Length variation and distribution of the lesser stag beetle *Dorcus parallelipipedus* (Coleoptera: Lucanidae)

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Biometry, body length, sexual dimorphism

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The lesser stag beetle (*Dorcus parallelipipedus*) varies considerably in length. To learn more about this variation, an analysis was made of the length of 1282 individuals throughout its distribution range in Europe. Specimens were from museum collections and from populations. The length distribution of this beetle is clearly affected by sexual dimorphism, the males having larger mandibles than the females and thus greater lengths. Therefore, length distributions of this beetle were analyzed separately for males and females. The maximum and minimum lengths found in this study match with the lengths given in the literature. The information given in this study allows comparison of lengths of beetles under different (environmental) conditions or populations to its general distribution of lengths.

Introduction

The lesser stag beetle, *Dorcus parallelipipedus* Linnaeus (figures 1-2), occurs throughout nearly the whole of Europe, southern Scandinavia, Turkey and into southern Russia. The beetle lives in rotting wood (Klausnitzer 1995). Although related to the stag beetle, *Lucanus cervus* (Linnaeus), its appearance is far less impressive, being two to three centimeters long, uniformly black in colour and with much smaller mandibles. Males and females of *D. parallelipipedus* appear similar in length, but the males have larger mandibles and broader heads (figures 1-2). Large numbers of adults and larvae can be found in rotting wood of standing trunks, stumps, thick branches or logs of deciduous trees (Klausnitzer 1995 and personal observation).

There, the beetles (figure 3) live closely together in tunnels that they have created by splintering and moving the wood with their mandibles. The places in between the tunnels are inhabited by the larvae. Larvae also create tunnels, but these are densely packed with wood splinters and their fecal pellets on which they feed occasionally. The larvae pupate in or near the harder parts of the wood. Unlike *L. cervus*, the adults of *D. parallelipipedus* may live for several years (Fremlin & Hendriks 2011). We have an incomplete picture of the species' biology and behaviour due to its secluded life in decaying wood. This makes it difficult to spot and observe the species.

I am performing rearing experiments to study *D. parallelipipedus* behaviour and biology, including whether adult length depends on the conditions under which the larva develops. Earlier studies (Hendriks 2007, Rink 2006, Sprecher-Uebersax 2001) have revealed that fungal activity in white rotted wood is important for the development of larvae of stag beetles (*Lucanus cervus*) and rhino beetles (*Oryctes nasicornis*). To compare the lengths of reared beetles with those of beetles in the field, I searched the literature for the length distribution of *D. parallelipipedus*, but these data appeared not to be available. In various publications, minimum and maximum lengths were given, but these differed considerably (see table 5). The aim of the current study was to provide a length distribution of *D. parallelipipedus* across Europe that will make it possible to compare the lengths of reared and wild beetles, and to compare the lengths of beetles from different populations or different locations. To this end, specimens from museum collections and from the field were measured, besides using data from the internet. Based on these three data sets, I provide a length distribution and maximum and minimum lengths for *D. parallelipipedus*, which I checked against the literature.

Material and methods

Data sets

To assess the length distribution of *D. parallelipipedus*, I collected data from three sources. First, 950 specimens from various museum collections were measured, with samples throughout the species' distribution range. This group is referred to as 'collections'. The second data set consisted of beetles measured in the field, such as beetles found together in dead wood, or in a restricted area, such as a forest or group of trees. It was made sure that this group consisted of beetles that were collected randomly within populations and not with the aim to collect the largest or smallest beetle (table 1). In this way a bias in the measured length due to potential preference of the collector was minimized. The groups of beetles measured in restricted areas were named 'populations' and consisted of a total of 332 individuals. In addition, I placed an appeal for length data of *D. parallelipipedus* on the internet site of the 'European stag-beetle discussion group'.

1. Female of *D. parallelipipedus*. Photo: Paul Hendriks
1. Vrouwtje van *D. parallelipipedus*.

2. Male of *D. parallelipipedus*. Photo: Paul Hendriks
2. Mannetje van *D. parallelipipedus*.

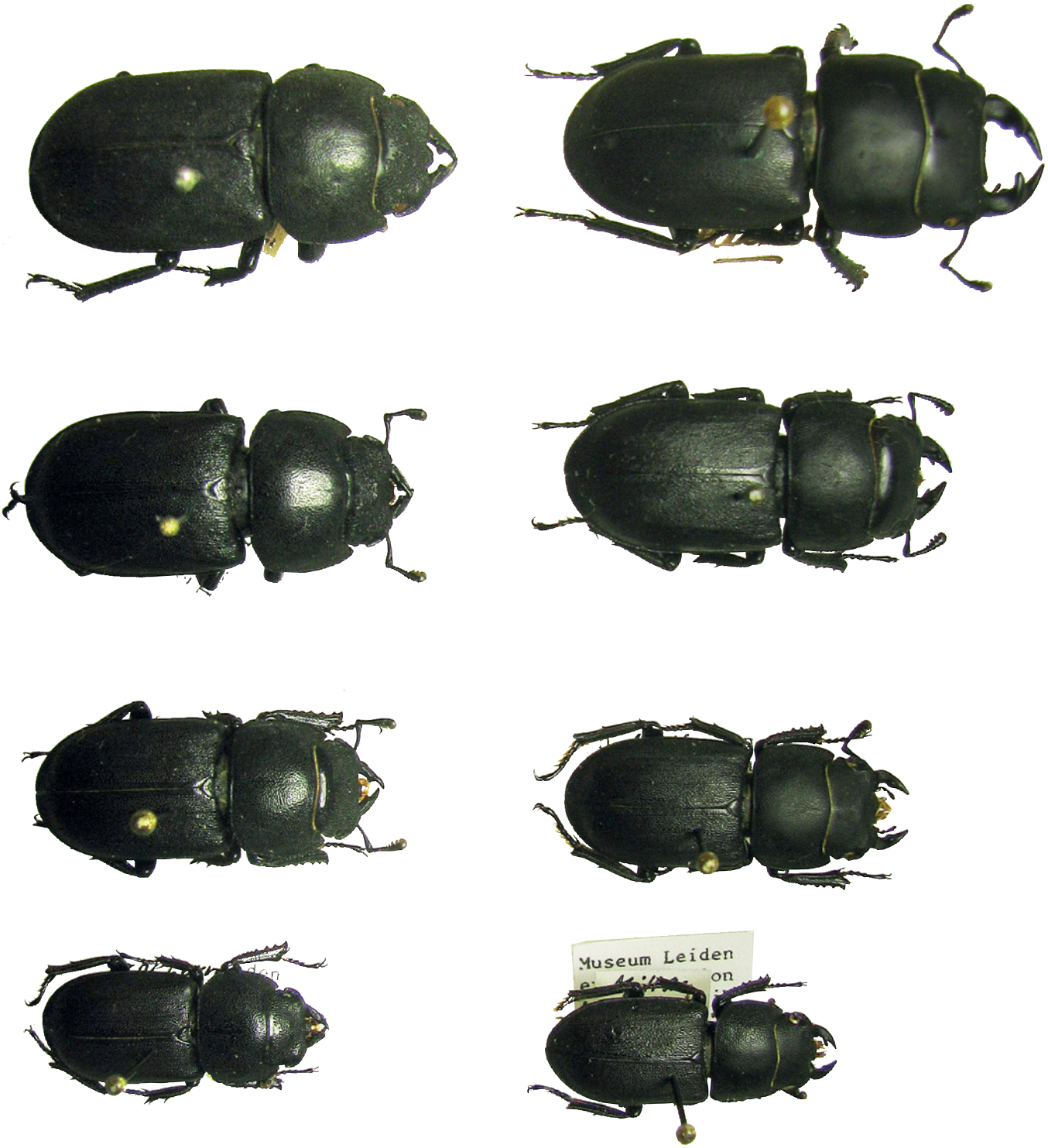
The total length of all beetles was taken in millimeters from the end of the elytra to the end of the mandibles because lengths in literature are given this way. Finally, I gathered records of maximum and minimum lengths of *D. parallelipipedus* from the internet, only using measurements that could be verified, for example, from photos with a ruler alongside the beetle.

To compare the data obtained in my study with literature, I carried out a literature survey, starting from the reference lists of several studies on Lucanidae, such as those of Klausnitzer (1995) and Franciscolo (1997).

Statistical analysis

Length data per group (collections or populations) were first analyzed with a normality test (Kolmogorov-Smirnov) for males and females separately. Male and female length of the collection and population groups were then compared using the Mann-Whitney U-test. I provide descriptive statistics (the mean, medium, 25 and 75 percentiles and standard deviations as well as maximum and minimum length) for collections and populations separately, and for the combined data set to provide general insight in the beetles' length distribution throughout Europe.

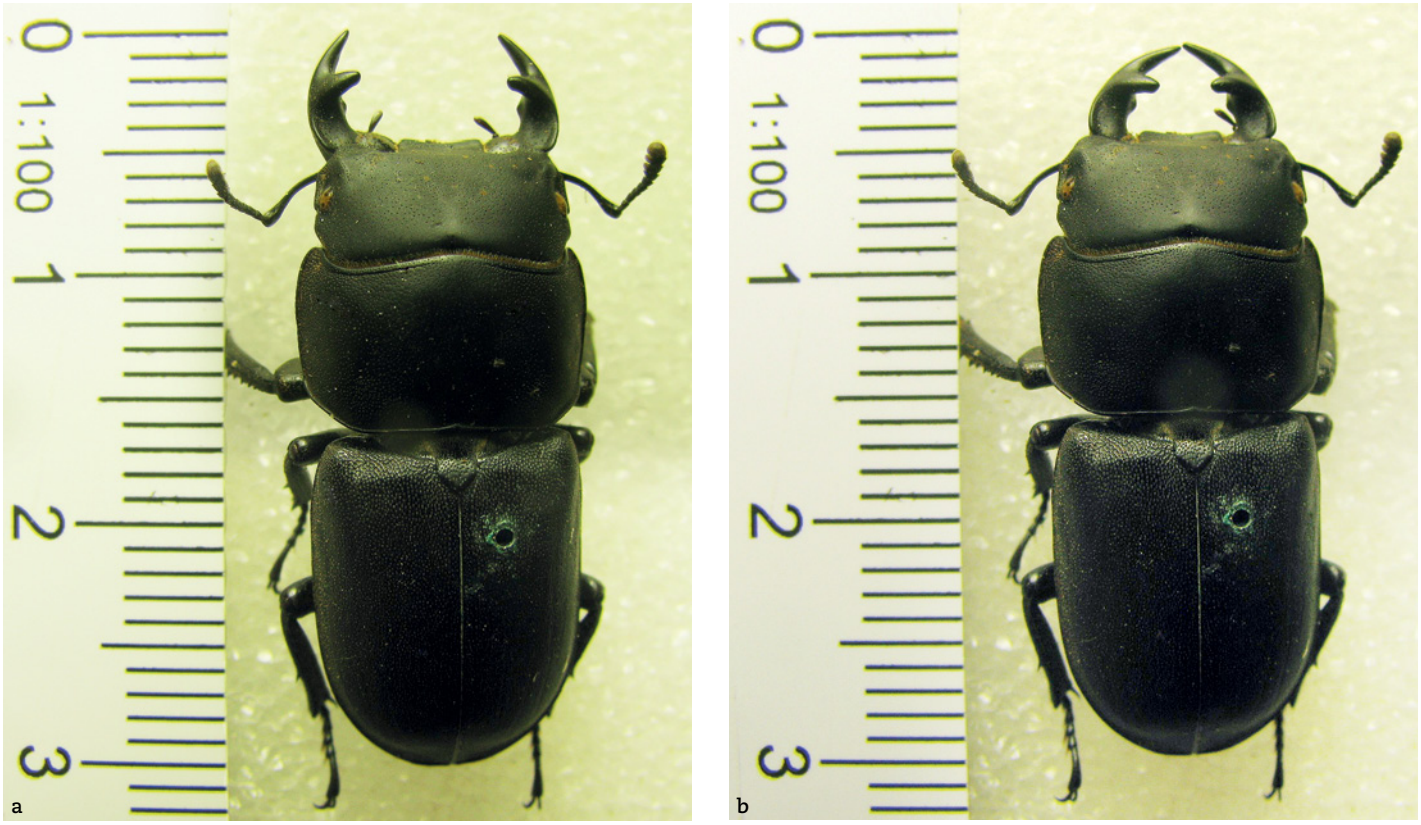
I carried out a second analysis of length data to establish whether the sexual dimorphism of *D. parallelipipedus* can be explained by a difference in mandible length between the male and the female. For this, I took the total length of 91 available beetles (58 males and 33 females), as well as the length from the end of the elytra until the front part of the head (mouth parts) of these beetles, thus excluding the mandibles. I refer to this latter measurement as body length. Via correlation and regression, I established the relation between total length (including mandibles) and body length (without mandibles) for these 91 beetles. This relationship was then



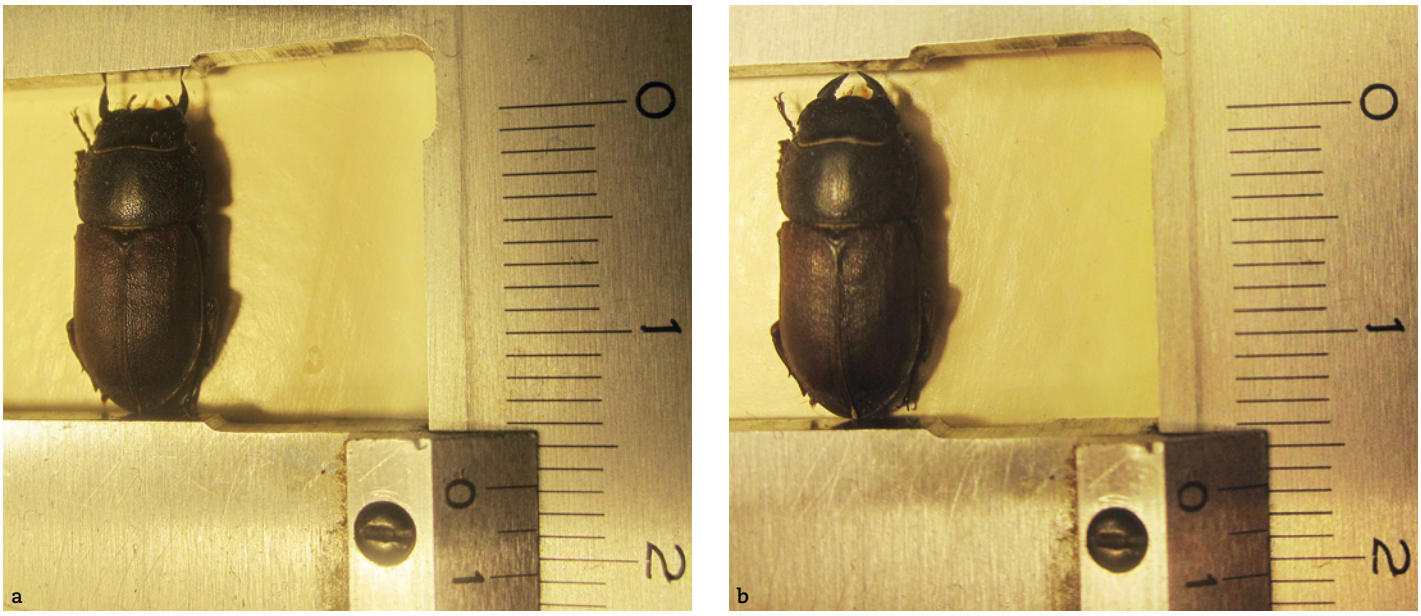
3. Length variation in *D. parallelipipedus*. Males, left row, 29-18 mm. Females, right row, 26-18 mm. Photo: Paul Hendriks
3. Lengte variatie van *D. parallelpipedus*. Mannetjes, linker rij, 29-18 mm. Vrouwtjes, rechter rij, 26-18 mm.

used to calculate body length from total length for the entire set of beetles. Total length and body length of males and females for the entire set of beetles were statistically analyzed, using the Mann Whitney U test. One set of length data from English beetles (C. Hawes, Ipswich, table 1) consisted of body lengths. Table 1 shows the estimated minimum and maximum total lengths of these beetles to allow comparisons with the other groups of beetles.

While measuring the dried individuals in museum collections, I noticed that the mandibles varied in position, being either folded to the head, open wide or in a position somewhere in between. This gave a problem in the analysis of the results; fully opened or closed mandibles sometimes leading to a difference in total length of 3 to 4% in the largest beetles (see figure 4); in females, this difference is 1 to 2%. As it was not always clear whether the beetles were measured with open or closed mandibles, the extra length of beetles with open mandibles was added to the total length of the largest beetle in the descriptive statistics of the total group of beetles (table 3). This was done to make sure that the maximum length was established. The largest male beetle in the entire data set was 30 mm. Adding 4% extra length results in



4. Difference in total length of a large male beetle with (a) open or (b) closed mandibles. Photos: Paul Hendriks
4. Verschil in lengte van een groot mannetje met (a) open en (b) gesloten kaken.



5. Difference in total length of a small male beetle with (a) open and (b) closed mandibles. Photos: Paul Hendriks
5. Verschil in lengte van een klein mannetje met (a) open en (b) gesloten.

a maximum length for male beetles of 31 mm. In females the added 2% led to a maximum length of 27 mm (largest measured female was 26 mm). Adding extra length was not done for the smallest beetles, as there is no discernible difference in length when measured with opened or closed mandibles (figures 5). Lastly, I compared the mean values and standard deviations of the population groups from the various countries with these parameters for the total group (717 males and 565 females). It indicatively shows the variation of length between countries.

Results

Beetles from collections and field populations

Table 1 shows the collected length records of *D. parallelipipedus* from various European countries. In Sweden and England, internet groups were asked to collect length data. In total, 1282 beetles were measured, 332 from field populations and 950 from collections (table 1).

It was difficult to measure large numbers of beetles from field populations. Most beetles are found within decayed wood

Table 1. Collected length data of *D. parallelipipedus*.
Tabel 1. Verzamelde lengtedata van *D. parallelipipedus*.

Information about collection or population	male min. / max. length	female min. / max. length	male n	female n
Populations				
Population from Ipswich, Suffolk, England. Measured by C. Hawes, England	18-26 mm	20-25 mm	25	14
Population from Colchester, Essex, England. Measured by M. Fremlin, England	18-28 mm	19-24 mm	17	14
Population from Meckelenburg, Germany. Measured by E. van der Ploeg, The Netherlands	16-28 mm	17-22 mm	20	20
Populations from Málaga, Granada, Huesca, Asturias, Algarve, Spain. Measured by Á. Martínez via M. Mendez, Spain	18-25 mm	18-25 mm	20	16
Populations from Limburg, Belgium. Measured by E. Stassen, Belgium	20-27 mm	16-23 mm	13	7
Populations from Jabeek, Ransdaal, Eckelrade and Grathem, South Limburg, The Netherlands. Measured by P. Hendriks, The Netherlands	17-23 mm	18-24 mm	18	11
Population from Teuven, Belgium. Measured by P. Hendriks, The Netherlands	22-27 mm	18-22 mm	4	7
Population from Diesfordt, Germany. Measured by P. Hendriks, The Netherlands	20 mm	19-25 mm	1	5
Collection CNBF specimens mainly (from populations), Bosco Fontana, Italy. Measured by I. Toni, Italy. Via A. Campanaro, Italy	17-25 mm	16-25 mm	42	78
Total 'populations'			**160**	**172**
Collections				
Collection British Entomological & Natural History Society (BENHS), England. Measured by M. Smith, England	20-28 mm	19-23 mm	23	10
Collections (private) of D.N. Franc, S. Björn, B. Andersson, O. Nodmar, Sweden through Beetlebase.com, Sweden via D. Isaksson / J. ten Hoopen, Sweden / The Netherlands	20-24 mm	14-25 mm	8	5
Collection (private) of E. Sahlin, Sweden. Measured by E. Sahlin. Via J. ten Hoopen, Sweden / The Netherlands	23-28 mm		4	
Collection Everts, Naturalis Leiden, The Netherlands. Measured by J.T. Smit, The Netherlands	20-30 mm	18-23 mm	18	8
Collection Naturalis, Leiden, The Netherlands. Beetles from Europe with large numbers from France. Measured by P. Hendriks, The Netherlands	17-29 mm	16-26 mm	313	217
Collection former Zoölogisch Museum Amsterdam, The Netherlands. Beetles from Europe. Measured by P. Hendriks, The Netherlands	17-30 mm	16-26 mm	191	153
Total 'collections'			**557**	**393**
Entire data set (populations plus collections)			**717**	**565**

Internet data **Measured minimum and maximum lengths**	**max./min. length**	**Remarks**
B. Andersson (Sweden)	14 mm	female
S. Gould (England)	26 mm	female, estimated from photo
D. Telnov (Latvia)	29 mm	for 50 Latvian beetles
L. Bartolozzi (Italy)	29 mm	for several hundred beetles
A. Vrezec (Slovenia)	30 mm	for 287 mainly Slovenian and Croatian beetles
P. Whitehead (England)	31 mm	
Kaeferforum.com (Germany)	33 mm	Turkey (unverified)
J. I. López-Colón (Spain)	30 mm	for thousands of Spanish beetles

in the vicinity of their larvae. Most collectors only measured beetles that were easy to find, as breaking down decayed wood in search of adults would not only destroy their habitat but that of the vulnerable larvae as well. Thus, specimens measured were the beetles walking on or sitting just below the surface of decayed wood, under loose bark or trapped in sugary liquids.

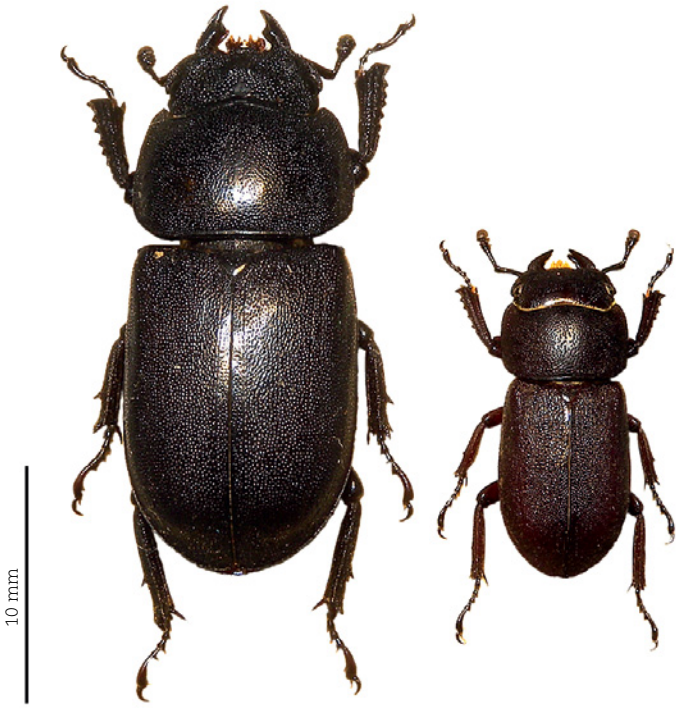
Apart from actual length measurements, several collections were scanned for the largest and smallest beetles to further establish the maximum and minimum lengths (table 1). This additional information was obtained from several websites, the European stag beetle group and published photos.

The smallest recorded female beetle is from Sweden (figure 6). The largest male beetle length was recorded on a German internet site: Kaeferforum.com. As I was unable to obtain a photo with a measurement of its length, this record remains unverified. The observer mentioned that he regularly found relatively large beetles in Turkey.

Statistical analyses

Normality tests (Kolmogorov-Smirnov) for all four groups (male and female for 'collections', male and female for 'populations') were significant ($p \leq 0.002$), indicating that the data are not normally distributed.

Data in all groups was positively skewed (table 2, figures 7-8), indicating that the tail of the distribution of lengths on the right side is longer than the tail on the left side. This skew is more prominent in the distribution of lengths of male beetles



6. Females of *D. parallelipipedus* from Sweden; 25 mm (left) and 14 mm (right). Photo: B. Andersson
6. Vrouwtjes van *D. parallelipipedus* uit Zweden; 25 mm (links) en 14 mm (rechts).

(table 2, figure 7). In females (figure 8), the distance between the mean value and minimum and maximum values is nearly equal.

The length of males from 'collections' and 'populations' was not significantly different (Mann-Whitney U test, p = 0.356), while females from 'collections' were slightly but significantly larger than those from 'populations' (p = 0.030).

Length distribution of *D. parallelipipedus*

Even though females of 'collections' and 'populations' differed significantly in length, I combined both groups to provide an overall length distribution of *D. parallelipipedus* (table 3).

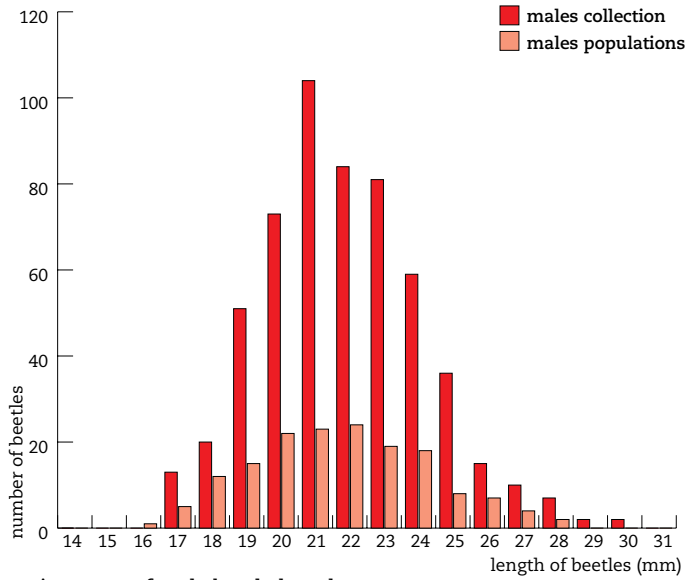
Relation between total length and body length

Figure 9 shows the correlation between total length (including mandibles) and body length (without mandibles) for a subset of beetles (58 males and 31 females). For both males and females the relation between body length and total length is evident (R^2 respectively 0.95 and 0.99). The relationship found in this subset of beetles was used to calculate body length from total length (figure 10) for the remaining beetles to obtain a histogram of body length of all males and females (figure 11).

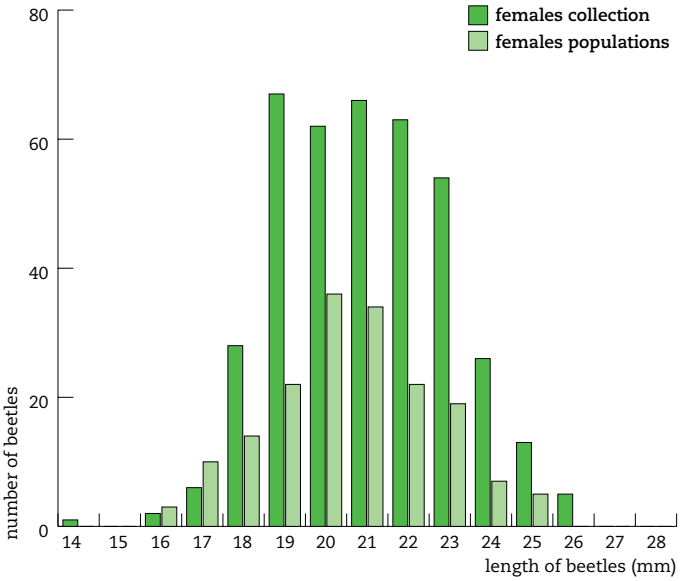
Figure 10 clearly shows a larger number of lengths of males above 21 mm compared to those of females. This difference disappears when comparing body lengths (figure 11), thus suggesting that the difference in total length is due to larger mandible size in males.

Table 2. Descriptive statistics of total length in mm.
Tabel 2. Beschrijvende statistiek van de totale lengte in mm.

	Sample size	Max	Min	Mean	Std Dev	Median	25%	75%	Skewness	Kurtosis
males collections	557	30.0	17.0	21.9	2.4	22.0	20.0	23.0	0.4	0.2
males populations	160	28.0	16.0	21.7	2.5	22.0	20.0	23.0	0.2	-0.4
females collections	393	26.0	14.0	21.0	2.0	21.0	19.0	22.3	0.08	-0.3
females populations	172	25.0	16.0	20.6	2.0	21.0	19.0	22.0	0.008	-0.3



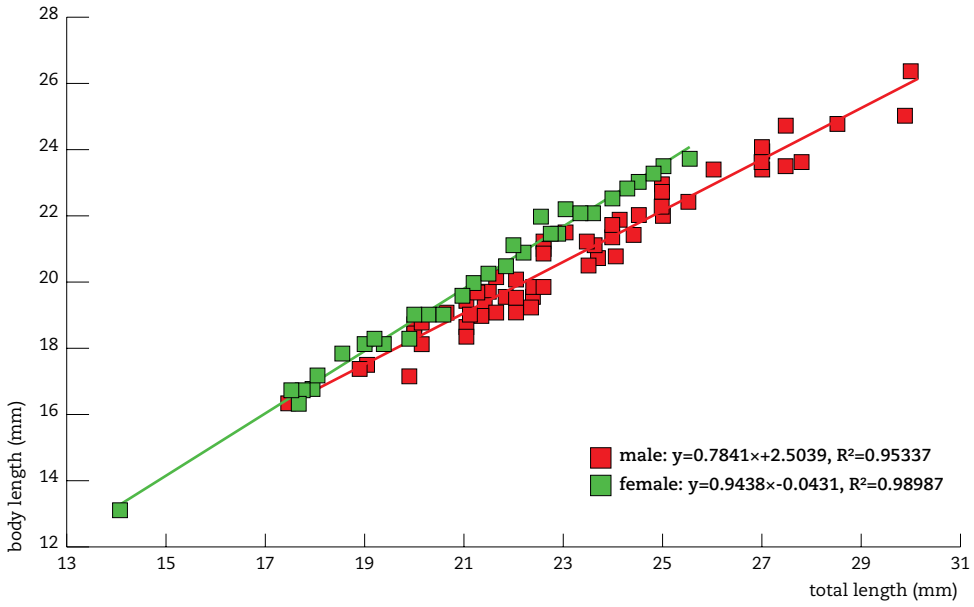
7. Histogram of male beetle length.
7. Histogram van de lengte van mannetjes.



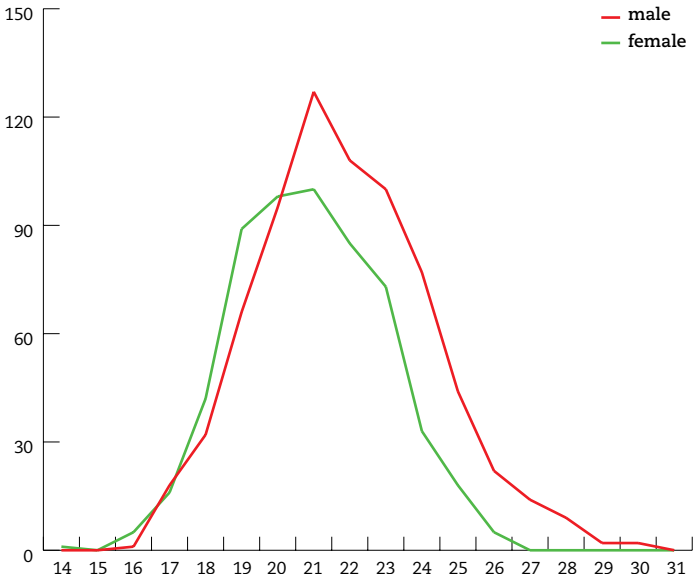
8. Histogram of female beetle length.
8. Histogram van de lengte van vrouwtjes

Table 3. Descriptive statistics of total length (mm) for all males and females of *D. parallelipipedus*
Tabel 3. Beschrijvende statistiek voor de totale lengte (mm) van alle mannetjes en vrouwtjes van *D. parallelipipedus*

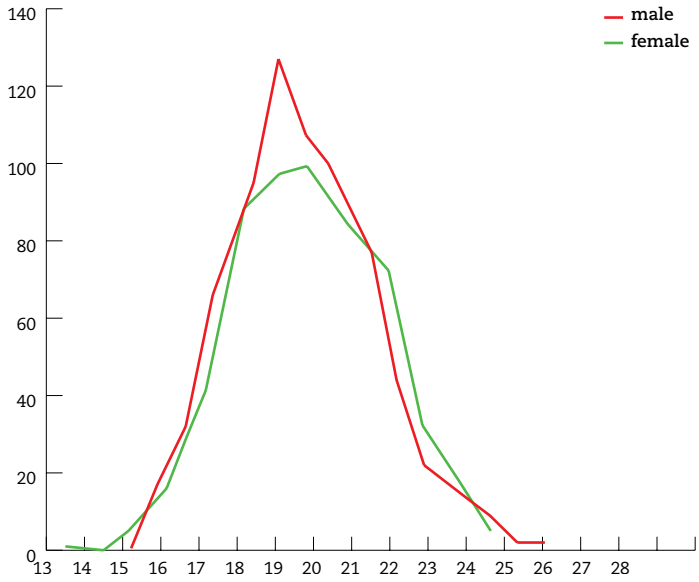
	Sample size	Max	Min	Mean	Median	25%	75%
male beetles	717	31	16	22	22	20	23
female beetles	565	27	14	21	21	19	22



9. Relation between total length and body length for 58 male beetles and 31 female beetles.
9. Relatie tussen de totale en lichaamslengte voor 58 mannetjes en 31 vrouwtjes.



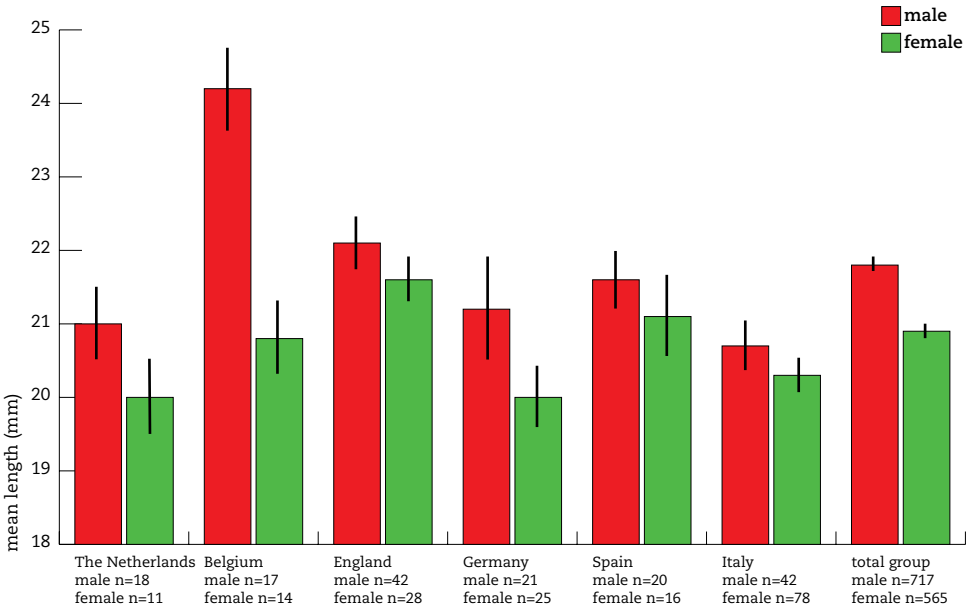
10. Histogram of total length of all beetles.
10. Histogram totale lengte van alle kevers.



11. Histogram of calculated body length of all beetles.
11. Histogram van de berekende lichaamslengte van alle kevers.

Table 4. Descriptive statistics of body lengths (mm)
Tabel 4. Beschrijvende statistiek van lichaamslengtes (mm)

	Sample size	Max	Min	Mean	Std Dev	Median	25%	75%	Skewness	Kurtosis
males collections	557	26.0	15.8	19.7	1.9	19.8	18.2	20.5	0.4	0.2
females collections	393	24.6	13.3	19.9	1.9	19.9	18.0	21.0	0.08	-0.3
males populations	160	24.5	15.0	19.5	2.0	19.8	18.2	20.5	0.2	-0.4
females populations	172	23.6	15.1	19.4	1.9	19.9	18.0	20.8	0.008	-0.3



12. Mean length (and standard error) of male and female beetles from populations and the total group of male beetles.
12. Gemiddelde lengte (en standaardfout) voor mannetjes en vrouwtjes van populaties en van de totale groep mannetjes.

Body length of males and females was not significantly different (Mann-Whitney U test, p = 0.373).

The average, 25 and 75 percentiles of body lengths of male and female beetles (table 4) are also very similar with differences smaller than 2.5%; when rounded off to whole millimeters, they do not differ at all.

Lengths of beetles from different countries

To get a first idea about variation in beetle length across Europe, I determined the mean length of populations from different countries (figure 12). The last bar in each figure shows the mean length of the total group of beetles (collections and populations) as a comparison. Male beetles from Belgium were the largest (24.2 ± 0.56 mm), while males from Italy were the smallest (20.7 ± 0.34 mm). Females from England were the largest (21.6 ± 0.30 mm), while females from Germany were the smallest (20.0 ± 0.42 mm). Because of low sample sizes, statistical analyses to compare data per country were not done.

Length variation in the literature

Only a few publications report length variation of *D. parallelipipedus* (table 5), but it is unclear how length variation was established.

Table 5. Records of *D. parallelipipedus* length in the literature.
Tabel 5. *D. parallelipipedus* en de vermelde lengte variatie in de literatuur.

Reference	Length variation
Reitter (1892)	19 – 32 mm
Escherich (1923)	18 – 32 mm
Balthasar (1956)	20 – 32 mm
Harde & Severa (1982)	19 – 32 mm
Klausnitzer (1995)	19 – 32 mm
Franciscolo (1997)	male: 18 – 35 mm female: 15 – 35 mm
Martin-Piera & López-Colón (2000)	14.5 – 36 mm

Discussion

Measurements of 1282 beetles in this study showed that length of *D. parallelipipedus* varied between 16-31 mm (males) and 14-27 mm (females) (table 3). The only beetle larger than 31 mm was reported from Turkey. Although I was not able to verify this measurement, it might be possible that the specific circumstances in Turkey can lead to such large beetles. No evidence was found to suggest that in Central and Western Europe beetles with a length of more than 31 mm occur in spite of earlier reports of lengths of 32 to 36 mm (table 5). Occurrences of such large beetles can be considered as extremely rare, as also that of individuals smaller than 14 mm.

Differences between males and females

Comparing the body length rather than the total length of male and female beetles of *D. parallelipipedus* (figure 11), shows that there is no difference between them. Because of their similar body length, it can be concluded that the difference in total length between the sexes is caused by the larger mandibles of the males. Sexual dimorphism in larval length and head capsules is also less pronounced in *D. parallelipipedus* (personal observations) than in other species of the Lucanidae, where great differences in length already appear in the larval stage. An example of such a species is *L. cervus* (personal observation). Larval length differences in this species are reflected in the adult beetles, with males being considerably larger than females (Harvey & Gange 2006). The small variation in the length of larvae of *D. parallelipipedus* can be explained by the fact that in the male the mandibles only represent a small part of the body of the beetle.

Length comparison between countries

The population groups from the various countries were too small to compare them statistically, but do provide a first insight into potential differences between locations. For example, males and females from England appear to be relatively large (figure 12). The Belgian males are very large compared to males of other populations. This is caused by a relatively large number of bigger males in this sample. Differences between populations from various countries may be caused by environmental conditions such as climate or nutrition. It is known that fungal activity in white rotted wood is important for the development of

13. Male *D. musimon* (left) and male *D. parallelipipedus* (right). Photo: Paul Hendriks
13. Mannetje van *D. musimon* (links) en mannetje van *D. parallelipipedus* (rechts)

larvae of stag beetles (*L. cervus*) (Rink 2006, Sprecher-Uebersax 2001) to such an extent that it may influence adult length (Hendriks 2007). Climate may be important because it influences the duration of larval stages, which in turn could influence adult length (personal observation). With my rearing experiments under different nutritional conditions, I aim to find out more about the potential causes of adult length variation in *D. parallelipipedus*.

Comparison with the literature

The length records I found in the literature are quite similar and this could imply that the given lengths originate from the same early source, although this could not be confirmed. Moreover, no information on length *variation* was available in any of the consulted literature. A maximum length of 32 mm for males roughly agrees with the maximum length of 31 mm established in this study.

Although minimum lengths of 18 to 20 mm, are mentioned by Reitter (1892), Escherich (1923), Balthasar (1956), Harde & Severa (1982) and Klausnitzer (1995), a considerable number of the 1282 beetles measured in this study was smaller than 18 mm (n = 41, 3%) and 115 beetles were smaller than 19 mm (9%).

The maximum lengths mentioned by Franciscolo (1997) in his Fauna d'Italia and Martin-Piera & López-Colón (2000) in their Fauna Ibérica, differ considerably from the maximum lengths in this study. Franciscolo (1997) mentions a maximum length for both sexes of 35 mm. If this is the case, the body length of the female beetles he described is greater than that of the maximum length of the male beetles measured in my study. This seems unlikely because I did not find a significant difference in body length between male and female beetles. A possible explanation for these large lengths could be that the larger specimens were actually *Dorcus musimon* Gene, a species that is only found in Europe on the islands of Sardinia (Italy) and Corsica (France) (Franciscolo 1997). The males of *D. musimon* can become considerably larger than the males of *D. parallelipipedus*; on various websites, males of 34 mm or larger are mentioned and I have also measured a 34 mm long male specimen in the former Zoölogisch Museum Amsterdam. Figure 13 shows how morphologically similar these species are.

In order to find out more about the way the maximum length of *D. parallelipipedus* (36 mm) was established in Fauna Ibérica (Martin-Piera & López-Colón 2000), I contacted the second authors. He replied to me: 'In Spain, *D. parallelipipedus* is the most common species and most abundant Lucanidae. In those years I studied many thousands of specimens of Spanish collections (more than a hundred private collections and museums). However, most individuals are between 18 and 27 mm (most of them, about 90 %, between 20-25 mm), there being few of varying length. Surely I have not seen specimens of more than 30 mm and I took extreme lengths from the literature (Baraud, Franciscolo, etc.)'. This leaves open the possibility that these maximum lengths were taken from *D. musimon*. López-Colón mentions that about 90% of the beetles are between 20 to 25 mm. In my study, 75% of the beetles are in this length range, suggesting that Spanish beetles may be a bit smaller. The minimum lengths reported by Franciscolo (1997) and Martin-Piera & López-Colón (2000) (14.5 and 15 mm respectively), match the minimum lengths found in this study.

Conclusion

The length distribution of *D. parallelipipedus* reported in this study confirms that the length of the adult beetles varies considerably, not only between individuals of the same sex, but also between males and females. Interestingly, length variation within males is even greater than between males and females. This study can lead to further comparison of length distributions of populations of *D. parallelipipedus* in different parts of its range and can form a basis for length comparisons in studies of their development under different environmental conditions and in different places.

Acknowledgements

I am very grateful for all the length records I received from various people (named in table 1 in this article) and the stimulating discussions I had with some of them. The European stag beetle discussion group proved to be a great instrument in gathering information throughout Europe regarding the lesser stag beetle. I want to thank Claire Hengeveld for her contribution and stimulating discussion about the text of this article. I thank Kerstin de Vries for sharing her knowledge of statistics and article writing with me.

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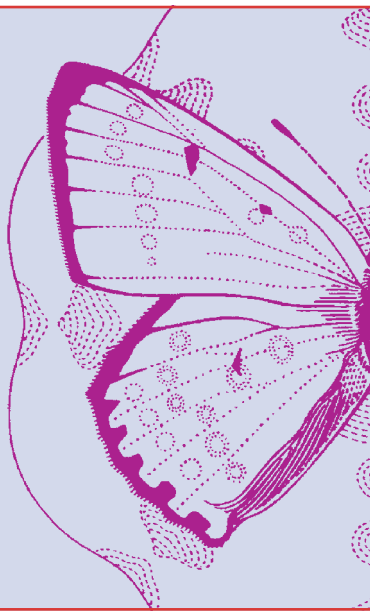
Samenvatting

Lengtevariatie van het klein vliegend hert, *Dorcus parallelipipedus* (Coleoptera: Lucanidae)

Het klein vliegend hert kent een aanzienlijke lengtevariatie. Om deze variatie te documenteren zijn 1282 lengterecords afkomstig uit het complete verspreidingsgebied geanalyseerd. Dit is apart gebeurd voor mannetjes en vrouwtjes uit museumcollecties en uit natuurlijke populaties. Op basis van de lengtewaarnemingen van de kevers uit zowel populaties als collecties, is in dit artikel de lengteverdeling beschreven. Hierbij is gebleken dat de maximale lengte voor mannetjes 31 mm bedraagt, voor vrouwtjes is deze 27 mm. De minimale lengte bedraagt voor mannetjes 16 mm en voor vrouwtjes 14 mm. De minimum en maximum lengtes van de kevers zoals gevonden in deze studie, komen overeen met de lengtes zoals beschreven in de literatuur. Ook bleek dat de verschillen in lengte tussen mannetjes en vrouwtjes wordt veroorzaakt door het verschil in kaaklengte; mannetjes hebben grotere kaken dan vrouwtjes. De beschrijving van de lengteverdeling van het klein vliegend hert maakt het mogelijk om kevers in verschillende omstandigheden, plaatsen of populaties te vergelijken met deze verdeling.



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