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Pheromones

Exploitation of gut bacteria in the locust

The congregation of locusts into vast swarms can cause crop devastation of biblical proportions1. Here we show that guaiacol, a key component of a pheromone derived from locust faecal pellets that promotes the aggregation of locusts2–5, is produced by bacteria in the locust gut. This adaptation by an insect to exploit a common metabolite produced by indigenous gut bacteria has wide implications for our appreciation of the role of the gut microbiota in insects.

Guaiacol (2-methoxyphenol) and phenol are volatile compounds that are both released from the faecal pellets of conventionally reared larvae and mature adult desert locusts, Schistocerca gregaria (Table 1). Guaiacol production from locusts has been shown to be associated with the release of odours that is derived from its digestive waste products by the action of bacteria acquired serendipitously with its food. The gut bacteria also help the locust to defend itself against microbial pathogens, mainly by producing antimicrobial phenolic compounds6–11. These contributions by the insect’s gut microbiota to its behaviour and survival were previously unsuspected.

Axenic mature adult Not detected 0.3
Monoassociated adult Not detected 0.3
Monoassociated young adult 1.0 2.0
Monoassociated adult 4.9 8.7
Normal fifth instar (without seedling diet) 44.5 10.7
Normal fifth instar (with grass diet) 4.9 13.1
Normal mature adult (without seedling diet) 10.6 12.3
Normal mature adult (with grass diet) 38.5 1.4
Normal mature adult (filter paper-vanillic acid diet) 2.6 0.7
Asexual locusts were reared according to ref. 7. Conventional insects contain the gut bacterium P. agglomerans and were fed a γ-irradiated diet. Conventional insects contain a normal gut bacterial flora. Volatiles released from locust faeces (derived from > 10 insects per experiment) were analysed by gas chromatography (GC) and the identity of compounds was confirmed by GC-mass spectrometry. The amount of compound was estimated per gram of dry weight of faecal pellets. Further methodological details are available from the authors.

Table 1 Volatile phenolic compounds released from locust faecal pellets

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brief communications

Recovery of breeding success in wild birds

We have found that the breeding success of two insectivorous forest passerines, the great tit Parus major and the pied flycatcher Ficedula hypoleuca, has markedly improved in the vicinity of a copper-smelting plant during the seven years since it reduced its emissions of heavy metals. Our results demonstrate that reduced pollution loads can positively affect breeding performance of wild bird populations over a relatively short period, even in an area that has suffered decades of heavy-metal pollution.

We collected the data around a copper smelter in Harjavaltta (61° 20’ N, 22° 10’ E) in southwest Finland during 1991–97. Concentrations of heavy metals have increased in the surrounding area of the factory because of long-term deposition14,15. An earlier study of the same area indicated that other insects, are considered to be either commensal or facultatively pathogenic16, and therefore to have little effect on their hosts. Our results show that locusts have adapted to use a pheromonal component that is derived from its digestive waste products by the action of bacteria acquired serendipitously with its food. The gut bacteria also help the locust to defend itself against microbial pathogens, mainly by producing antimicrobial phenolic compounds6–11. These contributions by the insect’s gut microbiota to its behaviour and survival were previously unsuspected.

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brief communications

P. major and F. hypoleuca produced fewer fledglings there, clutch sizes of *F. hypoleuca* were small, and their eggshells were thin and porous when laid in the vicinity of the pollution source. These poor-quality eggshells were linked to large amounts of heavy metals consumed by the birds in their invertebrate prey and with the paucity of calcium-rich food in the acidified forests. Emission of sulphur dioxide decreased by about 66%, particulate dust by 63%, and metals consumed by the birds in their invertebrate prey and with the paucity of calcium-rich food in the acidified forests. These factors were linked to large amounts of heavy metals consumed by the birds in their invertebrate prey and with the paucity of calcium-rich food in the acidified forests. Emission of sulphur dioxide decreased by about 66%, particulate dust by 63%, and heavy metals accumulated in the soil, which affected breeding success. Lead concentrations in tree foliage decreased in the vicinity of the reduced-pollution source, but remained the same at more distant sites (Fig. 2a). The clutch size of *P. major* failed to show a pollution-related decrease along the pollution gradient in either period, and there were no significant changes between the two periods (Fig. 2c).

The number of fledglings increased by about 1.6 chicks per nest at points close to the source in both bird species during 1991–93 and 1994–97 (Fig. 2b,d), reflecting partly the increased clutch size of *F. hypoleuca*. We found no significant effects of habitat on clutch size or on fledgling number in either species, so any changes in habitat type along the gradient do not bias the results. The relative fledging production (fledglings in the furthest zone/fledglings in the nearest zone) correlated negatively and significantly with yearly emissions of lead (log 1,000 kg yr⁻¹) in *F. hypoleuca* (r = -0.83, P = 0.042, n = 6 years; we omitted 1994 because of insufficient data) and was marginally significant in *P. major* (r = -0.71, P = 0.071, n = 7 years).

Both bird species probably benefited from the recovery of forest vegetation. The decreased concentration of sulphuric oxides and heavy metals in tree leaves and needles probably promotes the recovery of herbivorous insect populations, as well as their food plants. This is an important change for foliage-gleaning birds that rely strongly on tree-living insect larvae for feeding their nestlings.

Our results indicate that bird populations can recover relatively rapidly in an area that has suffered long-term pollution from heavy metals, as evidenced by the larger clutch sizes of *F. hypoleuca* and the increase in fledging production for both bird species by more than one chick during the seven-year period. The heavy-metal residues found in birds, as well as their breeding parameters, seem to reflect the level of current emissions more closely than heavy-metal accumulation in the soil over the past decades.

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