

# Essential Issues Related to Construction Phases of Road Networks in Protected Areas: A Review

Dursun Şakar, Abdurrahim Aydin, Abdullah Emin Akay

## Abstract

*Protected areas play an active role in protecting natural resources and wildlife habitat. These areas must be accessible within protection-use balance. For this reason, road networks in protected areas are one of the main functions of sustainable infrastructure services. The construction phases of road networks in these sensitive areas should be considered in planning within the balance of protection-use with interdisciplinary studies. Especially during the construction of the road network, it is necessary to pay attention to the construction machinery used, geotextile materials, hydraulic and ecological road structures, plantation of the slopes, fences that increase the visual quality and work schedule. Based on a related literature survey, the issues to be considered during the construction phases of road networks (i.e. road planning, tree felling and removing, excavation and embankment, subgrade finishing, road structures and surfacing) in protected areas were evaluated under nine headings. The implementation phases of these issues are important in reducing the adverse effects that will occur in protected areas. In this regard, during the construction phases of road networks, the issues to be considered were evaluated together with the conceptual indicators in terms of management, technique, economy, ecology, and aesthetics. Matters needing attention according to the sensitivity of conceptual indicators during the construction phases of road networks in and around protected areas that contain sensitive ecosystems have been identified and presented in a framework to further the discussions on this issue. Accordingly, the use of the issues to be considered in the planning and construction of road networks with conceptual indicators will help evaluate the planning phase before and after construction. In particular, it can be expected to lead to the creation of a checklist after the planning phase. Thus, the continuity of the issues to be considered during the maintenance, repair, and construction phases of the new road networks or existing road networks planned to be built in a protected area and surrounding areas will provide significant contributions to the functions of the protected areas. The main contributions may include increasing the number of visitors to the protected areas, reducing impacts on wildlife in protected areas by implementing innovative technologies, and developing alternative modes in tourism industry.*

*Keywords: protected areas, road networks, construction phases, conceptual indicators*

## 1. Introduction

Rapid urbanization, population growth, and increased environmental impacts as a result of the effects of climate change and socio-economic activities, force practitioners to develop new solutions in the development and management of sustainable transport infrastructure (Umer et al. 2016). It is important to consider environmental impacts, costs, and socio-economic factors in the design of sustainable road network infra-

structure, securing the balance between them (Sarsam 2015). However, today, solutions to minimize ecological costs by maximizing socio-economic benefits in the development of environmentally sustainable road networks are unlikely due to human demand for nature (Riggs et al. 2020). This is why innovative approaches have been developed to reduce people's demand for nature. These innovative approaches will constitute an important part of the good planning of the optimum

technical implementation of sustainable road network projects, which includes location selection, engineering, construction, maintenance, and alternative materials (Ledec and Posas 2003, Mayer et al. 2012).

Transport infrastructures, with a wide range of impacts on ecological processes, can have both positive and negative impacts on biodiversity (Karlson and Mörtberg 2015). For example, in the construction and use of road construction, it is easier to increase and maintain access to natural resources in terms of biodiversity. At the same time, long-term positive benefits can be seen, such as an increase in economic revenues due to the rise in the number of visitors due to the formation of landscapes caused by land change (Findlay and Bourdages 2000). Protected areas are one of the essential tools available for biodiversity conservation (Possingham et al. 2006). The protected areas are defined as sensitive sites that are dedicated and managed to achieve the long-term conservation of nature with associated ecosystem services and cultural values (Borrini-Feyerabend 2013). According to the International Union for Conservation of Nature and Natural Resources (IUCN) Protected Area Categories System, the protected areas are classified into six categories (i.e. nature reserve and wilderness areas, national parks, natural monument or feature, habitat/species management area, protected landscape/seascape, protected area with sustainable use of natural resources) according to their management objectives (Dudley et al. 2013).

The protected areas play an important role in prevention of deforestation, while minimizing the impacts of logging operations, hunting, forest fires, and grazing (Bruner et al. 2001). On the other hand, the impact of building road networks in protected areas is becoming increasingly alarming. In particular, road construction and use produce various direct or indirect impacts on ecosystem such as habitat loss and fragmentation, wildlife mortality, exhaust emissions, and noise pollution (Arévalo and Blau 2017, Hoffmann et al. 2019). For instance, according to Makki et al. (2013), the construction phases and development of roads in protected areas and ecologically sensitive areas have detrimental effects on wildlife populations. In addition, development and improvement of roads can facilitate access to poachers and uncontrolled tourism, which have a variety of detrimental effects on protected areas.

The United Nations World Tourism Organization reports that international tourist circulation (overnight visitors) has reached 1.5 billion in 2019 (URL1). Protected areas constitute a large part of the global tourism industry. For this reason, the demand for basic infrastructure, employment, service, and protection requirements is increasing due to the large number of

visitors coming to protected areas (Leung et al. 2018). The most important of these, road networks, are essential for increasing the access and satisfaction of visitors. In particular, road networks in protected areas have crucial impacts not only on the access of incoming visitors but also on the protection and control of the protected areas and their environment (Eagles et al. 2010). Therefore, before and after road network construction works in these areas, eco-friendly sustainable approaches should be adopted, both economically and technologically (Tarimo et al. 2017).

In light of this information, the use of road networks to provide transport and protection in and around protected areas is inevitable. Some potential impacts may emerge during the construction, maintenance, and repair phases of road networks in sensitive areas. This article aims to explain the considerations for reducing potential impacts on protected areas. Practices related to these issues are presented within the conceptual framework. In addition, practices related to the issues to be considered during the construction phases (i.e. road planning, tree felling and removing, excavation and embankment, subgrade finishing, road structures and surfacing) of road networks in protected areas have been evaluated through a wide-ranging literature review.

## 2. Issues to Consider During Construction Phases of Road Networks

Within the scope of the study, considerations for reducing potential impacts during the construction phases of protected areas and surrounding road networks have been collected under 9 (nine) headings:

- ⇒ Determination of work machines used during the construction phases of road networks in an ecological manner
- ⇒ Necessity of geotextile materials used in road networks construction
- ⇒ Importance of hydraulic structures in protected areas
- ⇒ Planting slopes for visual and ecological purposes during road construction in addition to erosion prevention purpose
- ⇒ Impacts of habitat fragmentation during road construction in protected areas
- ⇒ Importance of ecological road structures in protected areas
- ⇒ Fence applications that increase visual quality of road construction in protected areas
- ⇒ Effects of noise pollution during road construction in protected areas
- ⇒ Determination of work schedule of road construction phases in protected areas.

**Table 1** Conceptual indicators of issues to be considered during construction phases of road networks

Issues to Consider During Construction Phases of Road Networks	Managerial	Technical	Economical	Ecological	Aesthetical
Determination of work machines used during construction phases of road networks in an ecological manner	X	X	X	X	X
Necessity of geotextile materials used in road network construction		X	X	X	
Importance of hydraulic structures in protected areas		X	X	X	
Visual and ecological planting of slopes during road construction in protected areas		X	X	X	X
Impacts of habitat fragmentation during road construction in protected areas	X	X	X	X	
Importance of ecological road structures in protected areas	X	X	X	X	X
Fence applications that increase visual quality of road construction in protected areas	X	X	X	X	X
Effects of noise pollution during road construction in protected areas	X	X		X	
Determination of work schedule of road construction phases in protected areas	X	X		X	

In the study, the issues that should be considered during the road construction phases are discussed with a literature-based conceptual overview, with managerial, technical, economical, ecological, and aesthetical indicators. Conceptual indicators of these issues are reviewed and explained in a holistic way through a literature review. Table 1 shows the indicators that were considered for each specified issue. The results from the highway road construction related studies were also discussed in the literature review. Although there are differences in terms of road standards and road construction methods, the fundamental road location problem normally involves similar phases for both forest roads and highways. Thus, the suggestions provided by highway construction studies can be suitable to some extent for the construction of forest road network in protected areas.

### 2.1 Determination of Work Machines Used During Construction Phases of Road Networks in an Ecological Manner

Road network construction works in and around protected areas have negative impacts on biodiversity (Quintero 2002). Before starting road network projects in these areas, it is necessary to determine protection measures against ecological harm in terms of biodiversity (Ledec and Posas 2003). Thus, in the planning phase of the road networks, the necessary protection inventory should be made and the area should be evaluated before the road network construction begins (Arıcaç and Acar 2008). Unplanned road networks can cause damages that are irreparable and sometimes even impossible to compensate environmentally (Winkler 1998). For this reason, it is very important to use modern road network construction machines in

road networks constructions (Çalışkan and Çağlar 2010). Technologically selected road network construction machines should be determined to best suit economic and ecological conditions (Fannin and Lorbach 2007). In the literature, it is suggested to use hydraulic excavators instead of dozer machines in terms of ecological damage in road constructions in woodland areas (Öztürk et al. 2010), because, during road construction, it offers the advantage of a construction technique that is more sensitive to ecological impacts such as road width, landscape structure, water drainage and effective erosion control (Winkler 1998). Comparisons of other characteristics of environmental impacts of work machines in road construction practices are shown in Table 2 (Çalışkan and Çağlar 2010, Winkler 1999).

Tunay and Melemez (2004) assessed the environmental damage caused during the construction of forest roads with dozers and excavators in steep slopes and difficult terrain conditions. In their study, both ecological and visual damages caused by road construction machinery in forest road construction were revealed. Excavator was found to have less impact on the forest area during the road construction practice than on the area where the dozer was working. They determined that the construction of a forest road that is environmentally friendly and suitable for road planning techniques can be done by using an excavator. However, while using road construction technique, the protection of landscape values in the forest areas should be considered with an environmentally sensitive approach (Winkler 1998). In particular, the visual quality of the landscape of the forest area should be designed integrally in the planning of road construction and the necessary equipment should be preferred

**Table 2** Environmental impact of excavator and bulldozer during road construction practices

Excavator	Bulldozer
The excavator can be operated fixed or parallel to the road centerline, keeping the subgrade width to the minimum determined by safety and anticipated use	Bulldozers can hardly be used in areas where minimum subgrade width is required for maneuvering
The excavated material is best placed as the excavator operates by digging, swinging and depositing material with accuracy and care	Excess filling inside the bulldozer blade is insufficient to lay the material by pushing or dragging into areas where it is needed
The excavated material can be separated and temporarily stacked by the excavator taking account of its anticipated use in building up the fill	Excavation material cannot be placed in suitable layers in the filling
Construction width is minimized as subgrade width and length of fill slope is reduced	The disturbance of the landscape and area that is dedicated to forest roads is higher when compared to road construction by excavator
Since the excavation material joins the road, the erosion tendency decreases	Unconsolidated side cast material increases the risk of erosion
The damage to the roadside forest is insignificant as excavators enable the operator to efficiently dig, swing and place material	During construction, excess material is thrown downhill, causing serious damage to the roadside forest
The fill slope can be shortened in length; the solid fill facilitates road construction on the steep slope	Depending on the angle of the material thrown to the side on the slope with a slope of more than 75%, the fill slope cannot be fully constructed
Culverts and retaining walls can be built up at any time during road construction	Culverts and retaining structures can be placed after completion of bulldozer work

during the implementation phase. The visual quality value of forest after the use of hydraulic excavators in road construction is higher than after dozers (Tunay and Melemez 2004). Thus, it is possible to avoid the high costs that arise in subsequent improvement efforts to eliminate unwanted effects and scars in the forest visual landscape (Winkler 1998).

The application times of construction machines used during road construction can also have negative effects on wildlife from an ecological point of view. During the construction practices in protected areas and their surroundings, depending on the noise, as the working distance of the work machines increases, the working time also increases (Kantová and Motyčka 2014). It is necessary to encourage the use of innovative technologies to reduce ecological impacts. For example, using new intelligent compaction technology and equipment during road construction, it is possible to ensure rapid compaction of the roller machine in the optimum vibration mode and to measure the compaction level continuously (Quintero 2002). This leads to a decrease in behavioral changes, such as stress and the need to relocate wildlife in the region (Boston 2016).

## 2.2 Necessity of Geotextile Materials Used in Road Network Construction

Geosynthetic is made of polymer materials (synthetic or natural) and is used together with other materials related to soil, rock or geotechnical engineering (Burhan and Soyaslan 2016, Leão et al. 2012). There are several geosynthetic materials that have been developed according to design functions (Akhmetshin and Kovalenko 2019). Geosynthetic material types can be grouped according to areas of use such as geotextile, geogrid, geonet, geomembrane, geosynthetic clay liner, geopipe, geocomposite, geofoam, geotube, geocell (Yılmaz and Eskişar 2006).

Geosynthetic materials are widely used in low-volume, unpaved and forest road network construction (Powell et al. 1999). These materials increase the strength of road structures and provide high resistance to environmental conditions (Akhmetshin and Kovalenko 2019). Geotextile materials are also available for use during road construction. Geotextiles basically perform six identical functions: separation, filtration, drainage, reinforcement, sealing and protection, and also can execute one or more than one task at a time. (Annu and Verma 2018). Thus, geotextile material has the potential to serve as a filter fabric and a fabric supplement to stabilize and maintain weak lower echelons in road construction (URL2). For example, as the effect of surface drainage is significantly reduced as a result of heavy rains on unpaved roads, an increase in groundwater level occurs, and

geotextiles with high transmissivity provide a continuous drainage between the basic layers (URL3). In addition, geotextile material can be effectively applied in necessary road infrastructure practices such as soft landfilling, landfilling with vertical drainage on very soft soil, strengthening infrastructure layers and causeway filling (URL4).

Geotextile material also plays a critical role in the performance of road networks (Khan et al. 2014), being versatile, easily available and environmentally friendly. While these materials reduce the cost, especially in road network construction and maintenance-repair works, they also provide a long-lasting use of the road and have the ability to be easily assembled (Akhmetshin and Kovalenko 2019, Powell et al. 1999).

### 2.3 Importance of Hydraulic Structures in Protected Areas

Inland water ecosystems (streams, groundwater, other brackish and freshwater habitats, etc.) have an important place in protected areas (Worboys et al. 2015). These areas holistically maintain hydrological and biophysical functions such as water volume, flow quality, water habitat, and sustainability in their natural environment (ICEM 2003). Therefore, inland water ecosystems must be well defined in the planning process. The ecological effects of these sensitive areas should be well determined, especially in road network planning. Otherwise, inland water ecosystems can have many ecological negative effects, such as the disintegration of natural flows such as surface water and groundwater flow, alterations in water flow directions with the increase of floods caused by the rise of peak flows in streams and rivers and they may also cause the pollution of streams and rivers caused by sediment flow, as well as a decrease in water habitat types and populations (Eker et al. 2010, Trombulak and Frissell 2000). Therefore, it is important to use hydraulic structures to reduce these effects in the road network planning process.

Hydraulic structures planned in protected areas should be designed in harmony with the natural environment. In particular, these engineering structures should be sized according to their technical functions (Çalışkan and Acar 2003). For this reason, the hydraulic structures (culverts, pipes, bridges and tunnels, etc.) used in surface waters, groundwater and stream crossings on road networks should also be designed to be used for the transition of wild animals between fragmented habitats (Çalışkan and Acar 2003, Quintero 2002). This is why hydraulic structures have an important place not only in the inland water ecosystem but also in the wildlife habitat that benefits from it.

Clevenger et al. (2001) investigated the use of box culverts in the road corridors in Banff National Park in Canada intended for small and medium-sized mammals to increase fragmented habitat connectivity. The culvert performance of groups of wildlife species has been evaluated according to environmental impacts. To maximize connectivity across roads for the wildlife, Clevenger et al. (2001) have stated that future road construction schemes should include frequently spaced culverts of mixed size classes and that there should be plenty of vegetal cover near the culvert entrances.

Engineering structures are needed in order to maintain the functions of water resources encountered in protected areas, their surroundings and in forest road networks. For this reason, Çalışkan and Acar (2003) stated the reasons why hydraulic structures should be used in forest roads. These reasons are listed as follows:

- ⇒ in areas with abundant rainfall, precipitation waters cannot leave the road platform quickly, leading to disruption and destruction on the platform
- ⇒ sediment deposition on road networks at the river crossing points
- ⇒ at river crossing points, the water disrupts the road platform and creates deep crevices
- ⇒ surface destruction on the road platform caused by material detachments and landslides in slopes
- ⇒ slippage over time on the damaged and moving road platform during road construction.

Wetlands have an important place in the hydrological system in protected areas. Practices in these areas have a sensitive impact on terrestrial and aquatic ecosystems. Especially during road construction, engineering structures should be designed considering the land conditions suitable for hydrological and geological functions (Gülci 2014). Otherwise, bridges, pits, culverts, ditches and all impermeable surfaces associated with road construction can change water flow patterns and destroy wetlands through silts (Eagles and McCool 2002). Accordingly, the necessary measures to protect water resources during road construction in wetlands are as follows (Quintero 2002, Lindström-Jönsson et al. 2014, Partington et al. 2016):

- ⇒ a crossing over water should be located where the foundation can be set in bedrock or in soil type of frictional qualities
- ⇒ avoiding the passage of roads through steep slopes as much as possible

- ⇒ minimizing the number of water crossings wherever possible
- ⇒ using only clean fill materials around water-courses
- ⇒ avoiding to protection zoning of existing plantations in areas between road sites and bodies of water
- ⇒ reducing the amount of sediment transport during the paving process of dirt and gravel road platforms close to water bodies
- ⇒ soil and granular materials should be used for roads constructed across wetlands
- ⇒ geosynthetic materials (i.e. s geotextiles, geogrids, and geocells) should be used to reduce any impacts of roads on wetland hydrology
- ⇒ placing appropriate size of culverts (transverse hydraulic structures) that will drain the flow that may come from the basin in river crossings
- ⇒ not disturbing the stability of slopes that may be sources of sediment around the water resources during road construction
- ⇒ keeping openings wide in bridge construction and limiting their impact on water resources
- ⇒ designing bridges and culverts with hydraulic properties that ensure safe passage to the habitat areas of aquatic creatures.

#### 2.4 Planting Slopes for Visual and Ecological Purposes During Road Construction in Protected Areas

It is important to ensure biodiversity and protect plant species in protected areas. Planning road networks to these areas can have direct effects on biodiversity in terms of landscape and ecology (Ledec and Posas 2003). Therefore, the most affected part of the planned road networks occurs in the plant diversity in and around the roadside construction site. In particular, these areas and most plant species around them may be under threat from a landscape and ecological point of view (Heywood 2019). Roadside vegetation is often an important part of the natural vegetation that remains in an area. It, therefore, provides a valuable habitat and connection between vegetation blocks (Lamont et al. 2005). For this reason, it is important to preserve the ecological, biological and aesthetic values contained in roadside habitat (Jackson 2002).

Before starting the planned road network construction practices in protected areas, the vegetation in the area should be moved. Especially after construction, these original plant species should be re-evaluated on both cut and fill slopes of road network (Ledec and Posas 2003). For this reason, the preference of native species found in the area for re-planting roadsides is

more ecologically appropriate for protected areas (Akbar et al. 2003). During the construction of road networks, on the other hand, topsoil extracted from the cut slopes is compacted towards the fill slope. Therefore, due to the compression in this area, the physical properties of the soil (depth, density, infiltration capacity, water holding capacity, etc.) may change and difficulties may occur in the re-vegetation process (Eker et al. 2010). It should be remembered that the soil must be processed sensitively when doing plant work in such areas.

Slope stabilization in protected areas and the surrounding road network construction practices should be included in the planning in a natural and visually aesthetic way. Especially during the construction of the road, the application of slopes in accordance with the topographic structure and as flat as possible causes the road to look better visually and planting work to be easy and maintenance costs less (Türk 2006). In addition, applications of technical and biotechnical measures that can be taken in terms of landscape restoration of road slopes that are in danger of landslides or situated in landslide areas should be made from a perspective that will prioritize drainage and maintenance work (Öztürk et al. 2016).

Akbar et al. (2003) surveyed 183 road users for their views on their perception of the natural beauty and natural value of Northern England's roadside vegetation. 83 percent of the participants described the scenic quality of roadside vegetation as an important feature of the roadside environment. They showed a positive attitude towards establishing a variety of vegetation types rather than one type. According to their natural and aesthetic demands, they have raised awareness of the landscape aspects for the choice of different combinations of plant species on the side of the road. They found that especially the flowering plant species near the road is more preferred than the trees and grass on the far side of the road.

Since the measures that can be taken regarding the slopes in road construction practices in protected areas are very effective on the visual quality, this issue should be handled with sensitivity. While planning roads in these areas, the following should be taken into consideration in protecting the visual aesthetic values of endemic natural vegetation, wildlife habitat and slopes (Lamont et al. 2005):

- ⇒ trees to be removed from the site and protected for road construction must be marked in advance
- ⇒ habitat of sensitive species to be protected must be identified, (e.g. endemic plants found in the area, threatened wild animals, etc.)

- ⇒ materials brought for road construction should be placed in unused places or away from the water sources as much as possible
- ⇒ dead trees and snags in the area that do not pose a problem in terms of safety should be stored in places that can create visual aesthetic value
- ⇒ materials released during road construction must be quickly removed from the area by selecting suitable areas outside the site
- ⇒ as a part of road construction and maintenance-repair activities, cleared areas should be restored to their natural state
- ⇒ along with existing road networks, areas where natural vegetation is bare or badly degraded, as well as areas used to obtain road construction materials, should be re-planted with species suitable for the region
- ⇒ to reduce roadside plant species loss, stabilization should be minimized in terms of soil and nutrients loss in the area
- ⇒ in order to reduce noise and disturbance, especially along wetland crossings, and to provide replacement habitat for wildlife, it is important to increase the plantings that will reduce the negativities by growing later on the roadsides (NEIWPC 2010).
- ⇒ destruction of habitat during road building
- ⇒ modification of the environment next to roads
- ⇒ increased road traffic resulting in animal mortalities
- ⇒ increased road speed resulting in animal mortalities
- ⇒ greater frequency of fires
- ⇒ litter dumped on the road and its immediate surroundings
- ⇒ impediment of wildlife movement between two sides of the road and, outside of reserves
- ⇒ increased accessibility of natural resources leading to increased exploitation
- ⇒ increased settlement of people into areas traversed by roads (Caro 2015).

Although planning of road network construction in protected areas has harmful consequences such as habitat loss and fragmentation, it may also lead to the protection of habitat types indirectly depending on the area in geographical conditions (Haddad et al. 2015, Quintero 2002). For example, Brun et al. (2015) used spatial modelling with remote sensing maps of land-use change from 2000 to 2010 to analyze deforestation patterns in Indonesia and the effectiveness of protected areas. The existence of road networks, the type of lands (roads, rivers, agricultural land and forest) and the slope of the lands were taken into account in the development of the modeling. They have explained the spatial pattern of deforestation by transport cost, agricultural rent and history of nearby illegal logging. As a result, they found that protected areas managed for scientific or wildlife conservation have an effect on slowing down deforestation. They also determined that monitoring and prevention of road construction depending on the geographical prioritization in protected areas will be suitable for conservation. On the other hand, in different parts of the same habitat in the protected area, wildlife species exhibit different behaviors according to the types of road networks. For example, Blake et al. (2008) examined the wildlife activity of forest elephants in the Congo Basin in relation to roads and roadless wilderness. Especially by monitoring forest elephants in the protected area with GPS, they determined that they exhibit different behavior on the unprotected road, that is outside protected areas compared to within protected areas, and they recorded a 14-fold increase in their speed of movement. They also determined that monitoring and preventing road construction in protected areas and planning according to the geographical prioritization in the area would be appropriate for conservation.

## 2.5 Impacts of Habitat Fragmentation During Road Construction in Protected Areas

Protected areas, which are one of the most effective tools for the protection of biodiversity, are important for landscape and wildlife. In particular, they contribute to the prevention of habitat loss and disintegration of landscape and wildlife species (Çağlayan 2011). All kinds of large and small-scale man-made constructions (irrigation projects, roads and highways, sports and tourism facilities, communication and energy transmission lines, urban expansion, etc.) have the potential to create serious pressures on ecosystems and species (Worboys et al. 2015). It can be said that protected areas and road networks planned to be built around, which is also one of these pressures, will create negative ecological impacts on biodiversity (Ledec and Posas 2003). Habitat fragmentation and habitat loss, which are the leading ecological effects of road network construction and use, can affect the mobility and distribution of wild animals and cause their death (Arévalo and Blau 2017, Wemple et al. 2018). However, UNESCO has identified 9 (nine) main reasons that may be grounds for removing road networks from protected areas due to increasing human activity. These are:

Solutions to reduce the impact of road networks on wildlife also have a positive impact on protected areas (Lesbarrères and Fahrig 2012). Caro (2015) planned to upgrade a Murram road in Western Tanzania Katavi National Park, which connects regional capitals to preserve the sanctity of the protected area. Despite empirical evidence suggesting upgrading would damage trees, increase traffic, adversely affect large mammals, and result in more litter, the ecological data was not taken into account. In order to preserve the sanctity of the protected area, it has been decided not to make upgrades for environmental and socio-political reasons. Caro has shown that it is necessary to work with politicians to achieve environmentally friendly results on the roads in these areas.

Biodiversity varies by species in studies on habitat loss and fragmentation caused by road network in wetlands from aquatic ecosystems of protected areas. For example, Findlay and Bourdages (2000) examined the lag in biodiversity loss in different taxa related to road construction in existing lands around wetland biodiversity in Canada. They found that the full effects of road construction on wetland biodiversity have been undetectable in some taxa for decades. Rainfall et al. (1982), on the other hand, examined the physical and chemical effects of an existing bridge highway construction on water quality in the Louisiana wetland. They determined that the impact on the site tended to be temporary, and that the increase in turbidity and color during construction gradually returned to pre-construction conditions when construction was completed. For this reason, differences can occur depending on the degree of impact and duration of habitat loss and fragmentation. Therefore, they noted that the long-term degradation and recovery effects on biodiversity and the function of the species could not be fully determined (Haddad et al. 2015).

## 2.6 Importance of Ecological Road Structures in Protected Areas

Protected areas play an active role in the conservation of biodiversity, which has many ecological and biological criteria (Asaad et al. 2017). Any intervention in these areas has an ecological impact on biodiversity. Of these impacts, it is not possible to ignore the ecological impact of road networks (Gülci and Akay 2014). The main threats to the preservation of biodiversity in particular are habitat loss and fragmentation (Ćurčić and Đurđić 2013). This is often associated with habitat areas of wildlife in and around the protected area (Hansen and DeFries 2007). For this reason, habitat areas should be protected for wild animals to feed, breed and to have shelter (Gülci and Akay 2014).

In recent years, the use of ecological road structures has become widespread in reducing ecological impacts in road network practices in protected areas. Especially in studies on minimizing wildlife losses and fragmentation in protected areas, ecological road structures come to the fore as an important solution. For this reason, research and practices on ecological road structures and wildlife overpasses are evaluated within the concept of road ecology. Generally, in addition to highways, ecological road structures can be constructed in order to provide passage over railways, rivers and dams (Gülci et al. 2014). Therefore, research on wildlife crossing practices used for wild animals is increasing every day (Gülci 2014). For example, ecological overpasses are used as an ecological road structure in the road network practices in Turkey. These are 2 (two) in total: Northern Marmara Motorway and the Pozanti-Mersin Gülek Pass Motorway. On the other hand, there are also different practices related to ecological passages in different countries around the world (Tercan 2017):

- ⇒ Banff National Park in Canada, which is one of the best practice examples in protected areas and divided by the Trans-Canada Highway, has 24 wildlife crossing points built along the road, 2 (two) above, 22 (twenty-two) below, for 10 (ten) mammal species living in the area
- ⇒ the Netherlands has 66 (six-year) underpasses and overpasses providing wildlife crossings for other wildlife species in the region along with European badgers. 9 (nine) of these crossings, with an average width of 50 m, are located on roads that intersect Veluwe Park, the largest plain in North-Western Europe
- ⇒ there are wildlife crossings built on the Interstate (I-90) highway, which connects through the northern part of the United States. Especially pronghorns use Highway 191 as a wildlife crossing point on their 273 km migration journey from Grand Teton National Park to the south
- ⇒ there is a 62-meter wide ecological passage that connects Singapore's Bukit Timah Natural Reserve habitat with the habitat in the Central Catchment Nature Reserve
- ⇒ there is an ecological road structure built to ensure that the red crabs living in Australia's Christmas Island, who travel from the rainforest to the sea to breed every year, reach the sea by ecological passages (URL5).

Ecological road structures are classified in 2 (two) main groups as ecological underpasses and overpasses according to the characteristics of wild animal

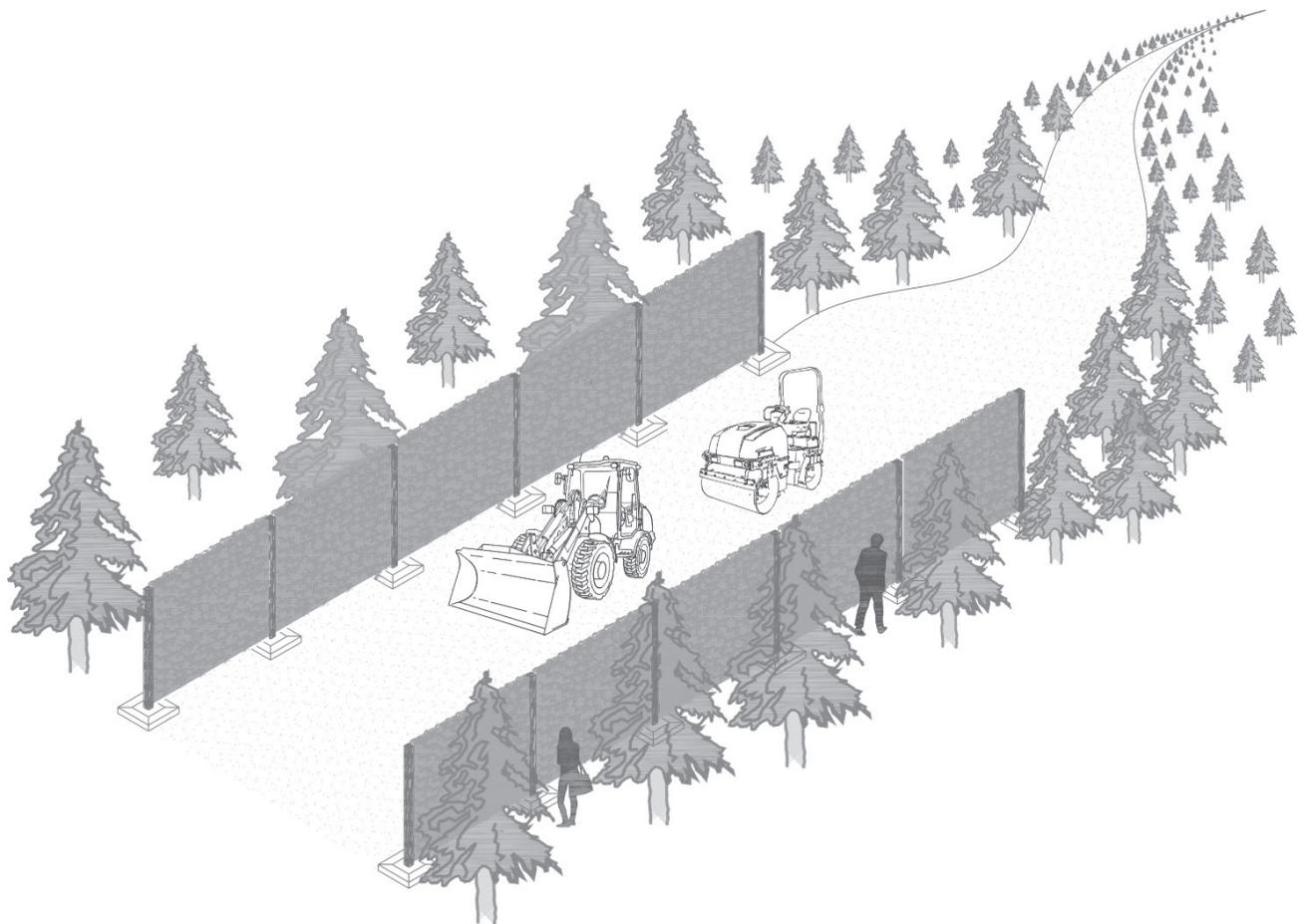
species. While ecological underpasses are determined as small size underpasses, medium size underpasses, large size underpasses, and viaducts, ecological overpasses are determined as wildlife overpasses and bridge overpasses (Gülci and Akay 2014, Kintsch and Cramer 2011). Therefore, when planning road networks in protected areas, it is necessary to determine which group of ecological road structures will be used (Clevenger et al. 2001). That is, the ecological road structures to be applied in these areas are important for the continuity and protection of the habitats of wild animals.

### 2.7 Fence Applications that Increase Visual Quality of Road Construction in Protected Areas

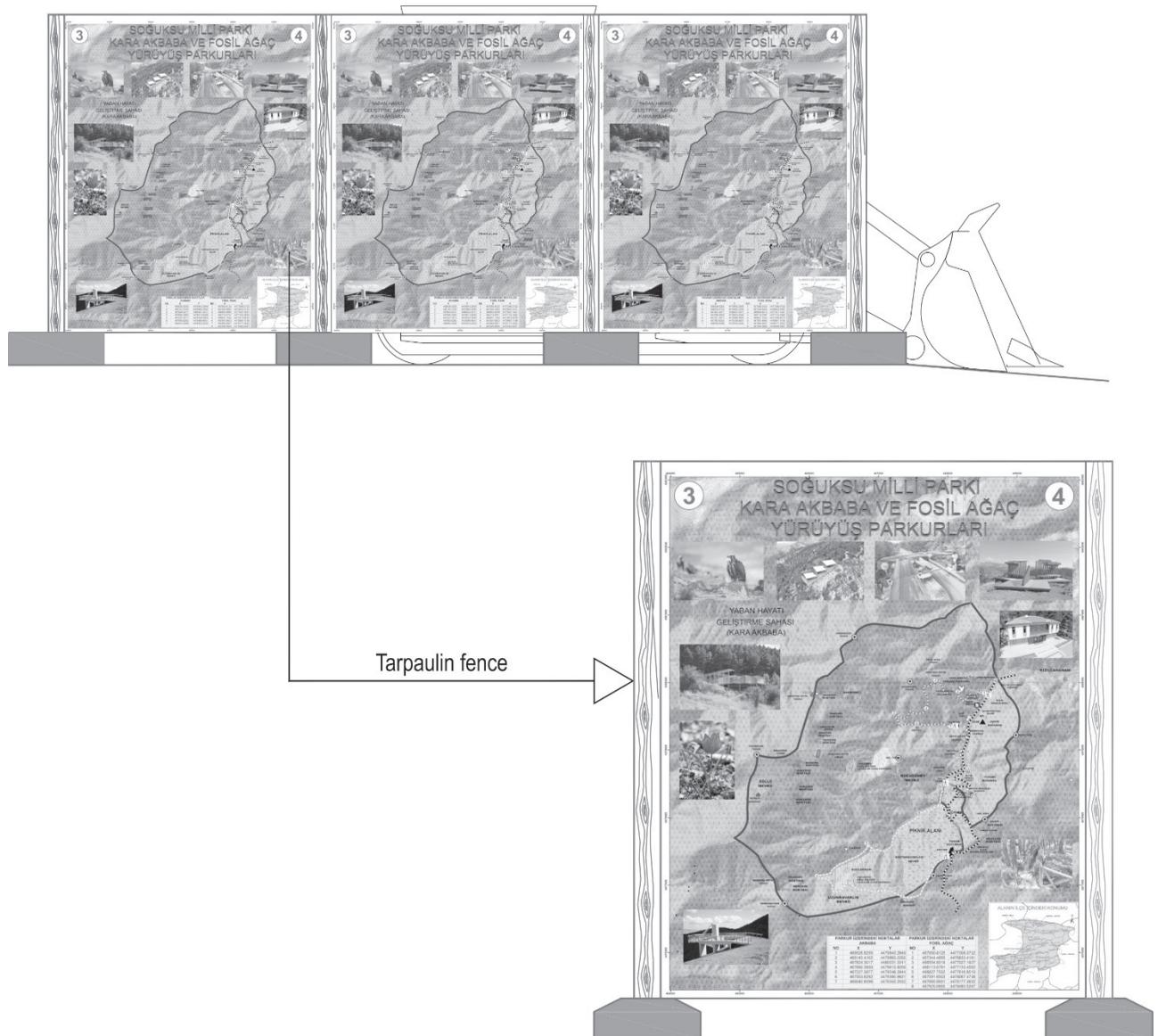
Road networks are often one of the most difficult parts in managing transport infrastructures in protected areas (Eagles et al. 2010). As well as road network planning and designing of these areas, necessary measures must be taken and managed during road

construction. Especially in road network practices, a safe working area should be provided with fences (Worboys L. et al. 2015). For this reason, fencing practices must be determined to minimize the risk of deterioration of the area during road network construction (URL6). For example, the fences used during the construction of the road network provide a safe working area and can be used to improve visual quality for visitors to the area, as well as make an important contribution to wildlife.

Visual screen walls can be used as an effective tool to prevent noise and air pollution as well as visual pollution during road construction (Fig. 1). Especially in screening works, using fences that are compatible with nature, easy to install, reusable, low cost, cost-effective can be a solution to this issue. Therefore, in terms of economy and continuity, it is important to screen the constructed parts of the road during the construction and to shift the screening fences in the finished part to the ongoing parts of the construction.



**Fig. 1** Screening of road construction in protected areas with fences for visual quality

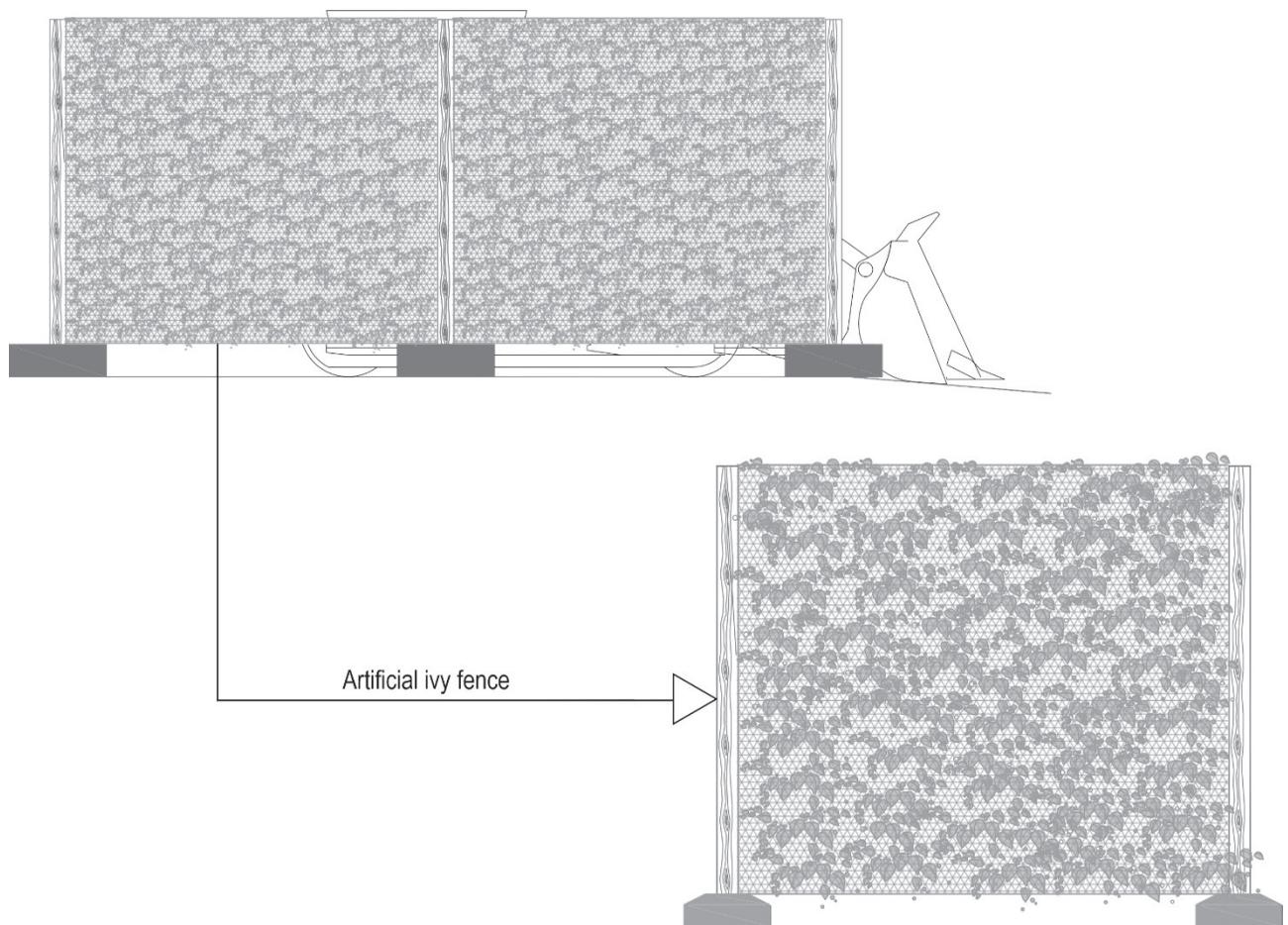


**Fig. 2** Tarpaulin fence curtain containing field information in order to guide and inform visitors

On the other hand, fences used for safety for pedestrians and drivers should be designed within the limits of visibility at protected area entrances and crossings (Da Andalucia 2009). For this, screening fences for visual quality can be made using animate and inanimate materials. However, given the negative effects caused by road construction and the fact that it will increase the cost, it is not recommended to implement animate materials in the fence construction that increase visual quality. Especially in applications, baseless carriers (lugs, pontoons, etc.) or movable (lockable wheeled) systems should be preferred to keep the fence stable without being fixed to the ground in order for the fence to be easily installed-uninstalled and reusable. For this

purpose, tarpaulin, artificial ivy or jute fence can be used in order to hide the unwanted image and reduce noise and air pollution in road construction in protected areas (Fig. 2, Fig. 3 and Fig. 4).

In addition to road construction in and around protected areas, fence curtains that increase visual quality are used in bridge sections as well. Especially in the practices planned at crossing points important for wildlife, fences with escape ramps that increase visual quality should be applied. For this purpose, during road construction phases, these fences can be placed on the edges of the bridges without gaps and in appropriate size according to the conditions of the region. With this application, by using fences on one



**Fig. 3** Fence curtain made using artificial planting (artificial ivy) to create a background that increases visual quality in harmony with nature

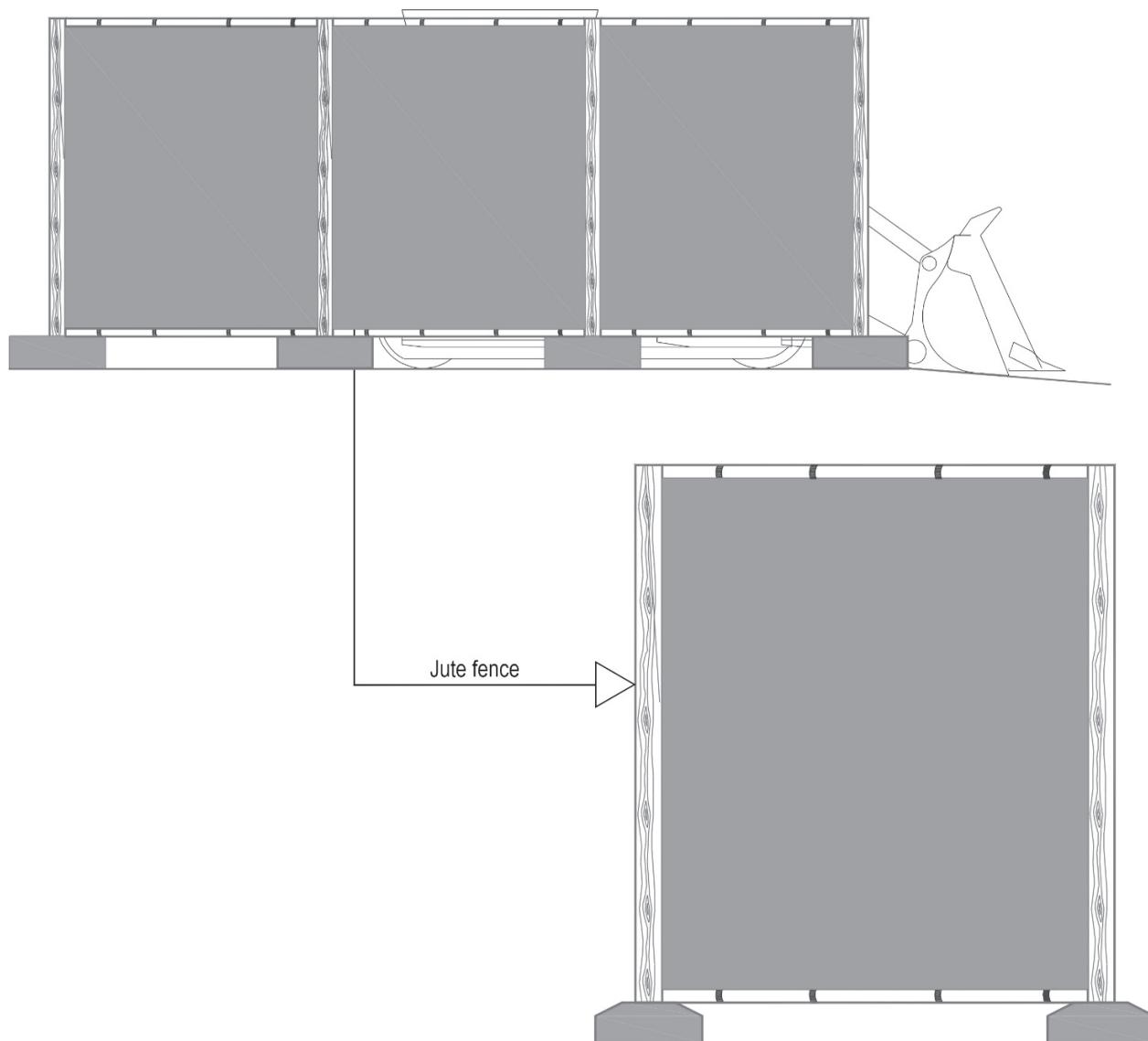
or both sides of the bridge, the passage of wildlife species will not be prevented (Arizona Game and Fish Department 2008).

### 2.8 Effects of Noise Pollution During Road Construction in Protected Areas

Increases in road networks in protected areas can lead to habitat loss and fragmentation in terms of biodiversity, as well as negative effects such as habitat change (Bennett 2017). Noise, in particular, due to the construction and use of road networks, has negative effects on wildlife in protected areas (Arévalo and Blau 2017). Of these, traffic noise pollution was found to have an impact on wildlife according to 242 articles published between 1990 and 2013, and terrestrial wildlife responded to a noise level of 40 dB (Madadi et al. 2017). For this reason, an increase of this level can have chronic effects for wild animals, including high-stress levels and associated physiological responses (Blickley and Patricelli 2010). As a result, traffic noise pollution has a permanent and long-term negative impact on

wildlife. On the other hand, noise pollution caused by road network construction has a short-term negative impact. In literature studies on the impact of the use of work machines on wildlife, especially during construction in protected areas and their surroundings, it has been reported that the duration of work and distance between the machines and the nests of wild animals are two important parameters (Kantová and Motyčka 2014). These parameters can prevent communication disruption by masking acoustic signals that affect wild animal behavior (Cardoso 2014, Iglesias-Merchan et al. 2015). As a result, it has been emphasized that it can cause temporary or permanent hearing loss and stress of wild animals (Parris 2015).

Noise pollution also has physical, physiological and psychological effects on human health (Yılmaz and Özer 1997). For this reason, while providing access to the protected areas and its surroundings within the field, security is also of great importance. Therefore, within the scope of visitor management, visitors who go to see the protected areas should be informed



**Fig. 4** Fence curtain made using jute to create a background with colors that are in harmony with nature and to gain spatial depth

before road construction begins. At the same time, technical measures such as placing video screens in the field, placing guiding signs and warning signs that ensures a safe transportation network, and closing the work area by placing sound-resistant panel fences should be taken by the relevant institutions. On the other hand, measures to minimize noise pollution during the construction of protected areas and surrounding road construction can be listed as follows (Integrated Environments Ltd. 2010, Kantová and Motyčka 2014, Parris 2015, Quintero 2002):

- ⇒ during the construction phases of the road network, the working schedule should be planned and the speed limit should be placed on the service roads
- ⇒ suitable and well-maintained equipment should be used
- ⇒ materials leaving the construction site shall be transported during non-peak hours in order to minimize traffic noise due to the increase in traffic volumes
- ⇒ applicable electrically powered equipment should be used instead of fuel-powered equipment. In addition, by reducing vibration with air-powered equipment, smooth transport for tools and materials should be provided
- ⇒ noise pollution reduction should be planned to protect wild animals and their acoustic environment before road construction

- ⇒ mobile noise-canceling barriers or natural noise barriers should also be arranged according to the site layout plan
- ⇒ during the road construction phases, renewable, natural, quiet and recycled road products should be used at low temperatures, because the surface coatings of these products, which have a noise-reducing effect, can provide a 9 dB reduction in traffic noise compared to traditional mixtures.

### 2.9 Determination of Work Schedule of Road Construction Phases in Protected Areas

Planned road networks in protected areas should be done in an environmentally sensitive and secure manner (Eagles et al. 2010). During the planning phase, it is very important that it is programmed and completed on time as part of an effective protection of the area. Therefore, a working schedule should be prepared in accordance with the flowcharts of the planning phase (Worboys L. et al. 2015). Especially when planning a work schedule for the road construction in and around the protected areas, in addition to ensuring visitor safety, measures should also be taken to ensure that endemic plant species are protected and that the wild animals in the area are least affected by the activities performed.

Before starting planning, the necessary information about the protected area should be collected. Feeding, sheltering and breeding periods of the endemic species or wildlife species in the area and the visitor information should be known, and the working schedules should be determined accordingly. For example, when creating a work schedule, planning should be made for the times other than the days and hours when the area is most crowded (URL7). On the other hand, planning should be carried out based on information such as nutrition, shelter and breeding periods for wild animals habitats in the area. Thus, when creating the work schedule for the protected areas and the road construction around it, the most appropriate periods and the factors affecting these periods should also be included in the analysis of the process.

## 3. Discussion

Planning and implementation processes must be handled delicately when constructing sustainable road networks in and around protected areas. In this context, issues that should be considered in the development and improvement of road networks were evaluated. Accordingly, the points to be considered during the construction phases of the road networks

presented in the study are determined within the framework of conceptual indicators. In particular, the conceptual indicators determined in the study and the issues that need to be considered are presented within the scope of implementation and planning studies based on literature. In addition, the planning and implementation phase of road networks has been evaluated with an interdisciplinary approach to determine the difference of conceptual indicators from research in the literature. For this reason, the issues that should be considered during the construction of road networks have been addressed in a holistic way with conceptual indicators and efforts have been made to contribute to the development of these issues.

Issues to be considered during the planning and construction of road networks in protected areas have been evaluated together with the conceptual indicators in terms of management, technique, economy, ecology, and aesthetic. Technical and ecological assessments, in particular, seem to contain more elements in terms of innovative technologies and sensitive protection in applications than other indicators. The reasons for this may be mainly due to the difficulties faced in practice against environmental sensitivity in the construction of road networks in protected areas, as well as confusion as a result of unplanned processes, because the importance of environmental sensitivity in road network practices is increasing day by day as part of sustainability in protected areas. Accordingly, when the development and improvement of road networks is not well planned in terms of sustainability, it can create difficulties in practice (Tarimo et al. 2017). This situation may create an interdisciplinary effect among the conceptual indicators in road network practices (Caro et al. 2014). Therefore, it is stated that technical and ecological indicators belonging to the issues that should be considered in the development and improvement of the road network in protected areas should be included in the design and implementation of road projects. Therefore, these indicators can support the importance of how the goal of environmentally sustainable development can be translated into a concrete reality (Ledec and Posas 2003). On the other hand, the volume of traffic used in road networks in protected areas was not addressed in determining the issues that should be considered in road network projects. The reason is that there are many evaluations in the literature regarding road networks and traffic volume. The ecological effects of road network traffic, particularly in protected areas, on natural resources, habitats and species have been identified in the short and long term (Spellerberg 1998). It has also been noted that, while there are few studies within the

scope of these ecological impacts, there are many studies in terms of mitigation measures (Cheng et al. 2015).

Regarding the necessity of the geotextile material used in the construction phases of road networks, the importance of hydraulic structures and the visual and ecological vegetation applications of the slopes, the managerial indicator is insufficient. The reason for this is that road network planners may be exposed to restrictive factors in design in protected areas during the implementation phase (Ledec and Posas 2003). However, the managerial indicator was considered to be not developed politically, as the road networks in areas protected by social-economic pressures remain naturally (Caro et al. 2014). On the other hand, it can be revealed that the managerial indicator has its strengths and weaknesses compared to other indicators in road network construction and maintenance. It can help develop solutions, especially in the measures that need to be taken for road networks after implementation (Tarimo et al. 2017). However, these solutions may not be applicable in all areas depending on the topographical conditions in protected areas.

When the aesthetic indicator of the road networks in protected areas is evaluated during the construction phases, it is seen that it is preferred less than other indicators in terms of priority in practice. This may be due to factors such as planning, time and cost, which are included in the managerial and economic indicators. However, when considering these factors in terms of ecotourism in protected areas, it can be said that they will make a significant contribution to the development and use of road networks. In particular, in order to provide access to these areas, the development of road networks with visual views compatible with nature and the environment should be encouraged. However, it has been stated that it is necessary to construct a road network design that meets the aesthetic expectations, prevents ecological disruption and ensures traffic safety (Cheng et al. 2015).

The economic indicator is less important than other indicators in determining the effects of noise pollution and the work schedule during the construction phases of road practices in protected areas. This may be due to the increase in construction items in providing safety measures in the area of road network construction and maintenance. Therefore, this can affect the increase in construction cost and related working time. In addition, it can be determined how this economic increase in road network construction and maintenance work can affect other indicators, especially the ecological indicator, in the short and long term (Caro et al. 2014).

In the light of the information obtained from the literature, the planning phase can be implemented with a checklist in line with the conceptual indicators of the issues to be considered during the construction phases of road networks. The issues that should be evaluated during the construction and maintenance of road networks in and around these protected areas increase the protection functionality.

#### 4. Conclusions

In the study, the issues to be considered during the construction phases of protected areas and surrounding road networks were evaluated within the scope of literature-based studies and integrated within the framework of the relevant conceptual indicators. The considerations determined in this context have been supported by including the literature practices.

Ecological and technical indicators, which are the main considerations that should be considered during the construction phases of road networks in protected areas, seem to have the most important place in the implementation practices. Especially when planning new road networks, ecological value and conservation priority should be taken into account depending on the nature of habitats in protected areas. For this purpose, before construction begins, road networks in protected areas should be planned according to the ecological value index of the area within the framework of sustainable infrastructure services (Hoffmann et al. 2019). Thus, areas in sensitive ecosystems should be designed with innovative approaches and with ecological indicators (noise pollution prevention, habitat improvement, etc.) during the planning phase. It is necessary to reduce the ecological impact with the understanding of the managerial indicator along with the ecological indicator and pay attention at the planning phase in terms of the technical indicator. In particular, more research is needed on the various effects of noise pollution on wildlife and their ecological communities. As far as wildlife habitats are concerned, it is quite important to protect natural acoustic environments from high noise levels caused by road constructions. Therefore, appropriate noise reduction strategies should be considered at the beginning of the road planning process. If necessary, the construction phases of road networks should be followed within the scope of managerial and technical indicators, and in unusual cases such as an increase in noise levels, construction activities should be terminated and a new working schedule should be prepared (Environmental Services Group 2004).

In terms of economic indicators, Mayer et al. (2012) determined that effective practices should be used to minimize the costs associated with construction and maintenance during the construction of road networks. These practices include optimizing the soil to balance tillage, optimizing the coating thickness for loads according to expected conditions, along with supplying materials locally sourced, and planning the efficient implementation of fast delivery. In addition, it is seen that primarily natural improvement on road slopes is important in terms of cost maintenance within the scope of landscape restoration.

Before road network construction practices, inventories related to endemic species should be determined in protected areas in terms of administrative and aesthetic indicators. In this context, decision support systems and designs for the positioning of ecological road structures should be planned. Ecological road structures created according to this planning should be applied aesthetically in accordance with nature. In addition, when planning protected areas and road networks passing through them, in order to prevent damage to landscapes, limitations such as slope restrictions must be determined (Monavari and Mirsaed 2008). In this way, it can be seen that roadside landscapes are part of the road network practices from an aesthetic point of view. On the other hand, in construction practices in protected areas, visitor safety should be carried out sensitively by the relevant institutions. For this purpose, construction site selection should be planned in such a way that it does not cause environmental and social discomfort.

In terms of technical indicators, it should be ensured that smart technological construction equipment is widely used in road construction practices in protected areas. Especially in the conservation of the ecosystem in the field, low-emission new technology work machines should be used to minimize fuel consumption and improve fuel efficiency (Quintero 2002). In addition, recycling technologies related to waste materials resulting from road construction should be developed. In this way, during road construction, it will be possible to use geotextile materials produced from renewable alternative materials, which are ecologically the least costly and long-lasting.

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Authors' addresses:

Dursun Şakar, MSc \*  
e-mail: archery\_542@hotmail.com  
Düzce University  
Institute of Science  
Konuralp Campus  
81620-Düzce  
TURKEY

Prof. Abdurrahim Aydın, PhD  
e-mail: aaydin@duzce.edu.tr  
Düzce University  
Faculty of Forestry  
Konuralp Campus  
81620-Düzce  
TURKEY

Prof. Abdullah Emin Akay, PhD  
e-mail: abdullah.akay@btu.edu.tr  
Bursa Technical University  
Faculty of Forestry  
Eflak Cad. No:177  
16310 Yıldırım-Bursa  
TURKEY

\* Corresponding author

Received: September 11, 2020  
Accepted: March 07, 2021