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Mitigating the effects of road construction on arboreal Japanese mammals: benefits for both wildlife and people

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Abstract – Fragmentation of forest habitat has negative effects on arboreal mammals, compromising their natural dispersal and foraging movements. This paper describes an evolving series of mitigation measures aimed at creating cost-effective continuity pathways for arboreal mammals in Japan. The projects have focused on the endemic Japanese dormouse (*Glirulus japonicus*) a scarce, but popular and iconic species which provides an effective vehicle for environmental education and public engagement.

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Introduction

Dormice inhabit the arboreal realm and face many of the same threats that result from human activities. The construction of new roads through forest habitats, and widening old ones, poses a particular problem. Gaps in the tree canopy and disruption of woody shrubs in the understorey will compromise free movement, dispersal and access to arboreal food resources. The negative effects of roads are considered potentially cumulative (Forman et al., 2003) and mitigating them is included in the United Nations Sustainable Development Goals (SDGs), especially with reference to 'Life on Land', creating an implicit need for action to conserve habitat integrity and enhance national prestige.

The status and specialised ecology of the Japanese dormouse (*Glirulus japonicus*) highlight a need for particular consideration. These are small animals (18-30 g) that forage at night, seeking insects, fruits and flowers among the branches of woody vegetation. They also nest in the canopy and rarely come to the ground except for hibernation. They may play an important role in pollinating the trees and shrubs on whose flowers they feed. They are rare and have full legal protection (Minato, 2018). Like their European counterpart, the hazel dormouse (*Muscardinus avellanarius*), conservation measures designed to benefit dormice will benefit a wide variety of other species too, including many insects and plants. Dormice are also attractive animals, popular with the public, and are considered a 'National Icon' in Japan. Consequently, it is ecologically desirable to maintain habitat integrity and incumbent upon road builders to mitigate the effects of their work as far as possible.

The principle of creating arboreal 'bridges' for Primates to help overcome barriers formed by roads is well-known (Donaldson and Cunneyworth, 2015). In Japan, the focus has been on supporting the endemic Japanese dormouse, but the successful creation of arboreal pathways across Japanese roads has not been widely publicised outside that country, apart from a brief note (Minato et al., 2012) and occasional conference proceedings. This paper offers a timely review of several Japanese projects and their value to local communities of both wildlife and people.

Background

In Japan, studies of the negative ecological impacts of roads on wild mammals have focused on roadkill and the barrier effect (Sonoda et al., 2011). The roadkill on Japanese highways has been studied by the Japan Highway Public Corporation since the 1980s. In 2002, at least 35,933 mammals, birds, snakes and turtles were reported killed on expressways (Japan Highway Public Corporation, 2005) Mammalian roadkills include Japanese raccoon dog (*Nyctereutes procyonoides*), Japanese hare (*Lepus brachyurus*), Japanese weasel (*Mustela itats*i), red fox (*Vulpes vulpes*), wild boar (S*us scrofa*), sika deer (*Cervus nippon*) and Japanese macaque (*Macaca fuscata*). Avian victims include pigeons (Columbidae spp.), black kite (*Milvus migrans*), crows (*Corvus* spp.) and Japanese pheasants (*Phasianus* spp.). The number of roadkills has increased as more roads were built (Japan Highway Public Corporation, 1989). Approximately 49 000 roadkills were reported nationwide by expressway corporations in the Financial Year 2019, and the total number on national roads reported to the Ministry of Land, Infrastructure, Transport and Tourism in that year was about 68 000 (Ministry of Land, Infrastructure, Transport and Tourism, 2019).

In response to the environmental impact of road construction, and other building projects, the Japanese government approved the implementation of an environmental assessment for national large-scale projects. Environmentally-friendly roads ('eco-roads'), designed for compatibility with both natural environments and wildlife, began to be constructed. In 1996, the Environmental Policy Framework was enacted (by the then Ministry of Works), and eco-roads were ranked as leading environmental projects

(East Nippon Expressway Company Limited, 2010). Eco-roads have mitigated impacts on the natural environment and actively created environments friendly for wildlife. The Environmental Impact Assessment legislation was enacted in 1997, and road crossing structures were constructed as a mitigation measure to provide corridors for the movement of animals (Kameyama, 1997).

Eco-roads can be generally divided into two types: those designed to increase traffic safety (for example, measures for the Sika deer in Shari, Hokkaido) and those designed to preserve endangered species like the Okinawa rail (*Gallirallus okinawae*) in Okinawa Prefecture and the Iriomote cat (*Prionailurus bengalensis iriomotensis*) on Iriomote Island. Eco-roads could also be a useful mitigation measure for smaller species. In England, country lanes (even those narrower than 6 m) proved to be a barrier for small mammals (Macpherson et al., 2011). At Mt. Fuji in Japan, the Fuji Subaru Line road (width: 5.4 m) was shown to affect the population genetics of an arboreal mouse (*Apodemus argenteus*), (Sato et al., 2020). In western Tokyo, Japanese squirrels (*Sciurus lis*) have lost genetic diversity due to restricted migration into the forest fragmented by the Chuo Expressway (Tamura and Hayashi, 2007).

An eco-bridge for the Eurasian squirrel (*Sciurus vulgaris orientis*) in Hokkaido was constructed on a municipal road in Obihiro City, and supporting structures for the Siberian flying squirrel (*Pteromys volans orii*) were constructed on the Obihiro-Hiroo Expressway (Yanagawa et al., 2004; Asari et al., 2005; Asari, 2008). An eco-bridge for Japanese squirrels was also constructed over the approach road to a housing development in Otsuki City, Yamanashi Prefecture (Sato et al., 2006).

In addition to these larger species, research on the Japanese dormouse (a 'national treasure') indicates that it too requires consideration. This predominantly arboreal animal is highly dependent on the food and nest sites provided by the forest canopy and understorey, and it relies heavily upon habitat continuity (Minato, 2018). Thus, habitat fragmentation by roads would seriously affect its behaviour and survival.

In 1996, the Japanese dormouse was threatened by the construction of a toll road in Yamanashi Prefecture. We began to investigate protection for this species (and the Japanese squirrel), continuing until 2021. Three objectives were pursued: first, to study how small arboreal animals travel off the ground from place to place; second, to explain to the public the importance of corridors used by arboreal animals; and third, to contribute to the achievement of a Sustainable Development Goal. A series of practical projects was initiated, each building on what had been learnt before, adjusted to suit local circumstances. We have carried out three types of canopy-linking projects in Japan: tunnels, a dormouse bridge and suspended arboreal animal-pathways (see table 1).

Project 1 – The tunnel (see table 1, nos. 1 and 11)

Before 1996, when first planning the new road Yamanashi Prefectural Road Public Corporation had intended to cut the forest and level the soil where dormice live. We proposed that they should build a tunnel for the road instead. The initial plan was changed and in 1997, the tunnel was constructed (length: 361 m). The forest remained intact without influencing the dormice or their habitat (fig. 1). However, those benefits came at a high cost, equivalent to more than US$ 17 million, including paving and lighting for the tunnel. Less expensive options were needed.

Nevertheless, two more tunnels (718 m and 343 m long) were constructed later at Owase in Mie Prefecture to avoid destruction of dormouse habitat when a new road was built. The Ministry of Land, Infrastructure, Transport and Tourism had to fell many trees around the tunnel openings and we proposed that they should be replaced by planting young trees grown by local children. This would be especially worthwhile because of the educational value of growing and planting trees to support the Japanese dormouse, an attractive national treasure. They nursed the seedlings of dormouse food trees such as *Rubus buergeri* and *Maesa japonica* from 2016 to 2021 (fig. 1). The highway was

Table 1. Canopy bridges in Japan. Japan has three types of canopy-linking projects: the first is a tunnel, the second is a rigid steel dormouse bridge and the third is a series of suspended arboreal animal pathways. They have been built from Obihiro in the north to Owase in the south.

No.	Year of construction	Type of canopy bridge	Location (city/pref.)	Latitude	Longitude	Type of road	Monitoring method and *monitoring hours	Time from construction to first use	Used by animals
1	1997	Tunnel for dormouse and wildlife	Hokuto/Yamanshi	N35°92′09.21″	E138°43′34.26″	Toll road	Unnecessary	–	–
2	1998	Dormouse bridge	Hokuto/Yamanshi	N35°54′35.32″	E138°25′35.59″	Toll road	Nest box Automatic camera	1 month	*Glirulus japonicus* *Apodemus argenteus* *Sciurus lis* *Parus major*
3	2005	Animal-pathway (demonstration unit)	Hokuto/Yamanshi	N35°54′48.96″	E138°25′44.70″	Private road	Video camera Automatic camera	6 months	*Glirulus japonicus* *Sciurus lis*
4	2007	Animal-pathway	Hokuto/Yamanshi	N35°55′45.21″	E138°25′08.78″	City road	Video camera *2674 hrs	18 days	*Glirulus japonicus* *Apodemus argenteus* *Sciurus lis* *Parus major*
5	2010	Animal-pathway	Hokuto/Yamanshi	N35°56′02.09″	E138°25′15.90″	Prefectural road	Video camera *8.068 hrs	46 days	*Glirulus japonicus* *Apodemus argenteus* *Martes melampus melampus*
6	2011	Animal-pathway	Nasu town/Tochigi	N37°07′14.71″	E140°00′47.28″	National highway	Video camera *5761 hrs	7 hrs	*Apodemus argenteus* *Peteromys momonga* Invertebrates: e.g., *Micadina yasumatsui*

Table 1. (Continued.)

No.	Year of construction	Type of canopy bridge	Location (city/pref.)	Latitude	Longitude	Type of road	Monitoring method and *monitoring hours	Time from construction to first use	Used by animals
7	2013	Animal-pathway	Nagoya/Aichi	N35°15′01.98″	E137°03′27.81″	City road	Irregular surveys	–	–
8	2016	Animal-pathway	Morioka/Iwate	N39°46′04.09″	E141°07′51.01″	National highway	Video camera *4512 hrs	47 days	*Sciurus lis*
9	2019	Animal-pathway	Obihiro/Hokkaido	N42°53′04.06″	E143°10′58.65″	City road	Automatic camera	–	–
10	2021	Four *Mie-no-wa* animal-pathways	Owase/Mie	N34°03′58.74″	E136°10′20.11″	Highway construction roads	Automatic camera *2040 hrs (in an animal-pathway)	85 days (in an animal-pathway)	*Glirulus japonicus* *Apodemus argenteus*
11	2021	Two dormouse tunnels	Owase/Mie	N34°04′21.50″	E136°10′38.44″	Highway	–	–	–

(A)

(B)

Figure 1. Tunnels were an expensive means of avoiding forest fragmentation. A) Fragmentation of forest habitat was avoided in Yamanashi Prefecture by construction of a tunnel, allowing continuous forest to be retained above it. Photograph by H. Aiba. B–C) A similar tunnel was built in Owase to avoid fragmenting forest habitat. Tree saplings were planted around the entrance portals, including species that provide specialist foods for dormice. They were grown from seed for five years by local school children whose contribution to the project was commemorated on a signboard nearby. Photographs by T. Nakamura (B) and K. Kamimura (C). D) Japanese dormouse (*Glirulus japonicus*), a national icon.

completed in August 2021 and the tunnel was in use, leaving most of the forest habitat undisturbed (table 1, no. 11).

Project 2 – the 'Dormouse Bridge' (see table 1, no. 2)

In 1996 trees were felled on the foothills of Mt. Akadake (Yamanashi Prefecture) to construct a toll road. The trees were cut during the winter where dormice had hibernated the previous year. Dormice hibernate in shallow soil, about 4 cm deep, and in decaying tree trunks (Minato, 1992). It takes about 90 minutes for hibernating dormice to begin moving in response to stimulus (Minato et al., 1997), so they cannot easily escape. Therefore, tree felling in winter (especially using heavy machinery) was likely to subject the 'natural treasure' to a crisis. Moreover, constructing the highway would divide the habitat used by dormice.

We argued that the construction of the toll road in Yamanashi Prefecture should not be

(C)

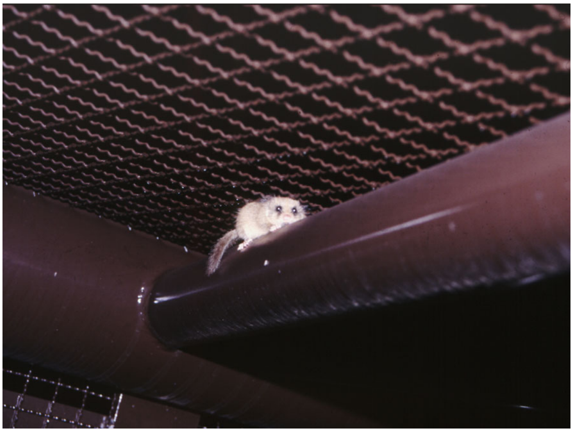
(D)

Figure 1. (Continued.)

allowed to adversely affect the Japanese dormouse, and ways to reduce the harmful effects of the road were discussed with the Corporation. In 1988, ecological surveys were begun around the site, an area covered with deciduous forest on the slopes of Mt. Akadake. The new road would divide the forest and interfere with the movements of arboreal mammals. Surveys confirmed the presence of Japanese dormice and studies were begun to investigate its food and habitat requirements, home range, arboreal behaviour and places used for hibernation (Minato et al., 1997). When the road was built a decade later, a dormouse bridge was designed and sited, taking account of these studies. The 'Dormouse Bridge' itself was created by modifying the overhead steel gantry, square in cross-section, that would accommodate direction signs that guide the traffic approaching a road junction. Alongside these overhead navigation sign boards, a pathway was made using branches, wooden planks and ropes, all supported by the surrounding steel framework (fig. 2).

The bridge (length: 15.11 m, height: 8.9 m) was covered with wire netting (mesh size 3.5 cm × 3.5 cm) through which dormice could move freely, whilst predators were excluded. Another supportive measure was to provide nest boxes, placed inside the bridge as shelters. It was also thought necessary to alleviate fear in animals when using the bridge over a two-lane road, so mesh covered by wooden planks formed the floor of the bridge. This would hide the moving traffic and block

(A)



(B)

Figure 2. The dormouse bridge in Yamanashi Prefecture (table 1, no. 2). A) The dormouse bridge is a rigid steel structure intended to support highway information boards, modified to allow use by arboreal animals. B) Japanese dormouse using in the dormouse bridge.

car headlights at night. Trees were planted at both ends of the bridge to attract dormice and to help them access the bridge, including Korean whitebeam (*Sorbus alnifolia*), Toringo crab apple (*Malus sieboldii*), chocolate vine (*Akebia quinata*) and Japanese clethra (*Clethra barbinervis*). Research had shown that dormice use these as arboreal sources of food and nesting materials (Minato et al., 1997). Tall Korean whitebeam trees were especially suitable because dormice eat aphids from the underside of their leaves. Trees, as high as the bridge itself were planted, screening car lights from the entrances of the bridge. Dead branches were set up to connect the bridge to nearby forest trees. We informed the gardeners in charge of planting trees of the purpose of the dormouse bridge so that they better understood what they were doing and why. Dormice moved to live on the bridge within a month following its construction, and made a breeding nest in the nest boxes (fig. 2). Afterwards Japanese wood mice and Japanese great tits (*Parus major*) used the nest boxes within the bridge as breeding sites. Squirrels used the bridge too, choosing it as a safe route across the road. The Dormouse Bridge, built with steel in 1998, remained in good condition. Maintenance was performed in 2005, replacing wooden flooring, ropes and nest boxes, also the dead branches that linked the bridge to the surrounding forest. This has been the only maintenance necessary in 23 years and cost US$ 5868. However, this bridge incurred a high construction cost, over US$ 165 300, a problem for nationwide popular acceptance.

Project 3 'Arboreal animal-pathways' (see Table 1, nos. 3-10)

In 2003, the Keidanren Nature Conservation Committee of the Japan Business Federation held a meeting on the theme "Utilization of Technologies to Protect Nature". The first author spoke at the meeting to call for bridges that were low in cost and easy for animals to use. SHIMIZU Corporation and TAISEI Corporation responded favourably, offering to collaborate, and in 2004 the Animal-pathways Research Society was formed and began to study arboreal animal-pathways that would be suitable for use by all arboreal animals, not just dormice.

Selecting materials and design

The arboreal animal-pathway is a type of low-cost suspension bridge. Target species include all small arboreal animals. Reducing cost was a priority, but would involve novel designs and using artificial materials unfamiliar to wild mammals. Limited resources, including the problem of working with rare species, meant that formal experiments with statistically robust sample sizes would be impractical. Nevertheless, it was considered necessary to test the feasibility of using artificial materials and observe animals' reaction to structures made with them.

Four studies were conducted to assess suitable materials and functional structure for a suspended animal-pathway that could be used by both dormice and squirrels. We recognised that the materials used must be low-cost, maintenance-free, obtainable anywhere, safe and acceptable to dormice. We chose artificial materials because they are more durable than natural materials which would decompose and could fall on cars and/or people. We tested materials using small indoor observation cages (157 × 87 × 85 cm) made of acrylic sheet for the front and sides, with wire mesh for the roof.

We chose wire netting that is widely available across the country and observed captive dormice to find the best wire size for dormice to pass through and walk on. Wires of different thickness (0.38, 1, 2, and 6 mm) were placed in the observation cages to observe how dormice used them for climbing. In order to avoid influencing the behaviour of the animals ('habituation') the positions of wires of different sizes was changed every two hours. Wire with a diameter of 6 mm was preferred by dormice when climbing (used in 80% of the observations, compared with 18% for 2 mm wire and only 2% of observations involved 1 mm wire).

A larger observation cage (2.5 × 5.0 × 3.0 m), with sides of wire mesh, was built outdoors to test sections of the proposed pathway. We adopted a structure triangular in cross-section (designed by co-author Kazuaki Iwamoto) for the suspended section of animal-pathways. The floor was made of expanded metal netting, which is widely available. Considering the likely deployment of the animal-pathway to snowy regions, aluminium was chosen as the roof material because snow does not readily accumulate on it. One quarter of the roof was made of metal sheet and the rest of wire mesh. Trees were planted inside the cage and dead branches provided runways connecting them with the cage wall. A sample of animal-pathway was installed in the cage to examine the reaction of dormice to its presence and to see whether they would pass through it.

Two dormice used the animal-pathway 301 times during the 7-day observation period. Dormice used the horizontal metal mesh floor in 115 out of 301 observations (38%). The metal mesh roof was also used, accounting for 18.9% of observations (57/301). Although we had worried about dormice slipping on the aluminium roof, they walked on it, apparently without difficulty. A one-way analysis of variance (ANOVA) and Tukey's test ($p < 0.05$) was carried out to evaluate statistical differences in the use of the five component parts of the pathways. Only the count data during first four days were used for the statistical analysis; during the last three days we only recorded the total amount of use. Although the horizontal metal mesh floor seemed to be most frequently used, no significant differences were found, probably due to large variations in daily behaviour. These observations suggest that dormice would freely use all of the artificial materials they encountered. The triangular cross-section of the pathway was also acceptable to the dormice.

The size of the tunnel is known to affect the frequency of use in small mammals (Jackson and Griffin, 2000; McDonald and St Clair, 2004). Triangular wire mesh tunnels with different side lengths between 25 cm and 40 cm were prepared and set up in a natural forest environment in Hokuto, Yamanashi Prefecture. Walnuts were placed at the far end of each type to see if the squirrels would enter and eat them. It was confirmed that squirrels entered and ate walnuts in all sizes of tunnels within a week, so the length of the sides had no effect on their behaviour. Since dormice will use small spaces, we decided to set the side length of the passage as 25 cm.

Initial demonstration site

In 2005, a demonstration pathway was built over a road in a private property in Yamanashi Prefecture (see table 1, no. 3), constructed at a place where there were traces, on both sides of the road, of squirrels feeding in pine trees and bark peeled by dormice. A utility pole was chosen to support the animal-pathway at each end as these are available in all regions in Japan. Using them would contribute to making arboreal animal-pathways more common. Direct observation, auto-camera and video were used to monitor animal behaviour and the effects of snow and formation of icicles. Video cameras at both ends of the animal-pathway recorded motion images of all animals using it for 24 hours. An infrared unit was also set up to study nocturnal behaviour. A car battery provided power.

This demonstration experiment confirmed that both dormice and squirrels would use the animal-pathway. Icicle formation was monitored because it would be dangerous if ice fell and hit cars or people. From 1 October 2015, when the demonstration structure was built, to 23 February 2016, snowfalls were observed on three occasions. Although snow accumulated on the roof and pathway floor, it was insufficient to cause a significant obstruction. It was confirmed that sunlight warmed the aluminium plate of the roof and soon melted any snow and ice. Icicle formation did not occur frequently or pose a risk to traffic below. Following the experiments over the private road, we proposed that arboreal animal-pathways should be constructed over public roads.

Constructing arboreal animal-pathways above public roads

To select a construction site for an animal-pathway we searched for signs of feeding by dormice or squirrels on both sides of the (public) road. We marked the site with coloured tape, blue for dormice and red for squirrels. High-priority sites were those where blue and red tapes occurred on both sides of the road. Presence of evergreen trees was another positive factor, as they provide shelter and cover from predators.

Arboreal animal-pathways were constructed on seven sites, with the basic design modified to suit local conditions. For example, at the animal-pathway in Tochigi Prefecture (table 1, no. 6) the structure had to tolerate strong winds, up to 40 m/s, that occur in this area. The unique feature of the Animal-pathway at Iwate (table 1, no. 8) is that it was assembled in units, also that the roof has a steep slope. It spans a busy road with approximately 28,100 vehicles passing daily. It was not possible to stop traffic for long and we assembled the units that make up the animal-pathway in advance. Each unit was one metre long, with a floor and a roof. We stopped the traffic for five minutes, during which we threaded the units along the wire suspension rope one after the other. The road is four lanes wide, so the animal-pathway needed a median support pole to make it safe. Its roof has a steep slope to prevent snow from accumulating on it as snowfall in Iwate can be up to 80 cm deep.

At Owase, four *Mie-no-wa* Animal-Pathways (table 1, no. 10) were built in 2021. The name was proposed by the Ministry of Land, Infrastructure, Transport and Tourism based on three elements, 1) “*Mie*” is a prefecture in Japan, 2) “*no*” is a conjunction like “*of*” in English, 3) “*Wa*” represents the harmony of symbiosis and environmental cycles in Japanese. “*Wa*” is also part of the word "*Wappa*", a wooden steaming container used for the animal-pathway. Several features distinguish this construction. The first is the construction site, formerly a temporary access road for an expressway. This access road cut through the forest where dormice live, dividing the habitat. Once this animal-pathway was complete, it was intended that no vehicles would pass underneath. Its main purpose was to connect the separated forests with each other until the planted trees in the cleared areas grew up. The materials used here were also different from previous constructions. We chose *Wappa seiro*, a container used for Chinese steamed dumplings (diameter 15 cm; see fig. 3) suspended along ropes 2-3 m above the ground to form shelters. The wappa sections were cheap, lightweight and added to the soil by decomposing. To prevent attack by owls, the sections were set only 30-60 cm apart. The vegetation was also distinctive, and we planted appropriate trees to provide food for dormice (including *Eurya japonica*, *Rhododendron kaempferi* and *Morela rubra*). We designed this wooden animal-pathway to decompose and return to nature, while the planted trees grew to span some of the open space. This animal-pathway was linked to environmental education and SDGs, as discussed later. Dormice began to use the pathway three months after construction.

Utility poles were erected to support the pathways at each end (fig. 4). They were wrapped with sheets of fiber matting to assist climbing by arboreal animals. A supporting cable was strung between the poles and sections of the triangular pathway were hung along it. Aluminium sheet was used to make small shelters along the pathway, providing refuges from predators and snow (fig. 3). They might also offer security for animals moving high above a busy road. Any nesting materials would need to be removed after reproduction and this work would be an expensive burden. An open triangular shelter that provided protection, but did not encourage nest building, was preferable. Branches and flexible tubes were used to span the gap between the utility poles and nearby trees, linking the bridge to the surrounding forest. Rope was provided within the triangular tunnel, in the apex of the roof, because our studies in observation cages (Vogel et al., 2002) and in the wild showed that dormice often travel by hanging upside down on the underside of branches.

Monitoring animals using the arboreal animal-pathways

Monitoring confirmed that arboreal Japanese mammals will use the animal-pathway, including the small Japanese field mouse, Japanese dormouse, Japanese squirrel (*Sciurus lis*) and the Japanese marten (*Martes melampus*) (fig. 5). Camera trap images and videos show that dormice travelled by hanging under a rope below the roof of the bridge. The mice ran quickly through, using the floor of the animal-pathway, but martens walked slowly. From 2007 to 2009 the first animal-pathway in Yamanashi Prefecture (table 1, no. 4) was used 1510 times for 2674 hours in total, between 9th August in 2007 and 27th November, with an average of seven per night. In 2010, the second animal-pathway (table 1, no. 5) was used 378 times for a total of 4518 hours between 3rd May and 5th December, with an average of twice per night. In the first Animal-pathway the mouse (*Apodemus argenteus*) was most frequently recorded on the bridge (79.5% of observations), the Japanese dormouse less often (19.1%). Squirrels (1.1%) and martens (0.3%) used it only occasionally. In the second animal-pathway *Apodemus argenteus* was again the most frequent user (81.1% of observations), while the dormouse was recorded less often (15.6%) and martens used it infrequently (3.3% of records).

Mice were active for the longest period during the night, from 18:00 h to 05:00 h, with the most frequent use between 20:00 h and 21:00 h. Dormice were active from 19:00 h to 05:00 h the next morning. martens used the animal-pathways between 19:00 h and 03:00 h. (fig. 6).

When using the pathway, the animals usually travelled on the metal mesh floor, despite the mesh allowing them to clearly see the road below. This demonstrates that a see-through floor was acceptable for these arboreal animals. Round pipes linking the bridge to nearby trees were used by both dormice and mice. Shelters

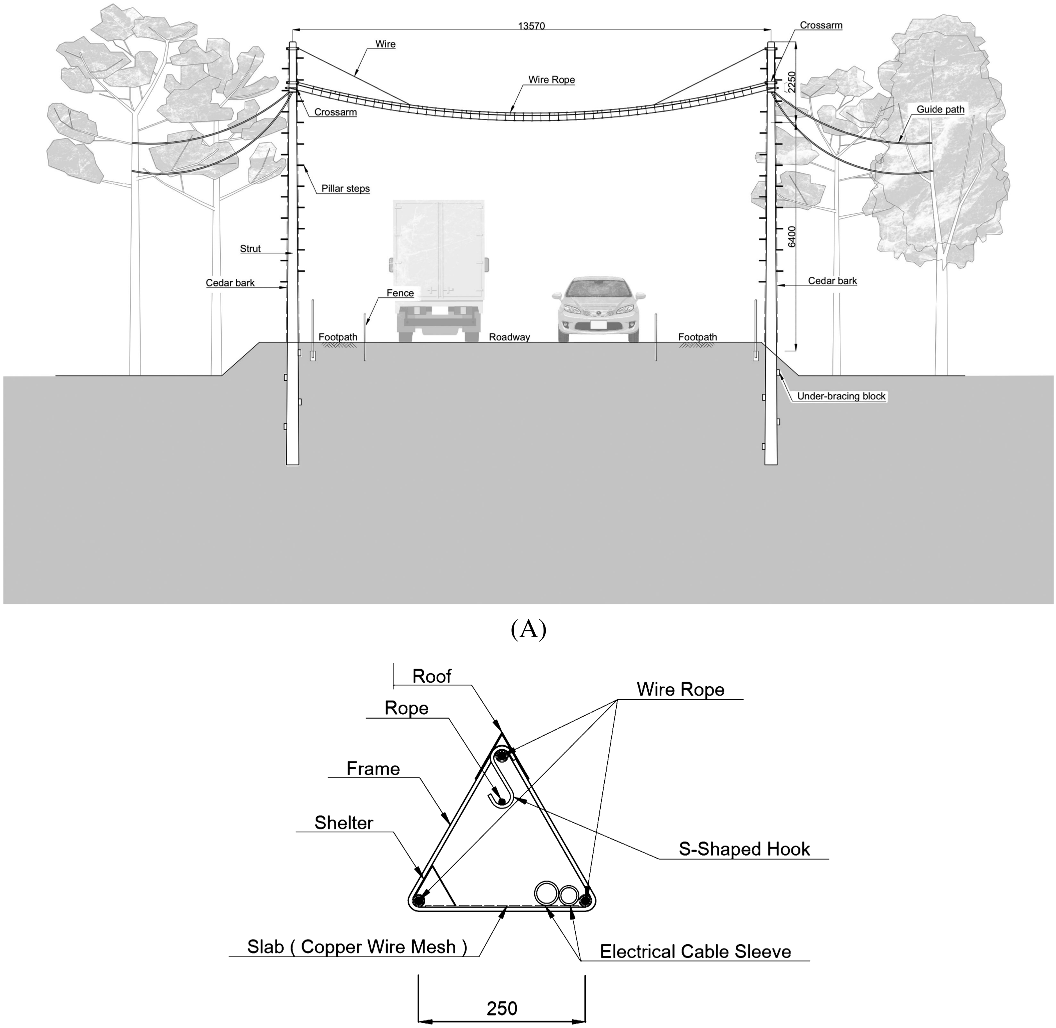


Figure 3. Structure of the animal-pathway designed to enable small arboreal mammals to cross roads without coming to the ground. A) The animal-pathway is a suspension bridge between two utility poles with access routes provided by branches linking the bridge to nearby forest trees. B) The animal pathway has an aluminium roof and wire mesh floor. The triangular frame supports are stable and hang from a central cable. C) The suspended animal pathway has an aluminium roof and expanded metal or wire mesh floor. The triangular supporting frames hang from a central cable and are spaced closely to deter attacks by owls.

along the pathway were also frequently used, especially by mice (table 2).

In Tochigi Prefecture, the activity of mammals, and some invertebrates was monitored, revealing that a dormouse used the animal-pathway at 00:17 h on the same night that the installation was completed. It was later used by the Japanese lesser flying squirrel (*Pteromys momonga*) and many invertebrates including Opiliones, Phasmids (*Micadina yasumatsui*) and earwigs (*Anechura harmandi*), also the larvae of Lepidoptera.

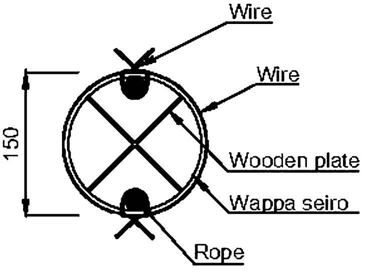
Environmental education and popularization

The Ministry of Land, Infrastructure, Transport and Tourism asked us how to protect dormice where they were constructing an expressway in the mountains near Owase City.

(C)

Figure 3. (Continued.)

(A)



(B)

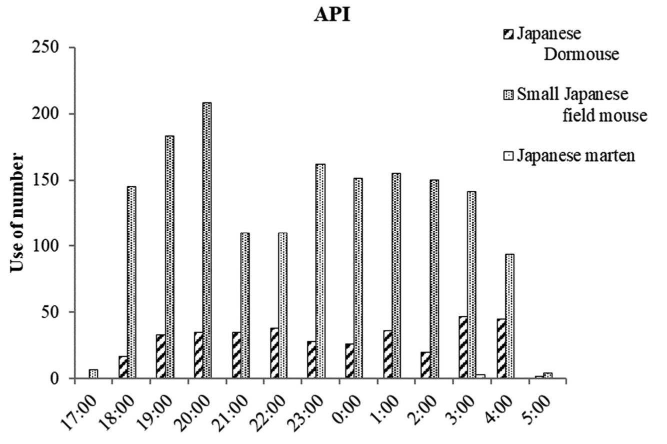
Figure 4. Four wooden *Wappa* animal-pathways were erected in Owase where forests had become separated by the construction of a highway. A) This wooden Wappa Animal-pathway in Owase was installed below the highway, with seedlings grown by local school children planted around it to provide food for dormice and deer. Photograph by H. Aiba. B) The wooden rings were supported along two ropes and designed to decay and fall off as the vegetation below matured.

(A)

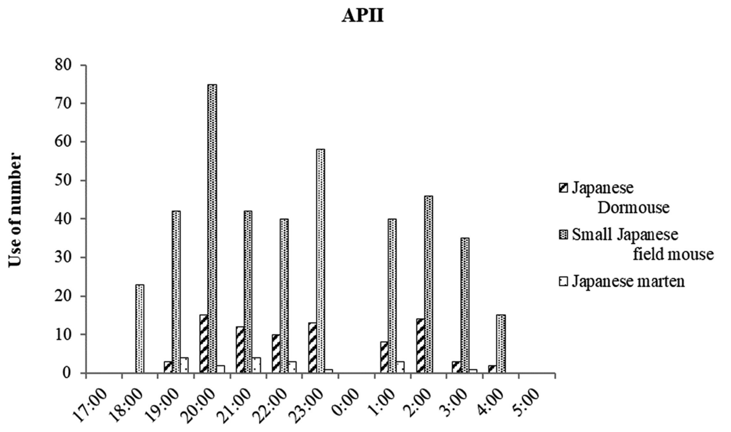
(B)

(C)

Figure 5. Animals using the pathway. A) Squirrel using the Dormouse Bridge in Hokuto. Runs quickly, along the mesh floor. Photograph by K. Otake. B) Marten using the pathway at night, moving slowly along the floor. Source: Animal-pathway & Wildlife Association. C) A Japanese dormouse using the central rope to travel along the pathway, typically, hanging upside down below it. Source: Animal-pathway & Wildlife Association.



(A)



(B)

Figure 6. Periods of use of two animal-pathways during the night by three species (*A. argenteus*, *G. japonicus*, *M. melampus*). A) Periods of use of the Animal-pathway AP1 in Hokuto, (table 1, no. 4) during the night by three species (*A. argenteus*, *G. japonicus*, *M. melampus*). B) Periods of use of the Animal-pathway AP2 in Hokuto (table 1, no. 5) during the night by three species (*A. argenteus*, *G. japonicus*, *M. melampus*).

We proposed a dormouse survey, installation of arboreal animal-pathways and a major focus on environmental education. Owase City lies in a seismic area where earthquakes and tsunamis are inevitable. The new expressway leading to a forest inhabited by dormice will be used as a refuge from a future tsunami for the citizens of Owase and provide an escape route in the event of a serious disaster. We therefore ran an SDGs education project from 2016 to 2021, linking dormouse conservation, expressway development and disaster prevention. The children saw and learned about dormice and visited the tunnel, expressway and animal-pathway under construction. At the *Mie-no-wa* animal-pathway, some appropriate trees to provide food for dormice had been grown from seeds for five years by children at Owase elementary school.

At Hokuto City, in 2016-2021, we made picture books to popularize the arboreal animal-pathways and donated about 2000 copies to all 5th grade elementary school pupils. Participation by everyone is important, not just experts and administrators, but also ordinary citizens. So, we encouraged local people to participate by using their computer for a project: “You are also a researcher”. We made available on the web recorded images from our monitoring cameras.

Table 2. Components of the Animal-pathway used by arboreal animals (% of observations). Animal-pathways consists of roof, floor, frame, pipe, rope and shelter. All arboreal animals used the floor, but the part and frequency of use varied by species.

Part	Japanese dormouse	Small Japanese field mouse	Japanese marten	Japanese squirrel
Roof	1	0	0	9
Floor	53	64	100	68
Frame	5	1	0	4
Pipe	36	14	0	14
Rope	4	1	0	0
Shelter	1	20	0	5

Participants could select their preferred time period to analyse, watch the videos and note which species were seen and at what times. We received 287 reports from 141 volunteers during about four months, stimulating local interest and saving ourselves much time.

In 2010 an international meeting (COP10) was held in Japan. We contributed the 'Animal-Pathway Booth', visited by 3336 people, held a symposium (3 countries and 72 persons participated) and led a post-conference excursion (10 countries and 30 persons participated). Nationally, we promoted the animal-pathway using TV and radio programs, newspapers and academic conferences, with a total of 129 media contributions (2005-2015). The Japanese government has described our animal-pathway projects via Twitter and Facebook, suggesting that a focus on dormice has influenced national policy. On 7th November 2021 the official website of the Government of Japan introduced our animal-pathways to the world. We also received many civic awards from nature conservation organisations, the Japan Society of Civil Engineers and both local and national Government. In 2015 we were awarded The Grand Prize for the Global Environment from the Fujisankei Communications Group in the presence of the Crown Prince. The present Emperor's family visited the animal-pathway in Tochigi Prefecture in 2018.

Discussion

Between 1997 and 2021, three tunnels, a bridge and eleven arboreal animal-pathways were built in Japan to protect dormice associated with different types of roads (table 1). Most species of Japanese arboreal mammals have used them, and also some invertebrates, indicating that these artificial structures provide a useful form of forest canopy connection for a wide variety of species, despite the unfamiliar materials of which they are made.

Sharing research and experience has provided guidance and inspiration for projects abroad. Knowledge of artificial structures in Japan helped to persuade the British authorities to construct a habitat bridge in England (Morris and Minato, 2012) to assist conservation of the hazel dormouse (*Muscardinus avellanarius*). It was built in 2006 with planted shrubs and some tree stumps. Most of the stumps died, but the rotting wood began to support invertebrates, supplementing the relatively impoverished soil used on top of the bridge. By 2009, at least eight mammal species used the bridge including a mole (*Talpa europaea*) and in 2011, dormice bred in nest boxes on the bridge. The Peoples Trust for Endangered Species (in London) was supplied with a blueprint by the Animal-pathway & Wildlife Association and a modified version was subsequently constructed in the UK across a small railway line; others are planned.

The projects reviewed here represent an evolution of ideas, leading to progressive improvements in efficiency and cost. The first Japanese Dormouse Bridge was made of steel and is very robust. The initial cost was high, but maintenance cost was low. The later arboreal animal-pathways were much cheaper. It was shown that their triangular cross section is mechanically effective, prevents snow from accumulating and can withstand strong winds. The structure is versatile and can be modified to suit the construction site. In Owase, perishable materials were used that could decay as planted trees grew to provide natural arboreal routes for travel. Animal-pathways were used by some invertebrates and mitigation measures to support them are urgently needed (Reck and van der Ree, 2015). Arboreal animal-pathways might help. These structures are economically viable, being made of cheap materials that are available everywhere. They can be constructed in one day, and the maintenance cost is low. But they need careful surveys before construction to ensure that they are built in the best places. They also need to be safe for animals and humans.

To advance the new science of road ecology, widespread collaboration is needed (White, 2015). To involve a diversity of people in the protection of biodiversity, it is essential to provide information that engages their interest. Focusing on charismatic species, like dormice, fosters public engagement and active participation. Conservation measures to protect arboreal animals benefit many other species that use the same habitats, but receive little attention.

Our projects, specifically those in Japan, support national attainment of desirable goals and fully contribute to the criteria set by United Nations SDGs:

1. To “Life on the land”: Arboreal animal-pathways support conservation of forest animals.
2. To “Industry, innovation and infrastructure”: They enhance new infrastructures and assist stakeholders to contribute to wildlife conservation.
3. To “Quality education”: Our projects successfully engaged the interest of schoolchildren and encouraged their active participation in practical outdoor activities. Learning about the wonder of dormouse biology and understanding the importance of sensitive development for highways are components of good citizenship.
4. To “Partnership”: Animal-pathway projects have facilitated collaboration between researchers, commercial companies, local and national government and the nation’s citizens. The combination of different talents and mutual cooperation are key to success.

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Statement of ethics

This study was non-invasive and purely observational.

Conflict of interest statement

The authors have no conflicts of interest to declare.

Author contributions

All authors made significant contributions. S.M., K.O., and K.I.: study design: S.M., H.A., and Y.S.: wrote paper: S.O., H.K., M.I., Y.S., J.S., A.O., O.Y., S.I., Y.K., K.F., T.K., K.K: collected data: S.I. analyzed data. P.M. and M.Y. revised the manuscript. All authors approved the final paper.

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