Larval development of *Anomala dubia* (Scarabaeidae) in coastal dunes: Effects of sand-spray and *Ammophila arenaria* root biomass

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In coastal dunes larvae of the Scarabid beetle *Anomala dubia* feed on roots of *Ammophila arenaria* and other grasses. *A. arenaria* shows vital growth of roots if fresh wind-blown beach sand is being deposited. Due to increased atmospheric nitrogen deposition and active dune stabilisation Dutch dunes have become grass-encroached and sand-spray is strongly limited. Here, *A. dubia* is much less abundant than in pristine dynamic coastal dunes.

A comparative study between Dutch and pristine Danish dune areas showed that the density of larvae of *A. dubia* is highest if sand is deposited, *A. arenaria* is vital and fresh root biomass is produced. In these optimal conditions larvae probably complete their development within one year, whereas their development takes two years in less optimal conditions. In several Dutch coastal dune areas where restoration measures resulted in renewed sand-spray, larval densities were comparable to densities in pristine Danish dunes.

Keywords: Scarabaeidae, coastal dunes, lifecycle, root biomass, sand-spray

In the last century the Dutch coastal dune landscape changed dramatically. The formerly dynamic dunes were reclaimed by planting trees and marram grass (*Ammophila arenaria*). Increased atmospheric deposition of nitrogen and sulphur, desiccation, decline of the rabbit population and termination of agricultural use, resulted in grass encroachment of the formerly open dune vegetation (Kooijman *et al.* 2004). In this dense vegetation of tall grasses more litter is produced and sand-spray is limited. These changes have a negative impact on fauna diversity, especially on thermophilous and large insects (Nijssen *et al.* 2001a,b, Van Turnhout *et al.* 2003). As a result, bird species like Night Jar (*Caprimulgus europaeus*), Little Owl (*Athene noctua*), and Red-backed Shrike (*Lanius collurio*) that depend on large insects for prey, declined and disappeared from the coastal dunes (Beusink *et al.* 2003). For an effective restoration management we have to understand which changes in the processes and structures of the coastal dune landscape cause bottlenecks in the lifecycle of declined and disappeared species (Van Duinen *et al.* 2004b).

In the pristine dune area near Skagen (Northern Denmark) the adults of the Scarabid beetle *Anomala dubia*, emerging in late June and the first half of July, are the main prey species in the nestling diet of Red-backed Shrikes in the dynamic foredunes. In the diet of the last Red-backed Shrikes in the Dutch coastal dunes scarabid beetles were almost lacking (Beusink *et al.* 2003, Van Duinen *et al.* 2004a). Although data are not available and densities of Scarabid beetles can fluctuate considerably, the abundance of *A. dubia* and other Scarabid beetles, like *Phyllopertha horticola*, *Melolontha hippocastani*, and *Polyphylla fullo*, is generally decreased in the Dutch coastal dunes. According to literature references these species were common in the Dutch dunes in the first half of the last century (*e.g.* Everts 1898-1922, Prud'homme van Reine 1950, Van Heerdt & Mörzer Bruyns 1960).

The larvae of these Scarabid beetles eat plant roots (Koch 1989). In the Danish coastal dunes *A. dubia* is very abundant in the dynamic dunes adjacent to the beach, where *A. arenaria* and *Leymus arenarius* are growing (Beusink *et al.* 2003). Research has shown that due to root pathogens growth conditions for these grasses deteriorate (Van der Putten *et al.* 1988, Greipsson & El-Mayas 2002). However, if freshly wind-blown beach sand is deposited *A. arenaria* plants have five to ten times more vital root biomass than plants growing in stable dunes, where most roots degenerate and only bark remains (Willis 1989, De Rooij-Van der Goes *et al.* 1995). Therefore, we hypothesise that sand-spray is an important factor in the production of sufficient high quality food for *A. dubia* larvae and that the decline of sand-spray in Dutch coastal dunes have caused decline of *A. dubia*.

To study whether the development and density of *A. dubia* larvae are indeed affected by sand-spray and root biomass, a comparative field study was started in Dutch and Danish coastal dune areas. The density of *A. dubia* larvae was assessed in *A. arenaria* stands, differing in sand-spray, vegetation density and root biomass. The Dutch sampling sites included sites in which sand-spray still

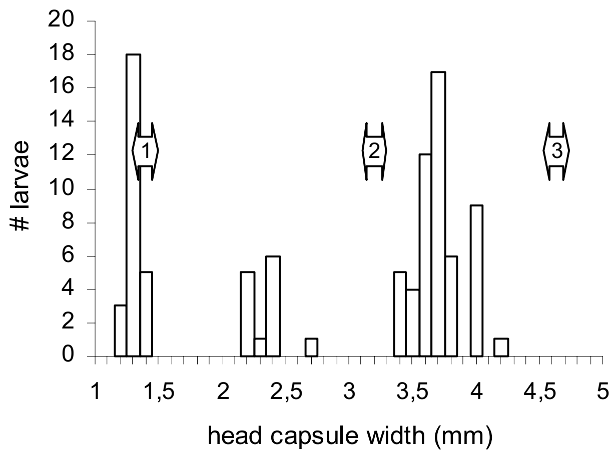

Figure 1. Head capsule width of the three larval stages of *Anomala dubia* measured on 93 larvae collected in Dutch and Danish dunes. Arrows indicate the head capsule width of the larval stages according to Klausnitzer & Krell (1996).

occurred and in which sand-spray was reactivated. In the pristine dune area near Skagen dynamic, less dynamic and stable dunes were sampled, serving as a reference for the Dutch situation.

MATERIAL AND METHODS

Anomala dubia larvae were collected by excavating 1 m^2 to a depth of 1 m. The sand was spread and the larvae were collected from the spread sand. Larval stages were determined by measuring head capsule width. Twenty-nine sites in eight Dutch coastal dune areas were sampled between the end of October and half December 2003 (see Van Duinen *et al.* 2004a) and November 2004. The Dutch sampling sites were classified in categories according to the intensity of sand-spray and the succession stage and root biomass of *A. arenaria*. In the pristine coastal dunes near Skagen, Denmark, 3 sites were sampled in September 2003: one site in a dynamic dune, one in a less dynamic dune, and one in a stable dune. In June and July 2004 five sites of each of these three categories were sampled near Skagen and fresh weight of the root biomass was measured.

RESULTS

At the sampling sites only second- and third-stage larvae (L2 and L3) and pupae of *A. dubia* were found. Larvae were mainly found between 30 and 60 cm depth and never at a depth of more than 80 cm. The ranges of the head capsule width of the larvae are presented in Figure 1. The head capsule width of first stage larvae was measured on larvae collected by means of rearing eggs deposited in sand-filled pots by collected females. The head capsule width showed clear clusters for each of the three larval stages. For the L2 and L3 the size ranges appeared to differ from the ranges given by Klausnitzer & Krell (1996).

In September 2003 the highest number of *A. dubia* larvae were found in the most dynamic Danish site (Fig. 2a). Only in the stable dune site a L2-larva was found. In June/July 2004 almost no larvae and pupae were found in the most dynamic sites, whereas several pupae and L2 and L3-larvae were found in the less dynamic sites (Fig. 2b). The average root biomass was highest in the dynamic dunes, but variation was high (ANOVA: $P=0.13$; Fig. 2c).

In 17 of the 29 Dutch sites larvae were found. In nine of them 5-8 larvae per m^3 were found. These numbers are between the 4 and 9 larvae per m^3 found in the less dynamic and dynamic Danish dunes, respectively, in September 2003. These relatively high densities were found in still active dunes (De Blink and Buizerdvlak), as well as in areas that have been reactivated (De Kerf, Kraansvlak and a filled-up infiltration lake in the Helmduinen area).

In vital expanding *A. arenaria* stands the average density of larvae was more than three times higher than in the other succession stages (ANOVA: $P=0.02$; Fig. 3a). In sites with moderate or much sand-spray more larvae were found than in sites with little or no sand-spray (ANOVA: $P=0.19$; Fig. 3b). In these stands relatively much fresh root biomass is produced. The density of larvae was highest if a high and vital root mass was present (ANOVA: P=0.08; Fig. 3d). In sites with a litter layer the density of larvae was significantly lower than in sites with open sand (T-test: P=0.02; Fig. 3c). The highest densities of larvae were found when the vegetation cover was 30-50%, although the number of sampling sites with low or high vegetation cover were very small and variation in density was high (Fig. 4).

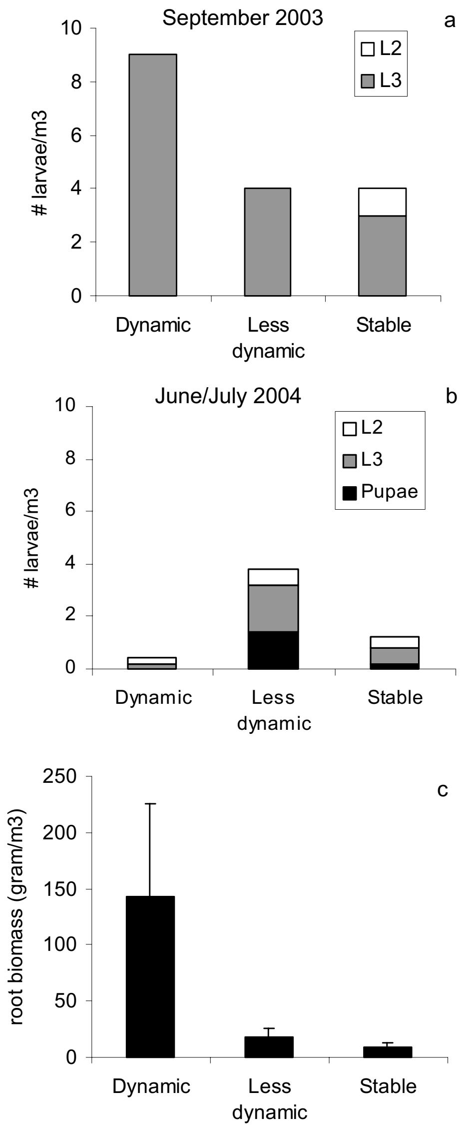

Figure 2. Number of larvae collected in a.) September 2003 (n=1), b.) and June/July 2004 (n=5), and c) average fresh weight of root biomass (±SE; n=5) in dynamic, less dynamic and stable dunes near Skagen.

DISCUSSION

The density of *A. dubia* larvae is highest in the sites with substantial sand-spray and where *A. arenaria* is vital and produces new shoots and a high root biomass. Most larvae live at 30-60 cm depth. At this depth most vital root biomass is present (Willis 1989). Few or no larvae are present in stabilised dunes, with a dense

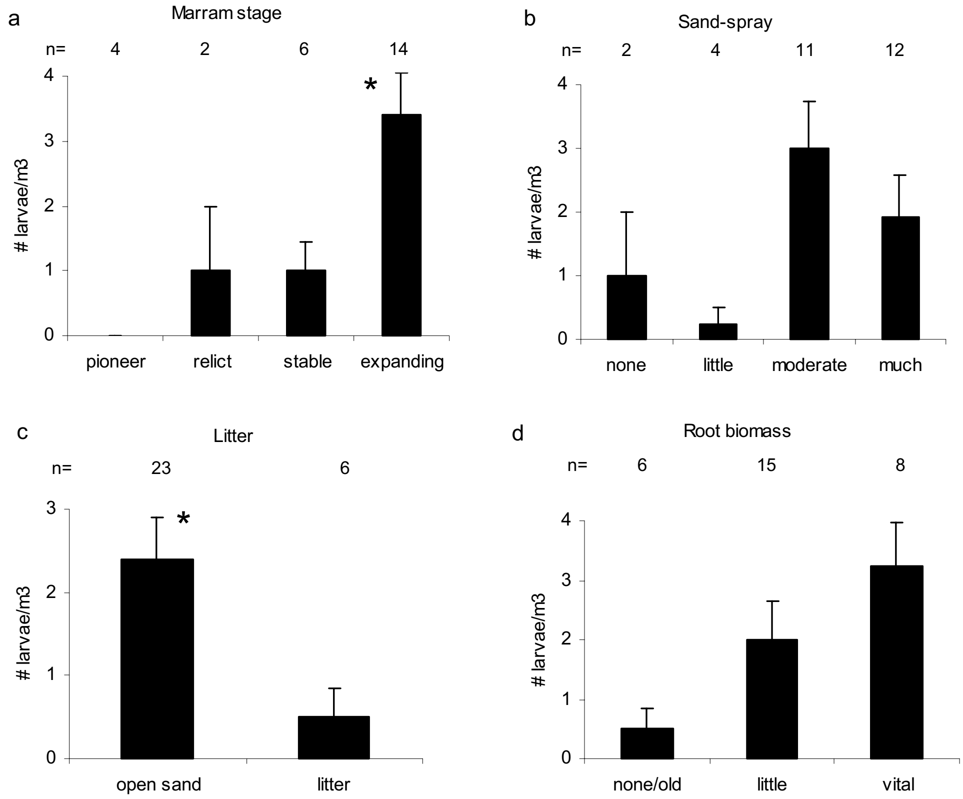

Figure 3. Average numbers (±SE) of larvae/m³ in the distinguished categories of site conditions in Dutch coastal dunes. * indicates P<0.05.

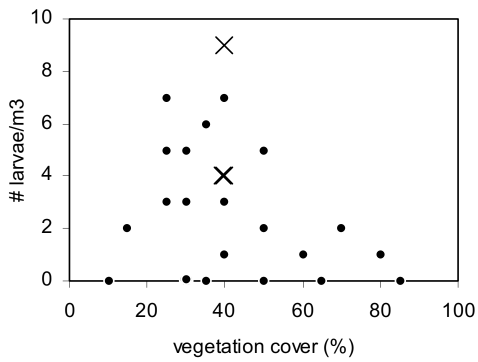

Figure 4. Number of larvae plotted against the vegetation cover at the sampling sites in The Netherlands (black dots; n=25) and Denmark (crosses; n=3).

vegetation and no or little sand-spray. In pioneer stages of A. *arenaria* vegetation with still a lot of open sand and a low vegetation cover the larval density is generally low. As there are few plants growing in these pioneer situations, root biomass is probably still too low to provide a sufficient amount of food for A. *dubia* larvae, or plants were not yet present at the sampling sites at the time of egg deposition.

At some of the sampling sites no or few larvae were found, although the conditions seemed to be similar to sites where a high density of larvae was found. On the other hand, several larvae were found in some of the sampling sites in fairly stable dunes, with a litter or moss layer. These 'exceptions' might be due to the population size of A. *dubia*, the total area of suitable biotope and (historical) developments in the area. In the Dutch coastal dunes suitable conditions for A. *dubia* are generally limited to relatively very small areas, surrounded by large areas with grass and moss encroached vegetation. Here, suitable sites might be 'missed' by A. *dubia*, as the population size is generally small. Contrary to the Dutch situation, in the pristine Danish dune area suitable conditions are present in a very large area along the coast. Here, a larger (meta-)population is present and there might be a higher chance that eggs are deposited in sites adjacent to the more optimal area. Data on this aspect are not available. Moreover, the number of sites sampled in this study is still relatively small, especially in the less optimal sites, whereas the variation in the density of larvae is fairly large. Furthermore, the nutritional value of the root biomass, one of the most important characteristics of the larval biotope, has not yet been analysed, but was roughly classified based on the appearance of the roots.

Rittershaus (1927) studied the life-cycle of A. *dubia* in an inland situation. The larvae went through the three larval stages in two years. The pupal stage lasted 30-40 days and the adults emerged in the end of June and the first half of July. According to Medvedev (in: Allenspach 1970) larval development can be completed in one year. In the most dynamic pristine dune sites very few larvae were found in June/July 2004 (Fig. 2b). Probably, almost all larvae are able to complete their development in one year in this optimal situation and almost all individuals were emerged before we took the summer samples. In the preceding autumn all larvae found in the dynamic dune site were already in their third stage. Then, only one second-stage larva was found in the (less optimal) stable dune site (Fig. 2a). Overall, in the Dutch sites sampled in late autumn 2003 the relative number of second-stage larvae was higher than in the Danish sites sampled in September. This might be due to a slower larval development in the Dutch dunes, because of less optimal conditions. Additional samples will be taken to better understand the larval development rate in optimal and marginal conditions. If the larval development rate is indeed lower if A. *arenaria* produces less root biomass and/or roots having a lower nutritional value for A. *dubia*, this will cause a considerably lower abundance of adult beetles above ground.

The density of larvae in sites with a litter layer is much lower than in open sandy sites (Fig. 3c). Open sand might be important for the adults to dig into the sand to deposit their eggs and a litter layer might hamper egg deposition. A litter layer – as well as a dense vegetation cover – might also subdue temperature fluctuations in the sandy soil, even at several decimetres below the surface (Van Duinen *et al.* 2004a). Changes in the microclimate might influence the larval development rate, as was shown for the dung beetle *Typhaeus typhoeus* (Brussaard 1983).

In several areas that have been reactivated by means of restoration measures the density of larvae was comparable to those in pristine coastal dunes. Other herbivores on roots and shoots, like larvae of Elateridae, Curculionidae, Noctuidae and Homoptera are probably affected by plant biomass production and quality in the same way as *A. dubia*. Thus, reactivation of sand-spray is a promising restoration measure in coastal dunes.

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