

Review

Noise as an Environmental Pressure Factor: Implications for Shaping Environmental Standards and Sustainable Environmental Management

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Abstract

Anthropogenic noise represents a significant form of environmental pollution, with consequences for both human health and ecosystem functioning. The aim of this study was to critically assess the adequacy of current environmental standards in light of the scale and nature of anthropogenic noise impacts on human health and ecosystem functioning, with particular emphasis on forested and protected areas. The methodology included a review of the scientific literature, an analysis of legal and institutional documents from the European Union and Poland, and a comparison with selected international approaches, in particular the practices of U.S. national parks, where the soundscape is regarded as an environmental resource requiring active protection. The review findings indicate that, in humans, exposure to noise is associated with, among other effects, an increased risk of cardiovascular disease, sleep disturbances, impaired cognitive functioning, and reduced psychological well-being, with nighttime noise being of particular significance. At the same time, numerous field and experimental studies demonstrate that, in many taxa, behavioral and physiological responses occur at levels lower than the thresholds applied to protect human health; ecologically significant effects have been reported at levels as low as approximately 40 dB, particularly in species dependent on acoustic communication. The analysis of existing regulations reveals the absence of operational standards and criteria for protected areas understood as natural habitats, which hinders the effective management of the acoustic climate. The proposed values of 40 dB for the nighttime period and 50 dB for the daytime period should be treated as indicative precautionary thresholds resulting from a qualitative synthesis of the literature and requiring empirical validation across different habitat types and geographical contexts. Their implementation may support the achievement of sustainable development objectives by simultaneously protecting human health, preserving biodiversity, and strengthening ecosystem resilience to anthropogenic pressures.



Academic Editors: Paulo Henrique Trombetta Zannin and Margret Sibylle Engel

Received: 1 June 2026

Revised: 23 June 2026

Accepted: 4 July 2026

Published: 9 July 2026

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Keywords: anthropogenic noise; noise pollution; protected areas; acoustic climate; sustainable environmental management

1. Introduction

The acoustic climate is a fundamental element of environmental quality. It comprises the entirety of acoustic phenomena occurring in a given area and is characterized by parameters describing sound levels in the environment. However, contemporary approaches to the assessment of the acoustic environment go beyond the analysis of noise indicators

alone and also take into account the soundscape, defined by ISO 12913-1:2014 [1] as the acoustic environment as perceived, experienced, and/or understood by a person or people in a given context. This means that the assessment of acoustic environmental quality includes both objective physical parameters of sound and the subjective experiences of users of a given space. Noise is an unwanted or harmful sound that interferes with the perception of acoustic information and may cause health, social, and ecological effects. According to the WHO definition, it is an unwanted or harmful sound resulting from human activity [2]. Anthropogenic noise has become a significant environmental and social problem, posing a serious threat to the quality of life of the population. It represents one of the most significant environmental threats to public health in the 21st century [3,4]. The mechanisms by which noise affects the human body are complex and include direct auditory effects as well as non-auditory health effects, such as activation of the endocrine and sympathetic nervous systems, sleep disturbance, cardiovascular risk, and deterioration of mental well-being [5–8].

In Poland, it is estimated that more than 3 million people in urban agglomerations are exposed to excessive road traffic noise over a 24 h period, while 1.2 million people outside agglomerations are exposed to road noise from major roads exceeding permissible levels [9]. According to the latest strategic noise mapping data, 38% of residents in agglomerations are exposed to road traffic noise exceeding 55 dB L_{den} , and Poland ranks 12th among European countries in terms of exposure [10]. Studies of the acoustic climate confirm that road traffic noise regularly exceeds permissible standards, and acoustic conditions in large human settlements (e.g., campuses) are characterized by a moderate to high level of nuisance, which negatively affects the comfort and health of urban space users [11,12]. The significance of road traffic noise in shaping the acoustic climate also requires consideration of methods for predicting it. Road traffic noise prediction models, including classical approaches, GIS tools, and machine learning-based methods, may be important tools for assessing the spatial extent of noise pollution and for supporting the planning of protective measures in the vicinity of forests and protected areas. Therefore, the development of road traffic noise prediction methods is of significant importance for both environmental impact assessments and more effective acoustic-climate management [13].

A growing body of research indicates that many animal species respond to anthropogenic noise at levels below the limits established for humans. Behavioural effects (e.g., habitat avoidance, changes in activity patterns) may already occur at around 40 dB, and a significant proportion of adverse effects have been observed below 50 dB [14,15]. For bird species that depend on acoustic communication, effects have been reported at levels as low as approximately 38 dB [16]. This implies that even moderate anthropogenic acoustic pressure can significantly disrupt animal functioning in forests and protected areas, where the natural acoustic background is typically low. In this context, a fundamental regulatory problem becomes apparent: the dominant legal systems governing environmental noise (including those in the EU and Poland) are designed primarily to protect humans (comfort, nuisance, health risk) and are subsequently implemented through broad land-use categories. This leads to a situation in which formal compliance with the law does not equate to the protection of biodiversity or the maintenance of conditions conducive to the functioning of animal populations [15,17,18].

Studies conducted in Roztocze National Park (Poland) demonstrated that road traffic noise dominated over natural environmental sounds at distances of up to 250 m from public roads, disrupting the functioning of forest ecosystems and indicating the need for an integrated approach to managing protected areas, including acoustic monitoring and the implementation of noise protection regulations [19].

There is a lack of operational, biologically grounded criteria and thresholds for forest habitats and nature-protected areas, and consequently a lack of a basis for consistent management of the soundscape as a natural resource. Despite growing public awareness of the value of the soundscape in Poland, effective legal instruments to protect it remain scarce. Existing tools, such as quiet zones, are not consistently implemented by local authorities, which hinders the systemic management of the soundscape as a natural resource [20]. A spatial analysis of quiet areas in Polish cities indicates that their designation and planning require consideration not only of human acoustic criteria but also of ecological and landscape values, which have not yet been reflected in current legal regulations [21].

This review focuses on Poland and the EU as the main subjects of analysis, but its conclusions may also provide a useful reference for other regions. The Polish context is particularly useful analytically because it combines the application of the EU legal framework with the national system of permissible noise levels and substantial transport pressure in agglomerations and along major roads.

The aim of the study was to critically assess the adequacy of current environmental standards in the context of the scale and nature of anthropogenic noise impacts on human health and ecosystem functioning, with particular emphasis on forested and protected areas. Specifically, the study sought to: (1) identify noise exposure levels that induce significant health effects in humans and behavioural and physiological effects in animals, (2) compare these values with existing environmental acoustic protection standards in Poland and the European Union, (3) identify normative gaps in the protection of natural habitats from noise pollution, and (4) propose ecologically justified, indicative protection thresholds for environmentally valuable areas as a basis for operationalising the acoustic climate.

In addition to legal gaps, the review reveals certain research gaps. There is a lack of comparable, multi-season measurements of the acoustic background in different types of forests, national parks, and reserves in Central Europe. Only some studies combine noise level measurements with population-level responses, such as breeding success, survival, habitat use, or changes in trophic networks. Moreover, there is a lack of studies that validate specific management thresholds under European conditions, particularly for Natura 2000 sites, national parks, and forest complexes in the vicinity of transport infrastructure.

2. Methodology

The literature review was conducted in accordance with the PRISMA 2020 [22] guidelines to increase transparency, reproducibility, and control over the source selection process. The search covered publications from 2010 to 2026, with selected older sources included if they addressed fundamental concepts, methods, or regulations related to environmental noise. The final search was conducted on 1 May 2026. The analysis primarily included English- and Polish-language sources, with selected publications and documents in other European languages included when directly relevant to legal, regulatory, or institutional comparisons.

The search was conducted in the Scopus, Web of Science, PubMed, and Google Scholar databases. In addition, official legal and institutional sources were used, including legal acts of the European Union and Poland, documents on environmental noise management, materials on protected areas, and selected documents on soundscape management. The keyword sets used included various combinations of terms referring to anthropogenic noise, environmental noise, transportation noise, road, railway, and aircraft noise, soundscape, quiet areas, protected areas, national parks, forest ecosystems, fauna, human health, physiological stress, acoustic communication, behavioral effects, legal regulations, and environmental management.

A total of 20,824 records were identified in the databases: Scopus, Web of Science, PubMed, and Google Scholar, while an additional 22 records were obtained from other sources, mainly legal and institutional documents. Before the screening stage, 7452 duplicate records and 9978 records for other reasons were removed. A total of 3394 records were qualified for screening. Based on titles, abstracts, source type, full-text availability, and consistency with the thematic scope, 3274 records were excluded. A total of 120 publications and reports were qualified for full-text retrieval and assessment. All qualified reports were retrieved and assessed for eligibility. After full-text assessment, 34 reports were excluded, including 14 outside the review's final thematic scope, 9 technical or engineering-oriented acoustics studies, 7 studies primarily concerning occupational, indoor, or clinical exposure, and 4 insufficiently relevant to the assessment of environmental noise. Ultimately, 86 sources were included in the review.

Due to the diverse nature of the included sources, a qualitative assessment of their usefulness and reliability was conducted. The type of source, thematic scope, relevance to the main synthesis, presence of numerical data on noise levels, relationship to the assessment of health, ecological, or regulatory effects, and usefulness for the analysis of protected areas were considered. Sources used in the main synthesis were treated as stronger bases for inference than sources used solely as contextual background. This approach made it possible to avoid treating empirical studies, review papers, legal documents, and supporting materials as equivalent sources of evidence.

Due to differences in study designs, analyzed species, habitat types, exposure indicators, exposure duration, and reported effects, no meta-analysis was conducted. The included studies also differed in the acoustic indicators used, such as L_{Aeq} , L_{den} , L_{night} , L_{dn} , L_{50} , and other sound-level measures, which limits the possibility of direct quantitative comparison of the results. For this reason, the synthesis was qualitative and comparative. The 86 included sources were considered sufficient to achieve the study's aim, which was to critically synthesise the state of knowledge and compare the effects of anthropogenic noise on humans and fauna with the existing legal framework. At the same time, this number does not provide a basis for determining universal, quantitatively validated ecological thresholds; therefore, the proposed values should be treated as indicative and require further empirical verification.

3. Human Sensitivity to Anthropogenic Noise

The impact of noise on the cardiovascular system is one of the best-documented areas of research on the health effects of anthropogenic noise. Long-term exposure to transport noise is associated with a significant increase in the risk of cardiovascular diseases, with evidence indicating associations with ischemic heart disease, heart failure, and stroke [5,6]. Epidemiological studies show that each 10 dB increase in noise is associated with an 8% increase in the risk of cardiovascular disease [23,24]. In a large cohort study conducted across five U.S. states, long-term exposure to anthropogenic noise was significantly associated with increased cardiovascular mortality, with daytime noise levels L_{50} , nighttime noise levels L_{50} , and overall day-night sound pressure levels L_{dn} all demonstrating associations with mortality outcomes. Importantly, these associations were stronger in women and showed monotonic positive trends up to thresholds of 45–55 dB [25]. The pathophysiological mechanisms linking noise to cardiovascular diseases include endothelial dysfunction, inflammation, and hypertension [5,6]. Traffic noise, particularly at night, causes sleep fragmentation and reduced sleep duration, elevated stress hormone levels, and increased oxidative stress in the vasculature and brain, which in turn lead to vascular dysfunction, inflammation, and hypertension, thereby increasing cardiovascular risk [5–7]. Studies show that exposure to noise above 70 dB is associated with a 50% higher risk of hypertension

compared with exposure to levels of 60–65 dB, while a 5 dB increase in noise leads to a 0.5 mmHg increase in blood pressure. Occupational noise increases the risk of hypertension by 68% and the risk of other cardiovascular diseases by 34%, as well as increasing cardiovascular mortality by 12% [23]. In the study by Roscoe et al., conducted in a nationwide cohort of women in the United States, it was shown that each increase of 3.67 dB in nighttime noise L_{50} and 4.35 dB in daytime noise L_{50} was associated with a hazard ratio of 1.04 for cardiovascular disease events, including myocardial infarction and stroke [26]. In the study by Hahad et al. [27], a pooled analysis of human field studies demonstrated that acute exposure to simulated nighttime traffic noise is associated with significantly impaired endothelial function and increased mean arterial blood pressure. Chronic exposure to noise increases the risk of cardiometabolic diseases, including hypertension, coronary artery disease, type 2 diabetes, and stroke [7].

Sleep disturbances are among the most direct and widespread effects of exposure to anthropogenic noise. Studies indicate that noise levels of 50–60 dB are sufficient to disrupt sleep and cause fatigue upon waking [28]. In a study conducted near Dhaka Airport in Bangladesh [29], 35% of patients were exposed to sound levels of 55–60 dB (L_{Aeq} , 24 h), while 21% were exposed to levels of 60–65 dB. Road traffic noise exceeding 55 dB L_{Aeq} and aircraft noise in the range of 60–80 dB and above 80 dB were associated with increased severity of sleep disturbances. Urban populations exposed to environmental noise levels above approximately 55–65 dB L_{eq} showed a significantly higher risk of sleep disorders [30]. In an ecological study near a military base in Okinawa, Japan, sleep disturbances were most prevalent in the high aircraft noise exposure community (46.6%), followed by the low-exposure community (46.3%) and the non-exposed community (29.0%). Multivariate logistic regression using the Athens Insomnia Scale showed that high-exposure communities had 1.98 times higher odds, and low-exposure communities had 2.04 times higher odds of experiencing sleep disturbances compared with non-exposed communities [30]. Hahad et al. showed that acute exposure to simulated nighttime traffic noise significantly impaired subjectively assessed sleep quality, sleep restorative function, and morning well-being [27]. Sleep disturbances, including sleep fragmentation and reduced total sleep time, are associated with impaired cognitive function and worsening symptoms of attention-deficit/hyperactivity disorder in children, whereas adults in noisy environments report significantly greater difficulty falling asleep, more nocturnal awakenings, and poorer sleep quality [29].

Cognitive functions and work performance are particularly sensitive to anthropogenic noise exposure. The literature emphasizes that noise can significantly reduce task performance by impairing concentration, lowering efficiency, hindering speech comprehension, and degrading the perception of warning signals, thereby indirectly increasing accident risk. These effects include impairments in cognitive and memory processes, as well as difficulties sustaining attention, with particular relevance to precision tasks, conceptual work, and activities requiring verbal information processing [23,31]. Population studies indicate that with high occupational exposure, the consequences are clearly perceptible. Among traffic police officers exposed to noise levels of 85–106 dB, 93% reported loss of concentration and 55% reported reduced performance [32,33].

Mental health and stress responses represent another key domain of noise effects on humans. Noise can induce emotional irritation, psychological strain, and anxiety; in environmental terms, it may lead to a broad range of non-auditory effects, including disruptions to activity, sleep, and communication, which contribute to irritation and chronic stress [7,34]. Repetitive activation of the stress axis is important, as chronically elevated cortisol levels may contribute to visceral obesity and insulin resistance, thereby increasing cardiovascular risk [23]. Noise pollution has been identified as a risk factor for affective

disorders, with this relationship potentially partially mediated by circadian rhythm disruption. At the same time, noise annoyance and individual noise sensitivity have been shown to influence psychological well-being and health-related quality of life. In this context, it is also important to confirm the association between environmental exposure and the risk of psychopathology in vulnerable populations, including pregnant women and children [8]. Cohort data further indicate long-term life-course consequences, showing an association between early-life exposure to air pollution and noise and mental health outcomes from adolescence into early adulthood [35]. In a study of communities exposed to aircraft noise, a higher prevalence of poor mental well-being was observed in both high-exposure (38.2%) and low-exposure (36.1%) groups compared with non-exposed communities (21.9%), corresponding to odds ratios of 1.84 and 1.94 for poor mental well-being [30]. In occupational exposure settings, a broad profile of psychosocial consequences has been reported, including increased depression (58%), stress (65%), public conflicts (71%), irritation (54%), behavioral disturbances (59%), and speech interference (56%), as well as quantitative exposure–response relationships for selected outcomes [32]. Studies conducted in urban environments also indicate the presence of depressive symptoms, anxiety, and fatigue in noise-exposed populations [29].

WHO guidelines and regulatory frameworks are important reference points for assessing health risks associated with anthropogenic noise. Epidemiological studies in large European cities, including Poland, indicate that a substantial proportion of urban populations is exposed to noise levels exceeding 55 dB during the day and 50 dB at night. In Poland, permissible environmental noise levels vary by land use, ranging from 40 to 70 dB. At the EU level, nighttime exposure above 55 dB affects approximately 30% of the population. National guideline comparisons in the literature also cite recommended values for public spaces, such as 85 dB in Finland [23,36].

The literature indicates that anthropogenic noise should be treated as a significant environmental stressor with measurable health effects, justifying its consistent consideration in spatial planning, impact assessment, and management actions aimed at reducing both noise pollution and population exposure.

4. Sensitivity of Fauna to Anthropogenic Noise

Faunal sensitivity to anthropogenic noise varies taxonomically, with responses encompassing both behavioural and physiological effects. Research indicates that response thresholds for many species are substantially lower than regulatory limits designed for humans. Behavioural effects (e.g., habitat avoidance, changes in activity patterns) may occur at levels around 40 dB, and a substantial proportion of negative impacts have been observed below 50 dB [14,15]. For birds, particularly those dependent on vocal communication, effects have been reported at levels as low as approximately 38 dB [16]. This means that even moderate anthropogenic acoustic pressure can significantly disrupt animal functioning in forests, where the natural acoustic background is typically low. “Phantom road” experiments have demonstrated avoidance of high-noise areas and deterioration in the condition of individuals remaining in road-noise-exposed environments [37,38]. For raptors, it has been reported that cinereous vultures (*Aegypius monachus*) avoided nesting sites when L_{Aeq} exceeded 40 dB, resulting in a road influence zone extending up to approximately 500 m and a reduction in breeding habitat by about 11% [39]. Mechanisms of impact include, among others, masking of biologically relevant acoustic signals. In owls, a decrease in hunting efficiency has been demonstrated with increasing noise levels, interpreted as impaired prey localization based on sound [38]. In an experiment with black-capped chickadees (*Poecile atricapillus*), it was shown that the ability to recognize individuals based on song is significantly degraded at 40 dB of anthropogenic noise,

while at 75 dB, acoustic signal discrimination is substantially impaired, directly affecting intraspecific communication [40].

Measurements of noise from specific anthropogenic sources in forest ecosystems provide important reference data for environmental management. In mountainous protected areas of Italy, studies of road traffic noise found that traffic on high-speed highways produced noise levels of 60 to 71 dB in adjacent forest habitats, which correlated with a significant decline in bird species diversity [41]. In forest reserves in Nigeria with industrial activities, measured noise levels reached at least 40 dB even in areas distant from direct sources, indicating extensive penetration of anthropogenic noise into theoretically protected ecosystems [42]. Birds exhibit a broad spectrum of responses, depending on species characteristics and the nature of the sound source; a systematic review found that behavioural effects and disruptions to communication and acoustic perception (76.9% of observed effects) predominated over physiological changes (23.1%), with negative outcomes prevailing overall [43]. Analysis of avian responses to aircraft noise indicates that birds located approximately 300 m from a jet take-off site may be exposed to noise levels of around 100 dB, which promote stress responses, escape behaviour, and avoidance of such environments. Some species, such as the European serin (*Serinus serinus*), increase singing activity up to approximately 70 dB, after which a decline in vocal activity is observed, suggesting the existence of a threshold beyond which acoustic communication becomes ineffective [44]. In non-songbird species such as the little bustard (*Tetrax tetrax*), an increased rate of signal emission and reduced vocalisation duration were observed under higher noise levels, with no change in peak frequency, which may indicate behavioural constraints that reduce communication effectiveness [45]. Anthropogenic noise also alters the ability to assess and respond to predation risk: in free-living barn swallows (*Hirundo rustica*), exposure to traffic noise increased vigilance and reactivity, and males initiated escape responses at greater distances under noisy conditions than in quiet environments [46].

In large mammals (white-tailed deer, *Odocoileus virginianus*), strong avoidance of areas with noise levels exceeding 70 dB has been observed, with site occupancy in such areas decreasing by approximately 73%, indicating functional habitat loss over hundreds of meters [47]. In forest-dwelling primates, significant behavioral changes have been observed even along a noise gradient with minimal values of 44–52 dB, including reduced movement time, indicating modifications of activity patterns at relatively low exposure levels [48]. Responses to noise may depend on temporal scale: in mule deer (*Odocoileus hemionus*) and coyotes (*Canis latrans*), acute road noise increased the likelihood of escape responses, whereas chronic noise led to more complex changes, including increased vigilance in coyotes and increased foraging combined with reduced vigilance in mule deer in noisier conditions [49]. In plateau pikas (*Ochotona curzoniae*), chronic exposure to road traffic noise has been associated with both behavioral and physiological changes, including alterations in activity patterns and stress indicators [50]. Particularly important threshold data come from studies on mantled howler monkeys (*Alouatta palliata*): exposure to chainsaw noise at levels as low as 40 dB resulted in increased glucocorticoid metabolite levels and behavioral changes that intensified with increasing noise intensity, while field observations indicate parallel shifts in male activity patterns in natural environments [51].

Amphibians, which are highly dependent on acoustic communication during reproduction, show particular sensitivity to anthropogenic noise. In the European tree frog (*Hyla arborea*), chronic exposure to road traffic noise has been associated with disruptions in communication as well as physiological effects, including elevated corticosterone levels and immunosuppression; a reduction in the intensity of male vocal sac coloration has also been observed [52]. In urban environments, brown tree frogs (*Litoria ewingii*) compensated for acoustic interference by increasing vocalization frequency; however, modeling sug-

gests that this strategy produces only a small increase in communication range and may reduce male attractiveness to females that prefer lower frequencies. Analyses of the active acoustic space further indicate that larger amphibian species producing lower-frequency signals experience a proportionally greater reduction in communication distance in noisy environments, despite having lower auditory thresholds [53].

Although less frequently studied in the context of noise than vertebrates, insects also exhibit behavioural and physiological consequences. Experiments with the field cricket (*Gryllus bimaculatus*) have shown that anthropogenic noise disrupts all components of acoustic mating signals, while physiological analyses suggest energetic costs associated with modifying signals in response to noise, which may translate into reduced individual condition [54].

Controlled laboratory and field experiments in recent years have enabled the establishment of intervention thresholds for nature conservation. Playback studies under controlled conditions indicate that even short-term exposure to levels around 40 dB can induce measurable physiological and behavioral changes, while exposure to 75 dB leads to significant impairment of cognitive functions related to acoustic signal recognition [40]. Particularly important are findings on developmental and transgenerational effects: in zebra finches (*Taeniopygia guttata*), exposure to road traffic noise during prenatal and postnatal development cumulatively impaired chick growth and physiology and increased telomere shortening, with effects persisting into adulthood. Early-life exposure to noise, especially during the prenatal period, led to reduced lifetime reproductive output in adults across their entire reproductive lifespan and, in extreme cases, caused embryonic mortality [55]. In migratory songbirds, road traffic noise has been shown to reduce body condition and the efficiency of migratory stopover, which may translate into a lower probability of survival during long-distance migration [37].

Noise impacts extend beyond individual organisms, affecting the dynamics of entire acoustic communication networks within ecosystems. Studies based on large-scale acoustic monitoring networks have shown that noise events trigger an immediate increase in avian bioacoustic activity, followed by a gradual decline, with effects persisting for more than 3 h after the cessation of noise exposure; concurrently, the detectability of alarm and contact vocalizations in mammals increases [56]. Studies covering a wide range of terrestrial animal species indicate that anthropogenic noise systematically alters communication strategies in wild animals [42,43,57]. From the perspective of forests and national parks, this implies that thresholds established for humans cannot be treated as surrogate ecological safety limits.

5. Synthesis of Research on the Effects of Anthropogenic Noise on Humans and Fauna

The ranges of noise levels reported in the literature, including approximate threshold values associated with behavioral, physiological, and health-related changes, represent a synthesis of findings from field studies, experimental research, and review analyses. A summary of key studies on the impacts of anthropogenic noise, together with proposed implications for the development of regulatory standards, is presented in Table 1.

The compiled studies indicate that biologically relevant thresholds for fauna are often lower than existing regulatory limits, confirming a discrepancy between ecological sensitivity and legal standards primarily designed to protect human health. As exposure increases, physiological effects emerge, including stress responses, hormonal changes, and disruptions in organismal functioning. In human populations exposed to levels typical of urban environments, particularly above 50 dB, effects such as sleep disturbances and an increased risk of cardiovascular diseases are observed. This gradient of effects indicates increasing complexity of underlying mechanisms with rising noise intensity.

Table 1. Overview of selected studies on the impacts of anthropogenic noise.

Study Subject	Type of Study	Noise Level (dB)	Main Effects	Conclusions	Proposed Implications for Legal Standards	Refs.
People	Literature review, epidemiological studies, and mechanistic studies	No single threshold identified; particular importance of nighttime and traffic noise exposure	Activation of the stress response, oxidative stress, endothelial dysfunction, and increased risk of cardiovascular diseases	Traffic noise should be regarded as a significant environmental health risk factor	Permissible limits should be more closely aligned with WHO health guidelines, particularly for nighttime noise	[5–7]
People	Cohort study	45–55 dB	Increased cardiovascular mortality; associations observed for daytime L ₅₀ , nighttime L ₅₀ , and L _{dn}	Health effects may occur already at moderate noise levels	There is a need to reassess permissible exposure limits, particularly with regard to long-term population exposure	[25]
Humans, residents of urban areas and populations living in the vicinity of an airport	Field study	55–65 dB L _{Aeq,24h} ; for aircraft noise also 60–80 dB and >80 dB	Sleep disturbances, fatigue, depressive and anxiety symptoms, and reduced well-being	Typical urban noise levels may cause significant health effects	Regulations should more strongly account for sleep quality and non-auditory effects, rather than focusing solely on hearing damage risk	[29]
People	Experimental studies/exposure to simulated nighttime traffic noise	No exact value expressed in dB reported	Impaired endothelial function, increased mean arterial blood pressure, reduced sleep quality, and poorer morning well-being	Nighttime noise is particularly harmful due to its disruption of physiological recovery processes	Nighttime noise standards should be more stringent, and impact assessments should incorporate physiological effects	[27]
Humans with occupational exposure, specifically traffic workers exposed to road traffic noise	Field study	85–106 dB	Loss of concentration, reduced performance, stress, irritation, speech interference, and psychosocial effects	High occupational exposure leads to pronounced cognitive and psychological effects	There is a need to strengthen control of occupational exposure, improve personal protective measures, and implement work organization strategies that reduce exposure time	[32]
Fauna, various animal groups	Literature review	Approximately 40–50 dB	Behavioral changes, habitat avoidance, and changes in activity patterns	Faunal response thresholds are often lower than those applied in human standards	For protected areas, human-health-based standards should not be applied automatically	[14]
Fauna, various animal groups	Literature review	Some negative effects observed below 50 dB	Communication disruption, signal masking, and changes in behavior and ecosystem functioning	Noise affects organisms and ecological processes even at relatively low levels	There is a need to define separate “safe noise levels” for ecosystems and natural habitats	[15]

Table 1. Cont.

Study Subject	Type of Study	Noise Level (dB)	Main Effects	Conclusions	Proposed Implications for Legal Standards	Refs.
Birds dependent on vocal communication	Empirical study	Approximately 38 dB	Disruption of acoustic communication and responses occurring at very low exposure levels	Birds may respond to noise at levels below 40 dB	In protected areas, consideration should be given to protective thresholds below 40 dB for habitats of acoustically sensitive species	[16]
Birds/species dependent on acoustic cues	Field experiment (phantom road type) and studies on masking mechanisms	No exact value expressed in dB reported	Avoidance of noisy areas, degraded habitat quality, and reduced effectiveness of acoustic signal use	Road traffic noise can reduce the functional quality of habitats even in the absence of a physical road	Environmental impact assessments of road projects should include the spatial extent of noise pollution, not only land take	[38]
Birds	Field study	No exact value expressed in dB reported	Avoidance of noisy areas and deterioration in the condition of individuals remaining in noise-exposed environments	Noise can impose energetic costs and reduce the effective use of habitats	Standards for natural areas should protect the functioning of animal populations, not only limit human annoyance	[37]
Cinereous vulture (<i>Aegypius monachus</i>)	Field study	>40 dB L _{Aeq}	Avoidance of nesting sites; road influence zone extending to approximately 500 m; reduction in breeding habitat by approximately 11%	Road traffic noise can significantly reduce the availability of breeding habitats for birds of prey	Acoustic buffer zones for breeding habitats should be established around roads passing through protected areas	[39]
Black-capped chickadees (<i>Poecile atricapillus</i>)	Experiment	40–75 dB	Impaired recognition of individuals based on song; significant reduction in signal discrimination at 75 dB	Noise disrupts intraspecific communication even at moderate levels	Stricter protection thresholds and seasonal restrictions during breeding periods should be implemented in areas inhabited by acoustically communicating species	[40]
Birds in mountainous protected areas	Field study	60–71 dB	Decrease in bird species diversity in forest habitats adjacent to a highway	Traffic noise can reduce the quality of bird habitats in protected areas	Road planning near protected areas should incorporate acoustic impact zones and mitigation measures	[41]
Fauna and forest habitats in reserves; areas under industrial pressure	Field study	At least approximately 40 dB, also beyond the immediate vicinity of sources	Intrusion of anthropogenic noise into forest ecosystems and the associated risk of pressure on fauna	Noise can propagate into the interior of areas that are ostensibly protected	Noise monitoring should be a standard component of the management of nature reserves, national parks, and forest complexes	[42]

Table 1. Cont.

Study Subject	Type of Study	Noise Level (dB)	Main Effects	Conclusions	Proposed Implications for Legal Standards	Refs.
Birds	Systematic literature review	Different exposure levels, dependent on the noise source	Predominance of behavioral effects and disruptions in communication and acoustic perception over physiological effects; overall dominance of negative outcomes	Birds are among the groups particularly sensitive to anthropogenic acoustic disturbances	Protective standards should recognize behavioral responses as a legitimate ecological effect, not only physiological damage	[43]
White-tailed deer (<i>Odocoileus virginianus</i>)	Field study	>70 dB	Strong avoidance of noisy areas; approximately 73% reduction in site occupancy in such areas	Noise leads to functional habitat loss in large mammals	Buffer zones should be established around noise sources for large mammals, and exposure should be limited in key migration corridors	[47]
Forest primates	Field study	44–52 dB	Behavioral changes, including reduced movement time	Behavioral responses may occur at relatively low noise levels	Standards for forest habitats should account for lower response thresholds of primates and other disturbance-sensitive mammals	[48]
Mantled howlers (<i>Alouatta palliata</i>)	Experiment with chainsaw noise	Approximately 40 dB	Increased glucocorticoid metabolite levels and behavioral changes that intensify with increasing noise levels	Physiological effects may occur even at low exposure levels	Forestry operations and the use of loud equipment in protected areas should be subject to temporal and seasonal restrictions	[51]
European tree frog (<i>Hyla arborea</i>)	Field study/exposure to road traffic noise	No exact value expressed in dB reported	Communication disruption, increased corticosterone levels, immunosuppression, and weakening of male signal traits	Amphibians are particularly sensitive to noise due to the importance of acoustic communication in reproduction	Lower noise thresholds and seasonal restrictions on traffic and noisy activities should be applied near amphibian breeding sites	[52]
Amphibians, including tree frogs (<i>Litoria ewingii</i>)	Modeling and analysis of acoustic communication	Variable values, dependent on experimental exposure conditions	Reduced communication range, compensatory increase in vocalization frequency, and potential reduction in signal attractiveness	Noise reduces the effectiveness of reproductive communication, particularly in species relying on low-frequency signals	Standards should consider not only sound level but also noise spectrum and the potential for masking biological signals	[53]

Table 1. Cont.

Study Subject	Type of Study	Noise Level (dB)	Main Effects	Conclusions	Proposed Implications for Legal Standards	Refs.
European field cricket (<i>Gryllus bimaculatus</i>)	Experiment	Variable values, dependent on experimental exposure conditions	Disruption of mating signals and energetic costs of signal modification	Noise also affects invertebrates, although they are less frequently considered in regulatory frameworks	Environmental noise impact assessments should also include insects and other invertebrate groups dependent on acoustic communication	[54]
Sunda zebra finch (<i>Taeniopygia guttata</i>)	Exposure to road traffic noise. Developmental experiment/prenatal and postnatal study	No exact value expressed in dB reported	Telomere shortening, impaired growth and physiology of chicks, reduced adult reproductive success, and in extreme cases embryonic mortality	Noise can cause developmental, long-term, and transgenerational effects	Standards should account not only for immediate responses but also for developmental and reproductive effects	[55]
Bioacoustic communication networks of birds and mammals	Bioacoustic monitoring; noise events	No exact value expressed in dB reported	Immediate increase in avian bioacoustic activity followed by a gradual decline; effects persisting for more than 3 h; increased detectability of alarm and contact vocalizations in mammals	Noise acts not only on individual organisms but also on the dynamics of acoustic communication at the ecosystem level	Bioacoustic monitoring should be used as a tool for assessing noise impacts in national parks and nature reserves	[56]

The synthetic review of the literature enabled the identification of approximate ranges of anthropogenic noise levels at which key biological and health effects have been reported. These values should be interpreted as generalized ranges derived from the analyzed studies, rather than as single, definitive experimental thresholds. A comparison of ranges corresponding to faunal and human responses, WHO health guidelines, and current regulatory standards in the EU and Poland is presented in Figure 1.

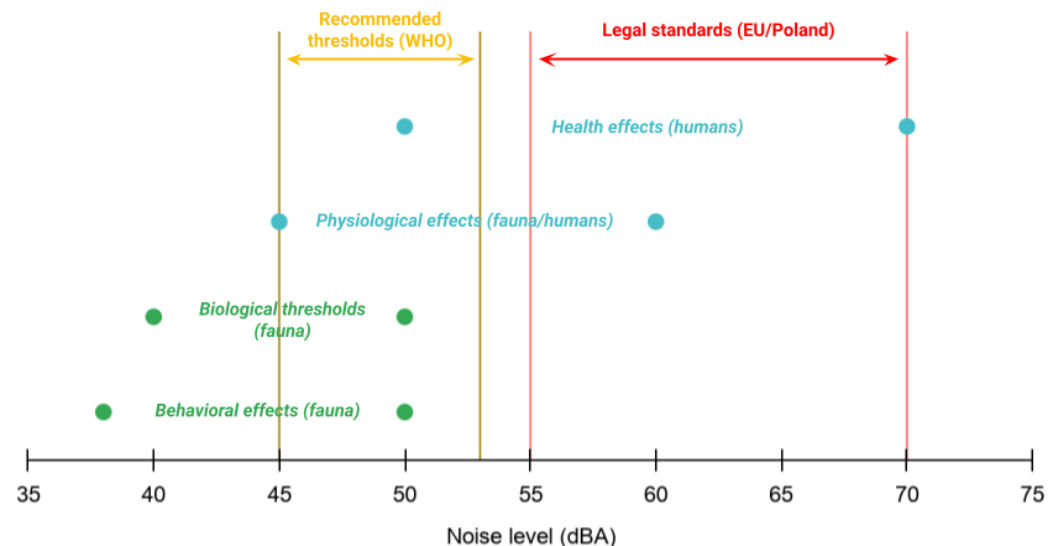


Figure 1. Ranges of anthropogenic noise levels corresponding to biological and health effects, and reference values from WHO and EU/Polish standards (based on Table 1, Polish and European regulations, and WHO guidelines).

Behavioral and physiological effects in fauna have been reported at relatively low exposure levels, with some studies indicating responses within the approximate range of 38–50 dB, whereas WHO recommendations for human health protection fall roughly within the 45–53 dB range. Meanwhile, current regulatory limits in the EU and Poland allow levels of around 55–70 dB. This means that existing legal standards are substantially higher than thresholds considered biologically relevant in the literature. In practice, this may lead to situations in which areas that comply with formal legal requirements are still exposed to noise capable of inducing behavioral or physiological responses in living organisms. This discrepancy indicates a structural gap in environmental protection systems, as compliance with existing standards does not necessarily imply ecological safety.

A complementary element of the range-based synthesis is a conceptual threshold model illustrating the approximate escalation and possible overlap of effects with rising noise levels (Figure 2). The model should not be interpreted as a strictly linear sequence, because behavioral, physiological, and health-related responses may overlap depending on species, habitat type, exposure duration, and noise characteristics. At lower exposure levels, reported effects often include behavioral changes in fauna, which may occur already at levels around 40 dB. As exposure increases, a transition to physiological effects is observed, including stress responses and functional changes in organisms, which are reported in the literature at approximately 50 dB. At higher levels, around 60 dB, health-related effects in humans become increasingly significant, while levels exceeding 70 dB may be associated with strong stress responses, habitat avoidance, and loss of functional habitat suitability for some species.

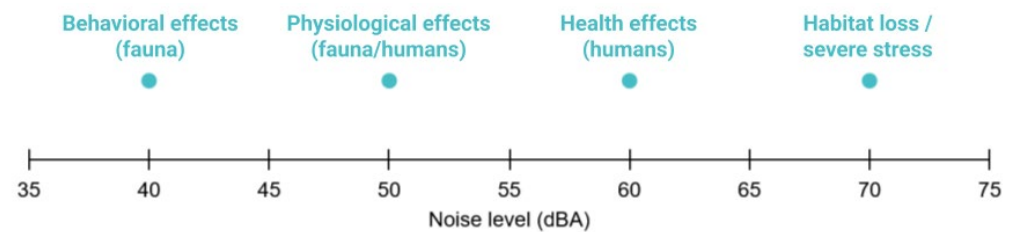


Figure 2. Conceptual model of threshold escalation of anthropogenic noise effects (based on Table 1).

Such an approach indicates that noise impacts should be understood as a cumulative mechanism in which successive types of effects emerge with increasing acoustic exposure. It is particularly important that biological responses in fauna may occur at levels lower than those assumed in environmental regulations. This implies that the current regulatory framework, primarily focused on human health protection and permissible noise levels in urban environments, may be insufficient to assess risks in ecologically valuable ecosystems, including forested and protected areas.

The values of 40 dB at night and 50 dB during the day proposed later in this paper are not based on original measurements, noise-propagation modeling, or a formal meta-analysis. They constitute a precautionary synthesis of dispersed findings in which faunal responses, especially those of species dependent on acoustic communication, were often reported within a range of approximately 38–50 dB. Their role should be interpreted as a starting point for adaptive management and monitoring planning, rather than as a universal boundary of ecological safety. Due to the diversity of the analyzed species, habitats, noise indicators, and research methods, they require further empirical validation in different ecological and geographical contexts.

6. Legal Gaps Regarding Noise in the Context of EU and Polish Regulations

The European Union's policy aims to achieve a high level of protection of human health and the environment, including protection against noise. The European legal framework for environmental noise protection is primarily based on Directive 2002/49/EC of the European Parliament and of the Council of 25 June 2002 [58] relating to the assessment and management of environmental noise. It establishes a common approach to preventing, avoiding, and reducing the harmful effects of noise exposure, as well as mitigating noise from various sources, including transport noise. Environmental noise measurements provide important information about environmental conditions and are useful for developing strategic noise maps within environmental protection plans [59]. The results of noise monitoring indicate the direction for implementing corrective measures. The Directive establishes a framework for the assessment and management of environmental noise and recommends the use of L_{den} and L_{night} indicators and methods (including CNOSSOS-EU), but it does not itself set specific thresholds for national parks and forests. The Directive requires the identification of “quiet areas” in agglomerations and open countryside; however, it lacks precise selection criteria, binding legal definitions, and legal consequences for their protection, which limits the effectiveness of conservation measures [60,61]. Consequently, Member States apply differentiated permissible values, but the reference point remains anthropocentric.

The fundamental problem with contemporary noise regulations, both at the EU level and in Poland, is the absence of standards for nature-protected areas and forest environments, understood not as “human recreational spaces” but as habitats and ecosystems with their own acoustic requirements. In practice, the legal system relies on indicators and thresholds derived from a human-centred logic (comfort, annoyance, health risk), which are

then applied to general land-use categories. This results in a situation where formal legal compliance does not necessarily align with biodiversity protection or with the maintenance of conditions conducive to the functioning of animal populations [15,17].

The anthropocentric nature of current regulations is evident in several dimensions. First, definitions of key concepts such as “noise,” “acoustic pollution,” and “permissible levels” are consistently formulated with reference to humans as the primary receptor of exposure [62]. The assessment of the acoustic climate focuses on indicators that reflect human population exposure rather than the sensitivity of ecosystems or animal species. Secondly, emission and immission standards defined in national regulations refer to residential, recreational, and built-up areas, while overlooking the specific characteristics of ecologically valuable natural areas [62,63].

In Poland, permissible environmental noise levels are differentiated by land-use type and source groups and apply to areas associated with residential, health, or recreational functions for humans, without a separate category for nature-protected areas, understood as habitats of wild fauna. Executive regulations specify the use of indicators such as L_{Aeq} , while the system of limit values remains derived from functional land classification [64]. In practice, this means that even areas of high natural value, if they do not formally constitute a separate regulatory category, may be assessed using thresholds designed for humans rather than for the ecological requirements of habitats.

Additionally, WHO environmental noise guidelines for human populations (e.g., 53 dB L_{den} and 45 dB L_{night} for road traffic noise, and 54 dB L_{den} and 44 dB L_{night} for railway noise) are markedly lower than the permissible values adopted in many legal systems, revealing a structural discrepancy even within the strictly health-related domain [2]. If such divergence exists at this level, the lack of a separate and more stringent regulatory pathway for noise levels in forests and nature-protected areas becomes even more evident, particularly in light of studies indicating that biologically relevant effects in many taxa occur below 50 dB [14–16].

A particularly important legal gap is the lack of operational definitions of acoustic thresholds for forest fauna and other wild animal species. The law does not define what sound levels are appropriate for forest wildlife, which noise parameters are critical (e.g., intermittency, spectral composition, masking of biophony), nor how exceedances should be interpreted in terms of ecological risk [15,17,18]. In practice, environmental impact assessments (EIAs) and planning documentation are often limited to verifying compliance with permissible human exposure levels, rather than assessing acoustic impacts on environmental components [17,65]. It is precisely the absence of standards and criteria for nature-protected and forest areas that creates a gap, preventing effective enforcement of acoustic protection of the natural environment.

Implementation problems with Directive 2002/49/EC in the context of protected areas have been documented in the European literature. An analysis of its implementation in the Czech Republic found that, despite the formal obligation to designate quiet areas in open country, national legislation lacks specific legal instruments for their establishment and protection. Moreover, noise assessment remains focused on human health, tranquility, and quality of life, without clearly defined environmental objectives or documented consideration of impacts on wildlife [61]. Similar conclusions emerge from Greek studies, which show that existing regulations adopt a quantitative approach by setting maximum permissible noise levels for individual sources but do not encompass a broader concept of the acoustic environment, resulting in a fragmented regulatory framework [66]. Research on the implementation of the “quiet areas” concept in the European Union highlights the absence of universally applicable selection criteria, as well as open questions regarding their legal binding force and the consequences of designating such areas [60]. Analysis of

implementation in Central and Eastern European countries reveals additional challenges, including partial transposition of regulations and deficiencies in monitoring and acoustic zoning [67].

In Poland, the Environmental Protection Law and its executive regulations define permissible noise levels for different land-use categories; however, they do not include specific provisions for ecologically valuable areas. National parks and nature reserves are subject to general immission standards that do not account for the ecological specificity of these areas or the sensitivity of resident species. There is also a lack of systematic acoustic monitoring in protected areas, which prevents the assessment of the actual acoustic environment and its temporal changes. Furthermore, Polish regulations do not define the concept of a natural soundscape nor establish qualitative objectives for the acoustic landscape in areas of high natural value [62,65,68]. Studies on industrial noise in Poland confirm that measurements and statistical analyses focus exclusively on human exposure, without accounting for impacts on forest ecosystems or wildlife [63].

From an institutional perspective, the approach to noise in ecologically valuable areas in Poland remains largely marginalized: noise is often treated as a technical issue or reduced to compliance with anthropocentric standards, without a consistent link to nature conservation objectives, continuous monitoring, or operational criteria for assessing impacts on fauna and habitats [17,65]. This state of affairs encourages regulatory avoidance: since there are no dedicated thresholds for national parks and forests, noise is not a central element of conservation management, even when scientific evidence indicates biologically significant effects at levels below those used in human health protection standards [14,15]. It is also worth noting that the European approach to noise assessment, based on the CNOSSOS-EU methodology, focuses on strategic noise mapping in accordance with the requirements of Directive 2002/49/EC, without accounting for the specificity of ecologically valuable areas and their ecological requirements [69].

In summary, the European and Polish legal systems governing environmental noise are characterized by pronounced anthropocentrism, a lack of operational definitions of acoustic thresholds for fauna, and regulatory gaps concerning protected areas. Despite progress in noise mapping and the planning of mitigation measures in urban agglomerations, the protection of the acoustic climate and soundscape in areas of high natural value remains marginalized, while the ecological needs of wildlife are not reflected in current legal standards.

7. Other Legal Systems Addressing Noise

A different approach can be observed in some jurisdictions, particularly in the United States, where national parks have developed a framework that treats the soundscape as a natural resource requiring active protection, supported by systematic measurements, mapping, and management guidelines aimed at reducing noise pollution at the scale of protected areas [70,71]. Consequently, where noise management policy is more mature and better integrated into natural resource conservation practice, monitoring results are more readily translated into mitigation measures, whereas in Poland, the issue more often remains at the level of fragmented provisions and inconsistent implementation [17,18].

The American model of soundscape protection in protected areas exemplifies a well-developed, restrictive, ecologically oriented approach to noise regulation. Its legal foundation lies in the Wilderness Act of 1964 [72] and the National Park Service Director's Order #47 of 2000 [73], which established an operational policy requiring the protection, maintenance, or restoration of the natural soundscape resource in an unimpaired condition, free from inappropriate or excessive noise, to the greatest extent possible [71]. A key aspect of the American approach is treating the soundscape as the acoustic environment of a given

area, which influences perceived environmental quality, particularly in protected areas such as national parks [74]. The NPS Natural Sounds and Night Skies programme exemplifies a proactive management strategy that encompasses acoustic monitoring, identification of pressure sources, and mitigation measures, linking soundscape protection not only to visitor experience but also to ecological integrity and wildlife welfare [75].

Studies on soundscape protection in U.S. national parks highlight the complexity of legal and institutional challenges, including debates over whether anthropogenic noise originating from outside designated areas constitutes an impact that warrants assessment and regulation [71]. Analyses of regulations and management practices indicate the use of legal instruments and policies for regulating noise in protected areas, as well as gaps in current legal frameworks [76]. The literature also highlights the institutional role in noise regulation and the importance of a comparative perspective for managing wildlife-centred soundscapes [77].

The development of restrictive approaches to soundscape protection is not limited to the United States. Studies on environmental noise assessment and acoustic climate in protected areas in Spain indicate that, although the concept of “natural sound reserves” has emerged, there is a lack of clear sound-level thresholds and binding quality objectives for natural environments, limiting the effectiveness of protection. An example of legal evolution is the development of underwater noise regulations in Spain and Norway, where there has been a transition from sectoral mechanisms to a more holistic, ecosystem-based approach. [78].

The issue of underwater noise is of considerable environmental importance; however, because of differences in underwater sound propagation, distinct groups of organisms, and specific regulatory frameworks, it requires a separate, in-depth analysis. For this reason, in the present study, underwater noise was treated only as an example of the broader problem of environmental noise pollution, while a detailed synthesis of research in this area should be the subject of a separate study.

Within the EU, it is also worth noting more practical examples of quiet area management. In Sweden, some municipalities include quiet areas in comprehensive plans and planning documents, although the level of advancement of procedures and criteria varies [79]. In Ireland, work by the Environmental Protection Agency focused on establishing baseline data for quiet areas in agglomerations and open areas, demonstrating the possibility of linking the Environmental Noise Directive with planning practice and monitoring [80]. The EEA, in turn, indicates that potentially quiet areas may benefit both humans and wildlife populations, but their protection requires clear criteria for identification, monitoring, and maintenance of acoustic quality [81].

Similar, although less legally formalized, approaches to soundscape protection in protected areas are also developing in South America. In Brazil, passive acoustic monitoring (PAM) is used to manage protected areas. Studies in Serra do Cipó National Park showed that anthropogenic sounds accounted for only 1% of recordings within the park, but as much as 63% in surrounding agricultural lands, supporting the use of monitoring as an early-warning instrument [82]. In Chile, efforts to protect soundscapes are embedded in the National System of Protected Wild Areas (SNASPE), and studies in Queulat National Park have shown that visitors identify anthropogenic sounds as problematic and advocate implementing protection policies and continuous monitoring [83]. In Argentina, acoustic values have been incorporated into management plans for protected areas in the Andean Yungas forests as part of natural heritage, although there is a lack of binding legal instruments that regulate permissible noise levels [84].

In Australia, soundscape protection in protected areas faces a specific institutional challenge: each state and territory has its own legislation governing national parks, leading

to fragmentation of the noise management system and limiting park managers' ability to regulate noise sources originating outside their boundaries [85]. Studies in Australian marine protected areas, including the Great Barrier Reef Marine Park, have shown that vessel noise is regularly recorded; however, biological components of the soundscape (dolphins, fish, and migratory whales) still dominate long-term acoustic patterns, providing a basis for monitoring-based management approaches [86].

A notable example of a state-level soundscape conservation policy is Japan, where, in 1997, the Environmental Protection Agency completed the "100 Soundscapes of Japan" program (Nihon no Oto Fūkei Hyakusen), which identified and documented sites of exceptional acoustic value as part of the natural and cultural heritage [87]. The legal basis for environmental acoustic protection in Japan is provided by the Basic Environment Law and the Noise Regulation Law, which establish environmental quality standards and mechanisms for controlling noise sources [88]. In Japan, national park management is based on a zoning system and regulation of activities, which can be used to control noise sources within protected areas, although park management plans do not uniformly require explicitly formulated objectives for protecting the acoustic resource.

A comparison of global models with the European approach reveals differences in soundscape protection strategies. While European regulations primarily focus on protecting human health in urban environments, other systems, particularly the American one, treat the natural soundscape as a natural resource requiring active protection on par with other ecosystem values. As a result, solutions developed by the NPS in the United States demonstrate the feasibility of a more restrictive and ecologically oriented approach to soundscape protection, based on monitoring, mapping, management guidelines, and mitigation measures [71]. Implementing solutions from the United States in Europe does not require treaty changes or a fundamental restructuring of the legal system. The most realistic approach is to integrate the American model with existing European instruments. It would be possible to supplement noise maps with audibility maps, recognize the soundscape as an object of protection in national park protection plans, introduce acoustic objectives into Natura 2000 documents, and monitor the quality of the acoustic climate in a manner similar to the monitoring of habitats or species.

8. Conclusions

The literature review confirms that anthropogenic noise should be regarded as a full-fledged form of environmental pollution, with effects on both human health and ecosystem functioning. The adverse impacts of noise on human health are increasingly recognized, and the evidence demonstrates well-documented associations between noise exposure and cardiovascular risk, sleep disturbances, impaired cognitive function, and reduced psychological well-being. Mechanistically, chronic stress responses and sleep fragmentation play a key role, triggering a cascade of adverse metabolic and vascular changes. In practice, this means that even relatively low levels commonly encountered in urban environments may generate measurable population-level consequences, and health protection criteria should be interpreted with caution, particularly in areas where high environmental quality is expected.

Negative impacts of noise on animals are also widely observed. In many field studies and controlled experiments, behavioural and physiological responses occur at levels below thresholds established for humans. Species that depend on acoustic communication are particularly sensitive, with some effects already reported at around 40–50 dB. Importantly, the literature also indicates developmental and potentially long-term consequences (including reduced reproductive success), shifting risk assessment from short-term responses to persistent changes in population condition and habitat quality. In forests and other

protected areas, where the natural acoustic background is typically low, even moderate anthropogenic noise pressure may lead to tangible habitat degradation.

The analysis of legal and institutional aspects shows that the fundamental barrier to nature protection is the anthropocentric character of regulations. EU frameworks and Polish legislation primarily support the assessment and management of noise in the context of human exposure, but do not provide operational thresholds for forest ecosystems and protected areas. In practice, the concept of “quiet areas” is difficult to enforce due to the lack of clear criteria and legal instruments. As a result, environmental impact assessments (EIAs) and planning documents are dominated by the verification of compliance with human-derived thresholds, even though this is not equivalent to biodiversity protection. A comparison with approaches implemented, among others, in U.S. national parks indicates that an alternative framework is possible: treating the soundscape as a natural resource and basing management on monitoring and quality objectives linked to ecological values.

The findings indicate the need to consider separate, biologically justified reference values for noise. Based on the literature review, which repeatedly reports ecologically relevant effects around 40 dB, it is proposed to adopt indicative protective thresholds of 50 dB during the daytime and 40 dB at night. These values should be understood as a starting point for further validation and adaptive management to safeguard key ecosystem functions, including communication, foraging, reproduction, and stress avoidance, rather than as a compromise based on human comfort. At the same time, achieving them typically translates into a high-quality visitor experience and well-being, which constitute an important added value, though they are not ends in themselves. Their implementation would provide a basis for consistent noise management in national parks, nature reserves, and forest complexes, including acoustic zoning, temporal restrictions on noise sources, and improved infrastructure planning in the vicinity of protected areas.

The current noise regulatory system, designed primarily for human protection, is insufficient for nature conservation. The introduction of pilot, lower reference values for protected areas, supported by monitoring and management tools, represents a precautionary step, proportionate to the current state of knowledge, towards real protection against noise as a component of environmental quality and a condition for maintaining biodiversity, as well as an element of sustainable environmental management in areas of high natural value.

It should be noted that this review is integrative and problem-oriented in nature, rather than exclusively systematic in a narrow quantitative sense. Its aim was not only to summarize research findings on the effects of noise but also to compare them with existing regulatory frameworks and protected area management practices. This approach enables the identification of discrepancies between biological knowledge and how noise is currently addressed in environmental standards, while also requiring interpretative caution. Conclusions about protective thresholds should be treated as management hypotheses requiring further validation, rather than as normative values derived from a meta-analysis.

A limitation of the present review is the heterogeneity of the studies analyzed, which vary in acoustic indicators, measurement methods, habitat types, noise sources, and taxonomic groups. For this reason, the recommendations should be treated as a proposed direction for further action. Future research should prioritize quantitative reviews and meta-analyses, long-term bioacoustic monitoring programs, experimental validation of thresholds across different ecoregions, and assessment of the effectiveness of specific mitigation measures in national parks, reserves, and areas of high natural value.

Author Contributions: Conceptualization, J.W. and J.S.-B.; methodology, J.W.; software, J.W.; validation, J.W. and G.Z.; investigation, J.W. and J.S.-B.; resources, J.W.; data curation, J.W.; writing—original draft preparation, J.W. and J.S.-B.; writing—review and editing, J.S.-B. and G.Z.; visualization, J.W.;

supervision, G.Z.; project administration, J.W.; funding acquisition, J.W. and J.S.-B. and G.Z. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by the University of Life Sciences in Lublin, Poland (project number: SD.WTA.25.139).

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: The original contributions presented in this study are included in the article. Further inquiries can be directed to the corresponding author.

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

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