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Composition of road-killed insects on coastal roads around Lake Shikotsu in Hokkaido, Japan

Yoshiki YAMADA[1], Hitoshi SASAKI[1] and Yutaka HARAUCHI[2]

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INTRODUCTION

Although the ecological effects of roads and traffic are of the same magnitude and importance as any environmental issue, this is not well-known amongst environmental managers and ecologists (Spellerberg 2002). Recent studies have examined the ecological effects of road construction and traffic, including the alteration of the original habitat (Spellerberg 1998; Forman et al. 2003), deaths of individuals (Forman et al. 2003), road lighting (Outen 2002), habitat fragmentation (Angold 2002; Spellerberg 2002), barriers (Anderson 2002; Spellerberg 2002), physical and chemical impacts (Ashmore 2002; Spellerberg 2002; Forman et al. 2003) and roadkill (Ohtaishi et al. 1998; Spellerberg 1998, 2002).

Animal road killings may threaten the sustainability of animal populations (Gloyne and Clevenger 2001; Dickson and Beier 2002). Many reports have examined mammalian (e.g. Gloyne and Clevenger 2001; Saeki and Macdonald 2004), bird (e.g. Dhindsa et al. 1988; Tsutsubuchi et al. 1999), amphibian (e.g. Hels and Buchwald 2001; Yanagawa et al. 2003) and reptilian (e.g. Rosen and Lowe 1994; Row et al. 2007) roadkill, but most such studies have focused on vertebrates. Although some studies have examined insect roadkill, including reports on all orders of insects (Seibert and Conover 1991; Rao and Girish 2007), dragonflies (Beckemeyer 1996; Riffell 1999) and butterflies (Munguira and Thomas 1992; Mckenna et al. 2001) in a variety of countries, very few reports have addressed insect roadkill in Japan (Ohtani 1983; Sunose 2002; Yamada 2002).

The group of insects most frequently affected by road killings varies amongst reports. We speculate that this is partly due to environmental differences. However, the differences in the composition of insect roadkill across variable environmental conditions are not well-known. Riffell (1999) showed that roads located near water enable road killings of dragonflies. In addition, Seibert and Conover (1991), as well as Rao and Grishi (2007), showed that dragonflies and butterflies are easy victims of road killings.

We conducted a survey of insect roadkill to evaluate the order and/or species most frequently targeted by road traffic accidents and how the roadside environment affects the occurrence of roadkills at two environmentally different roads along Lake Shikotsu in Hokkaido, Japan.

MATERIALS AND METHODS

Road-killed insects were collected 12 times at two 1.2-km transects along Route 276 and Route 453 from mid-June to mid-September in 2007 (Fig. 1). Both roads are asphalt pavement with two lanes having widths of 9.50 m and 8.25 m, respectively. Route 276 is located 50–100 m distant from the lakeshore, passes through woodland and crosses several small creeks with bridges and culvert structures. The dominant tree species in the woodland on both sides of the road include *Quercus mongolica* ssp. *crispula*, *Acer mono*, *Abies sachalinensis* and *Picea jezoensis*, and the dominant forest floor plant is *Sasa senanensis*. The slopes along the road edges are covered with grass. Route 453 is situated alongside the lakeshore and crosses several small creeks with culvert structures. The dominant tree species along the hillsides and within the forest on the opposite

[1] Laboratory of Entomology, Graduate school of Rakuno Gakuen University, Ebetsu, Hokkaido 069-8501, Japan
[2] Docon Co., Ltd, Sapporo, Hokkaido, Japan

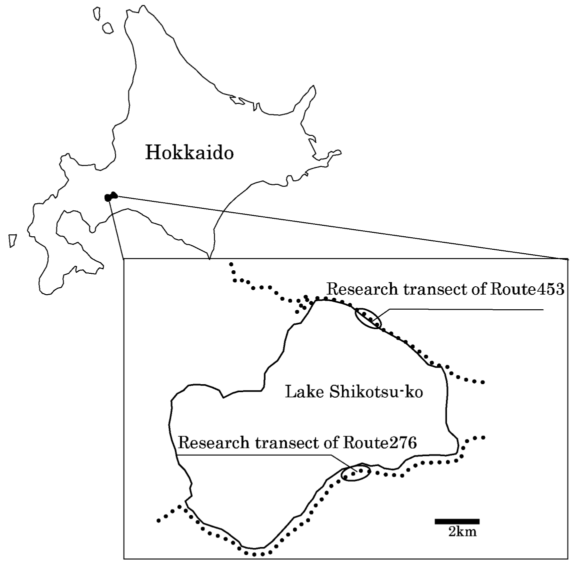

Fig. 1 Location of the study transect, Hokkaido, Japan

side of the lakeshore from the road are *Q. mongolica* ssp. *crispula*, *A. mono* and *Tilia japonica*, and the dominant forest floor plant is *S. senanensis*. The lakeshore side of the road is next to a concrete block revetment. The speed limit on both roads is 50 km/h and the daily traffic volumes on weekdays are 5295 (Route 276) and 4188 (Route 453), and those on holidays are 10662 (Route 276) and 8998 (Route 453) (Japan Society of Traffic Engineers 2007).

Two pairs of investigators walked along both sides each road and collected all dead insects at the same times on the same days. Collections were conducted every Wednesday from 12:00 to 16:00 unless it was raining, in which case the investigation was performed on the following day. If it rained on both days, the investigation was not conducted. The collected road-killed insect specimens were identified by order, and dragonflies and butterflies were identified by species. Data were analysed using a *G*-test with Williams' adjustment (Sokal and Rohlf 1995) to compare the two roads.

RESULTS

Order

In total, 5004.3 dead insects were collected per kilometre, with 2590.1 per kilometre on Route 276 and 2414.2 per kilometre on Route 453 (Table 1). Along Route 276, Lepidoptera accounted for 32.79% of all collected insects, followed by Coleoptera (25.29%) and Diptera (18.52%). On Route 453, Coleoptera accounted for 25.47% of collected insects followed by Diptera (21.33%) and Odonata (17.02%). When classified by order, the composition of collected insects differed significantly between the two roads ($P<0.001$, $G_{adj}=677.504$, $df=7$, *G*-test); i.e., significantly more insects were collected on Route 276 than on Route 453 (Sum *G*, $P<0.001$; pooled *G*, $P<0.05$). The heterogeneity *G* differed significantly ($P<0.001$) between the two roads. Significantly more Odonata and Diptera were collected along Route 453 than on Route 276 ($P<0.001$). Conversely, significantly more Orthoptera and Lepidoptera were collected on Route 276 than on Route 453 ($P<0.001$).

Dragonflies

Along both roads, 444.1 dragonflies in total

Table 1 G-test with Williams' adjustment for insect roadkills on the two roads

Orders	R276[a]	R453[a]	Expected	G_{adj}	*df*	P^{b}
Odonata	33.3	410.8	222.05	378.662	1	<0.001
Orthoptera	106.7	5.0	55.85	113.504	1	<0.001
Hemiptera	221.7	192.5	207.10	2.058	1	ns
Coleoptera	655.0	615.0	635.00	1.260	1	ns
Hymenoptera	252.5	227.5	240.00	1.301	1	ns
Diptera	411.7	515.0	463.35	11.533	1	<0.001
Lepidoptera	849.2	389.2	619.20	174.959	1	<0.001
Others	60.0	59.2	59.60	0.005	1	ns
Sum G^{c}				683.282	8	<0.001
Pooled *G*	2590.1	2414.2	2502.15	6.177	1	<0.05
Heterogeneity G^{c}				678.119	7	<0.001

[a]roadkills/km. [b]'ns', not significant. [c]Sum of *G* and heterogeneity *G* calculated using unadjusted data

were collected per kilometre comprising 12 different species (Table 2). In total, 33.3 individuals were collected per kilometre, including ten different species along Route 276. The dominant species was *Macromia amphigena masaco*, which constituted 30.00% of the collection, followed by *Sympetrum frequens* (20.00%). *Sieboldius albardae*, *Somatochlora viridiaenea*, *Cordulia aenea amurensis*, *Epitheca bimaculata sibirica* and *Sympetrum pedemontanum elatum* were only found along Route 276. On Route 453, 410.8 dragonflies were collected per kilometre comprising seven different species. The dominant species was *Sympetrum infuscatum*, which constituted 50.91% of the collection, followed by *S. frequens* (30.22%). These two species were often observed crossing the road. *Anotogaster sieboldii* and *Anax parthenope julius* were collected only on Route 453.

Butterflies

Along both roads, 955.9 butterflies in total were collected per kilometre comprising 31 species (Table 3). On Route 276, 686.7 individuals were collected per kilometre, representing 24 species. The dominant species was *Bibasis aquilina chrysaeglia*, which constituted 80.58% of the collected butterflies. *Ochlodes venatus venatus*, *Parnassius glacialis*, *Maculinea teleius*, *Rapala arata*, *Strymonidia w-album fentoni*, *Ladoga camilla japonica*, *Neptis rivularis bergmanii*, *Nymphalis antiopa asopos* and *Polygonia c-album hamigera* were collected only on Route 276. On Route 453, 269.2 butterflies were collected per kilometre comprising 22 species. The dominant species along Route 453 was also *B. aquilina chrysaeglia*, which constituted 35.29% of the collected specimens, followed by *Neope niphonica niphonica* (14.86%). *Papilio machaon hippocrates*, *Pieris* (*Artogeia*) *brassicae brassicae*, *Pieris* (*Artogeia*) *melete melete*, *Pieris* (*Artogeia*) *napi nesis*, *Favonius aurorinus*, *Fabriciana adippe pallescens* and *Kaniska canace nojaponicum* were only found along Route 453.

DISCUSSION

Order

We previously reported that Diptera and Hymenoptera were the dominant orders of road-killed insects (Yamada et al. 2002). However, we found that Coleoptera, Lepidoptera and Diptera were the most common orders of insects killed on the roads examined in this study. Furthermore, Seiber and Conover (1991) reported that Diptera,

Table 2 G-test with Williams' adjustment for road-killed dragonflies on the two roads

Species	R276[a]	R453[a]	Expected	G_{adj}	*df*	*P*
Gomphidae						
Sieboldius albardae	4.2	0.0	–	–	–	–
Cordulegastridae						
Anotogaster sieboldii	0.0	0.8	–	–	–	–
Aeshnidae						
Anax parthenope julius	0.0	0.8	–	–	–	–
Corduliidae						
Macromia amphigena masaco	10.0	0.8	5.40	8.858	1	<0.01
Somatochlora viridiaenea	0.8	0.0	–	–	–	–
S. japonica	1.7	0.8	–	–	–	–
Cordulia aenea amurensis	0.8	0.0	–	–	–	–
Epitheca bimaculata sibirica	0.8	0.0	–	–	–	–
Libellulidae						
Sympetrum frequens	6.7	124.2	65.45	128.096	1	<0.001
S. pedemontanum elatum	0.8	0.0	–	–	–	–
S. infuscatum	1.7	209.7	105.70	272.633	1	<0.001
Pantala flavescens	3.3	5.8	–	–	–	–
Odonata spp.	2.5	68.3	35.40	75.985	1	<0.001
Total	33.3	410.8	222.05	378.662	1	<0.001

[a]roadkills/km

Table 3 G-test with Williams' adjustment for road-killed butterflies on the two roads

Species	R276[a]	R453[a]	Expected	G_{adj}	*df*	P^{b}
Hesperiidae						
Bibasis aquilina chrysaeglia	553.3	95.0	324.15	358.223	1	<0.001
Ochlodes venatus venatus	0.8	0.0	—	—	—	—
Polytremis pellucida pellucida	1.7	5.8	—	—	—	—
Thoressa varia	15.8	28.3	22.05	3.552	1	ns
Hesperiidae spp.	11.7	1.7	6.70	8.081	1	<0.01
Papilionidae						
Papilio bianor dehaanii	1.7	4.2	—	—	—	—
P. maackii	5.0	14.2	9.60	4.478	1	<0.05
P. machaon hippocrates	0.0	1.7	—	—	—	—
Parnassius glacialis	0.8	0.0	—	—	—	—
Papilionidae spp.	0.8	3.3	—	—	—	—
Pieridae						
Aporia crataegi adherbal	0.8	3.3	—	—	—	—
Colias erate poliographus	0.8	1.7	—	—	—	—
Pieris (Artogeia) brassicae brassicae	0.0	0.8	—	—	—	—
P. (A.) melete melete	0.0	4.2	—	—	—	—
P. (A.) napi nesis	0.0	3.3	—	—	—	—
Lycaenidae						
Favonius aurorinus	0.0	0.8	—	—	—	—
Maculinea teleius	0.8	0.0	—	—	—	—
Rapala arata	0.8	0.0	—	—	—	—
Strymonidia w-album fentoni	0.8	0.0	—	—	—	—
Nymphalidae						
Apatura metis substituta	7.5	2.5	5.00	2.492	1	ns
Araschnia burejana strigosa	0.8	0.8	—	—	—	—
Argynnis paphia tsushimana	15.8	8.3	12.05	2.325	1	ns
Fabriciana adippe pallescens	0.0	0.8	—	—	—	—
Kaniska canace nojaponicum	0.0	0.8	—	—	—	—
Ladoga camilla japonica	0.8	0.0	—	—	—	—
Neptis philyra excellens	0.8	2.5	—	—	—	—
N. rivularis bergmanii	0.8	0.0	—	—	—	—
Nymphalis antiopa asopos	3.3	0.0	—	—	—	—
N. vaualbum samurai	2.5	0.8	—	—	—	—
Polygonia c-album hamigera	2.5	0.0	—	—	—	—
Nymphalidae spp.	0.0	1.7	—	—	—	—
Satyridae						
Lethe diana diana	12.5	16.7	14.60	0.596	1	ns
Neope niphonica niphonica	14.2	40.0	27.10	12.676	1	<0.001
Zophoessa callipteris	26.7	25.0	25.85	0.055	1	ns
Satyridae spp.	2.5	1.7	—	—	—	—
Total	686.7	269.2	477.95	188.540	1	<0.001

[a]road-kills/km. [b]'ns', not significant

Lepidoptera and Hymenoptera were dominant orders of road-killed insects, whilst Rao and Grish (2007) found that Odonata and Lepidoptera were the main orders of road-killed insects. Notably, the methods used in each of these studies differed; however, we concluded that the differences in the orders of insects killed were due to differences in the environments of the surveyed roads. Indeed, we found that when classified by order, the compositions of the road-killed insects differed between Routes 276 and 453. In addition, we collected more individuals from Route 276 than Route 453. These differences are also likely due to the differences in the environments of the two roads.

The total number of road-killed insects per kilometre on the two roads was 5004.3. However, this is likely an underestimate of the actual number of insects killed because some individuals may have been carried away by vehicles (Mckenna et al. 2001), blown away by the slipstreams from the vehicles (Seibert and Conover 1991) or removed by ants and other insects, as well as birds and rodents (Mckenna et al. 2001).

Dragonflies

We collected 12 species of road-killed dragonflies. Harauchi (2007) reported that 22 species of Odonata reside in the Lake Shikotsu area. Our findings added *A. parthenope julius*, *S. viridiaenea*, *C. aenea amurensis* and *E. bimaculata sibirica* to this list.

More individuals of dragonfly species were collected from Route 453, which is situated beside the lakeshore, than from Route 276, which is located 50–100 m distant and separated from the lakeshore by woodland. Numerous *S. infuscatum* and *S. frequens* were killed along Route 453. These species, known as red dragonflies, prefer habitats near water when migrating to mountainous areas in the summer, which may make them vulnerable to becoming roadkill.

Harauchi (1990, 2007) reported that the nymphs of dragonflies (*S. albardae* and *M. amphigena masaco*) that inhabit Lake Shikotsu often emerge from the concrete block revetment along Route 453 at the north-side of the lake. However, we found more road-killed individuals of these species along Route 276. This is likely because the adults of both species inhabit the forest distant from the lakefront, and Route 276 passes through this habitat. Generally, dragonflies prefer gaps in the forest, such as the brooks and forest roads. This may explain why more dragonflies were found along Route 276, which passes through a forest and thus creates a gap. However, many vehicles pass along this route, creating a hazard for the dragonflies.

We found 46% of the dragonfly species listed in the Lake Shikotsu area along the roads. With the exception of *S. infuscatum*, *S. frequens* and *Pantala flavescens*, these species are consistently found in the Lake Shikotsu area, and thus are most vulnerable to becoming roadkill.

Butterflies

We collected 31 species of butterflies killed along the two roads examined in this study. Harauchi (2007) reported 74 species of butterflies in the Lake Shikotsu area. Our results added *P. glacialis* to the list. In addition, *M. teleius*, which is on the verge of extinction (Environment Agency, Japan 2007), was found along Route 276.

The dominant species collected from both roads was *B. aquilina chrysaeglia*, with more individuals collected along Route 276 than Route 453. This is likely because the species' host plant, *Kalopanax pictus*, is more common along Route 276 than Route 453. The species composition of road-killed butterflies differed between the two roads. This is likely due to differences in the flora found along the roads. In addition, the spatial disposition of Route 276, which passes through a forest, is also different from Route 453, which passes alongside the lakeshore.

We found 41% of the butterfly species listed in the Lake Shikotsu area as roadkll. Numerous species of road-killed butterflies were found along the forest road, gaps in the forest and within grass fields. This suggests that these species prefer these habitats, which may make them vulnerable to becoming roadkill.

Effects of road killings

Munguira and Thomas (1992) reported that motor vehicles kill 0.6%–0.7% of butterfly populations living near roads and suggested that those mortalities were insignificant compared to those caused by natural factors. However, Rao and Girish (2007) suggested that the severity of insect casualties on road is serious and that the conservation of insects near roads is necessary. In addition, Mckenna et al. (2001) suggested that increased rates of traffic and speed limits threaten Lepidoptera species living near roads.

The roadside habitat may act as a sink, source or ecological trap (Battin 2004) for insect populations. If the roadside habitat acts as a sink, it may not be a problem for the insect population; however, if it acts as a source or ecological trap, it may pose a threat of population reduction. In such cases, the insect populations may not be able to withstand road killings for the long term, although this hypothesis has not been tested.

Our results show that differences in roadside environments affect the composition of insects killed along the road. In this study, however, we could not clarify the effects of road killings on insect populations, which requires further studies conducted in a variety of environments.

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要　約

道路の設置環境が昆虫のロードキルに及ぼす影響を明らかにする目的で, 2007 年 6 月 13 日から 9 月 14 日までの期間, 週一回, 合計 12 回, 支笏湖の湖岸を通る国道 276 号線と, 湖岸との間に林を挟んで 50～100 m 離れた場所を通る 453 号線に, 各 1.2 km の調査区間を設定して, その区間内のロードキル個体を採集した。

その結果, 両道路で採集されたロードキル個体の目構成には違いがみられた。国道 276 号線では鱗翅目(32.79%), 鞘翅目(25.29%)及び双翅目(18.52%)が, 国道 453 号線では鞘翅目(25.47%), 双翅目(21.33%)及び蜻蛉目(17.02%)が多く採集された。また, 両道路で採集されたトンボ類とチョウ類のロードキル個体の種構成にも違いがみられた。

Abstract

Road-killed insects were collected 12 times along two environmentally different coastal roads of Lake Shikotsu, Hokkaido, Japan, from mid-June to mid-September in 2007. Route 276 is located 50-100 m distant from the lakeshore and separated from the water by woodland, whereas Route 453 is situated alongside the lakeshore; thus, flora along the two roadsides differ. In total, 2590.1 insects per kilometre were found along Route 276, whereas 2414.2 insects per kilometre were found on Route 453. When classified by order, the composition of the collected insects differed between the two roads: Lepidoptera (32.79%) was the dominant order on Route 276 followed by Coleoptera (25.29%) and Diptera (18.52%), whereas on Route 453, Coleoptera (25.47%) was the dominant order, followed by Diptera (21.33%) and Odonata (17.02%). The species composition of dragonflies and butterflies also differed between the roads. Our results suggest that differences in the composition of insects killed along roads are due to differences in roadside environments.

Key words: insect, invertebrate, Roadkill, road mortality, traffic accident, road ecology.