DISTRIBUTION AND HABITAT OF *GRAPHODERUS BILINEATUS* IN THE NETHERLANDS (COLEOPTERA: DYTISCIDAE)

Jan Cuppen, Bram Koese & Henk Sierdsema

The dytiscid beetle *Graphoderus bilineatus* is heavily protected by national and international law. In 2004 and 2005 more information was gathered on the exact distribution and habitat in the Netherlands. A century ago the species was present in large parts of the country, but nowadays it proves to be restricted to peat bog areas in the provinces of Friesland, Overijssel, Utrecht, and Zuid- and Noord-Holland. The main habitat is ditches and canals with a width between 1.5 and 20 m, a depth between 50 and 150 cm, with clear water and a sparse vegetation. A distribution model predicts the presence of *G. bilineatus* with a probability of 70% or more in 141 kilometre squares in peat bog areas.

INTRODUCTION

The water beetle *Graphoderus bilineatus* (Degeer, 1774) (fig. 1) is one of the five Dutch beetle species protected by the European Habitats Directive and Dutch Flora- and Faunalaw 2002. Notwithstanding the national and international protection status the distribution of *G. bilineatus* in the Netherlands was poorly known. The publication of Huijbregts (2003) can be considered the first step towards a better knowledge. The discovery by the second author of a new population of *G. bilineatus* in the Nieuwkoopse Plassen in 2003 was reason for the province of Zuid-Holland to request EIS-Nederland to start a study on the status of the species in this province. This project was carried out in 2004 (Cuppen 2005). On request of the Ministry of Agriculture, Nature and Food Quality, the status of *G. bilineatus* in other parts of the Netherlands was investigated in 2004 and 2005 (Cuppen & Koese 2005). In this paper we provide general information on the species with detailed notes on distribution and habitat.

IDENTIFICATION

Graphoderus bilineatus (fig. 2) is a middle-sized dytiscid beetle with a length of 14-16 mm. The body is broadly oval with its maximum width posterior to the middle. The main colour of the dorsal side are pale yellow and black, the ventral side is pale yellow. The main differences with *Graphoderus cinereus* (Linnaeus, 1758) (fig. 3) and *G. zonatus* (Hoppe, 1795) (fig. 4), the two other Dutch *Graphoderus* species, are:

1 The pale yellow transverse band on the middle of the pronotum is distinctly broader than the black bands at the posterior and anterior margins; in the other species the black bands are broader.
2 The epipleura of the elytra show a distinct constriction at the level of the hind margin of the first sternite, which is absent in both other species; here the epipleura taper gradually from base to apex.
3 The light parts of the dorsal and ventral side are pale yellow, in both other species these parts are more yellowish with traces of orange, especially at the underside of the abdomen.

Graphoderus bilineatus can be easily identified with the commonly used keys such as Schaeflein (1971), Van Nieukerken (1992) or Nilsson & Holmen (1995).

BIOLOGY

The development of the egg, three larval instars and pupa takes about 2-2.5 month (Galewski

Figure 1. *Graphoderus bilineatus*. Foto Theodoor Heijerman.
Figuur 1. *Graphoderus bilineatus*. Photo Theodoor Heijerman.

1990), from mid May to the beginning of October (Foster 1996). The presence of third instar larvae in the first decade of June even suggests an earlier start of reproduction than mid May in the Netherlands. Also, two couples of *G. bilineatus*, collected on 22 April 2005 and 10 May 2005 respectively, did not mate nor did lay eggs in captivity. However, it seems unlikely that these activities had already taken place. The larvae pupate on land, in a shallow pupation room under mosses, stones, wood, or plant debris, not far from the water's edge. The lifecycle is probably univoltine, the adults dying after the reproduction period. Not much is known about hibernation, possibly on land (Hendrich & Balke 2000 under reference to Foster 1996) as well as under water (Nilsson & Holmen 1995). Foster (1996) suggests hibernation between dense, submerged moss carpets, but actual observations are lacking. The species is reported to be able to fly (Nilsson & Holmen 1995, Hendrich & Balke 2000), but we did not find concrete records of this phenomenon.

Adults and larvae are carnivorous, feeding on small invertebrates. The larval morphology suggests that the larvae feed on cladocerans in open water (Galewski 1975), like the younger instars of *Graphoderus zonatus* (Denton 1997). When this resource is limited the young larvae spend more time near the bottom in search of other prey items, as do the older instars, which are also frequently hunting in dense submerged vegetation. Food preferences of the adult beetle are not known for certain as crop contents never have been investigated. The crops of *Graphoderus cinereus* contained, apart from tissue of higher plants, Chlorophycaeae and Bacillariophycaeae, remains of Crustacea, Ephemeroptera and Chironomidae (Deding 1988). However, only four larvae were investigated and possibly the vegetable matter is not consumed by the beetle itself but by its prey (e.g. ephemeropterans or chironomids).

DISTRIBUTION

The range of *Graphoderus bilineatus* reaches from Central-Europe via East-Europe to western Siberia and from northern Italy, Austria, Hungary and Romania to southern Scandinavia (fig. 5; based on Foster 1996). Nilsson & Holmen (1995) also give Spain, but the species is not mentioned in the Spanish list (Ribera 2006). In the surrounding countries of the Netherlands *G. bilineatus* is very rare. It is present only in some regions in Germany (Hendrich & Balke 2000), France (Bameul 1994, Foster 1996, Queney 2004) and Belgium (Bosmans & Van Stalle 1983, Dopagne 1995). In England the species has not been recorded for nearly a century and can be considered extinct (Foster 1996). In Norway it is recently recorded for the first time (Olsvik 1992). *Graphoderus bilineatus* is rare in Denmark, but widespread in Sweden and Finland (Holmen 1993, Nilsson & Holmen 1995). Large

Figure 2-4. Habitus of three *Graphoderus* species, 2. *G. bilineatus,* 3. *G. cinereus,* 4. *G. zonatus.* Collection Naturalis Leiden (RMNH). Photos Roy Kleukers.
Figuur 2-4. Habitus van drie *Graphoderus*-soorten, 2. *G. bilineatus,* 3. *G. cinereus,* 4. *G. zonatus.* Collectie Naturalis Leiden (RMNH). Foto's Roy Kleukers.

populations are known from the south of Scandinavia, Russia, Belarus and Ukraine (Hendrich & Balke 2000). In West- and Central-Europe the species seems to have declined in the second half of the 20th century (Nilsson & Holmen 1995, Foster 1996, Hendrich & Balke 2000, Huijbregts 2003). Despite this decline, new populations have recently been discovered in this area, e.g. in the surroundings of Bordeaux (Bameul 1994), Bremen (Haesloop 2001) and in several nature reserves in the Netherlands (Huijbregts 2003, Cuppen 2005, Cuppen & Koese 2005).

NEW RESEARCH

The main goals of the project were:
- Description of the current distribution and habitat of *Graphoderus bilineatus*
- Determination of the best sampling procedure (macrofauna net versus bottle traps)
- Determination of the potential distribution area in the Netherlands
- Finding reliable characters to separate the larvae of *Graphoderus* species

In this paper we will focus on the first goal, distribution and habitat. The results with respect to the different sampling techniques are presented in a second paper (Koese & Cuppen 2006), the development of the distribution model in a third (Sierdsema & Cuppen 2006). The study of the larvae is still in progress and will be published later.

METHODS

Period and investigated areas

The survey on *Graphoderus bilineatus* took place in the years 2004 and 2005. In total 85 samples were taken (distributed over 81 localities, 43 1x1 kilometre squares and 28 5x5 kilometre squares).

	Aanwezig	Afwezig
Zuid-Holland	3	12
Rest van Nederland	17	11

Table 1. Number of kilometre squares investigated in 2004 (province of Zuid-Holland) and 2004-2005 (rest of the Netherlands) with presence/absence data for *Graphoderus bilineatus*.
Tabel 1. Aantal onderzochte kilometerhokken met aan-afwezigheid van *Graphoderus bilineatus* in 2004 (Zuid-Holland) en 2004-2005 (rest van Nederland).

In both years sampling was concentrated between the end of April to the beginning of June and mid-August to the end of September. Within these periods the probability of catching adult beetles was highest, based on the available Dutch data.
The aim was to re-investigate the localities where the species was found between 1980 and 2003, supplemented with any new findings in 2004 and 2005. As a starting point localities with records of adults and/or presumed larvae since 1980 were selected from the EIS dataset (compiled by J. Huijbregts). The exact localities could most often be traced by the topographical descriptions on the labels, sometimes with assistance of the collector. The database contained 16 5x5 kilometre squares (sometimes containing more than one locality) with reliable records of adult *G. bilineatus* since 1980. All records of larvae were considered unreliable (Huijbregts 2003). In the 2004 survey 33 localities were investigated in the province of Zuid-Holland with the Nieuwkoopse Plassen as the most important area (Cuppen 2005). A relatively large number of sampling localities in this survey were controls of localities with doubtful records of larvae or lost adult material. The study also included a number of localities which were obviously not suitable for *G. bilineatus*. The localities were divided in three groups according to the results of our survey: localities were *G. bilineatus* was found, localities were the species was not found but probably is present (potential), and, finally, localities were the species was not collected and also is not expected.

Sampling procedure
Sampling was performed with a standard macrofauna net (width 30 cm, mesh size 0.5 mm), which was pushed over the bottom and through the vegetation, or scraped against the banks. The content of the net was emptied in a white tray and checked for *Graphoderus*. The locality was sampled up to a maximum period of 1.5 hours. Morphometrical measurements included depth and width or surface of a water body, and thickness of detritus/peat layers. The transparency and colour of the water and the amount of shade (by shrubs or trees) were visually assessed. A water sample was collected in a plastic bottle and the water was analysed for a number of parameters: pH, electrical conductivity, chlorinity, alkalinity and total hardness. The structure of the vegetation was assessed for all major layers (percentage cover): emergent, floating leaved, submerged, mosses and algae (flab). Special attention was paid to floating leaved and submerged plants, which were also assessed at the species level.
More detailed information on sampling procedures can be found in Cuppen (2005) and Cuppen & Koese (2005).

RESULTS

Distribution
The distribution of *G. bilineatus* in the Netherlands is given in figure 6. The map is based on the EIS database, to which the results of the present investigation are added. It shows that prior to 2000 the distribution area covered large parts of the Netherlands with the exception of the Delta region in the southwest, the northern coastal (often brackish) areas and large parts of the provinces of Drenthe and Overijssel. The actual distribution comprises only a minor part of the country with nearly all records confined to peat bog areas at the border of the provinces Utrecht, Zuid- and Noord-Holland in the centre of the Netherlands, and peat bogs in

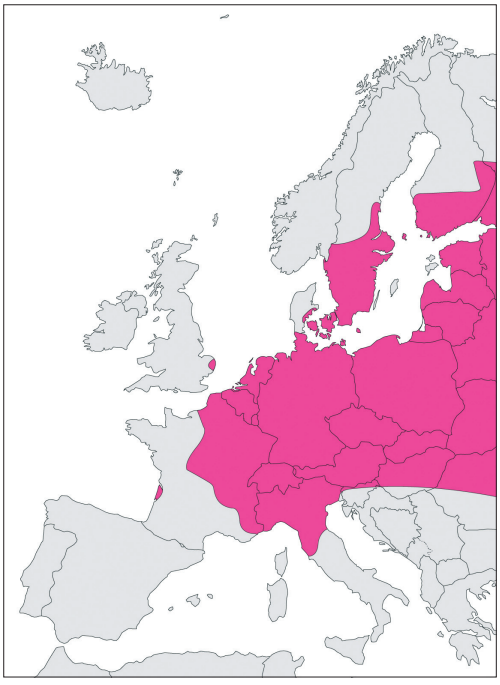

Figure 5. European distribution map of *Graphoderus bilineatus* (based on Foster 1996).
Figuur 5. Verspreidingskaart van *Graphoderus bilineatus* gebaseerd op Foster (1996).

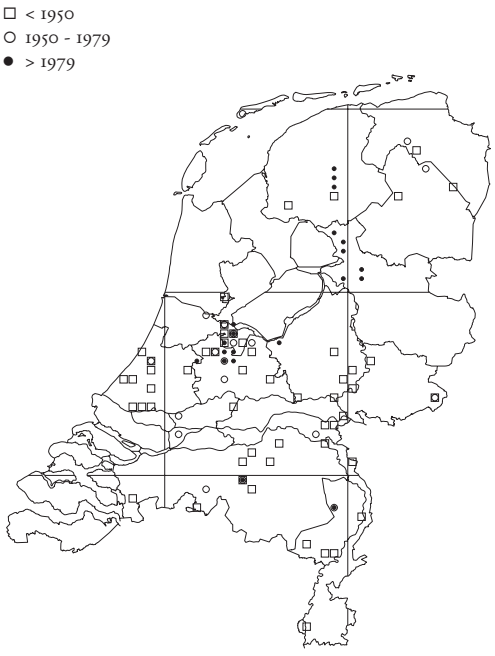

Figure 6. Records of *Graphoderus bilineatus* in the Netherlands (database EIS-NL).
Figuur 6. Vindplaatsen van *Graphoderus bilineatus* in Nederland (bestand EIS-NL).

Noordwest-Overijssel and adjacent Friesland. The populations in heath land ponds on sandy soils in the southern, eastern and central parts of the Netherlands have severely declined during the last century. Only one, probably small, population remains in one of the Oisterwijkse Vennen. Table 1 gives a survey of the presence and absence of *G. bilineatus* in the kilometre squares investigated during the two projects. The species was found in about half the examined grid squares. The differences in recoveries between the two projects are mainly due to the different starting points. More details can be found in Cuppen (2005) and Cuppen & Koese (2005).

Habitat

Our study shows that in the Netherlands localities with *Graphoderus bilineatus* have in common that the water is (nearly) stagnant and the water is permanent. Most often these waters are interconnected with each other within a certain area. Most water bodies in the Netherlands fulfil these requirements and it is obvious that the rarity of the species is not caused by rarity of these conditions. However, most other environmental variables investigated during this project vary considerably. For a correct interpretation of the results presented below it should be emphasized that, due to the goals of this project, the localities were not picked at random. Localities with records of *G. bilineatus* were strongly preferred. It is needless to say that measurements from hundreds of sampling localities without *G. bilineatus* could have been added to the dataset. In other countries *Graphoderus bilineatus* is frequently reported from isolated waters such as large ponds and lakes of various types (Nilsson & Holmen 1995, Foster 1996, Hendrich &

Figure 7. Ditch in the Westbroekse Zodden, a typical locality for *Graphoderus bilineatus* in the Netherlands. Photo B. Koese.
Figuur 7. Sloot in de Westbroekse Zodden, een karakteristieke vindplaats van *Graphoderus bilineatus* in Nederland. Foto B. Koese.

Balke 2000). Only two of our records stem from more or less isolated waters: the Voorste Goorven near Oisterwijk and the Wijde Blik in the Naardermeer nature reserve. Both waters are very large in comparison with waters entering or leaving these lakes. The majority of Dutch records of *G. bilineatus* originate from ditches (fig. 7) and canals. These waters show a considerable variation in width (fig. 8). No obvious preference for any of the six classes can be detected. About 50% of the records is from ditches with a width less than 5 metres, quite a contrast with literature. The narrowest ditch had a width of only 1.5 meter.

The distribution of the records over the different classes of water depth is given in figure 9. It shows that *G. bilineatus* is more frequently observed in waters with a depth of more than 75 cm. This observation is in agreement with literature (Nilsson & Holmen 1995, Foster 1996, Hendrich & Balke 2000). The shallowest water depth measured was only 20 cm in a ditch at the Westbroekse Zodden in the summer period; in the winter the water level had risen to 55 cm.

The soil at sampling localities with *G. bilineatus* consisted of either sand or peat with most often peaty, steep banks. The soil was covered by soft, muddy peat of a variable thickness, frequently more than 50 cm. Despite this peat, soils were never anaerobic, and the water itself was very clear or only slightly brown coloured by humic

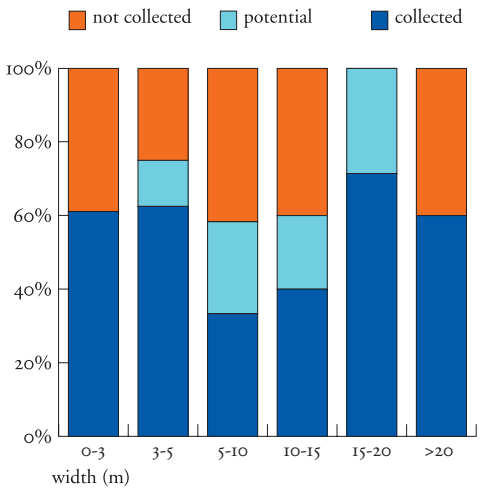

Figure 8. Percentual distribution of sampling localities with or without *Graphoderus bilineatus* in relation to the width of the water body.
Figuur 8. Procentuele verdeling van monsterpunten met en zonder *Graphoderus bilineatus* met betrekking tot de breedte van de watergang.

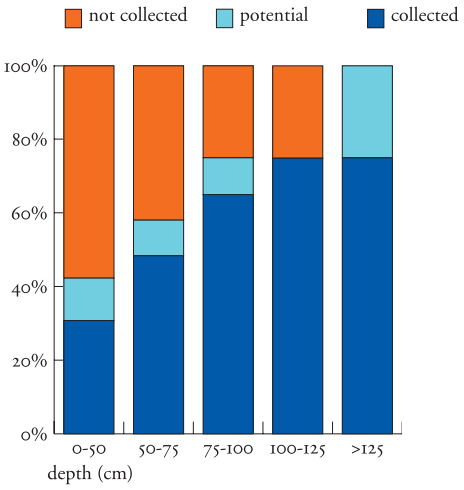

Figure 9. Percentual distribution of sampling localities with or without *Graphoderus bilineatus* in relation to the depth of the water body.
Figuur 9. Procentuele verdeling van monsterpunten met en zonder *Graphoderus bilineatus* met betrekking tot de diepte van de watergang.

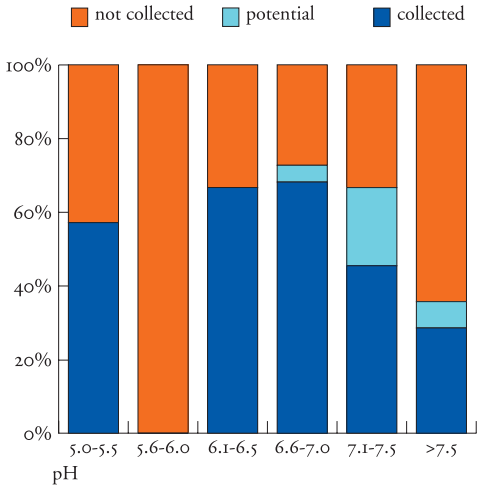

Figure 10. Percentual distribution of sampling localities with or without *Graphoderus bilineatus* in relation to pH.
Figuur 10. Procentuele verdeling van monsterpunten met en zonder *Graphoderus bilineatus* met betrekking tot de pH.

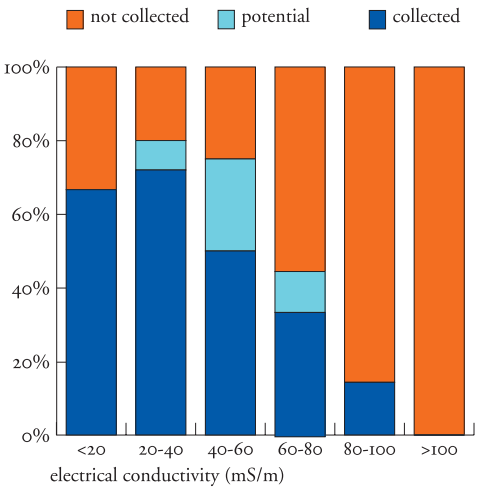

Figure 11. Percentual distribution of sampling localities with or without *Graphoderus bilineatus* in relation to electrical conductivity.
Figuur 11. Procentuele verdeling van monsterpunten met en zonder *Graphoderus bilineatus* met betrekking tot electrisch geleidingsvermogen.

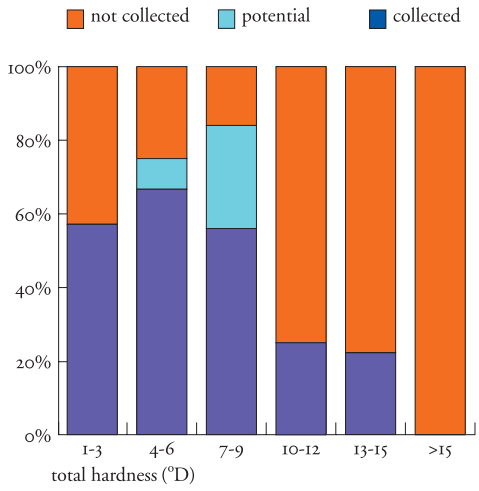

Figure 12. Percentual distribution of sampling localities with or without *Graphoderus bilineatus* in relation to hardness.
Figuur 12. Procentuele verdeling van monsterpunten met en zonder *Graphoderus bilineatus* met betrekking tot hardheid.

compounds. Most localities were situated in the large seepage areas of the Netherlands, but this was hardly visible in the field (no milky or rusty water, no bacterial films at the water surface, indicative plants species e.g. *Hottonia palustris* were not common).

Graphoderus bilineatus is an inhabitant of unshaded waters, which means that usually no trees or shrubs are growing on the banks. At some localities mowing activities were hindered by trees (most often at dead-ends of ditches), resulting in accumulation of trembling bog or a richer emergent vegetation, resulting in a better hiding-place for the beetles. Close to the banks the shading can increase considerably in the course of the season, due to the growth of helophytes on the banks. This of course also depends on the slope and exposition of the bank.
Graphoderus bilineatus is most often observed in waters with a pH between 6 and 7.5 (fig. 10), which seems to be the normal range abroad.

According to Holmen (1993) and Hendrich & Balke (2000) the species tolerates weakly acid water, circumstances which are encountered in the Netherlands only in the Voorste Goorven with a pH between 5.0 and 5.4 at different stations and times.

Electrical conductivity and chlorinity are strongly correlated in our dataset and therefore only the results for conductivity are presented (fig. 11). *Graphoderus bilineatus* is observed in all classes except the highest (> 100 mS/m). A 'preference' for the lower three classes (< 60 mS/m) is obvious, above this value the presence of *G. bilineatus* rapidly declines.
The hardness (°D), a measure for the total amount of calcium and magnesium, shows that *G. bilineatus* is observed more in the lower three classes (< 10 °D)(fig. 12) than in the higher three.
The structure, and to a lesser degree the composition, of the vegetation on the sampling localities is quite variable over the sample sites and also the season. In springtime (April-May) the water vegetation is usually sparsely developed and will be better developed in summer (August-September), when not cut. The emergent vegetation (only as far as it stands in the water) is sparsely developed with a cover of less than 5% by *Phragmites australis*, *Carex paniculata*, *C. acuta*, *C. acutiformis* and *Thelypterus palustris* as frequent and sometimes dominant species. Also the floating leaved vegetation (rooted as well as unrooted) is most often scarce, but occasionally *Nuphar lutea*, *Nymphaea alba* or *Hydrocharis morsus-ranae* are dominating. *Potamogeton* species are rare. Surface floating lemnids, though very frequent, are never dominant on localities with *G. bilineatus*. The submerged vegetation is well developed and often rather rich in species. Dominant and frequent is *Utricularia vulgaris*, less often *Elodea canadensis*, *E. nuttallii*, *Ceratophyllum demersum*, *Potamogeton* species, *Stratiotes aloides*, *Hottonia palustris* and *Lemna trisulca*. Mosses (mostly *Sphagnum*) and a floating layer of algae (flab) are sporadically present.

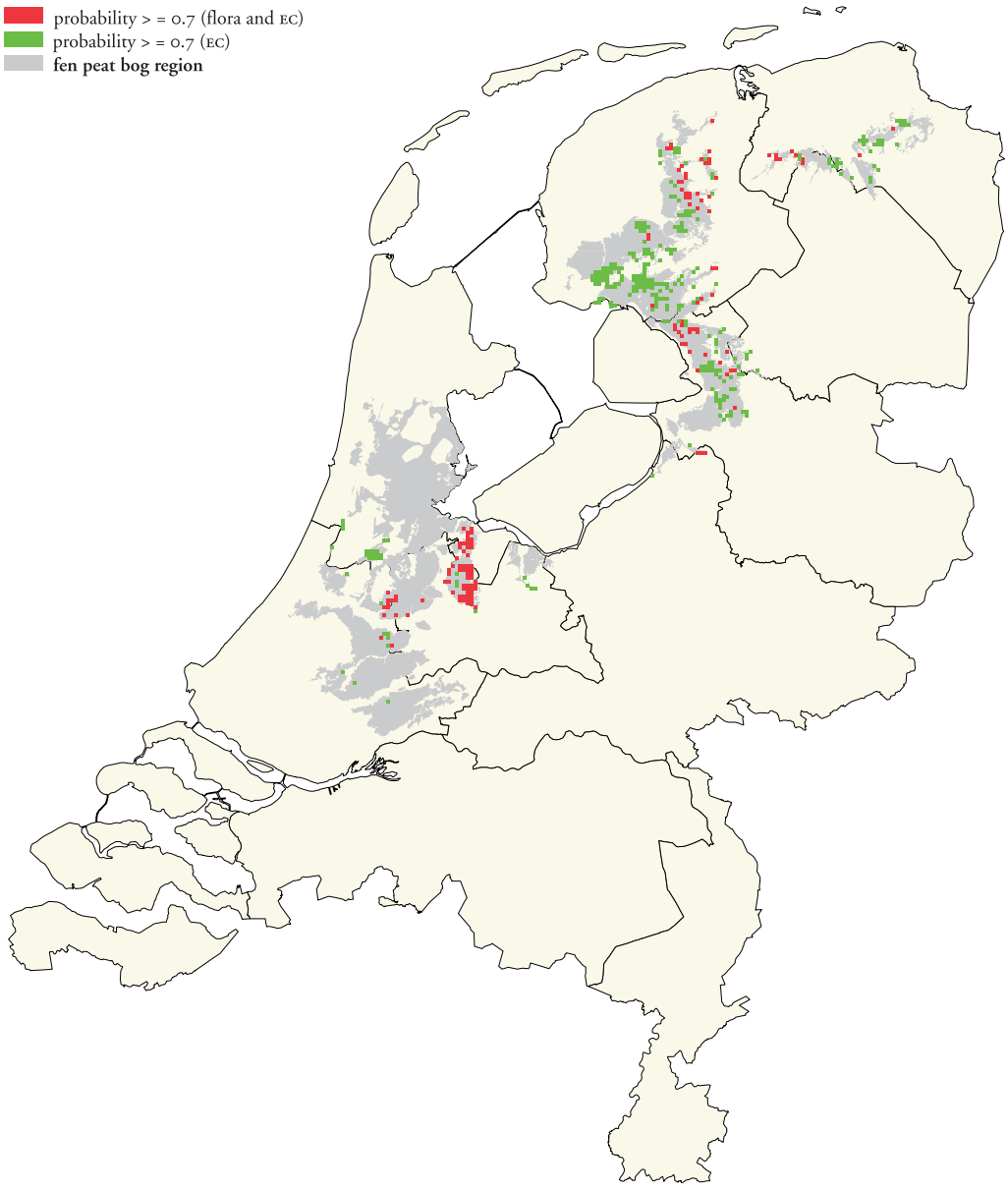

Figure 13. Predictive distribution model for *Graphoderus bilineatus*. In kilometre squares in peat bog areas (red), the probability of its occurrence is more than 70% based on electrical conductivity and associative plant species, in green squares the prediction is based only on electrical conductivity.
Figuur 13. Voorspellend verspreidingsmodel voor *Graphoderus bilineatus*. In de rode kilometerhokken in de laagveengebieden is de kans op aantreffen van deze soort meer dan 70% gebaseerd op electrisch geleidingsvermogen en geässocieerde plantensoorten, in de groene hokken is deze voorspelling alleen gebaseerd op electrisch geleidingsvermogen.

Potential distribution model
The development of the potential distributional model is reported in Sierdsema & Cuppen (2006). The final result is a map (fig. 13) that can be used for future investigations. The map shows, for peat bog areas only, the kilometre squares (in red) in which *G. bilineatus* can be expected with a probability of more than 70%. This expectation is based on electrical conductivity of the water and the presence of associative plant species. In the green kilometre squares a probability of more than 70% for *G. bilineatus* is computed on the basis of electrical conductivity only. For these squares no floristical data were available. Green squares are mainly found in the northern part of the country.

DISCUSSION

In the first half of the 20th century *G. bilineatus* occurred in large parts of the Netherlands, lacking only in brackish areas. In the second half of the 20th century the species declined severely in all regions of our country except for peat bogs. The reasons for this decline surely include acidification of moorland pools by wet and dry acidic deposition, eutrophication by intensification of agriculture (use of artificial fertilizers), intensified use of herbicides and pesticides, re-allotment and intake of nearly brackish and hard river water (Rhine). Survival of *G. bilineatus* in peat bog areas is probably due to seepage, resulting in a good water quality (poor in nutrients, relatively low conductivity and total hardness). Also the relatively low economic value of these areas for agriculture reduced some of the above mentioned human influences. The peat bog areas, functioning as nature reserves, recreation areas or sources of natural products (fish, reeds) have changed relatively little during the last century. The improvement of water management in some of the areas (stopping, reducing and/or dephosphatizing of river water taken in) probably has resulted in (re)colonization of the Naardermeer, Weerribben, Wieden and Nieuwkoopse Plassen by *G. bilineatus* in the last decade of the 20th century. Most of these areas were not very well investigated for invertebrates in the past but at least for the Naardermeer the restoration is well documented. Eight sites were sampled more or less regularly for invertebrates from 1981 onwards. Dephosphatizing of intake water from the IJmeer took place from 1985 onwards but, after problems in the initial stage, was effective from 1988 onwards (Boosten 1999). *Graphoderus bilineatus* was first recorded in 2002 at one site, followed by a second and third site in 2004 (pers. com. G. van Ee). Prior to the discovery of *Graphoderus*, the water turbidity strongly declined resulting in clear water that enabled the development of a closed submerged vegetation including stoneworts (Characeae) and *Najas marina*.
The distribution model predicts for the peat bog regions in the Netherlands the occurrence of *G. bilineatus* in 141 1x1 kilometre squares with a probability of more than 70% (fig. 13). A research project directed on especially these grid squares can improve the known distribution of the species in the Netherlands most succesfully. The predictive model can be validated by use of consistent sampling techniques and fixed time schedules.

For the validation the assessment of the model parameters (electrical conductivity, number of associative aquatic plant species) is necessary. Many grid squares in the northern peat bog areas are deficit in floristical data. It is advised to gather these floristical data first and to add them to the model. Hereafter, examination of the grid squares with the highest potentials for *G. bilineatus* can be conducted.
The predictive distribution model is based on measurements, maps and expert judgement. A major restriction of the model is its limitation to peat bog soils. To find new localities with *G. bilineatus* outside this area one can rely only on expert judgement. It is recommended to include in a new research project at least some heath land ponds in areas inhabited by the species in former days. Heath land ponds with an unaltered water table, not acidified nor eutrophicated, seem to be the best ones to look for.

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SAMENVATTING

Verspreiding en biotopen van *Graphoderus bilineatus* (Coleoptera: Dytiscidae)
De verspreiding en biotopen van de gestreepte waterroofkever *Graphoderus bilineatus* zijn in 2004 en 2005 onderzocht in opdracht van de provincie Zuid-Holland en het Ministerie van LNV. Deze waterroofkever is wettelijk beschermd middels de Flora- en Faunawet en de Habitatrichtlijn. *Graphoderus bilineatus* kwam vroeger in grote delen van Nederland voor, maar is tegenwoordig vrijwel beperkt tot de grote laagveengebieden in de provincies Friesland, Overijssel, Utrecht en Noord- en Zuid-Holland. De belangrijkste biotopen in Nederland zijn sloten en kanalen met een breedte tussen 1,5 en 20 meter, een diepte tussen 50 en 150 centimeter met helder water, en meestal een vrij spaarzame vegetatie van drijvende en submerse waterplanten. Uit het buitenland is *G. bilineatus* vooral bekend uit grotere wateren. Op basis van een verspreidingsmodel wordt voor de laagveengebieden van ons land het potentiële voorkomen van *G. bilineatus* voorspeld. In 141 kilometerhokken voorspelt het model de aanwezigheid van deze soort met een waarschijnlijkheid van meer dan 70%.

J.G.M. Cuppen
Aquatic Ecology and Water Quality Management Group
Wageningen University and Research Centre
Ritzema Bosweg 32a
6703 AZ Wageningen
jan.cuppen@wur.nl

B. Koese
EIS-Nederland
Postbus 9517
2300 RA Leiden
eis@naturalis.nl

H. Sierdsema
SOVON Dutch Centre for Field Ornithology /
IBED-University of Amsterdam /
Alterra-Wageningen University and Research Centre
Rijksstraatweg 178
6573 DG Beek-Ubbergen
henk.sierdsema@sovon.nl