36.7	35	6.7	7.5
S26	9.2	8.3	14.2	37.5	30.8
S27	16.7	21.7	20.8	20	20.8
S28	0.8	7.5	22.5	35	34.2
S29	4.2	8.3	23.3	28.3	35.8
S30	5	2.5	15.8	43.3	33.3
S31	0.8	3.3	15.8	39.2	40.8
S32	-	-	10	29.2	60.8
S33	3.3	1.7	10.8	35	49.2
S34	4.2	6.7	7.5	27.5	54.2
S35	-	0.8	7.5	21.7	70
S36	1.7	1.7	7.5	29.2	60

An examination of Table 4 shows that the "agree" and "strongly agree" options were dominant for a substantial proportion of the scale items. This indicates a consensus among experts regarding the existence and importance of the ecological impacts of road construction. In contrast, the low level of agreement observed for some items and the high rates of undecided responses for certain statements suggest that experts may evaluate some ecological processes differently depending on the context. The mean values of the responses to the scale items are presented in Table 5.

Table 5. Arithmetic Means of Scale Items by Professional Discipline.

Statement No	Arithmetic Mean Values				
	Civil Engineer	Forest Engineer	Landscape Architect	Urban and Regional Planner	Overall Score
S1	3.84	3.87	3.92	3.82	3.85
S2	3.96	4.07	4.04	3.97	3.92
S3	4.40	4.41	4.48	4.43	4.39
S4	3.76	3.84	3.86	3.84	3.76
S5	2.19	2.23	1.95	1.93	2.18
S6	3.03	2.98	3.13	2.91	3.01
S7	4.35	4.35	4.33	4.41	4.32
S8	1.80	1.70	1.77	1.93	1.80
S9	1.51	1.47	1.42	1.45	1.53
S10	4.74	4.75	4.79	4.71	4.75
S11	4.40	4.54	4.42	4.30	4.40
S12	4.17	4.19	4.14	4.00	4.14
S13	1.92	1.76	1.85	1.97	1.95
S14	3.53	3.73	3.48	3.32	3.51
S15	1.75	1.67	1.67	1.73	1.75
S16	3.58	3.84	3.48	3.21	3.52
S17	4.16	4.14	4.10	4.13	4.12
S18	1.53	1.37	1.35	1.54	1.55
S19	4.15	4.20	4.14	4.06	4.15
S20	1.71	1.65	1.69	1.69	1.73
S21	4.50	4.48	4.38	4.32	4.48
S22	4.58	4.58	4.60	4.65	4.57
S23	3.35	3.35	3.11	2.93	3.32
S24	3.73	3.82	3.82	3.89	3.72
S25	4.60	4.69	4.70	4.69	4.60
S26	2.56	2.52	2.47	2.56	2.56
S27	3.07	3.06	3.01	2.91	3.06
S28	3.99	4.07	3.94	3.73	3.94
S29	3.87	3.85	3.73	3.69	3.83
S30	3.99	4.07	3.95	4.00	3.97
S31	4.17	4.21	4.11	4.23	4.15
S32	4.52	4.57	4.51	4.50	4.50
S33	4.28	4.30	4.25	4.23	4.25
S34	4.26	4.35	4.35	4.30	4.20
S35	4.48	4.51	4.51	4.50	4.44
S36	4.64	4.69	4.61	4.54	4.60

Table 5 revealed that the general trends were largely similar across professional disciplines. This indicated a basic level of consensus across disciplines on the overall assessment of the ecological impacts of road construction in natural ecosystems. However, limited differences were observed in certain items.

An analysis of participants' self-assessments regarding the subject revealed that a certain segment perceives their knowledge as low. In contrast, the high level of consensus regarding the need for EIA (S10) indicated that experts have a high level of awareness of administrative tools. This was consistent with studies that emphasize the importance of EIA as a key tool for identifying alternative routes and ensuring environmental integration [133–135].

Before conducting factor analysis, the dataset's suitability was assessed using the Kaiser–Meyer–Olkin (KMO) test, which yielded a KMO value of 0.810. This value indicated a good level of sampling adequacy. The statistically significant result of Bartlett's test of sphericity (χ^2 = 1665.219; df = 435; p < 0.001) indicated that there was a sufficient correlation among the variables for factor analysis. During the analysis, the scale, which initially consisted of 36 items, was reduced to 30 items by removing items with low communality values (<0.40), low factor loadings, or cross-loadings. As a result of the analysis, a five-factor structure with eigenvalues greater than 1 was obtained, accounting for 55.851% of the total variance. Based on their content, the extracted factors were grouped under the following headings: road pressure and planning decisions (F1), perception of ecological damage (F2), rejection of ecological impacts (F3), conservation and sustainability approach (F4), and management-institutional capacity (F5) (Table 6).

Table 6. Factor Groups.

Factor	Factor Name	Number of Items	Variance (%)	Cumulative (%)
F1	Road pressure and planning decisions	9	14,267	14,267
F2	Perception of ecological damage	7	12,861	27,127
F3	Rejection of ecological impacts	6	12,275	39,402
F4	Conservation and sustainability approach	4	8500	47,902
F5	Management-institutional capacity	4	7949	55,851

After the general characteristics of the factor structure and the explained variance ratios were determined, the rotated factor loadings were evaluated to examine in greater detail the factors under which the items were grouped. At this stage, the primary factor loading each item, possible cross-loadings, and communality values were taken into account. Items with factor loadings of 0.40 or higher in absolute value were evaluated under the relevant factor; for cross-loaded items, theoretical appropriateness and the highest factor loading were taken as the basis. The rotated factor loadings and item communality (h^2) values are presented in Table 7.

When the factor loadings were examined, the items had primary factor loadings ranging from 0.489 to 0.802. The communality values were generally acceptable. Only item S24 had a relatively low h^2 value (0.375); however, this item was retained in the scale on theoretical grounds because it directly represented the conservation and sustainability approach. Cross-loadings were observed for items S6, S17, S21, S29, and S30, and these items were assigned to the relevant factors by considering their primary factor loadings and conceptual content.

The five factor scores obtained from the factor analysis were tested using one-way ANOVA to determine whether they differed across professional groups. The results showed no statistically significant differences among professional groups in the factors of road pressure and planning decisions (F1), rejection of ecological impacts (F3), conservation and sustainability approach (F4), and management-institutional capacity (F5). This indicated a strong convergence of views among disciplines in these dimensions. In contrast, a significant difference was found among professional groups in the ecological damage perception factor (F2), $F(3,116) = 3.098$, $p = 0.030$, $\eta^2 = 0.074$. According to Tukey's HSD post hoc test, the significant difference in the F2 factor was mainly attributable to the differentiation between civil engineers and forest engineers. The ecological damage perception factor score of civil engineers (Mean = −0.302) was significantly lower than that of forest engineers (Mean = 0.421; mean difference = −0.723, p = 0.025). Landscape architects (Mean = 0.037) and urban and regional planners (Mean = −0.156) were positioned at an intermediate level, and the differences between these groups and the other professional groups were not statistically significant. This indicated that forest engineers perceived the biophysical and ecological damage caused by roads in natural ecosystems to a greater extent than civil engineers. The absence of significant differences among professional groups in the other factors indicated that professional disciplines had similar evaluation tendencies in the dimensions of road pressure, rejection of ecological impacts, conservation-sustainability, and institutional capacity.

Table 7. Rotated Factor Loadings, Communalities, and Item Decisions.

Statement No	F1	F2	F3	F4	F5	h^2
S1	0.561					0.476
S2	0.675					0.551
S3	0.731					0.582
S4					0.591	0.597
S5	0.528					0.595
S6	0.574					0.565
S7			0.657			0.483
S8			0.776			0.698
S9				0.686		0.550
S10		0.538				0.521
S11		0.688				0.637
S12			0.802			0.678
S13		0.712				0.569
S14			0.746			0.709
S15		0.634				0.469
S16		0.588				0.505
S17			0.580			0.592
S18		0.729				0.579
S19			0.700			0.560
S20		0.569				0.484
S21				0.489		0.448
S22					0.789	0.647
S23	0.600					0.421
S24				0.524		0.375
S25					0.743	0.611
S26					0.724	0.555
S27	0.595					0.426
S28	0.607					0.573
S29	0.581					0.625
S30				0.655		0.674

Beyond its substantive findings, the study also provided an initial exploratory assessment of the EIRCNE scale developed to evaluate expert perceptions of the ecological impacts of road construction in natural ecosystems. The five-factor structure obtained through exploratory factor analysis suggested that expert assessments encompass multiple but related dimensions, including ecological damage perception, planning decisions, conservation-oriented approaches, and institutional capacity. While the obtained factor structure and reliability values provide preliminary support for the construct validity of the instrument, these findings should be interpreted as exploratory. Further studies involving larger and more diverse samples, as well as confirmatory factor analysis and additional validation procedures, would contribute to strengthening the psychometric properties and broader applicability of the EIRCNE scale.

The significant difference in the direct ecological damage group (H2) became more apparent, particularly in certain ecosystem processes. Indeed, significant differences among professional disciplines were detected for items related to the spread of invasive species ($F = 3.595$; $p = 0.016$) and biotic effects, such as insects and fungi ($F = 8.515$; $p < 0.001$). This difference may be associated with forest engineers and landscape architects evaluating the risks posed by invasive species and biotic damage as higher-level risks. The concept of the "edge effect," discussed by Spellerberg [136] and Laurance et al. [11], suggests that microclimatic changes along roadsides can make ecosystems more vulnerable and create conditions conducive to the spread of pathogens. This process may be perceived as a higher-level risk by disciplines with ecosystem-based training. In contrast, the relatively lower perception of these biotic processes in other disciplines suggested differences in assessment approaches. These results highlighted the importance of addressing biotic risks and processes, such as edge effects, more systematically in environmental assessments for road projects.

Ultimately, while experts demonstrated a general convergence regarding the legal and administrative framework for road construction (H3, H4), disciplinary disparities emerged in the assessment of mitigation hierarchy measures (H5) and biotic risks (H2).

When these results were evaluated within the framework of the research questions, RQ1 indicates that different professional disciplines did not assess the ecological impacts of roads in natural ecosystems in entirely different ways but rather exhibited limited differences in certain dimensions. In particular, differences emerged in perceptions of direct ecological damage and in assessments of implementation priorities, whereas stronger convergence was observed in assessments of indirect effects and administrative processes.

Within the scope of RQ2, it was observed that different disciplines vary in their tendency to prioritize certain ecological impacts. Engineering-oriented disciplines tended to emphasize direct, technical impacts, whereas ecosystem- and planning-oriented disciplines gave greater prominence to fragmentation, wildlife, and system-level impacts. This indicated that the assessment of ecological impacts was shaped not only by scientific knowledge but also by discipline-specific professional priorities and implementation perspectives.

While the present study did not directly investigate the sources of these disciplinary differences, several contextual factors may help explain the observed patterns. Variations in disciplinary education, professional responsibilities, and institutional contexts may influence how experts interpret and prioritize ecological risks. Civil engineers are typically trained to focus on technical feasibility, safety, and construction performance, whereas forest engineers, landscape architects, and planners are more frequently exposed to ecological, conservation-oriented, and spatial planning perspectives during their professional training and practice. These differences may influence how ecological risks are interpreted and prioritized, consistent with previous studies emphasizing that disciplinary expertise, methodological approaches, and professional perspectives can shape environmental impact assessments [31,113]. However, these explanations should be interpreted as plausible contextual factors rather than empirically verified causal mechanisms.

Overall, the results indicated that cross-disciplinary differences in assessment constitute an important factor that may affect decision quality in road planning and construction processes in natural ecosystems. Although there was a shared understanding across professional disciplines of the general framework of ecological impacts, differences related to fields of professional expertise may emerge, particularly in perceptions of direct ecological damage and in the determination of construction priorities. This suggested that decisions solely based on technical criteria may be insufficient to reflect all dimensions of ecological impacts as perceived by different professional groups. Therefore, systematically integrating differences in assessments across professional disciplines into decision-making processes was important for developing more balanced and ecologically sensitive planning approaches. This approach was also consistent with the need for interdisciplinary planning and ecosystem-based assessment emphasized in the literature. This study provides empirical evidence regarding how different professional disciplines evaluate and prioritize the ecological impacts of road construction in natural ecosystems. The findings highlight the relevance of incorporating diverse disciplinary perspectives into road planning and environmental assessment processes. It should be noted that these findings reflect differences in expert assessments and perceptions rather than directly measured ecological impacts.

An equally important finding was the absence of statistically significant differences among disciplines with respect to indirect ecological effects and environmental management processes (H3 and H4). While disciplinary differences emerged in the evaluation of direct ecological damage and construction priorities, experts from different professional backgrounds demonstrated a relatively shared understanding of broader environmental consequences and management responsibilities. This convergence suggests the existence of a common professional foundation regarding long-term ecological considerations and environmental governance. Such common ground may facilitate communication, cooperation, and consensus-building among different professional groups during road planning, environmental assessment, and mitigation processes.

A practical example of the implications of these perception differences can be observed during the route selection and environmental assessment stages of road infrastructure projects. While engineers may prioritize technical feasibility, construction efficiency, and cost considerations, forest engineers, landscape architects, and planners may place greater emphasis on habitat connectivity, ecosystem fragmentation, and long-term ecological consequences. As a result, the relative importance assigned to mitigation measures such as wildlife crossings, ecological corridors, or route modifications may vary among professional groups. Similar differences may also influence decisions related to post-construction monitoring, maintenance priorities, and the long-term management of road infrastructure in ecologically sensitive areas. Recognizing these differences at an early stage may contribute to more balanced decision-making processes and help reduce potential conflicts among stakeholders involved in road planning and environmental management. In practical terms, the findings highlight the importance of integrating ecological expertise alongside technical and engineering considerations throughout planning, environmental assessment, and mitigation processes.

4. Conclusions and Recommendations

The findings indicated a substantial consensus among experts concerning the overarching framework of ecological impacts; however, divergent interpretations remain prevalent at the operational and implementation levels.

The main contribution of the study was to provide empirical evidence regarding both areas of consensus and areas of divergence among professional disciplines in expert assessments of the ecological impacts of road construction in natural ecosystems. On the one hand, convergence across professional disciplines was evident in the general acceptance of environmental impacts and in assessments of administrative tools. On the other hand, discipline-related differences emerged in the perception of certain ecological processes and in the prioritization of intervention approaches. This indicated that, from a road ecology perspective, decision-making processes were shaped not only by technical knowledge but also by discipline-specific knowledge and implementation practices.

Within this framework, addressing road planning and construction processes in natural ecosystems through a one-dimensional approach may remain limited. To assess ecological impacts holistically, it is important to strengthen decision-making mechanisms that integrate knowledge and approaches from different disciplines. Increasing interdisciplinary interaction, evaluating ecological impacts not only in terms of direct effects but also in terms of indirect and system-level consequences, and making ecological priorities more visible in implementation processes are among the key issues in this context. This approach is also consistent with the need for holistic planning and ecosystem-based assessment emphasized in the road ecology literature. In addition, improving awareness among different professional disciplines of ecological processes will contribute to more balanced, holistic decision-making.

This study was conducted based on expert perceptions, and it would be useful to test the results in different geographical contexts and with larger target groups. Nevertheless, the data were collected using a self-report method, which may limit the ability to measure participants' perceptions. In addition, questionnaire-based expert studies may be influenced by individual interpretation, professional experience, and contextual factors that shape respondents' evaluations. As a result, the findings should be interpreted as reflecting expert judgments and perceptions rather than direct measurements of ecological conditions or impacts. Although expert-based approaches provide valuable insights into decision-making processes and professional priorities, they may not fully capture the complexity of ecological outcomes observed in real-world environments. Therefore, future studies incorporating observation, case studies, mixed-method approaches, and empirical environmental data would contribute to a more in-depth analysis of the results. In addition, integrating expert assessments with spatial data and geographic information systems (GIS) may enable a more comprehensive understanding of the impacts of road projects on different ecosystem types. Future research may also explore the underlying drivers of disciplinary differences, including the roles of professional education, institutional context, and decision-making experience in shaping expert evaluations of ecological impacts.

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Informed Consent Statement: Informed consent was obtained from all participants involved in the study. Participation was voluntary, and all responses were collected and analyzed anonymously.

Data Availability Statement: The data supporting the findings of this study are available from the corresponding author upon reasonable request. The data are not publicly available due to privacy and ethical restrictions related to participant confidentiality.

Conflicts of Interest: The authors declare no conflicts of interest.

Appendix A

Questionnaire for the Ecological Evaluation of Roads Constructed in Natural Ecosystems

This questionnaire has been prepared to identify the perspectives of experts working in the fields of natural sciences and engineering on the environmental impacts of road construction in natural ecosystems (e.g., mountains, plateaus, forests, and rangelands) and, accordingly, to develop a proposal for a common, environmentally friendly approach.

The questions in the questionnaire are asked solely for the research, and the responses you provide will be kept strictly confidential under the Law on the Protection of Personal Data No. 6698 (PDPL), will not be shared with third parties, and will be used only for academic purposes. The questionnaire does not request any data that would directly reveal participants' identities, and all responses will be evaluated anonymously. In addition, participants have the right to withdraw from the questionnaire at any time. The questionnaire takes approximately 3–4 min to complete. Thank you for your participation and valuable contributions.

Section 1: Demographic Characteristics

Age (year):	☐ 30–40 ☐ 41–50 ☐ 51–60 ☐ 61+
Gender:	☐ Female ☐ Male ☐ Other
Profession:	☐ Civil Engineer ☐ Urban and Regional Planner ☐ Forestry Engineer ☐ Landscape Architect ☐ Other
Institution:	☐ Public Sector ☐ Private Sector ☐ Academia ☐ CSO ☐ Other
Professional Experience (years):	☐ 5–10 ☐ 11–15 ☐ 16–20 ☐ 21+ yıl

Section 2:

How would you describe your level of knowledge regarding the ecological impacts of roads in natural ecosystems? (1: None, 2: Insufficient, 3: Moderate, 4: Sufficient, 5: Very good)

☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5

Please write about the three negative ecological impacts of roads in natural ecosystems.

1. ______________ 2. ______________ 3. ______

In your opinion, what are the three most important measures to reduce the ecological impacts of roads in natural ecosystems?

1. ______________ 2. ______________ 3. ______________

In your opinion, are stream improvement practices carried out in natural ecosystems necessary?

☐ Yes ☐ No ☐ Other: ______

Section 3.

Dear Participant, according to your level of agreement with the statements provided below regarding the environmental impacts of roads to be constructed in natural ecosystems (such as mountains, plateaus, forests, and rangelands), please select one of the following options: (1) Strongly disagree, (2) Disagree, (3) No opinion, (4) Agree, (5) Strongly agree.

	Statements	1	2	3	4	5
S1	Properly planned road networks make a positive contribution to the implementation of multiple activities carried out in natural ecosystems (mountains, plateaus, forests, rangelands, and agricultural areas etc.)					
S2	The presence and construction of roads adversely affect natural ecosystems					
S3	An increase in road density reduces core habitat and weakens ecosystem integrity					
S4	In our region, the road network in natural ecosystems is greater than necessary					

Figure A1. *Cont.*

S5	During road construction in natural ecosystems, the necessary measures are taken to prevent adverse effects on the ecosystem
S6	High-standard roads, such as **Yeşilyol* constructed in natural ecosystems, contribute to the development of tourism
S7	Easy access to natural ecosystems may trigger pressures in the region, such as tourism, construction, mining, illegal hunting, and illegal logging
S8	Fragmentation caused by roads does not adversely affect the diversity and distribution of plant and animal species in the area
S9	Fragmentation caused by roads in natural ecosystems does not create an ecological problem
S10	It is necessary to prepare an Environmental Impact Assessment (EIA) report for high-standard roads to be constructed in natural ecosystems
S11	Road construction on steep and rugged terrain triggers adverse effects such as erosion and landslides
S12	Roads constructed in natural ecosystems cause significant habitat loss
S13	Road construction does not adversely affect soil in natural ecosystems
S14	Roadside clearings in natural ecosystems facilitate the introduction and spread of invasive species in the area
S15	Road construction does not adversely affect water quality and aquatic life in the watershed
S16	Following road construction in natural ecosystems, infestations of insects or fungi in forests increase
S17	As the road network increases in natural ecosystems, the risk of fire and the likelihood of human-caused fires increase
S18	The use of explosives during road construction does not affect natural ecosystems or biotic components
S19	Encasing streams in concrete for flood and overflow protection is not an environmentally friendly practice
S20	Stream improvement does not harm wildlife or animal habitats
S21	The presence of roads and traffic in natural ecosystems creates stress on wildlife through noise, light, and human presence
S22	Measures to reduce the impacts of roads on ecosystems in road projects (erosion control, crossing structures, rehabilitation) should be included in the budget as mandatory items
S23	In roads planned for natural ecosystems, ecological impacts are taken into account as much as cost and technical characteristics
S24	The expansion of the road network in natural ecosystems is carried out without due consideration of environmental sensitivities
S25	Measures to reduce environmental damage should be implemented even if they are costly
S26	Specifications include sufficient provisions for the monitoring and prevention of the environmental impacts of road construction in natural ecosystems
S27	When determining the success of road projects, ecological impact performance is evaluated in addition to technical adequacy

Figure A1. *Cont.*

S28	Roadside clearings alter the microclimate and affect vegetation composition
S29	In road construction, the approach of selecting the shortest/cheapest route is generally ecologically problematic
S30	Designs that reduce the amount of cut and fill in road construction significantly reduce adverse ecological impacts
S31	Increasing road standards (such as widening and paving) increases adverse ecological impacts in most cases
S32	Thresholds and limits for road density should be defined in the planning of roads in natural ecosystems
S33	Restricting access to sensitive areas is a more effective conservation solution than constructing a new road
S34	When deciding on the construction of a new road, the option of "not building a road" should also be considered as an alternative
S35	Avoiding road routes that overlap with wildlife corridors should be a priority in planning
S36	Biodiversity monitoring data should be taken into account when making major decisions in road planning in natural ecosystems

**Yeşilyol*: A tourism-oriented road in the Eastern Black Sea Region that is considered highly important for development, provides safe and comfortable access to nature, and connects mountains and plateaus.

Figure A1. EIRCNE Scale Items.

Appendix B

Table A1. Descriptive Statistics and Distributional Properties of EIRCNE Scale Items.

Scale	Mean	Std. Dev.	Skewness	Kurtosis
S1	3.85	1.105	−0.989	0.258
S2	3.93	1.022	−0.808	0.182
S3	4.39	0.938	−1.920	3.672
S4	3.77	1.090	−0.669	−0.108
S5	2.18	1.360	0.987	−0.277
S6	3.02	1.420	−0.101	−1.352
S7	4.33	0.980	−1.893	1.706
S8	1.81	1.285	1.549	1.147
S9	1.53	0.925	1.102	1.363
S10	4.75	0.664	−1.521	1.955
S11	4.40	0.956	−1.879	0.309
S12	4.14	1.031	−1.177	0.823
S13	1.95	1.208	1.231	0.483
S14	3.52	1.069	−0.359	−0.236
S15	1.76	1.045	1.534	1.820
S16	3.53	1.077	−0.312	−0.277
S17	4.13	1.034	−1.323	1.558
S18	1.55	1.091	1.198	0.970
S19	4.16	1.230	−1.438	0.933
S20	1.73	1.059	1.418	1.354
S21	4.48	0.778	−1.070	1.835
S22	4.58	0.694	−1.654	1.368
S23	3.33	1.445	−0.230	−1.316
S24	3.73	1.243	−0.902	−0.125
S25	4.61	0.725	−1.335	1.546
S26	2.57	1.059	0.599	0.139

Table A1. *Cont.*

Scale	Mean	Std. Dev.	Skewness	Kurtosis
S27	3.07	1.389	−0.025	−1.256
S28	3.94	0.973	−0.606	−0.358
S29	3.83	1.133	−0.724	−0.240
S30	3.98	1.025	−1.236	1.550
S31	4.16	0.870	−0.939	0.711
S32	4.51	0.674	−1.037	−0.127
S33	4.25	0.955	−1.583	1.750
S34	4.21	1.107	−1.482	1.426
S35	4.44	0.838	−1.859	1.068
S36	4.61	0.665	−1.629	1.993

References

1. Kennedy, C.M.; Oakleaf, J.R.; Theobald, D.M.; Baruch-Mordo, S.; Kiesecker, J. Managing the Middle: A Shift in Conservation Priorities Based on the Global Human Modification Gradient. *Glob. Change Biol.* **2019**, *25*, 811–826. [CrossRef] [PubMed]
2. WWF. *Living Planet Report 2024: A System in Peril*; WWF: Gland, Switzerland, 2024.
3. Kopnina, H.; Washington, H.; Gray, J.; Taylor, B. The 'Future of Conservation' Debate: Defending Ecocentrism and the Nature Needs Half Movement. *Biol. Conserv.* **2018**, *217*, 140–148. [CrossRef]
4. Dinerstein, E.; Vynne, C.; Sala, E.; Joshi, A.R.; Fernando, S.; Lovejoy, T.E.; Mayorga, J.; Olson, D.; Asner, G.P.; Baillie, J.E.M.; et al. A Global Deal for Nature: Guiding Principles, Milestones, and Targets. *Sci. Adv.* **2019**, *5*, eaaw2869. [CrossRef] [PubMed]
5. Hansen, A.J.; Burns, P.; Ervin, J.; Goetz, S.J.; Hansen, M.; Venter, O.; Watson, J.E.M.; Jantz, P.A.; Virnig, A.L.S.; Barnett, K.; et al. A Policy-Driven Framework for Conserving the Best of Earth's Remaining Moist Tropical Forests. *Nat. Ecol. Evol.* **2020**, *4*, 1377–1384. [CrossRef] [PubMed]
6. Parsa, V.A.; Yavari, A.; Nejadi, A. Spatio-Temporal Analysis of Land Use/Land Cover Pattern Changes in Arasbaran Biosphere Reserve: Iran. *Model. Earth Syst. Environ.* **2016**, *2*, 1–13. [CrossRef]
7. Li, F.; Liu, X.; Zhang, X.; Zhao, D.; Liu, H.; Zhou, C.; Wang, R. Urban Ecological Infrastructure: An Integrated Network for Ecosystem Services and Sustainable Urban Systems. *J. Clean. Prod.* **2017**, *163*, S12–S18. [CrossRef]
8. da Silva, J.M.C.; Wheeler, E. Ecosystems as Infrastructure. *Perspect. Ecol. Conserv.* **2017**, *15*, 32–35. [CrossRef]
9. Coffin, A.W.; Ouren, D.S.; Bettez, N.D.; Borda-de-Água, L.; Daniels, A.E.; Grilo, C.; Jaeger, J.A.G.; Navarro, L.M.; Preisler, H.K.; Rauschert, E.S.J. *The Ecology of Rural Roads: Effects, Management, and Research*; Issues in Ecology, Report No. 23; Ecological Society of America: Washington, DC, USA, 2021. Available online: https://research.fs.usda.gov/treesearch/68966 (accessed on 27 May 2026).
10. Van Strien, M.J.; Grêt-Regamey, A. A Global Time Series of Traffic Volumes on Extra-Urban Roads. *Sci. Data* **2024**, *11*, 470. [CrossRef] [PubMed]
11. Laurance, W.F.; Clements, G.R.; Sloan, S.; O'Connell, C.S.; Mueller, N.D.; Goosem, M.; Venter, O.; Edwards, D.P.; Phalan, B.; Balmford, A.; et al. A Global Strategy for Road Building. *Nature* **2014**, *513*, 229–232. [CrossRef] [PubMed]
12. Laurance, W.F.; Peletier-Jellema, A.; Geenen, B.; Koster, H.; Verweij, P.; Van Dijck, P.; Lovejoy, T.E.; Schleicher, J.; Van Kuijk, M. Reducing the Global Environmental Impacts of Rapid Infrastructure Expansion. *Curr. Biol.* **2015**, *25*, R259–R262. [CrossRef] [PubMed]
13. Ascensão, F.; Yogui, D.R.; Alves, M.H.; Alves, A.C.; Abra, F.; Desbiez, A.L. Preventing Wildlife Roadkill Can Offset Mitigation Investments in Short-Medium Term. *Biol. Conserv.* **2021**, *253*, 108902. [CrossRef]
14. Angelstam, P.; Khaulyak, O.; Yamelynets, T.; Mozgeris, G.; Naumov, V.; Chmielewski, T.J.; Elbakidze, M.; Manton, M.; Prots, B.; Valasiuk, S. Green Infrastructure Development at European Union's Eastern Border: Effects of Road Infrastructure and Forest Habitat Loss. *J. Environ. Manag.* **2017**, *193*, 300–311. [CrossRef] [PubMed]
15. Kuncoro, E.; Wurarah, R.N.; Erari, I.E. The Impact of Road Infrastructure Development on Ecosystems and Communities. *Soc. Ecol. Econ. Sustain. Dev. Goals J.* **2024**, *1*, 78–79. [CrossRef]
16. Mansour, A.H. Using Landscape Architecture Design to Mitigate Climate Change Impacts Desertification Phenomenon: A Case Study. *J. Al-Azhar Univ. Eng. Sect.* **2024**, *19*, 1106–1120. [CrossRef]
17. Rahbarisisakht, S.; Labelle, E.R.; LeBel, L.; Gautam, S.H. Managing Forest Road Networks in the Face of a Changing Climate: A Conceptual Framework Based on a Comprehensive Review. *Curr. For. Rep.* **2025**, *11*, 19. [CrossRef]
18. Tafida, A.; Alaloul, W.S.; Zawawi, N.A.B.W.; Musarat, M.A.; Abubakar, A.S. A Review of Eco-Friendly Road Infrastructure Innovations for Sustainable Transportation. *Infrastructures* **2024**, *9*, 216. [CrossRef]

19. Đuka, A.; Papa, I.; Proto, A.; Latterini, F.; Mederski, P.S.; Borz, S.A.; Iordache, E.; Sokolović, D.; Karišik, A.; Stojnić, D.; et al. Forest Accessibility and Road Network Density: A Global Overview with a Special Focus on Europe. *Curr. For. Rep.* **2025**, *11*, 26. [CrossRef]
20. Ekka, P.; Patra, S.; Upreti, M.; Kumar, G.; Kumar, A.; Saikia, P. Land Degradation and Its Impacts on Biodiversity and Ecosystem Services. In *Land and Environmental Management Through Forestry*; Raj, A., Jhariya, M.K., Banerjee, A., Nema, S., Bargali, K., Eds.; John Wiley & Sons: Hoboken, NJ, USA, 2023. [CrossRef]
21. Gu, T.; Tong, Y.; Wang, S.; You, Z.; Li, D.; Jiang, Y.; Rafaqat, A.; Wang, C.; Zhang, Q. Identifying the Priority Areas for Ecological Protection Considering Ecological Connectivity and Ecosystem Integrity: A Case Study of Xianyang City, China. *Ecol. Indic.* **2024**, *163*, 112102. [CrossRef]
22. Lapin, K.; Hoffmann, J.A.; Braun, M.; Oettel, J. Identification and Prioritization of Stepping Stones for Biodiversity Conservation in Forest Ecosystems. *Conserv. Sci. Pract.* **2024**, *6*, e13161. [CrossRef]
23. Lyons, C.K.; Borz, S.A.; Harvey, C.; Ramantswana, M.; Sakai, H.; Visser, R. Forest Roads: Regional Perspectives from Around the World. *Int. J. For. Eng.* **2023**, *34*, 190–203. [CrossRef]
24. Parera, L.R. Implementation Strategy of Remote Sensing and Road Network Optimization in Forest Harvesting Operations Planning. *J. Acad. Sci.* **2025**, *2*, 1741–1749. [CrossRef]
25. Tampekis, S.; Kantartzis, A.; Arabatzis, G.; Sakellariou, S.; Kolkos, G.; Malesios, C. Conceptualizing Forest Operations Planning and Management Using Principles of Functional Complex Systems Science to Increase the Forest's Ability to Withstand Climate Change. *Land* **2024**, *13*, 217. [CrossRef]
26. Robinson, C.; Duinker, P.N.; Beazley, K.F. A Conceptual Framework for Understanding, Assessing, and Mitigating Ecological Effects of Forest Roads. *Environ. Rev.* **2010**, *18*, 61–86. [CrossRef]
27. Squires, V.R.; Dengler, J.; Feng, H.; Hua, L. (Eds.) *Grasslands of the World: Diversity, Management and Conservation*; CRC Press: Boca Raton, FL, USA, 2018. [CrossRef]
28. Wesche, K.; Ambarlı, D.; Kamp, J.; Török, P.; Treiber, J.; Dengler, J. The Palaearctic Steppe Biome: A New Synthesis. *Biodivers. Conserv.* **2016**, *25*, 2197–2231. [CrossRef]
29. Jungkunst, H.F.; Horvath, T.; Erasmi, S.; Krüger, J.P.; Meurer, K.H.; Schützenmeister, K.; Guillaume, T.; Scholten, T.; Baumann, F.; Schleuss, P.-M.; et al. Regionally Diverse Land-Use-Driven Feedback from Soils to the Climate System. In *Soil and Climate*; CRC Press: Boca Raton, FL, USA, 2018; pp. 61–130. [CrossRef]
30. Daigle, P. A Summary of the Environmental Impacts of Roads, Management Responses, and Research Gaps: A Literature Review. *BC J. Ecosyst. Manag.* **2010**, *10*, 65–89. [CrossRef]
31. Balafoutis, T.; Skandali, C.; Niavis, S.; Doulos, L.T.; Zerefos, S.C. Light Pollution Beyond the Visible: Insights from People's Perspectives. *Urban Sci.* **2025**, *9*, 251. [CrossRef]
32. Hauser, D.D.W.; Tobin, E.D.; Feifel, K.M.; Shah, V.; Pietri, D.M. Disciplinary Reporting Affects the Interpretation of Climate Change Impacts in Global Oceans. *Glob. Change Biol.* **2016**, *22*, 25–43. [CrossRef] [PubMed]
33. Sitas, N.; Prozesky, H.E.; Esler, K.J.; Reyers, B. Opportunities and Challenges for Mainstreaming Ecosystem Services in Development Planning: Perspectives from a Landscape Level. *Landsc. Ecol.* **2014**, *29*, 1315–1331. [CrossRef]
34. Uhde, B.; Hahn, W.A.; Griess, V.C.; Knoke, T. Hybrid MCDA Methods to Integrate Multiple Ecosystem Services in Forest Management Planning: A Critical Review. *Environ. Manag.* **2015**, *56*, 373–388. [CrossRef] [PubMed]
35. Yigitcanlar, T.; Dizdaroglu, D. Ecological Approaches in Planning for Sustainable Cities: A Review of the Literature. *Glob. J. Environ. Sci. Manag.* **2015**, *1*, 159–188. [CrossRef]
36. Suparna, K.; Bharani, A.; Manosri, V.; Rohinidevi, K. Ecological Services and Their Importance. In *Natural Resource Management and Environmental Security*; Sah, D., Ed.; Integrated Publications: New Delhi, India, 2025; pp. 1–26. [CrossRef]
37. WWF. *Living Planet Report 2022: Building a Nature-Positive Society*; Almond, R.E.A., Grooten, M., Juffe Bignoli, D., Petersen, T., Eds.; WWF: Gland, Switzerland, 2022.
38. Andrea, V. Mediterranean Forest Policy Beyond the Paris Climate Agreement. *Land Use Policy* **2022**, *112*, 105797. [CrossRef]
39. Manning, P.; van der Plas, F.; Soliveres, S.; Allan, E.; Maestre, F.T.; Mace, G.; Whittingham, M.J.; Fischer, M. Redefining Ecosystem Multifunctionality. *Nat. Ecol. Evol.* **2018**, *2*, 427–436. [CrossRef] [PubMed]
40. Smith, P.; Ashmore, M.R.; Black, H.I.J.; Burgess, P.J.; Evans, C.D.; Quine, T.A.; Thomson, A.M.; Hicks, K.; Orr, H.G. Review: The Role of Ecosystems and Their Management in Regulating Climate, and Soil, Water and Air Quality. *J. Appl. Ecol.* **2013**, *50*, 812–829. [CrossRef]
41. Kurdoglu, O. Why Should Mountains Be Protected? An Evaluation within the Scope of Green Road, HEPP and Mining Investments. In *Ecological, Economic and Political Assessments on Türkiye's Forests and Forestry*; Şen, G., Güngör, E., Eds.; Duvar Publishing: İzmir, Türkiye, 2023; pp. 271–290.
42. Sati, V.P. *Towards Sustainable Livelihoods and Ecosystems in Mountain Regions*; Springer International Publishing: Cham, Switzerland, 2014. [CrossRef]
43. Stahr, A.; Langenscheidt, E. *Landforms of High Mountains*; Springer: Heidelberg/Berlin, Germany, 2014. [CrossRef]

44. UN (United Nations). *Sustainable Mountain Development: Report of the Secretary General, August 2011*; United Nations: New York, NY, USA, 2011.
45. Zhang, Y.; Deng, B. Exploring the Nexus of Smart Technologies and Sustainable Ecotourism: A Systematic Review. *Heliyon* **2024**, *10*, e31996. [CrossRef] [PubMed]
46. Dixon, H.J.; Elmarsafy, M.; Hannan, N.; Gao, V.; Wright, C.; Khan, L.; Gray, D.K. The Effects of Roadways on Lakes and Ponds: A Systematic Review and Assessment of Knowledge Gaps. *Environ. Rev.* **2022**, *30*, 501–523. [CrossRef]
47. Ibisch, P.L.; Hoffmann, M.T.; Kreft, S.; Pe'er, G.; Kati, V.; Biber-Freudenberger, L.; DellaSala, D.A.; Vale, M.M.; Hobson, P.R.; Selva, N. A Global Map of Roadless Areas and Their Conservation Status. *Science* **2016**, *354*, 1423–1427. [CrossRef] [PubMed]
48. Kiesecker, J.M.; Naugle, D.E. (Eds.) *Energy Sprawl Solutions: Balancing Global Development and Conservation*; Island Press: Washington, DC, USA, 2017.
49. Jacobson, S.L.; Bliss-Ketchum, L.L.; de Rivera, C.E.; Smith, W.P. A Behavior-Based Framework for Assessing Barrier Effects to Wildlife from Vehicle Traffic Volume. *Ecosphere* **2016**, *7*, e01345. [CrossRef]
50. Martin, A.E.; Graham, S.L.; Henry, M.; Pervin, E.; Fahrig, L. Flying Insect Abundance Declines with Increasing Road Traffic. *Insect Conserv. Divers.* **2018**, *11*, 608–613. [CrossRef]
51. Sánchez-Fernández, M.; Barrigón Morillas, J.M.; Montes González, D.; de Sanjosé Blasco, J.J. Impact of Roads on Environmental Protected Areas: Analysis and Comparison of Metrics for Assessing Habitat Fragmentation. *Land* **2022**, *11*, 1843. [CrossRef]
52. Zhou, D.; Xiao, J.; Liu, S.; Huang, L.; Zhang, L.; Fan, J.; Zhao, S. Global Impacts of Transportation Infrastructure on Forest Degradation and Loss. *Nat. Commun.* **2026**, *17*, 2339. [CrossRef] [PubMed]
53. Arjmand, A.; Kiadaliri, H.; Kazemnezhad, F.; Nimvari, M.E. Effects of Forest Roads on Vegetation Biodiversity and Soil Characteristics in Hyrcanian Forests. *Nord. J. Bot.* **2023**, *2023*, e04039. [CrossRef]
54. Fullman, T.J.; Wilson, R.R.; Joly, K.; Gustine, D.D.; Leonard, P.; Loya, W.M. Mapping Potential Effects of Proposed Roads on Migratory Connectivity for a Highly Mobile Herbivore Using Circuit Theory. *Ecol. Appl.* **2021**, *31*, e2207. [CrossRef] [PubMed]
55. Bhuiyan, A.R.M.; Mia, A.; Sarker, A.; Khan, A. Effect of Transportation Infrastructure on Forest Plant Diversity and Soil Properties in Lawachara National Park, Bangladesh. *Acta Ecol. Sin.* **2022**, *42*, 110–120. [CrossRef]
56. Newbold, T.; Hudson, L.N.; Hill, S.L.L.; Contu, S.; Lysenko, I.; Senior, R.A.; Börger, L.; Bennett, D.J.; Choimes, A.; Collen, B.; et al. Global Effects of Land Use on Local Terrestrial Biodiversity. *Nature* **2015**, *520*, 45–50. [CrossRef] [PubMed]
57. Schulze, K.; Knights, K.; Coad, L.; Geldmann, J.; Leverington, F.; Eassom, A.; Marr, M.; Butchart, S.H.M.; Hockings, M.; Burgess, N.D. An Assessment of Threats to Terrestrial Protected Areas. *Conserv. Lett.* **2018**, *11*, e12435. [CrossRef]
58. Silva, I.; Crane, M.; Savini, T. High Roadkill Rates in the Dong Phayayen-Khao Yai World Heritage Site: Conservation Implications of a Rising Threat to Wildlife. *Anim. Conserv.* **2020**, *23*, 466–478. [CrossRef]
59. Ware, H.E.; McClure, C.J.W.; Carlisle, J.D.; Barber, J.R. A Phantom Road Experiment Reveals Traffic Noise Is an Invisible Source of Habitat Degradation. *Proc. Natl. Acad. Sci. USA* **2015**, *112*, 12105–12109. [CrossRef] [PubMed]
60. Arıcak, B.; Acar, H.H. The Modeling of Filling and Construction Impact Areas in Building Forest Roads by Using QuickBird Satellite Image. *Kastamonu Univ. J. For. Fac.* **2008**, *8*, 144–156. Available online: https://www.cabidigitallibrary.org/doi/full/10.5555/20093187033 (accessed on 27 May 2026).
61. Borowik, T.; Ratkiewicz, M.V.; Maślanko, W.; Kowalczyk, R.; Duda, N.; Żmihorski, M. Temporal Pattern of Moose-Vehicle Collisions. *Transp. Res. Part D Transp. Environ.* **2021**, *92*, 102715. [CrossRef]
62. Carter, N.; Killion, A.; Easter, T.; Brandt, J.; Ford, A. Road Development in Asia: Assessing the Range-Wide Risks to Tigers. *Sci. Adv.* **2020**, *6*, eaaz9619. [CrossRef] [PubMed]
63. Ellis-Soto, D.; Oliver, R.Y.; Brum-Bastos, V.; Demsar, U.; Jesmer, B.; Long, J.A.; Cagnacci, F.; Ossi, F.; Queiroz, N.; Hindell, M.; et al. A Vision for Incorporating Human Mobility in the Study of Human-Wildlife Interactions. *Nat. Ecol. Evol.* **2023**, *7*, 1362–1372. [CrossRef] [PubMed]
64. Gonçalves, L.O.; Alvares, D.J.; Teixeira, F.Z.; Schuck, G.; Coelho, I.P.; Esperandio, I.B.; Kindel, A. Reptile Road-Kills in Southern Brazil: Composition, Hot Moments and Hotspots. *Sci. Total Environ.* **2018**, *615*, 1438–1445. [CrossRef] [PubMed]
65. Shi, H.; Shi, T.; Yang, Z.; Wang, Z.; Han, F.; Wang, C. Effect of Roads on Ecological Corridors Used for Wildlife Movement in a Natural Heritage Site. *Sustainability* **2018**, *10*, 2725. [CrossRef]
66. Deljouei, A.; Sadeghi, S.M.M.; Abdi, E.; Bernhardt-Römermann, M.; Pascoe, E.L.; Marcantonio, M. The Impact of Road Disturbance on Vegetation and Soil Properties in a Beech Stand, Hyrcanian Forest. *Eur. J. For. Res.* **2018**, *137*, 759–770. [CrossRef]
67. Habibzadeh, A.; Arabkhedri, M.; Yarahmadi, J.; Majidi, A. Estimating Sediment Yield from a Forest Road Network Using SEDMODEL and GIS Technique (Case Study Arasbaran Forests). *Ecopersia* **2021**, *9*, 235–249. Available online: https://ecopersia.modares.ac.ir/article_17326.html (accessed on 27 May 2026).
68. Froude, M.J.; Petley, D.N. Global Fatal Landslide Occurrence from 2004 to 2016. *Nat. Hazards Earth Syst. Sci.* **2018**, *18*, 2161–2181. [CrossRef]
69. McAdoo, B.G.; Quak, M.; Gnyawali, K.R.; Adhikari, B.R.; Devkota, S.; Rajbhandari, P.L.; Sudmeier-Rieux, K. Roads and Landslides in Nepal: How Development Affects Environmental Risk. *Nat. Hazards Earth Syst. Sci.* **2018**, *18*, 3203–3210. [CrossRef]

70. Grimm, A.G.; Tirpak, R.A.; Winston, R.J. Monitoring the Impacts of Rainfall Characteristics on Sediment Loss from Road Construction Sites. *Environ. Sci. Pollut. Res.* **2024**, *31*, 32428–32440. [CrossRef] [PubMed]
71. Kastridis, A. Impact of Forest Roads on Hydrological Processes. *Forests* **2020**, *11*, 1201. [CrossRef]
72. Yousefi, S.; Emami, S.N.; Nekoeimehr, M.; Rahmati, O.; Imaizumi, F.; Gomez, C.; Valjarevic, A. A Hot-Spot Analysis of Forest Roads Based on Soil Erosion and Sediment Production. *Land* **2024**, *13*, 1583. [CrossRef]
73. Yüksek, Ö.; Babacan, H.T.; Yüksek, O. Flood Causes, Damages and Flood Management Studies in the Eastern Black Sea Basin. *Turk. J. Hydraul.* **2022**, *6*, 36–46.
74. Jones, R.; Llewellyn, J. Improving Infrastructure. *Natl. Inst. Econ. Rev.* **2019**, *250*, R61–R68. [CrossRef]
75. Ramos-Scharrón, C.E.; LaFevor, M.C. Effects of Forest Roads on Runoff Initiation in Low-Order Ephemeral Streams. *Water Resour. Res.* **2018**, *54*, 8613–8630. [CrossRef]
76. Zoker, M.E.; Karim, S.; Kargbo, B.; Kemoh, R.; Yorpoi, L.D. Impacts of Road Constructions on Ecological Biodiversity and Livelihood in Sierra Leone. *Int. J. Multidiscip. Res. Growth Eval.* **2022**, *3*, 280–296. [CrossRef]
77. Lemke, A.; Kowarik, I.; von der Lippe, M. How Traffic Facilitates Population Expansion of Invasive Species Along Roads: The Case of Common Ragweed in Germany. *J. Appl. Ecol.* **2019**, *56*, 413–422. [CrossRef]
78. Zamani, M.; Nikooy, M.; Pourbabaei, H.; Naghdi, R. The Effects of Roadside on Composition of Tree Communities in Forests of West Guilan Province, Iran. *Casp. J. Environ. Sci.* **2019**, *17*, 305–317. [CrossRef]
79. Unver, S.; Kurdoglu, O. Road Constructions: Mandatory for Forestry but Problematic for Conservation. In *Conservation of Natural Resources in the Context of Climate Change*; Şen, G., Güngör, E., Eds.; Duvar Publishing: Ankara, Türkiye, 2021; pp. 127–145.
80. Van der Ree, R.; Smith, D.J.; Grilo, C. The Ecological Effects of Linear Infrastructure and Traffic. In *Handbook of Road Ecology*; John Wiley & Sons: Hoboken, NJ, USA, 2015; pp. 1–9. [CrossRef]
81. Ament, R.; Clevenger, A.; van der Ree, R. (Eds.) *Addressing Ecological Connectivity in the Development of Roads, Railways and Canals*; IUCN WCPA Technical Report Series No. 5; IUCN: Gland, Switzerland, 2024. Available online: https://portals.iucn.org/library/sites/library/files/documents/PATRS-005-En.pdf (accessed on 27 May 2026).
82. Corazza, M.V. A Comprehensive Research Agenda for Integrating Ecological Principles into the Transportation Sector. *Sustainability* **2024**, *16*, 7081. [CrossRef]
83. Escobedo, F.J.; Giannico, V.; Jim, C.Y.; Sanesi, G.; Lafortezza, R. Urban Forests, Ecosystem Services, Green Infrastructure and Nature-Based Solutions: Nexus or Evolving Metaphors? *Urban For. Urban Green.* **2019**, *37*, 3–12. [CrossRef]
84. Kazama, V.S.; Corte, A.P.D.; Robert, R.C.G.; Sanquetta, C.R.; Arce, J.E.; Oliveira-Nascimento, K.A.; DeArmond, D. Global Review on Forest Road Optimization Planning: Support for Sustainable Forest Management in Amazonia. *For. Ecol. Manag.* **2021**, *492*, 119159. [CrossRef]
85. Reddiar, I.B.; Osti, M. Quantifying Transportation Infrastructure Pressure on Southeast Asian World Heritage Forests. *Biol. Conserv.* **2022**, *270*, 109564. [CrossRef]
86. Cai, X.; Wu, Z.; Cheng, J. Using Kernel Density Estimation to Assess the Spatial Pattern of Road Density and Its Impact on Landscape Fragmentation. *Int. J. Geogr. Inf. Sci.* **2013**, *27*, 222–230. [CrossRef]
87. Qin, X.; Wang, Y.; Cui, S.; Liu, S.; Liu, S.; Wangari, V.W. Post-Assessment of the Eco-Environmental Impact of Highway Construction—A Case Study of Changbai Mountain Ring Road. *Environ. Impact Assess. Rev.* **2023**, *98*, 106963. [CrossRef]
88. Maier, C.; Hebermehl, W.; Grossmann, C.M.; Loft, L.; Mann, C.; Hernandez-Morcillo, M. Innovations for Securing Forest Ecosystem Service Provision in Europe—A Systematic Literature Review. *Ecosyst. Serv.* **2021**, *52*, 101374. [CrossRef]
89. Qiu, W.; Jia, D.; Guo, R.; Zhang, L.; Wang, Z.; Hu, X. Unequal Impact of Road Expansion on Regional Ecological Quality. *Land* **2025**, *14*, 523. [CrossRef]
90. Mesquita, M.; Marques, S.; Marques, M.; Marto, M.; Constantino, M.; Borges, J.G. An Optimization Approach to Design Forest Road Networks and Plan Timber Transportation. *Oper. Res. Int. J.* **2022**, *22*, 2973–3001. [CrossRef]
91. Al Naqbi, K.K.M.; Ojiako, U.; Al-Mhdawi, M.K.S.; Chipulu, M.; Dweiri, F.T. How Different Stakeholders Perceive Benefits, Challenges, and Barriers in the Implementation of Green Technology Projects. *Sustainability* **2025**, *17*, 9849. [CrossRef]
92. Taktak, M. Professional Disciplines and Areas of Responsibility in Urban Transformation Projects in Turkey: A Social Network Analysis Approach. *J. Urban Plan. Dev.* **2026**, *152*, 04026023. [CrossRef]
93. Wimalasena, S.; Weerakoon, T.G.; Wimalasena, J. Integrated Approaches to Sustainable Urban Development: The Synergy Between Landscape Architecture and Civil Engineering. *Sci.-Future Lith.* **2025**, *17*, 1–17. [CrossRef]
94. Zhou, J. Synergizing Architectural Design, Structural Restoration, and Civil Engineering for Sustainable Urban Development. *SHS Web Conf.* **2024**, *192*, 01014. [CrossRef]
95. Oyebode, O.J.; Sunday, A.; Ahmed, S.A.; Ajibade, S.-S.; Chukwudulue, J.A.; Okokpujie, I.P.; Afolalu, S.A.; Coker, A.O. Building Resilient and Environmentally Conscious Infrastructure Landscape Through Integrated Approaches of Architectural, Urban Planning and Civil Engineering Design. *NIPES J. Sci. Technol. Res.* **2025**, *7*, 3855–3863. [CrossRef]

96. Guarini, M.R.; Morano, P.; Sica, F. Eco-System Services and Integrated Urban Planning: A Multi-Criteria Assessment Framework for Ecosystem Urban Forestry Projects. In *Values and Functions for Future Cities. Green Energy and Technology*; Mondini, G., Oppio, A., Stanghellini, S., Bottero, M., Abastante, F., Eds.; Springer: Cham, Switzerland, 2020; pp. 201–216. [CrossRef] [PubMed]
97. Agista, S.; Surya, M.A.; Hidayatullah, S.; Isradi, M.; Indriany, S. Analysis and Design of Road Infrastructure: Geometric Design of the Subang-Ciasem Road. *RIGGS J. Artif. Intell. Digit. Bus.* **2026**, *4*, 8964–8975. [CrossRef]
98. Salem, A.S. Road Infrastructure Design. Doctoral Dissertation, Université Mouloud Mammeri, Tizi Ouzou, Algeria, 2024.
99. Segerberg, B.; Noriega, A. Advancing Inclusive, Multimodal, Climate-Resilient Planning for Rural Networked Transport Infrastructure. *Sustainability* **2026**, *18*, 2842. [CrossRef]
100. Aktürk, G.; Hauser, S.J. Detection of Disaster-Prone Vernacular Heritage Sites at District Scale: The Case of Fındıklı in Rize, Turkey. *Int. J. Disaster Risk Reduct.* **2021**, *62*, 102238. [CrossRef]
101. Cervero, R.; Hansen, M. Induced Travel Demand and Induced Road Investment: A Simultaneous-Equation Analysis. *J. Transp. Econ. Policy* **2002**, *36*, 469–490. [CrossRef]
102. UK Department for Transport. *Latest Evidence on Induced Travel Demand: An Evidence Review; Project No. 1-396, Our Ref No. 70038415*; UK Department for Transport: London, UK, 2018.
103. Enaleeva-Bandura, I.; Kolesnikov, P.; Kunickaya, O.G.; Baranov, A.; Brovkin, S.; Nikitin, V.; Dolmatova, L. A Comprehensive Assessment of Forest Transport Network Planning Taking into Account the Project's Technical, Economic, Environmental, and Social Aspects. *Math. Model. Eng. Probl.* **2024**, *11*, 1071. [CrossRef]
104. Latterini, F.; Dyderski, M.K.; Horodecki, P.; Picchio, R.; Venanzi, R.; Lapin, K.; Jagodziński, A.M. The Effects of Forest Operations and Silvicultural Treatments on Litter Decomposition Rate: A Meta-Analysis. *Curr. For. Rep.* **2023**, *9*, 276–290. [CrossRef]
105. Rönnqvist, M.; Martell, D.; Weintraub, A. Fifty Years of Operational Research in Forestry. *Int. Trans. Oper. Res.* **2023**, *30*, 3296–3328. [CrossRef]
106. Ankomah, F.; Boateng, K.; Asante, W.; Ansong, M. Implementation Gaps in Forest Management Prescriptions and Noncompliance in Forest Regulations in Ghana: Case Study of Four Forest Reserves. *Environ. Dev. Sustain.* **2022**, *24*, 9355–9379. [CrossRef]
107. Acosta, F.C.; Rengifo, S.P.; García, M.L.; Trondoli Matricardi, E.A.; Castillo, G.B. Road Network Planning in Tropical Forests Using GIS. *Croat. J. For. Eng.* **2023**, *44*, 153–169. [CrossRef]
108. Dinca, L.; Constandache, C.; Postolache, R.; Murariu, G.; Tupu, E. Timber Harvesting in Mountainous Regions: A Comprehensive Review. *Forests* **2025**, *16*, 495. [CrossRef]
109. Huijser, M.P.; Fairbank, E.R.; Camel-Means, W.; Graham, J.; Watson, V.; Basting, P.; Becker, D. Effectiveness of Short Sections of Wildlife Fencing and Crossing Structures Along Highways. *Biol. Conserv.* **2016**, *197*, 84–93. [CrossRef]
110. Si, M.; Mu, Y.; Han, Y. Road Landscape Design: Harmonious Relationship Between Ecology and Aesthetics. *Forests* **2024**, *15*, 2008. [CrossRef]
111. Zhao, S.; Ibrahim, F.I. Landscape Design in the Perspective of Rural Revitalization. *E3S Web Conf.* **2024**, *565*, 01009. [CrossRef]
112. Unver, S.; Kurdoglu, O. A Comparative Analysis of Forest Engineers' Opinions on Forest Road Construction. *Appl. Ecol. Environ. Res.* **2024**, *22*, 4259–4275. [CrossRef]
113. Lucas, L.V.; Deleersnijder, E. Timescale Methods for Simplifying, Understanding and Modeling Biophysical and Water Quality Processes in Coastal Aquatic Ecosystems: A Review. *Water* **2020**, *12*, 2717. [CrossRef]
114. URL-1. Turkish Union of Chambers of Engineers and Architects. Available online: https://www.tmmob.org.tr (accessed on 5 May 2026).
115. Baştürk, S.; Taştepe, M. Universe and Sample. In *Scientific Research Methods*; Baştürk, S., Ed.; Vize Publishing: Ankara, Türkiye, 2013; pp. 129–159.
116. Campagne, C.S.; Roche, P.; Gosselin, F.; Tschanz, L.; Tatoni, T. Expert-Based Ecosystem Services Capacity Matrices: Dealing with Scoring Variability. *Ecol. Indic.* **2017**, *79*, 63–72. [CrossRef]
117. Wei, S.; Pfeffer, P.E.; Edelmann, J. State of the Art: Ongoing Research in Assessment Methods for Lane Keeping Assistance Systems. *IEEE Trans. Intell. Veh.* **2024**, *9*, 5853–5875. [CrossRef]
118. Manyara, A.M.; Purvis, A.; Ciani, O.; Collins, G.S.; Taylor, R.S. Sample Size in Multistakeholder Delphi Surveys. *J. Clin. Epidemiol.* **2024**, *174*, 111485. [CrossRef] [PubMed]
119. Nasa, P.; Jain, R.; Juneja, D. Delphi Methodology in Healthcare Research: How to Decide Its Appropriateness. *World J. Methodol.* **2021**, *11*, 116–129. [CrossRef] [PubMed]
120. Lynn, M.R. Determination and Quantification of Content Validity. *Nurs. Res.* **1986**, *35*, 382–385. [CrossRef] [PubMed]
121. Tabachnick, B.G.; Fidell, L.S. *Using Multivariate Statistics*, 7th ed.; Pearson: New York, NY, USA, 2022. Available online: https://lccn.loc.gov/2017040173 (accessed on 18 April 2026).
122. Hair, J.F.; Black, W.C.; Babin, B.J.; Anderson, R.E. *Multivariate Data Analysis*, 8th ed.; Cengage Learning: Boston, MA, USA, 2019.
123. Barbera, J.; Naibert, N.; Komperda, R.; Pentecost, T.C. Clarity on Cronbach's Alpha Use. *J. Chem. Educ.* **2021**, *98*, 257–258. [CrossRef]

124. Chan, L.L.; Idris, N. Validity and Reliability of the Instrument Using Exploratory Factor Analysis and Cronbach's Alpha. *Int. J. Acad. Res. Bus. Soc. Sci.* **2017**, *7*, 400–410. [CrossRef] [PubMed]
125. George, D.; Mallery, P. *SPSS for Windows Step by Step: A Simple Guide and Reference. 11.0 Update*, 4th ed.; Allyn & Bacon: Boston, MA, USA, 2003.
126. Podsakoff, P.M.; MacKenzie, S.B.; Lee, J.Y.; Podsakoff, N.P. Common Method Biases in Behavioural Research: A Critical Review of the Literature and Recommended Remedies. *J. Appl. Psychol.* **2003**, *88*, 879–903. [CrossRef] [PubMed]
127. Richardson, J.T.E. Eta Squared and Partial Eta Squared as Measures of Effect Size in Educational Research. *Educ. Res. Rev.* **2011**, *6*, 135–147. [CrossRef]
128. Forman, R.T.T.; Sperling, D.; Bissonette, J.A.; Clevenger, A.P.; Cutshall, C.D.; Dale, V.H.; Fahrig, L.; France, R.; Goldman, C.R.; Heanue, K.; et al. *Road Ecology: Science and Solutions*; Island Press: Washington, DC, USA, 2003. [CrossRef]
129. Arlidge, J.C.; Bull, J.W.; Addison, P.F.; Burgass, M.J.; Gianuca, D.; Gorham, T.M.; Jacob, C.; Shumway, N.; Sinclair, S.P.; Watson, J.E.M.; et al. A Global Mitigation Hierarchy for Nature Conservation. *BioScience* **2018**, *68*, 336–347. [CrossRef] [PubMed]
130. Benítez-López, A.; Alkemade, R.; Verweij, P.A. The Impacts of Roads and Other Infrastructure on Mammal and Bird Populations: A Meta-Analysis. *Biol. Conserv.* **2010**, *143*, 1307–1316. [CrossRef]
131. Van Dijck, P. *The Impact of the IIRSA Road Infrastructure Program on Amazonia*; Earthscan from Routledge, Taylor & Francis Group: London, UK; New York, NY, USA, 2013.
132. Kılıç, S. Cronbach's Alpha Reliability Coefficient. *J. Mood Disord.* **2016**, *6*, 47–48. [CrossRef]
133. Kolkos, G.; Stergiadou, A.; Kantartzis, A.; Tampekis, S.; Arabatzis, G. Effects of Forest Roads and an Assessment of Their Disturbance of the Natural Environment Based on GIS Spatial Multi-Criteria Analysis: Case Study of the University Forest of Taxiarchis, Chalkidiki, Greece. *Euro-Mediterr. J. Environ. Integr.* **2023**, *8*, 425–440. [CrossRef]
134. Mahale, V.N. Environmental Impact Assessment for Road Infrastructure and Development Projects. *Int. Res. J. Eng. Technol.* **2025**, *12*, 1–7. Available online: https://www.irjet.net/archives/V12/i4/IRJET-V12I412.pdf (accessed on 20 May 2026). [CrossRef]
135. Marzouk, M.; Abdelkader, E.M.; El-Zayat, M.; Aboushady, A. Assessing Environmental Impact Indicators in Road Construction Projects in Developing Countries. *Sustainability* **2017**, *9*, 843. [CrossRef]
136. Spellerberg, I.F. Ecological Effects of Roads and Traffic: A Literature Review. *Glob. Ecol. Biogeogr. Lett.* **1998**, *7*, 317–333. [CrossRef]

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