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Prof. Dr. Hasan AKGÜL
Prof. Dr. Hayri BABA
Prof. Dr. Murat KÜTÜK

Researches and Evaluations in the Field of

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Kızılay Mah. Fevzi Çakmak 1. Sokak
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0312 384 80 40
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gece kitaplığı

CONTENTS

CHAPTER 1

BIOLOGICAL ACTIVITIES AND USES OF GENUS *LAVANDULA*

Hatice ÜSTÜNER[1]

1 Akdeniz University, Faculty of Science, Department of Biology, Antalya, Türkiye h.ustuner1977@gmail.com

INTRODUCTION

Plants have been utilised for centuries for medicinal purposes by using their roots, leaves, flowers, fruits or substances such as milk, terebinth, resin, balsam (Emre, 2012; Sağında, 2014). Medicinal aromatic plants used for medical or therapeutic purposes are generally used in areas such as cosmetics, aromatherapy, traditional medicine, herbal medicine due to the essential oils in their content (Lubbe and Verpoorte, 2011). Numerous studies have reported that plants possess a multitude of biological activities, including but not limited to antioxidant, anticancer, antimicrobial, antiallergic, anti-inflammatory, antiproliferative, hepatoprotective, DNA-protective, and anti-aging properties (Horvathova et al., 2007; Bak et al., 2011; Ndlovu et al., 2013; Mohammed et al., 2019; Akgul et al., 2020; Mohammed et al., 2020; Mohammed et al., 2022; Unal et al., 2022; Özcandır et al., 2024; Mohammed et al., 2024; Şener et al., 2024).

The genus *Lavandula*, an important member of the Lamiaceae family, has species with aromatic leaves and flowers and rich phytochemicals (Bozyel and Bozyel, 2020; Héral et al., 2021). This genus, which includes 47 evergreen shrub species, has a wide distribution ranging from Europe to north and east Africa, the Mediterranean, southwest Asia and southeast India (Allaby, 1992; Lis-Balchin, 2002). Their odour, caused by monoterpenes and other volatile chemicals secreted and stored in the above-ground parts, has been their distinctive biological feature (Mahmoud et al., 2021). From the Romans, who used members of the genus as bath additives, to the Middle Ages and today, the genus has been used for medicinal, cosmetic and cleaning purposes. *Lavandula* species were one of the most valuable essential oil plants in the Middle Ages (Góra et al., 2005). The genus, which is generally used as an ornamental plant (Upson et al., 2004), is used in daily life and folk medicine in forms such as pills, powders, teas, ointments, alone or with other plants. The medicinal importance of the genus has been demonstrated in detail by different studies and many herbal medicines prepared from its members are registered in the Pharmacopoeia (Herraiz-Peñalver et al., 2013; Hartwell, 1971; Pochers, 1974; Mill, 1982; Leclerc, 1996; Sağında, 2014; Bozyel and Bozyel, 2020). In terms of phenolic content, rosmarinic acid, coumarin, quercetin, kaempferol, apigenin, lavandulol, linalool, campfer, 1,8-cineole, terpinen-4-ol, borneol are present in the essential oil (Yadikar et al., 2017; Cardia et al., 2018). The genus *Lavandula* is cultivated specifically for its essential oils, which have a highly variable composition depending on genetic, environmental and processing factors (Aprotosoaie et al., 2017) and 548 specific metabolites have been identified in its members (Héral et al., 2021).

Usage Areas

Members of the genus *Lavandula* have been widely used both as aromatic plants and for medicinal purposes since ancient times due to their high oil content (Sarkic and Stappen, 2018; Batiha et al., 2023). Due to its phenolic content and essential oil, anticancer, antioxidant, antimicrobial, anti-inflammatory, antiseptic, analgesic and anxiolytic effects have been reported. It is used in cosmetics, aromatherapy, digestive and sleep disorders for the treatment of folk and pharmacopoeia (Hajhashemi et al., 2003; López et al., 2017; Soheili and Salami, 2019; Başar and Karadağ, 2024).

Biological activities

The therapeutic effects of different species of the genus *Lavandula* have been known since ancient times (Büyükokuroğlu et al., 2003). Antifungal, antibacterial and anticholinesterase effects of oils (Hanamanthagouda et al., 2010) and neuroprotective, anti-inflammatory and antioxidant properties of extracts have been determined by different studies (Kovatcheva et al., 2001). In this study, the biological activities of the species belonging to the genus *Lavandula* reported in the literature were reviewed. In in vivo, in vitro and ex vivo biological activity studies on the species belonging to the genus, it was observed that water, ethanol, aqueous ethanol and methanol extractions were used (Table 1).

Table 1. *Biological activity of genus Lavandula.*

Plant species	**Biological activities**	**Extraction**	**Geographic regions**	**References**
Lavandula angustifolia	Antioxidant activity	Ethanol	Jastrebarsko, Croatia	(Blazekovic et al., 2010)
Lavandula coronopifolia, Lavandula multifida and *Lavandula stoechas* subsp. *stoechas*	Antioxidant activity	Methanol	National Park of Bouhedma (Sidi Bouzid region *L. multifida- L. coronopifolia*: National Park of Bouhedma (Sidi Bouzid region) *Lavandula stoechas*: Korbous Jebel Mountain (Cap Bon region)	(Messaoud et al., 2012)

Lavandula pedunculata subsp. *lusitanica* (Chaytor) Franco	Antioxidant activity	Water, ethanol, aqueous ethanol (50%)	South Portugal, Portugal	(Costa et al., 2013)
Lavandula stoechas L.	Antidiabetic and antioxidant activity	Water	Ain-Draham, North-West of Tunisia	(Sebai et al., 2013)
Lavandula angustifolia	Antioxidant, anti-inflammatory, analgesic activity	Ethanol	Xinjiang, China	(Zhao et al., 2015)
Lavandula stoechas L.	Anticandidal activity	Ethanol, ethyl acetate, chloroform	Çanakkale, Türkiye	(Gedik and Dülger, 2015)
Lavandula officinalis L.	Antidiabetic activity	Ethanol	Shiraz, Iran	(Azarmi et al., 2016)
Lavandula pedunculata (Mill.) Cav.	Antioxidant, antitumour, anti-inflammatory	Water, aqueous ethanol	Alentejo and Trás-os-Montes, Portuguese	(Lopes et al., 2018)
Lavandula stoechas	Antidiabetic activity	Ethanol	Rawalpindi, Pakistan	(Mustafa et al., 2019)
Lavandula dentata	Hypolipidemic and hypoglycemic activity	Tween 80	Taif , Saudi Arabia	(Almohawes and Alruhaimi, 2019)
Lavandula pedunculata (Mill.) Cav.	Antidiabetic activity	Water	Azrou, Middle Atlas, Morocco	(Boutahiri et al., 2021)
Lavandula officinalis L.	Phenol and antioxidant activity	Tris-HCl buffer and methanol	Rize, Türkiye	(Aykutlu et al., 2022)
Lavandula officinalis	Antibacterial and anticancer activity	Hexane, chloroform, ethyl acetate, methanol, water	Iğdır, Türkiye	(Başar and Karadağ, 2024)

Antioxidant activity

The presence of phenolic derivatives such as flavonoids and phenylpropanoids, which show antioxidant properties by preventing the damage caused by reactive oxygen species, has been effective in the use of medicinal plants in the treatment of different diseases (Kahkonen et al., 1999).

Hohmann et al. (1999) investigated the antioxidant activity of *Lavandula angustifolia* and stated that rozmarinic acid contained in the species may produce antioxidant effect. Kovatcheva et al. (2001) investigated the antioxidant and radical scavenging effects of ethyl acetate and methanol extracts obtained from *Lavandula vera* MM cell culture.

Gallego et al. (2013) investigated the antioxidant activities of leaf-flower-stem extracts of *Lavandula angustifolia* prepared with aqueous ethanol (50%). In the results of the study, it was determined that the antioxidant activity was ranked as lavender leaves, lavender stems and lavender flowers from the highest to the lowest and they stated that the antioxidant activity was related to polyphenol content.

Antimicrobial activity

Against antimicrobial resistance, which is a public health problem associated with morbidity and mortality, the use of natural products is needed since new antibiotics are not sufficient to combat antibiotic resistance for pathogenic bacteria (Ünlü et al., 2023). Essential oils, which are recommended as traditional, alternative or complementary treatment approaches, have been reported to have various effects such as antifungal, antibacterial, antiviral (Açar and Aktören, 2023). *Lavandula* genus is a valuable essential oil plant (Kara and Baydar, 2013). Along with linalyl acetate, which determines the quality of lavender oil, linalool and cineole are the most important essential oil components of lavender oil. Due to linalool and linalyl acetate, members of the genus *Lavandula* are used in the production of scented bath soap, bath foams, skin cleansing lotion (Turgut et al., 2017). While essential oils are extracted from different parts of the members of the genus, stems, which are plant residues rich in minerals and carbon, are left as by-products. Burying or burning these stems to change the soil composition is common among the people. Nasirjon (2024) stated in his study that the use of lavender straw residues in the production of various microorganisms and other bioproducts with antimicrobial, antioxidant, pharmaceutical and cosmetic activities will bring a different perspective in biotechnology.

Ünlü et al. (2023) investigated the antibacterial and anti-adhesive activity of *Lavandula stoechas* essential oils on clinical *S. aureus* isolates isolated from wound, biopsy and abscess samples and its effect on biofilm viability in vitro and found that the number of live bacteria in the biofilm increased as the doses applied at lower inhibitor doses decreased.

Okmen et al. (2022) investigated the antibacterial activity of *Lavandula angustifolia* L. against oral bacteria and reported that the methanol extract showed the highest inhibition zone against oral pathogen MBKK5. Kırcı et al. (2024) evaluated the antimicrobial activity of pharmacopoeial quality *Lavandula angustifolia* L. essential oil against skin pathogens such as *Candida albicans*, *Candida glabrata*, *Staphylococcus aur*eus and *Salmonella typhimurium* and examined the antibacterial synergy of kojic acid and essential oil as activity. The essential oil and kojic acid showed weak antimicrobial activity against *C. albicans* and *S. aureus*. Independent effect was observed in synergistic activity against *S. typhimurium*.

Other activity

Ghelardini et al. (1999) investigated the anaesthetic activity of *Lavandula angustifolia* Mill. Their experiments were carried out in vivo in rabbit conjunctival reflex test and in vitro in rat phrenic nerve-hemidiaphragm preparation. They confirmed the local anaesthetic activity observed in in vitro experiments with in vivo experiments.

Gilani et al. (2000) reported that aqueous-methanol extract of dried flowers of *Lavandula stoechas* L exhibited possible anticonvulsant and antispasmodic activities.

Büyükokuroğlu et al. (2003) investigated the effect of aqueous extract of *Lavandula angustifolia* flowers on glutamate-induced neurotoxicity and found that it significantly reduced neurotoxicity. They stated that the neuroprotective effect of *Lavandula angustifolia* flower extract may be related to the chemical composition of the plant, especially monoterpenes such as linalool.

Videira et al. (2013) found that the essential oil obtained from *Lavandula luisieri* inhibited the BACE-1 enzyme, which causes the formation and accumulation of neurotoxic β -amyloid peptide (A β), which is one of the most important factors in Alzheimer's disease, and reduced the amount of enzyme.

Algieri et al. (2016) found that the hydroalcoholic extracts of *Lavandula dentata* L. and *Lavandula stoechas* L. above-ground parts, which have potential for use as herbal medicine, have intestinal anti-inflammatory effects. Kulabas et al. (2018) carried out multi-targeted in vitro studies on the potential curative effects of the aqueous extract of *Lavandula stoechas* L., which has traditional use in Anatolia, on insulin resistance and inflammation models. Their results proved that *L. stoechas* contains phytochemicals that may be effective in the treatment or prevention of insulin resistance and inflammation.

Mushtaq et al. (2018) used aqueous and n-hexane fractions of the methanol extract of the above-ground parts to investigate the anti-amnesic activities of *Lavandula stoechas* L. They found that the aqueous fraction of *L. stoechas* had a memory-enhancing effect in mice compared to the n-hexane fraction and stated that antioxidant activity prevents memory loss by providing defence against neurodegeneration.

Costa et al. (2020) investigated the phanticholinesterase effect as well as the antioxidant effect of the extract obtained from the above-ground parts of *Lavandula viridis*, which is traditionally used in Portuguese folk medicine. They also determined its protective activity against Fe2+ -induced lipid peroxidation in mouse brain tissue.

CONCLUSION

In this study, the biological activities of members of the genus *Lavandula* reported in the literature were reviewed. Since different *Lavandula* species have different pharmacological effects, their biological activities have been studied in a wide range. In addition to antioxidant and antimicrobial activities, antidiabetic, antitumoural, anti-inflammatory and analgesic effects have also been reported in the literature. It is thought that *Lavandula* species, which are widely used in public health, can be used in different designs as a pharmacologically important natural material.

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CHAPTER 2

MYXOMYCETES (MYXOGASTRIA) GENUS TUBIFERA J.F. GMEL. IN TÜRKİYE

Hayri BABA[1], Emre Cem ERASLAN[2], Hasan AKGÜL[3]

1 Department of Biology, Faculty of Science and Arts, Hatay Mustafa Kemal University
2 Department of Biology, Faculty of Science and Arts, Akdeniz University
3 Department of Biology, Faculty of Science and Arts, Akdeniz University

INTRODUCTION

Myxomycetes are a group of amoeboid eukaryotes, placed phylum Amoebozoa of the kingdom Protozoa that produce fungus-like fruiting bodies in terrestrial ecosystems (Akgül et al., 2021; Baba and Akgül, 2024). Myxomycetes (plasmodial slime molds) have a unique life cycle, with the majority of it spent as myxoamoebae and plasmodia, the latter subsequently transforming into tiny sporocarps. Myxomycetes typically produce sporocarps, which release large quantities of airborne spores that are dispersed long-distance globally (Foissner, 2007). They feed on bacteria, yeasts, and other microorganisms and they are playing very important role in balancing soil microbial communities in forests (Gao et al., 2022). Myxomycetes are particularly abundant in forest regions on decaying bark, wood and dead ore live leaves (Stephenson and Stempen, 1994). Myxomycetes are the most numerous microorganisms constituting the soil protist communities (Stephenson et al., 2011). Myxomycetes are important members of the humus ecosystem and play an essential role in ecoregional systems (Novozhilov et al., 2017; Baba and Sevindik, 2024).

Tubifera genus was erected by J. F. Gmel, in 1791 and now this genus has 13 species reported from world (Lado, 2005-2024). Tubifera genus has got cylindric or ellipsoidal sporangia, free or connate on usually thick, spongy hypothallus forming pseudoaethalium (Kharat, 2019). Tubifera Sporophores united by sporothecae, sessile or on a common base. This slime mould is cushion shaped or in a tight cluster like a bunch of flowers. The separate parts sometimes look like hexagons from the top. Usually they have free tips from each other. The spores are coloured like cinnamon or rust.

309 myxomycete species reported so far in Türkiye. These species belong to 5 orders, 12 families and 45 genera (Baba and Sevindik, 2023).

TAXONOMIC CATEGORY OF *Tubifera* J.F. Gmel.

The genus Tubifera is in Liceida order and Reticulariaceae family. Order Liceida fruiting bodies sometimes with calcareous deposits in their structures or without, sessile or stalked. Columella absent. Capillitium absent, rarely there are very rudimentary. Pseudocapillitium sometimes present or absent, when present of tubular, irregular filaments or of perforated plates. Spores are bright colored in mass, sometimes olivaceous or brownish. Order Liceida consisting of 4 families, 12 genera and 187 species (Baba and Sevindik, 2020b).

Family Cribrariaceae fruiting bodies stalked, sporophore types sporocarpic or sometimes pseudoaethalioid. Peridium remaining as a preformed net, with spherical calcic granules 0.5–4 µm diam. Capillitium and

Pseudocapillitium absent. Spores are mostly bright colored in mass. Family Cribrariaceae consisting of 2 genera, 49 species. *Cribraria* Pers. genera has got 47 species and *Lindbladia* Fr. genera 2 species.

Family Dictydiaethaliaceae sporophores are sessile, mostly pseudoaethaloid. Peridium remaining in the upper part as polyhedral plates. Capillitium absent but Pseudocapillitium present, filiform. Spores are clear colored in mass. Family Dictydiaethaliaceae consisting of 1 genus, 3 species. *Dictydiaethalium* Rostaf. genera has got 3 species.

Family Liceaceae fruiting bodies are mostly sessile sometimes stalked, sporophore types sporangium or plasmodiocarp, very minute. Peridium remaining in the lower part; without spherical calcic granules. Capillitium and Pseudocapillitium mostly absent. Spores in mass bright color, sometimes olivaceous, brown or blackish color. Family Liceaceae consisting of 2 genus, 81 species. *Licea* Schrad. genera has got 80 species, *Listerella* E. Jahn genera 1 species.

Family Reticulariaceae fruiting bodies mostly sessile, rarely stalked, sporophores aethalium or pseudoaethalium types. Reticulariaceae is characterized by the absence of true capillitium and pseudoaethaliate or aethaliate structure of the fruiting bodies. Family Reticulariaceae consisting of 7 genera, 54 species. *Alwisia* Berk. & Broome has got 4 species. *Enteridium* Ehrenb. genera 2 species, *Lycogala* Adans. 23 species, *Reticularia* Bull. 8 species, *Siphoptychium* Rostaf. 3 species, *Thecotubifera* Leontyev, Schnittler, S.L. Stephenson & Novozh. 1 species, *Tubifera* J.F. Gmel. 13 species (Lado, 2005-2024).

MORPHOLOGICAL FEATURES OF *Tubifera* J.F. Gmel.

Description: Sporophores united by sporothecae, sessile or on a common base. Pseudoaethalium cylindric or ellipsoid, on a thick, spongy hypothallus, solitary or grouped, walls membranous, granular, persistent, brown, iridescent. Usually they have free tips from each other. Peridium semitransparent, light brown sometimes shining, dull or iridescent. External surface of the peridium is verrucose, internal surface of peridium smooth, with wavy folds and extremely rarely. Dehiscence apical. Hypothallus spongy, early period white but yellowish when mature. Capillitium: lacking. Pseudocapillitium: regularly present in one species, occasionally represented in the others as threadlike processes presumably derived from the walls of abortive sporangia. Columella mostly absent. Spores in mass rust-brown, ferruginous. Spores pale brownish, globose, coloured like cinnamon (Martin and Alexopoulos, 1969; Nannenga-Bremekamp, 1991; Neubert et al., 1993; Ing, 1999; Clark and Haskins, 2010; Baba and Sevindik, 2020b).

According to Lado (2005-2024) there are 13 species *Tubifera* J.F. Gmel. all over the world;

Tubifera applanata (Leontyev & Fefelov) Leontyev & Fefelov

Tubifera corymbosa Leontyev, Schnittler, S.L. Stephenson & L.M. Walker

Tubifera dimorphotheca Nann.-Bremek. & Loer.

Tubifera dudkae (Leontyev & G.Moreno) Leontyev, G. Moreno & Schnittler

Tubifera ferruginosa (Batsch) J.F. Gmel.

Tubifera glareata S.J. Lloyd, Leontyev & Dagamac

Tubifera magna Leontyev, Schnittler, S.L. Stephenson & T. Kryvomaz

Tubifera microsperma (Berk. & M.A. Curtis) G.W. Martin

Tubifera montana Leontyev, Schnittler & S.L. Stephenson

Tubifera papillata G.W. Martin, K.S. Thind & Sohi

Tubifera pseudomicrosperma Leontyev, Schnittler & S.L. Stephenson

Tubifera tomentosa S.J. Lloyd, Leontyev & Dagamac

Tubifera vanderheuliae S.J. Lloyd, Leontyev & Dagamac

According to Baba and Sevindik (2023) there are 1 species *Tubifera* J.F. Gmel. in Türkiye;

***Tubifera ferruginosa* (Batsch) J.F. Gmel. Description:**

Sporophores of *Tubifera ferruginosa* is Pseudoaethalium, solitary or grouped, 4–100 mm long, 4–15 mm wide, 2–6 mm high, rounded, pulvinate to hemispherical, often forming moniliform complexes, yellowish greyish brown the surface formed by the free tips of sporothecae. Sporothecae cylindrical, rounded in cross section, straight, directed from the base to the external surface of the fructification, 0.3–0.5 mm diam. With rounded apex. Hypothallus spongy, foamy white when fresh, sandy-yellow, pale yellow when mature. Peridium membranous, semitransparent, light brown in reflected light, moderately shining (Figure 1).

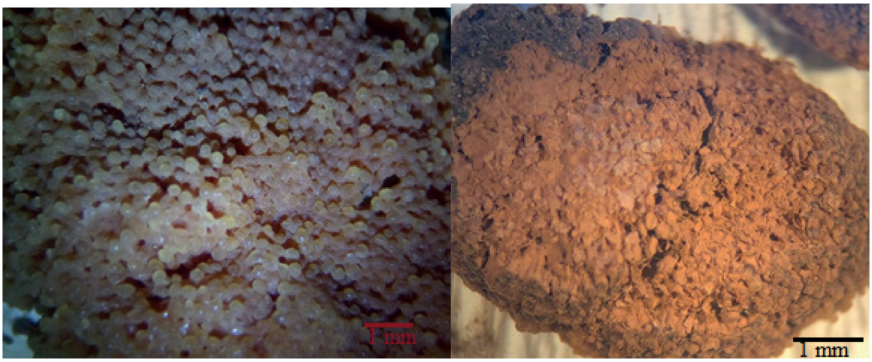

Figure 1. *Pseudoaethalium structure of Tubifera ferruginosa (Batsch) J.F. Gmel*

Columella mostly absent. Capillitium and pseudocapillitium absent. Spores in mass umber brown or rust-brown, in transmitted light pale brownish, globose, (5) 6–7 (9) micrometer in diam, banded-reticulate. Plasmodium bright scarlet (Figure 2).

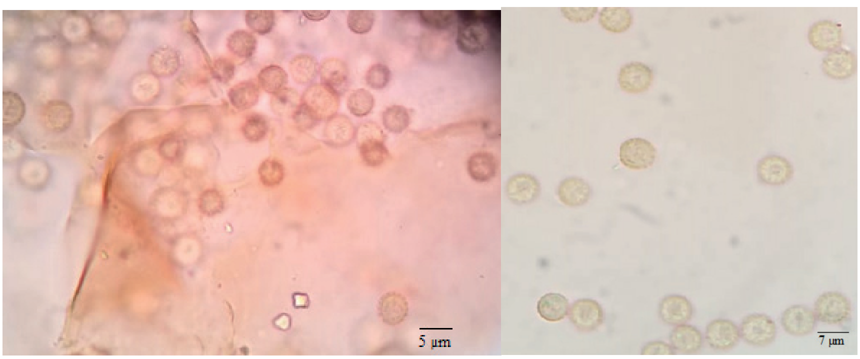

Figure 2. *Banded-reticulate spore structure of Tubifera ferruginosa (Batsch) J.F. Gmel*

DISTRIBUTION OF *Tubifera ferruginosa* (Batsch) J.F. Gmel. in TÜRKİYE

Ergül and Dülger, (2002c); Bursa, Uludadağ-Kirazlı yayla, alt. 1450 m, 24.IX.1999, on fallen twig, CE 192-5. Ergül et al., (2005b); Kastamonu Bartın Küre mountains. Ocak and Hasenekoğlu, (2005); Giresun, Kulakkaya plateau, Keseyol, on wood of *Picea orientalis*, alt. 1300 m, 27.08.1999, Ocak 236-3 (field collection). Yağız and Afyon, (2006a); Derebucak (Konya) and Akseki (Antalya) districts in Turkey, April 2006. Ergül and Akgül, (2011); Bursa Uludadağ-Kirazlı yayla on *Abies nordmanniana* subsp *bornmuellariana.* Baba et al., (2016a); Adana Obruk dead wood, and dead bark of plants on naturel materials. (Baba and Sevindik, 2023).

CONCLUSION

The genus Tubifera is a myxomycete genus easily distinguished by large cylindrical or ellipsoidal sporocarps, united into a pseudoaethalium, densely aggregated on a hypothallus and by the persistent, membranous peridium. Reticulate, small spores and the large fruiting bodies that in some species can reach up to 15 cm in length. This makes it one of the easiest genera to see and to recognize in the field. The absence of capillitium has been noted as a distinctive feature of the genus. In some species, a few thin filaments appear. There are 1 species in Türkiye, *Tubifera ferruginosa* (Batsch) J.F. Gmel.

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CHAPTER 3

THE IMPORTANCE OF WILDLIFE CROSSINGS FOR THE CONSERVATION OF NATURAL HABITATS

Mehmet COLAK[1]

1 Asst. Prof. Dr. , Department of Forest Entomology and Protection, Faculty of Forestry, Karabuk University, ORCID: 0000-0001-6879-6701

1. Introduction

1.1. The importance of wildlife crossings

The impact of human activities on natural ecosystems has increased dramatically in our age, known as the Anthropocene (Crutzen, 2006). Urbanization, the expansion of agricultural land, and the development of transportation infrastructure have fragmented once contiguous natural habitats and threatened the habitats of many species (Forman and Alexander, 1998; Haddad et al., 2015). Habitat fragmentation is considered one of the most important causes of biodiversity loss and threatens ecosystem functioning on a global scale (Wilson et al., 2015; Mitchell et al., 2015).

In this context, ecological passages have emerged as an innovative solution developed to mitigate the negative effects of habitat fragmentation caused by man-made barriers (Forman et al., 2003). Ecological passages are structures that connect natural habitats that are separated by roads, railroads or other man-made barriers. These structures aim to restore habitat connectivity and maintain biodiversity by allowing wildlife to move safely (Corlatti et al., 2009).

The importance of ecological passageways is not limited to the conservation of wildlife populations. These structures also support ecosystem health, genetic diversity and the continuity of ecological processes (Hilty et al., 2020). Recent studies have investigated the effectiveness of ecological culverts and their application in different ecosystems (Sawaya et al., 2014).

The design and implementation of ecological culverts requires an interdisciplinary approach. Effective and sustainable solutions can be created by bringing together fields such as ecology, engineering, landscape architecture and urban planning (van der Ree et al., 2015). In this context, ecological passages are not only an infrastructure project, but are also seen as a strategic tool for biodiversity conservation.

In today's world, where the effects of climate change are becoming more and more apparent, the importance of ecological passages is increasing even more. These structures also act as a kind of adaptation strategy against climate change by facilitating the migration of species that are adapting to changing climatic conditions (Keeley et al., 2018).

The aim of this section is to comprehensively discuss the importance of ecological passages for the conservation of natural life and to summarize current scientific knowledge in this field.

1.2 Habitat fragmentation and its consequences

1.2.1 Definition of habitat fragmentation

Habitat fragmentation is now recognized as one of the most important causes of biodiversity loss (Wilson et al., 2015). Habitat fragmentation is the process by which large and contiguous habitats are divided into smaller and more isolated areas. This process is usually a result of human activities and disrupts the integrity of natural ecosystems. Fragmentation can be accompanied by habitat loss, but it can also occur without changing the total area of habitat.

1.2.2 The main causes of habitat fragmentation

1. **Urbanization and infrastructure development:** The growth of cities and the construction of roads and highways lead to the fragmentation of natural areas.

2. **Agricultural activities:** Conversion of natural habitats or forests into agricultural land fragments large habitats.

3. **Deforestation:** Deforestation and destruction of forest areas leads to severe habitat fragmentation, especially in tree-rich areas and tropical regions.

4. **Mining and energy extraction:** Open-cast mines and the extraction of oil and gas fragment habitats.

5. **Climate change:** In the long term, climate change can lead to habitat fragmentation and displacement. Natural areas are being lost due to global warming.

1.2.3 Effects of habitat fragmentation

The result of habitat fragmentation is the division of large, contiguous habitats into small, isolated patches. This fragmentation process creates a disproportionate number of edge patches, leading to an ecological phenomenon called the "edge effect" These edge patches may have different microclimatic and ecological conditions than the inner parts of the habitat (Murcia, 1995). Higher temperatures, lower humidity and stronger wind influences can be observed at a forest edge compared to the interior. While these microclimatic changes can make living conditions more difficult for some species, they can open up opportunities for others, especially invasive species.

The edge effect not only changes the physical conditions, but also the biological interactions. Invasion by alien species is more likely in marginal areas (Laurance et al., 2007). These invasive species are usually organisms that adapt quickly to changing conditions and can compete with native species. As a result, populations of species specific to the interior of the habitat may decline or disappear completely.

Another important consequence of the edge effect is the reduction in species mobility. Fragmented habitats make it difficult for species to move, find food and reach breeding areas (Tucker et al., 2018). A bird species that previously lived in a single large forest may have to fly back and forth between small patches of forest due to habitat fragmentation. This situation increases energy consumption and makes them vulnerable to predators.

Habitat fragmentation also disrupts ecological processes. Important ecological processes such as food chains, pollination and seed dispersal are negatively affected by fragmentation. In a pollination relationship, a flowering plant and an insect species that pollinates it can be separated by habitat fragmentation. This situation jeopardizes both the reproduction of the plant and the insect's food source (Tilman et al., 1994).

Habitat fragmentation has many negative effects on ecosystems and biodiversity. Fragmentation constricts species' habitats and isolates populations, which can lead to a decline in genetic diversity and the extinction of some species, causing a loss of biodiversity.

Fragmented habitats can create a suitable environment for the spread of invasive species. Invasive species can often spread rapidly in degraded habitats and displace local species. An open area at the edge of a forest can allow invasive grass species to spread rapidly (With, 2002).

Ecosystem services are the benefits that nature provides to humans and include important functions such as carbon storage and regulation of the water cycle. A fragmented forest can store less carbon and regulate the water cycle less effectively than an intact forest.

There are various strategies to mitigate the effects of habitat fragmentation. These strategies should aim to maintain ecosystem integrity and biodiversity.

1.3. Solutions

It has been emphasized that habitat fragmentation poses a serious threat to the health of ecosystems and the conservation of biodiversity. Solving this problem is possible with a holistic approach and cooperation between different stakeholders.

Legislation includes the development of strategies that prevent habitat fragmentation and promote ecological connectivity. Such regulations form an important basis for the protection and restoration of habitats.

In addition, strategies such as the expansion of protected areas and sustainable land use are among the solutions aimed at preserving the integrity of ecosystems and maintaining biodiversity.

Ecological passages in particular are an important solution in this context. These structures contribute to the free movement of species and the conservation of genetic diversity by providing connectivity between fragmented habitats.

A combination of the above strategies can form the basis of an effective habitat protection and restoration program.

1.3.1 Habitat restoration

Habitat restoration is a process that includes the restoration of degraded areas to their former state and reforestation measures. Such measures play an important role in improving ecosystem functionality of ecosystems and biodiversity (Perring et al., 2015). Restoration is one of the most important steps in restoring the balance of nature and is crucial for the continuity of ecological equilibrium.

1.3.2. Protection Strategies

The expansion of protected areas takes place through the enlargement of existing protected zones and the establishment of new wildlife reserves. This expansion is particularly important for species that require a large distribution area. Large and contiguous habitats ensure the survival of species and the sustainability of ecosystems.

Sustainable land use is an approach that aims to meet human needs while conserving natural resources. Environmentally conscious planning of activities such as agriculture, forestry and urbanization is crucial for preserving biodiversity, maintaining ecosystem services and adapting to climate change. This approach aims to reduce habitat fragmentation and protect soil and water resources while addressing societal needs such as food production and economic development. In this way, the needs of present and future generations can be met in a balanced way

1.3.3. Wildlife Corridors

Wildlife corridors contribute to species mobility and the conservation of genetic diversity by connecting fragmented habitats. These structures play a crucial role in mitigating the negative impacts of large infrastructure projects on natural habitats.

The main contributions of wildlife corridors:

- Restoring habitat connectivity
- Reduce collisions between wildlife and vehicles
- Improve genetic diversity

- Facilitate gene flow between metapopulations
- Support the adaptation of species to climate change

2. Defınıtıon And Types Of Wıldlıfe Corrıdors

These corridors can exist in different types: 1. overpasses (wildlife bridges) 2. underpasses (tunnels and culverts) 3. specialized passages (amphibian tunnels, arboreal crossings)

2.1. Definition and Main Characteristics

Sawaya et al. (2014) demonstrated that wildlife corridors significantly increase gene flow between populations. Studies by Clevenger and Waltho (2005) and Huijser et al. (2009) have shown that these structures can both maintain ecological connectivity and improve road safety.

2.1.1 Definition of wildlife corridors

The identification of wildlife corridors requires a thorough knowledge of wildlife habitats. To this end, the distribution of wildlife populations must be determined using suitable methods.

2.1.2 Criteria for site selection

The optimal placement of wildlife crossings is crucial for maintaining ecological connectivity and increasing road safety. This complex process requires the integrated application of different methods for data collection and analysis. Each method has its own advantages and limitations; therefore, a holistic approach will provide the most effective results.

Data on killed animals can be used in the identification of wildlife passages. Road sections with high collision rates are identified. However, this method alone may not be sufficient to determine the distribution of wildlife populations and crossing zones. Therefore, road mortality data should be complemented by other methodological approaches.

Monitoring studies can be conducted using radio telemetry, satellite tracking devices and/or GPS-enabled collars. The use of collars enables the identification of wildlife locations. Modern GPS technologies in particular are a powerful tool for tracking animal movements. With this method, the movement corridors of animals can be precisely determined.

It is possible to identify crossing points by tracking wildlife signs along roads.

Camera traps make it possible to identify wildlife crossing routes and used passage zones. In addition, genetic analysis of various biological materials (hair, bones, feces, etc.) deposited in the field can determine areas of high population density. Environmental DNA analysis offers a timely application for this research.

Remote sensing systems, especially GIS-based models, can be used to identify fragmented habitats and establish suitable crossings.

Combining these methods to effectively place wildlife crossings will provide optimal results from both an ecological and safety perspective. This integrated approach will play a crucial role in coordinating infrastructure projects with natural habitats.

The location of the crossing has a major influence on the utilization rate. The crossing must be located along the natural movement routes of wildlife. It should create a link between existing habitat fragments. This connection between existing and isolated habitats is important for metapopulation dynamics. The location should be as far away as possible from human activities. Studies show that crossings are less utilized in areas with intensive human activity (Clevenger and Waltho, 2005).

2.1.3 Principles of planning and design

The planning and design of wildlife passages should aim to strike a delicate balance between ecological protection and human safety. This process usually focuses on three main categories:

First, the focus is on threatened or endangered species. This approach is crucial for the conservation of biodiversity. For example, transitions designed for endangered species such as the Anatolian leopard not only support the survival of the species, but also contribute to the conservation of genetic diversity. Such transitions are usually designed specifically with the behavioral patterns and habitat requirements of the target species in mind.

Secondly, transitions are planned for specific taxonomic groups. Passages designed for specific groups, such as amphibians, play a crucial role in maintaining ecosystem integrity. For example, tunnel systems for frogs and salamanders provide safe passage to breeding sites. These crossings are designed according to the specific needs of the target group.

Thirdly, the focus is on large mammal species that pose a threat to the safety of motorists and whose populations are very large. Crossings designed for species such as deer, roe deer, wild boar and jackals are important for both wildlife protection and human safety.

Each category has its own design requirements, which depend on factors such as the species' behavior, habitat preferences and movement patterns. While a crossing designed for lynx should take into account their need for cover, a crossing designed for roe deer should be more open and spacious.

2.2. Flyovers For Wild Animals

Wildlife overpasses are wide, landscaped bridges built over roads or railroad lines. These structures are designed as an extension of the natural habitat and are adapted according to the use by the target species.

2.2.1 Wildlife bridges

Wildlife bridges, or ecological overpasses, are structures that provide safe passage for wildlife between habitats fragmented by highways. These structures are crucial to mitigate the effects of habitat fragmentation and maintain biodiversity (Huijser et al., 2016).

Ecological flyovers are usually wide structures with integrated landscape elements. Clevenger and Huijser (2011) state that these structures should have a minimum width of 40-50 meters. Landscape bridges, which are wider structures, should be between 70 and 100 meters wide.

These structures should be designed to accommodate different species, including large mammals (deer, bears, wolves, etc.), medium-sized mammals (foxes, martens, badgers, etc.), small mammals (rodents), reptiles and amphibians. The effectiveness of overpasses should be improved by site-appropriate planting, noise barriers and light barriers. Research shows that properly designed and positioned ecological overpasses are effectively used by wildlife.

Wildlife bridges not only facilitate the movement of animals, but also contribute to road safety by reducing collisions between wildlife and vehicles. Huijser et al (2016) point out that appropriately designed and positioned wildlife crossings can reduce collisions with large mammals by 80-97%.

The development of wildlife bridges in Turkey has gained momentum in recent years. Turkey's first wildlife bridge was built on the 30th kilometer of the Tarsus-Pozantı highway at Gülek Pass. Subsequently, an ecological bridge was built in Uskumruköy as part of the Northern Marmara Highway ICA project. There are a total of eight ecological bridges in the road network under the responsibility of the Directorate General of Highways. One ecological bridge is under construction on the Aydın-Denizli highway. Fifteen new ecological bridges with different structural features are planned in places such as the Konya-Aksaray state highway, the Kaş-Kalkan road and the Batman-Hasankeyf Suçeken Pass road. In addition, an ecological bridge was opened on the Ankara-Eskişehir high-speed rail line in 2021 (KGM, 2021; 2024).

Considering Turkey's rich biodiversity and extensive road network, ecological crossing structures must be given more consideration in future highway projects. This number is expected to increase in the coming years with growing environmental awareness and sustainable infrastructure projects. In addition, existing highway or railroad bridges should be adapted for wildlife crossing by creating ecological strips along their edges (van der Ree et al., 2015).

2.2.2. Multi-Purpose Bridges (Landscape Bridges)

Multi-purpose bridges, also known as landscape bridges, are innovative structures at the interface between modern urban planning and ecological efforts. These bridges combine wildlife passage with human use by maintaining ecological connectivity while serving the recreational needs of the public. These structures, which essentially combine two main functions, are typically built over wide highways or railroads to maintain local ecosystem connectivity while providing people with access to safe and environmentally friendly transportation alternatives (Forman et al., 2003).

The most important consideration in the design of these bridges is the adequate separation of human and wildlife use areas through appropriate barriers. This separation is crucial to prevent disturbance of wildlife by human activities while ensuring human safety (Iuell et al., 2003). Barriers should be created by dense vegetation, naturalistic rock formations or landscape elements. While the sections intended for humans should include hiking trails, bike paths, running routes, observation points and information boards, the areas reserved for wildlife should have natural vegetation, small water sources, rock formations and microhabitats suitable for different species.

The success of these bridges depends on carefully balancing the needs of local ecosystems and human communities. Van Wieren and Worm (2001) have shown in their study of a landscape bridge in the Netherlands that appropriate design and management can successfully allow both wildlife passage and human use. The benefits of multi-use bridges include increased community support while maintaining ecological connectivity, promoting environmental awareness, supporting green infrastructure solutions in urban planning, and improving quality of life through recreational opportunities.

However, these bridges also face challenges such as high construction and maintenance costs, difficulties in maintaining the balance between human and wildlife use, potential negative impacts such as noise and light pollution, and the risk of sensitive species being disturbed by human presence. In the future, the importance of such multidisciplinary approaches will increase in the face of increasing urbanization and habitat fragmentation (Trocmé, 2005).

2.3. Underpasses For Wild Animals

Wildlife underpasses are structures that are located under roads or other infrastructure. They are generally less expensive than overpasses and are more suitable for certain species.

2.3.1 Viaducts

Viaducts are elevated road structures that span wide valleys or waterways. These structures allow the movement of various species by leaving wide and natural passage areas underneath (Clevenger and Huijser, 2011). They have minimal impact on natural areas. When planning roads, viaducts should be installed whenever possible, especially in ecologically important habitats. This will prevent transportation networks from fragmenting habitats.

2.3.2 Underpasses For Large Mammals

These underpasses are important structures specifically designed for the passage of large mammals such as deer, roe deer or brown bears. According to Clevenger and Huijser (2011), such underpasses should generally be built with a height of 7-8 meters and a width of 10-20 meters. These dimensions ensure a safe and comfortable passage for large mammals. The generous dimensions also allow for natural lighting and air circulation within the passageway, making the structure more natural and attractive. These underpasses are usually created in naturally low-lying areas such as valley bottoms or stream beds. This strategic placement allows animals to follow their natural movement patterns and increases the utilization rate of the passageway. In addition, these large underpasses are often multifunctional; they can be used not only by large mammals, but also by other species such as small mammals, reptiles and amphibians. The interior and surroundings of the underpass should be overgrown with native vegetation to mimic the natural habitat.

2.3.3 Multipurpose Culverts

Although culverts are primarily intended for the passage of water, they can also create safe passage areas for wildlife if they are appropriately designed. These structures, which can become effective crossing opportunities for small and medium-sized mammals, reptiles and amphibians in particular, require consideration of several important factors for successful implementation of wildlife passage. Critical factors include the appropriate configuration of the passage dimensions, the internal environment and natural light conditions according to the requirements of the animals. For example, the width and height of the passage should be suitable for the physical characteristics of the target animal species, the internal surface should facilitate animal movement and there should be sufficient natural light. In addition, appropriate vegetation at the entrances and exits of the culverts and a water flow that does not impede animal passage are important considerations. Mata et al. (2008) have studied the positive effects of culverts on these species. Such studies can help to design more effective culverts for wildlife by analyzing the use of culverts by different species and their preferences. Adapting culverts for wildlife passage can be a cost-effective solution for modifying existing infrastructure, benefiting both water management and wildlife conservation. Therefore, the potential for adapting culverts as wildlife passages should be explored in new road projects or when improving existing roads.

2.4. Specialized Crossing Structures

Some ecological culverts are specifically tailored to the physiological requirements of certain species.

2.4.1 Treelike Transitions

Tree canopy crossings or tree canopy bridges are special structural crossings designed for arboreal or climbing species. These crossings connect habitats that are fragmented by roads or other anthropogenic barriers and allow arboreal animals to move around their natural habitat. These structures, used primarily by primates, squirrels and other arboreal species, can be built with ropes, bridges, suspension systems or natural structures. Tree crossings are particularly effective in creating links between forested areas that have been separated by tree removal or road construction. If well planned, they help to mitigate negative impacts on wildlife and prevent habitat fragmentation. The effectiveness of these crossings depends on the behavioral characteristics of the target species and the design of the crossings. Some species prefer wider and more stable structures, while others prefer thin rope systems. Therefore, the design and placement of arboreal crossings require careful assessment of local ecosystem needs and target species requirements.

2.4.2 Fish Passages

Fish ladders are important structures designed to prevent dams or other hydraulic structures from blocking natural fish migration routes in rivers. Migratory fish follow the water flow, especially during the breeding season, and obstacles such as dams can interrupt this migration. Therefore, fish ladders restore these migration routes and allow fish to maintain their natural life cycle. Fish ladders are usually constructed in two ways: ladder-like structures and bypass channels. The ladder-like structures are equipped with graduated steps to overcome water level differences. The fish climb up these steps one by one to reach the other side of the dam. Bypass channels provide a natural riverbed simulation that directly bypasses the dam. These channels must be designed in accordance with the natural flow and water discharge rates to facilitate fish movement. Silva et al. (2018) emphasize the impact of fish passage on species and the crucial design considerations. Factors such as constructing passages suitable for different fish species and sizes and adjusting the water flow velocity ensure successful use of the passage by the fish. These structures not only ensure the survival of fish populations, but also play a crucial role in maintaining the overall health and biodiversity of river ecosystems.

2.4.3 Amphibian Tunnels

Amphibian tunnels are special culverts designed specifically for small amphibians such as frogs and salamanders. These tunnels prevent roads and other anthropogenic obstacles from interrupting the natural migration routes of amphibians (Beebee, 2013). Since amphibians rely on water and migrate seasonally to their breeding grounds during migration periods, mortality along roads can be significant. Amphibian tunnels prevent mortality and population losses by allowing these species to safely cross to the other side of the road (Hamer et al., 2014). These tunnels feature small and low structures, as amphibians generally prefer smaller passages. Maintaining sufficient moisture in the tunnels is crucial for the amphibians. Moist structures reduce the risk of desiccation and simulate the conditions of the natural habitat (Woltz et al., 2008). Fences may also be required to guide the animals to the tunnels. These barriers prevent amphibians from entering the roadway and guide them to the tunnels (Schmidt & Zumbach, 2008). Jarvis et al. (2019) investigated the effectiveness of amphibian tunnels and emphasized the importance of factors such as wet environment, light and tunnel dimensions in their design. These tunnels can provide safe passage not only for amphibians but also for small reptiles, thus contributing to the conservation of several species.

3. Advantages Of Wildlife Crossing Structures

Wildlife crossing structures are innovative designs developed to mitigate the negative effects of habitat fragmentation. They contribute to species mobility and the conservation of genetic diversity by providing connectivity between fragmented habitats.

Wildlife crossings are structures that connect natural habitats that are separated by roads or other anthropogenic barriers. These crossings can be either overpasses or underpasses and are designed to mitigate the negative effects of habitat fragmentation, especially the division of large natural areas into small and isolated patches. Here are the main benefits of these crossings:

3.1. İmprovement Of Habitat Connectivity

Habitat connectivity refers to the physical and functional links between different habitats. Crossing structures for wildlife serve as bridges between fragmented habitats and enable safe animal movements. This connectivity contributes to the conservation of biodiversity, which encompasses the richness of all living species and genetic variations within an ecosystem.

Studies by Clevenger and Waltho (2005) and Sawaya et al. (2013) have shown that large mammals (such as deer, bears and wolves) use these passages for their daily activities and seasonal migrations. In addition, Krosby et al. (2010) emphasized that these corridors play an important role in the adaptation of species to climate change.

3.2. Support Of Nutrient Cycles

Nutrient cycling represents the circulation of nutrient elements (such as carbon, nitrogen, phosphorus) between biotic and abiotic components in ecosystems. The interbreeding structures of wild animals facilitate the transfer of organic matter (e.g. leaf litter, animal excrement) between different habitats. This transfer increases soil fertility and accelerates the transformation of nutrients by supporting the activity of microorganisms.

Leaf litter transported from a forest ecosystem to a grassland ecosystem enriches the organic matter content of the grassland soil. This increases plant diversity and productivity in that region. Similarly, the droppings of large herbivores (such as deer and roe deer) serve as an important source of nitrogen, and the ability of these animals to move between different habitats allows nitrogen to spread over large areas.

3.3. Support Of Metapopulation Dynamics

A metapopulation refers to a network of interconnected but partially isolated subpopulations. Hanski's (1998) metapopulation theory emphasizes that the exchange of individuals between these subpopulations is crucial for the long-term survival of the species.

Wildlife crossing structures strengthen the metapopulation structure by enabling the movement of individuals between these subpopulations. This leads to: Increased gene flow between metapopulations: The exchange of genetic material between populations is facilitated.

Facilitation of colonization and recolonization: The colonization of empty habitats by new individuals or the reintroduction of locally extinct populations becomes possible.

Balance of source-sink dynamics: Some habitats act as “sources” (areas where the population is increasing), while others can be “sinks” (areas where the population is decreasing). Interbreeding helps to maintain the balance of populations by allowing individual flow between these areas. In source habitats, the birth rate exceeds the death rate and the population growth rate is positive ($r > 0$), leading to migration to sink habitats. In sink habitats, the mortality rate exceeds the birth rate and the population growth rate is negative ($r < 0$), so that the persistence of sink habitats depends on the out-migration of individuals from source habitats (Dias, 1996; Naves et al. 2003).

Reducing the effects of demographic stochasticity (random population fluctuations). Demographic stochasticity refers to random fluctuations in life events such as birth, death and reproduction within a population. This phenomenon, which occurs mainly in small populations, can have a significant impact on population size and structure (Lande, 1993).

Improving adaptive potential: Adaptive potential refers to the ability of a species or population to adapt to changing environmental conditions. Wildlife crossings increase this potential and improve the long-term survival probability of species. The ability of species to adapt to changing environmental conditions improves.

3.4. Conservation Of Genetic Diversity

Genetic diversity is the sum of genetic variation within a species. Frankham et al. (2002) emphasized that a reduction in genetic diversity significantly reduces the long-term survival probability of species. Interbreeding structures in the animal kingdom maintain genetic diversity by facilitating gene flow between populations. These crosses:

Improve gene flow: Sawaya et al. (2014) have shown that interbreeding structures between wild animals significantly increase gene flow between populations.

Reduce inbreeding depression: They reduce negative genetic effects caused by inbreeding (mating between close relatives) (Frankham et al., 2017).

Mitigate the effects of genetic drift: Genetic drift leads to random genetic changes, especially in small populations. Crossbreeding reduces these effects (Balkenhol et al., 2016).

3.5. Reduction Of Road Mortality

Collisions between wildlife and vehicles pose a serious risk to animals and humans. Crossing aids for wildlife reduce this risk by allowing animals to cross roads safely.

Huijser et al. (2009) have shown that wildlife crossing aids can significantly reduce road mortality of large mammals (such as deer, roe deer, wild boar and bears). Jarvis et al. (2019) pointed out that special crossings for amphibians and reptiles significantly reduce road mortality for these species.

3.6. Support Of Ecological Processes

Crossing structures for wildlife support basic ecological processes such as seed dispersal and pollination:

Seed dispersal: Tewksbury et al. (2002) have shown that seed-dispersing animals support the dispersal of plant species through the use of ecological corridors.

Pollination: Aguilar et al. (2006) emphasized that the movement of pollinators is crucial for plant reproduction, especially in fragmented habitats.

4. Evaluating The Effectiveness Of Wildlife Crossing Structures

Wildlife crossings are innovative structures developed to mitigate the negative effects of habitat fragmentation. They contribute to species mobility and the conservation of genetic diversity by providing connectivity between fragmented habitats.

Various scientific methods are used to evaluate the effectiveness of wildlife crossings:

Camera traps and motion detectors: Are used to identify species and numbers of animals using the crossings (Clevenger and Sawaya, 2010). GPS tracking studies: Used to understand animal movements and patterns of use of crossings (Sawaya et al., 2013). Genetic analyzes: Used to assess the impact of crossings on gene flow (Sawaya et al., 2014). Road mortality statistics: Used to measure the effectiveness of crossings in reducing wildlife-vehicle collisions (Huijser et al., 2009). Long-term biodiversity monitoring: Used to understand the impact of crossings on biodiversity over time (van der Grift et al., 2013).

Scientific studies on wildlife bridges in Turkey have increased in recent years. Some important studies in this field can be summarized as follows:

Özcan et al. (2024) conducted a temporal and spatial analysis of wildlife-vehicle collisions on the Ankara-Çankırı highway and provided collision rates for hedgehogs, foxes and martens. Özcan (2021) identified potential locations for wildlife bridges on the İzmir-Çeşme highway (case study) using Geographic Information Systems (GIS) and habitat suitabilityand connectivity models. This study found that approximately 8% of the highway was suitable for potential wildlife bridges.

Studies on wildlife-vehicle collisions in Turkey have generally focused on the species involved in accidents (Tok et al, 2011; Toyran et al, 2018; Bülbül et al, 2019; Çolak and Kabasakaloğlu, 2024). However, there are few studies that provide spatial and temporal information for the siting of wildlife bridges (Özcan and Özkazanç, 2017; 2020; Özcan, 2018).

Future wildlife bridges require comprehensive scientific studies that take into account factors such as wildlife movements, habitat connectivity and road features. In addition, evaluation and monitoring of existing wildlife bridges will ensure greater effectiveness of future projects.

These studies show that scientific interest in wildlife bridges is increasing in Turkey. However, there is a clear need for further research and implementation studies in this area. In particular, more studies are needed to evaluate the effectiveness of wildlife bridges and to investigate their impact on different species.

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