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Use of radio telemetry for studying dispersal and habitat use of *Carabus coriaceus* L.

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The use of small radio-transmitters (0.6–0.7 g) for tracing movements of *Carabus coriaceus* L. in the field is described. Compared to more established methods such as recapture experiments or the use of harmonic radar systems the main advantage of this method is the possibility of using different frequencies to trace and identify several specimens in the same area and at the same time. Transmission ranges of up to 400 m make it possible to detect beetles even when dispersed over a large area. However, the use of this method is currently restricted to very large carabid species which are able to carry these still relatively heavy radio-transmitters. In 1993 and 1994, behaviour and habitat use of *C. coriaceus* was studied both in a larger forest area and in a small river valley with wet meadows, smaller alder forests and semi-natural brook banks. *C. coriaceus* showed both diurnal and nocturnal activity, but activity was more frequent at night. In the study area this species has a clear habitat preference for ecotone habitats like forest edges. River near stripes of alder forest can serve as a guide-line for dispersal or for orientation within a habitat pattern.

1. Introduction

Dispersal plays an important role for exchange of genetic information between populations and for colonization or recolonization of habitats. Owing to human activity such as agricultural, road construction, new building etc. the number and size of natural and semi-natural habitats have been reduced dramatically. Consequently, populations of species in these habitats have become more and more isolated, and colonization and recolonization processes have been hindered (Mader 1980). This is a serious problem especially for smaller invertebrates with low dispersal ranges, like snails or wingless insects (Mader 1979, Mader *et al*. 1990). Linear or patchy natural and semi-natural landscape features may be important as guide-lines or stepping stones for these species. Therefore, the incorporation of habitat considerations within landscape planning and other nature conservation activities is very important in Germany. To that end a large number of hedges and other linear or patchy landscape features have been introduced by a range of different organizations. However, only little has been known until now about the ecological function of old linear landscape features as guide-lines or stepping stones.

Therefore, one theme within a larger scientific project on habitat and species protection in the "average countryside" is to analyse the ecological function of linear landscape features, e.g. as dispersal routes of carabid beetles and spiders.

Several methods, e.g. marking and recapturing, have been used to study the dispersal of epigeic invertebrates (e.g. Schøtz-Christensen 1965, Nève de Mévergnies & Baguette 1990, Petto 1991). Another method which has been applied with success is the harmonic-radar system (Mascanzoni & Wallin 1986, Wallin & Ekbom 1988, Hockmann *et al.* 1989). Both methods, however, have disadvantages. For the mark-release-recapture method it is impossible to study dispersal of single specimens for more than a few days or over longer distances (> 100–200 m), owing to low recapture rates or the limited number of traps that can be handled. With harmonic-radar systems in most cases only low transmission ranges (1 to 10 m)[1)] are possible and up to now this method has not allowed one to distinguish between individual specimens. For an overview on other remote sensing techniques in entomology, usually applied to airborne or migratory species (e.g. locusts), see Riley (1989).

The use of radio telemetry has been a standard method for many years for studying dispersal and home range of vertebrates (overview in Pride & Swift 1992). As far as we know there have so far been no experiments with similar radio-telemetry techniques on insects. To develop and test this method we started our study with *Carabus coriaceus* L., the largest Carabid species occurring in Western Germany (body length 30–40 mm). *C. coriaceus* is an eurytopic forest beetle, which can also be found in hedges or wet meadows (Thiele 1977, Blumenthal 1981, Lindroth 1985).

In this study we focused on the following questions: (1) Is it possible to use radio transmitters to trace carabid beetles? (2) How precisely can the animals be traced in the field? (3) How large are the dispersal ranges of *C. coriaceus*? (4) What is the habitat preference of *C. coriaceus*? (5) Are linear landscape features used for orientation and as guide-lines?

2. Study area, material and methods

The study area is a typical agricultural landscape southwest of Bonn (North-Rhine-Westfalia). The landscape is characterised by intensively-used arable land, meadows and orchards. Landscape features include smaller semi-natural river valleys with wet meadows, smaller alder forest stripes and semi-natural brook banks. The epigeic fauna of all the areas studied has also been investigated using pitfall traps (Riecken & Ries 1993).

We used transmitters with a weight of 0.6 to 0.7 g originally developed by HOLOHIL-Systems in Canada for tracing small bats (BD-2B crystal controlled two stage transmitter, frequency range: 150.025–150.175 mHz, 25 KHz steps). In 1992 we tested transmitters with different antennae lengths. Our results showed that the optimum length was 5 cm (Riecken & Ries 1992). A longer antenna (10 cm) had only little effect on transmission ranges. On the other hand, a shorter antenna (2.5 cm) reduced the range significantly. Transmitters were fixed on top of the elytra of *C. coriaceus* using a silicone glue (Fig. 1).

We used carbon dioxide as an anaesthetic. For some time after recovering from anaesthesia the beetles usually displayed characteristics of hyper-activity. So we kept them in the laboratory for several hours before releasing them back to the wild. In 1993, fifteen specimens were tagged with transmitters and released in three different areas; —1) six in two groups in a river valley with linear alder forest rows and other ecotone types (e.g. *Urtica dioica* stands) between these forest rows and meadows, — 2) five in a beech/pine forest, where *C. coriaceus* can usually be found, — 3) four in a meadow, where *C. coriaceus* usually does not occur.

Probably owing to bad weather conditions three of the third group's four transmitters broke down after few hours, the last after five days. So we repeated this part of the experiment in 1994, releasing 7 beetles into the same meadow.

As receivers we used FT-290 R/II VHF multi-purpose transeivers (YAESU MUSEN Co., LtD, Tokyo transmitter-unit switched off permanently owing to federal law). We located each specimen twice a day, in the early morning and in the evening. As a first step we took the bearing of the signal. Then we walked in this direction trying to get closer to the beetle. As we approached the transmitters, the angle of bearing usually increased. By reducing the receiver's sensitivity the angle decreased again. First the clarifier was switched on, then the receiver's antenna was shortened. As the final step we used attenuators to cause a reduction of the input signal of 20 dB or even 40 dB. Thus transmitting range could be reduced down to 50 or 100 cm. We stopped trying to locate the specimens at this point to preserve the tagged beetles from being crushed under foot.

[1)] A new system with much greater transmission ranges (up to 100 m) has been applied to bees (Riley *et al.* 1996 and pers. comm.). The main disadvantage of this system is that the 9.4 GHz illuminating transmissions and the 18 GHz return signals are easily blocked by vegetation. Because of this, this new technique can be used only with insects which fly above vegetation (Riley pers. comm.).

3. Results

The maximum transmission ranges were 50 to 400 m depending on landscape features, weather conditions and location of the beetles (e.g. on the surface, under leaves or in a mouse hole). Generally the range exceeded 100 m. In very few situations it was necessary to use an amplifier with the receiver's antenna.

The maximum life span of the transmitter batteries was 28 days. Generally, battery capacity enabled tracing for a 14 to 18 day period. In heavy rain

Fig. 1. Male of *Carabus coriaceus* tagged with a radio transmitter.

Table 1. Sex, body weight, number of activity periods and direct distances of the 12 specimens with functioning transmitters in 1993 (3rd to 20th Sept., A) and six in 1994 (6th to 19th Sept., B) N_{act} – number of 12-hour periods with activity, N_{pass} – number of 12-hour periods without activity, DD_{av} – average direct distance covered within periods with activity, DD_{max} – maximum direct distance per 12-hour period, DD/24h – average direct distance per day, DD_{tot} – total direct distance.

A

No.	sex	weight (g)	N_{act}	N_{pass}	DD_{av} (m) ± *S.D.*	DD_{max} (m)	DD/24h (m)	DD_{tot} (m)
meadow								
1	m	1.322	6	4	2.97 ± 2.9	7.55	3.56	17.80
2[1)]	m	1.355					2.26	5.65
3[2)]	f	1.658					3.64	25.50
river shore/alder forest								
4	m	1.195	9	18	2.38 ± 1.8	6.70	1.59	21.46
5[3)]	m	1.209					3.50	61,35
6	m	1.593	28	4	5.29 ± 4.3	6.70	9.26	148.23
7	m	1.310	15	5	4.70 ± 4.6	13.80	7.05	70.45
8	f	1.878	12	11	2.67 ± 1.4	6.2	2.79	32.05
forest								
9	m	1.353	19	5	10.0 ± 67.9	33.85	15.93	191.10
10	m	1.511	8	13	6.86 ± 6.10	15.10	4.80	48.00
11	f	1.555	4	3	1.76 ± 0.50	2.30	2.01	7.05
12	f	1.715	24	11	16.16 ± 15.0	51.25	22.16	387.80

B

No.	sex	weight (g)	N_{act}	N_{pass}	DD_{av} (m) ± *S.D.*	DD_{max} (m)	DD/24h (m)	DD_{tot} (m)
meadow								
13	m	1.442	16	12	3.93 ± 2.60	11.10	4.22	54.48
14	m	1.357	13	10	4.49 ± 5.00	20.10	5.07	58.35
15	m	1.400	8	5	4.93 ± 5.72	16.20	6.08	39.50
16	m	1.392	18	8	5.23 ± 4.39	16.70	7.25	94.30
17[4]	f	2.083	2	2	2.95	3.40	2.95	5.90
18	f	1.830	9	6	6.10 ± 7.96	28.10	7.32	54.90

[1–3)] signals only sporadic, calculation of DD/24h only based on days with contact

[4)] no signals after 48 h

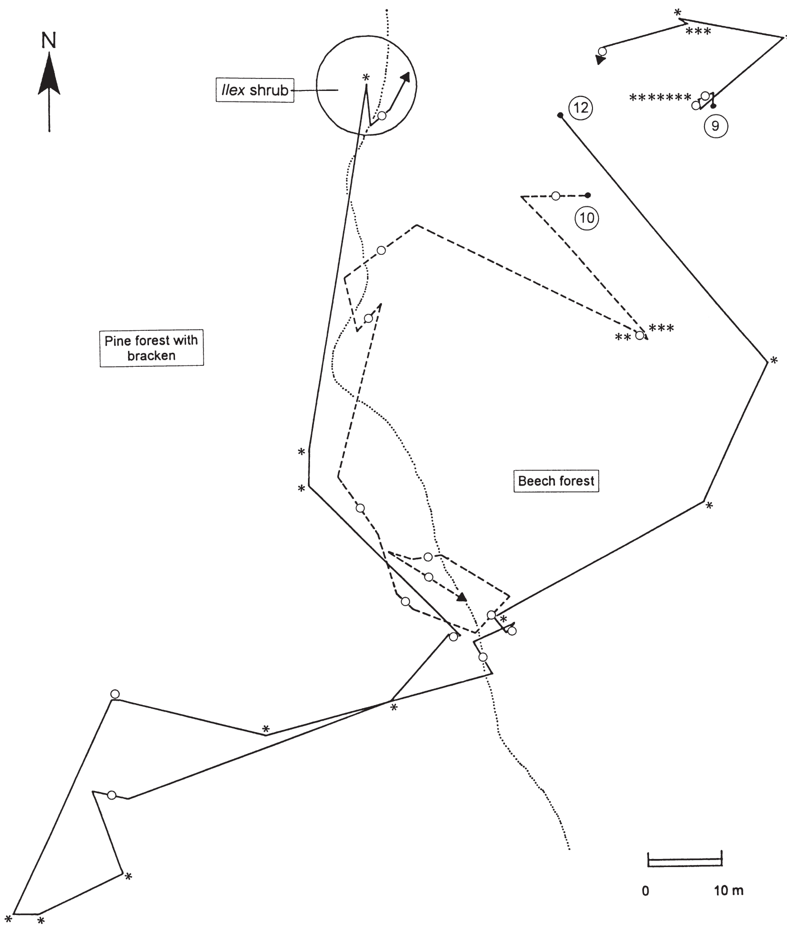

Fig. 2. Movement patterns of three individuals of *C. coriaceus* in a forest (3rd–20th Sept. 1993) * = 12-hour period with no activity or activity below 100 cm, lines with open circles indicate diurnal activity (7.00h–19.00h), lines without circles nocturnal activity (19.00h–7.00h).

some transmitters ceased to function either periodically or completely. In such conditions it was also difficult to get the correct bearing in forests, because wet trees reflect electromagnetic waves. Thus it was sometimes difficult to distinguish reflections from the original signal. On average it took 5 to 15 minutes to locate a specimen within a radius of one meter or below, which is usually sufficient to characterise the habitat. Finding the animals at the end of the experiment took more than half an hour in some cases, especially when the beetle was hidden in a mouse hole or under leaves etc. By watching the signal indicator on the receiver it was possible to locate the specimen within a radius of 15 to 20 cm. Thus all working transmitters were retrieved at the end of the experiment. Only those no longer functioning remained undiscovered.

Three transmitters tagged to the 15 individuals released in 1993 (Table 1A) and one of the 7 released in 1994 (Table 1B) had already stopped transmitting after only a few hours. These specimens cannot be considered. Table 1 gives an overview of the number of 12-hour periods with activity, average direct distance covered within activity periods, maximum direct distance per 12-hour period, average direct distance per day and total direct distance.

The maximum linear dispersal range was 51.25 m in the beech-and-pine forest within a 12-hour period. The average direct distances per activity period were also significantly higher in this area (Table 2). Maximum total distances of 387.8 m in 17.5 days and 191.1 m in 12 days were also recorded in the forest area (Table 1, Fig. 2). Within the forest, movement appeared random and without a preferred direction. The most impressive example was beetle no. 12, which came back close to the releasing point after 18 days and 387.8 meters. As a maximum distance from a releasing

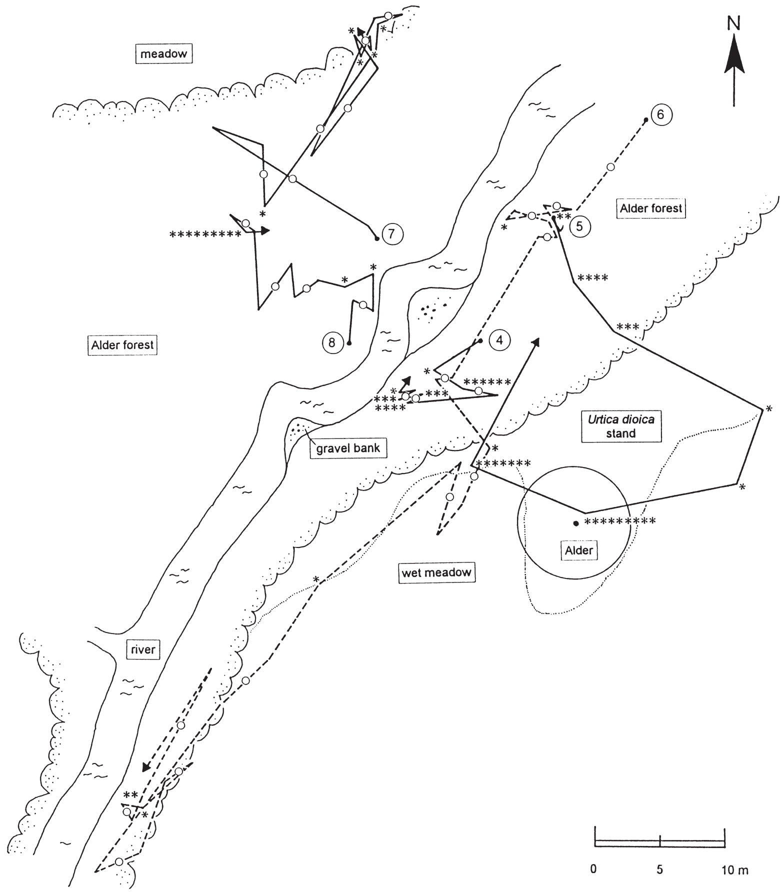

Fig. 3. Movement patterns of five individuals of *C. coriaceus* in a river valley with alder forest stripes and smaller alder forest plots (3rd–20th Sept. 1993) * = 12-hour period with no activity or activity below 100 cm, lines with open circles indicate diurnal activity (7.00h–19.00h), lines without circles nocturnal activity (19.00h–7.00h). The transmitter of specimen no. 5 worked only in the evening or periodically. Therefore diurnal and nocturnal activities can not be distinguished.

point 132.5 m after eight days was measured (again specimen no. 12).

Fig. 3 shows the movement patterns for the beetles released in the river valley. *C. coriaceus* never left the forest rows or the ecotone areas for long. A good example is beetle no. 6. This specimen moved within the alder stripe and the connected *Urtica* stands the whole time with the exception of one short period. After 11 days it reached its maximum distance (71 m) from point of release. Thus the ecotone between alder forest rows (including *Urtica dioica* stands) and the bordering meadows seems to be an important habitat feature for this species and might serve as a guide-line. On the other hand the meadow seems to be an unsuitable habitat for *C. coriaceus* and may even constitute a barrier.

Those specimens released into the meadow showed a distinct reaction. With the exception of beetle no. 15 all specimens moved towards the alder forest, reaching it after a few days (Fig. 4). The distance from the releasing point was 20 m and the horizon angle to the forest was between 53 and 57%. However, two specimens (no. 13 and 15) found plots of higher herb vegetation sufficient for several days. Beetle no. 13 moved towards the forest edge in two stages and stayed in a former ditch now covered with higher vegetation (30–40 cm) for 7.5 days between the two stages. Specimen no. 15 stayed in the *Polygonum* stand for four days before we picked up

Table 2. *t*-test of differences between average direct distances of periods with activity (DD_{av}).

	DD_{av} (m) ± *S.D.*	N_{act}	meadow	forest
river shore	4.30 ± 3.92	64	*n.s.*	$p < 0.001$
meadow	4.59 ± 4.83	70		$p < 0.001$
forest	11.74 ± 12.12	55		

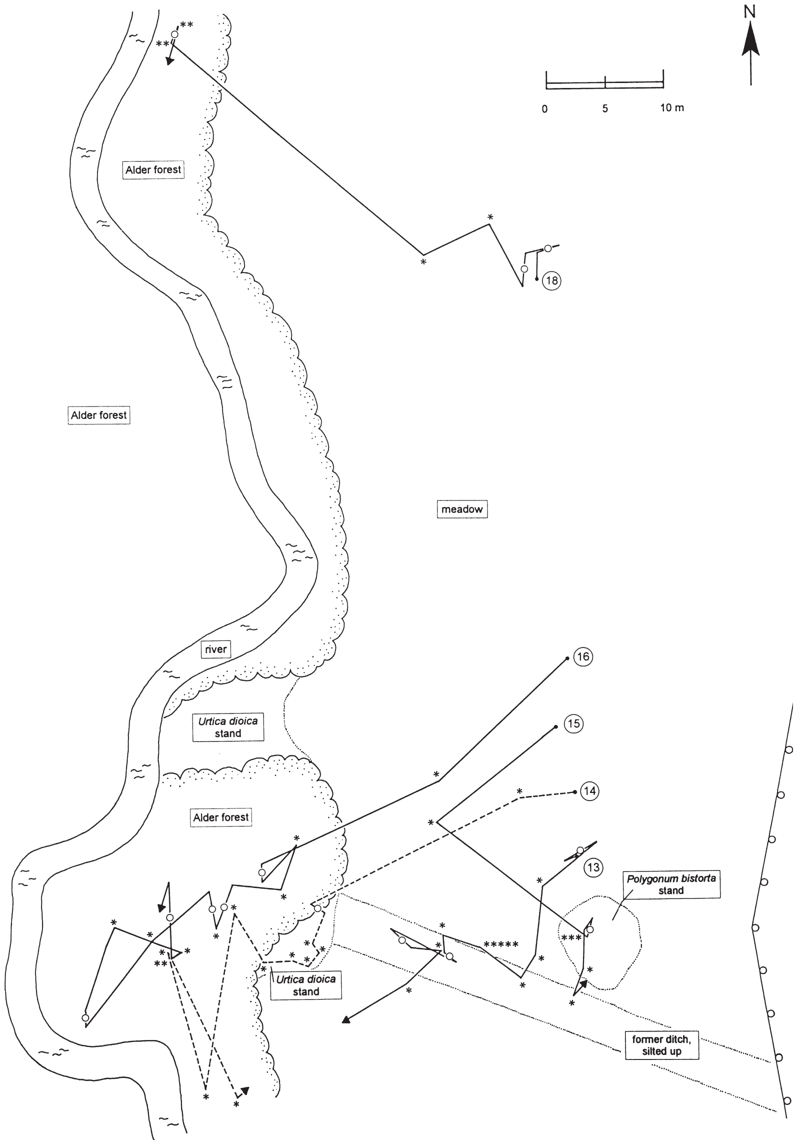

Fig. 4. Patterns of movement of five individuals of *C. coriaceus* in a meadow (6th–19th Sept. 1994) * = 12-hour period with no activity or activity below 100 cm, lines with open circles indicate diurnal activity (7.00h–19.00h), lines without circles nocturnal activity (19.00h–7.00h).

the lost transmitter 6.5 days after release. Owing to the loss of the transmitter we do not know whether this beetle also started to move towards the forest edge after its period in the *Polygonum* stand. One transmitter broke down after few hours another after two days (Table 1, specimen no. 17, not presented in Fig. 4).

C. coriaceus showed both nocturnal and diurnal activity (Fig. 5). During the night the number of activity periods as well as maximum and average direct distances were higher in all areas compared to those recorded during the day. Distances exceeding 20 m were recorded only at night (Fig. 5).

4. Discussion

4.1. Radio telemetry

The study proved that it is possible to use the radio telemetry method with carabid beetles in the field. This technique can be very useful in analysing dispersal, diurnal activity patterns and the habitat selection of larger invertebrates. In comparison with other methods there are some important advantages in using radio transmitters. Unlike the harmonic-radar method radio tracking makes it possible to use several different frequencies. Thus it is possible to identify several specimens individually in the same area. Owing to the relatively large transmission ranges it is also possible to study dispersal over greater distances (several hundred meters to several kilometers) or over longer intervals (i.e. only once or twice a day). However, in contrast to the harmonic-radar method specimens and transmitters can go astray owing to technical problems like short circuits caused by humidity or batteries which run down prematurely.

Another problem is that the use of this method is currently restricted to very large species which are able to carry the still relatively heavy radio-transmitters. The body weight of *C. coriaceus* ranges between 1.2 g in males and more than 2 g in females. Thus the weight of the transmitters ranges between 35% and 50% of the species' body weight. Of course the specimens' behaviour might be affected by the transmitters. In a study on orientation and activity patterns of *Carabus nemoralis* (Hockmann *et al.* 1992) the specimens that had been tagged with a small magnet of up to 101% of their body weight showed an increase in activity in comparison to untagged specimens. However, our experiments in 1992 showed that all recaptured specimens had put on weight during the experiment (Riecken & Ries 1992). Therefore, we concluded that the transmitters do not substantially reduce foraging success. To assess the impact of the transmitters on behaviour and dispersal ranges a comparison between tagged and untagged beetles could be carried out in a future study using the mark-release-recapture method. It is possible that much smaller transmitters will be developed soon. In August 1995, HOLOHIL-Systems completed development of a new transmitter generation weighing only 0.46 g, which is 23% less than the transmitters used in this study.

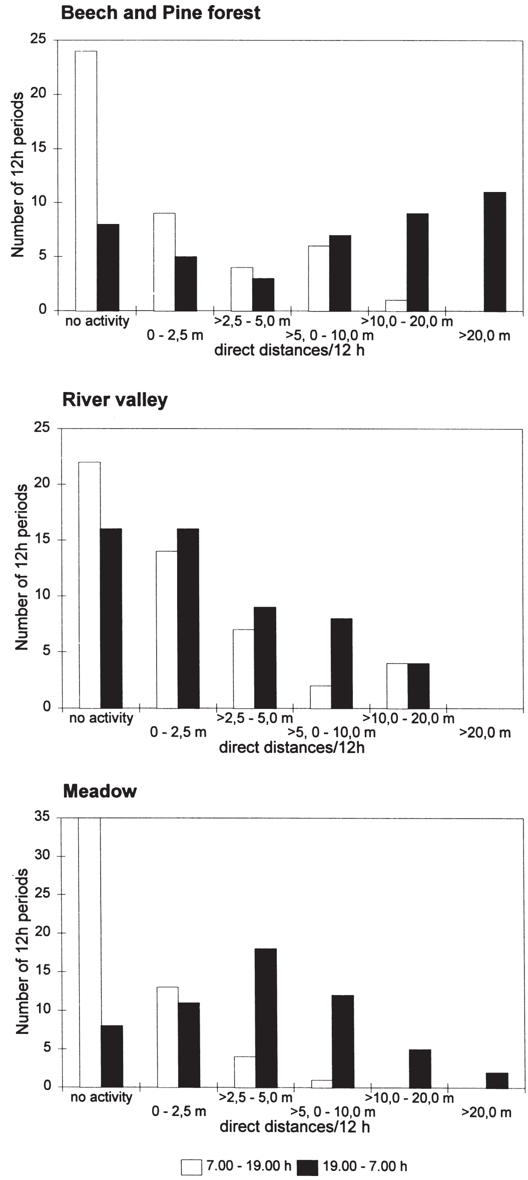

Fig. 5. Diurnal activity (open bars) and nocturnal activity (black bars) and direct distances of movement of *C. coriaceus* in the different study areas.

4.2. Habitat preference and orientation behaviour of *Carabus coriaceus*

In this study *C. coriaceus* showed a clear preference for ecotones and forest edges. In a few cases the alder forest stripes could serve as guide-lines for dispersing specimens. The meadow seemed to be an unsuitable habitat for this species. These results only partly correspond with information given, e.g. by Lindroth (1985) and Thiele (1977), who described *C. coriaceus* as an eurytopic forest species that can also be found outside forests in hedges as well as wet or dry meadows. Most studies on habitat preference of ground beetles have been carried out using pitfall traps. For species with high mobility or dispersal rates, results obtained from this method often do not give an indication of whether the species are indigenous or only caught during dispersal or preycatching activities. Owing to the relatively high dispersal ability and its preference for ecotone habitats including the use of edges of bordering habitats, it seems that former pitfall-trap catches have not reflected the real habitat preference of *C. coriaceus* in all cases. Thus, it can be concluded that *C. coriaceus* is less eurytopic than described in literature hitherto.

Forest edges or linear forest rows seem to play an important role in the orientation of dispersal of *C. coriaceus*. This is also true for other forest ground-beetles like *Abax ater* (Lauterbach 1964, Neumann 1971), *Carabus problematicus* (Neumann 1971) and *C. auronitens* (Weber pers. comm.). In further studies the maximum range and the minimum horizon angle for this effect should be analysed. However, conclusions about the function of linear forests are not nesessarily directly applicable to newly planted hedges. Gruttke and Kornacker (1994) found no evidence of forest species in 9 year old hedges situated in close proximity (200 m) to habitats populated by these species.

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