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Original article

Distribution and variation of size of *Apis florea* F in Iran

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Summary — Fifteen samples of *Apis florea* worker bees were collected from nests found in Iranian provinces near the Persian Gulf, up to more than 33° north and to 1 900 m altitude. This indicates a wider range of ecological adaptability than had previously been assumed. A south–north geocline exists in size characteristics over about the same range as for *A mellifera*. The vertical ecocline, although present, was only partial and rather irregular. No climate-related variation in hair length was found in the species. The data are discussed in view of the rudimentary thermoregulation and possible seasonal migration behavior in *A florea*.

***Apis florea* / Iran / *Apis mellifera yemenitica* / geographic variation / cline**

INTRODUCTION

Apis florea F, an open-air nesting species of honeybees, is supposed to be restricted to lower altitudes of the tropics. Since this species was detected as far north on the Iranian coast of the Persian Gulf and on the slopes of the Zagros mountains (Tirgari, 1971; Ruttner *et al,* 1985), it was possible to investigate the adaptability of this species to lower temperatures and climate-related changes in the size of body parts (clines corresponding to Bergmann's rule) as established earlier for *A mellifera*.

MATERIALS AND METHODS

Samples from 15 *A florea* nests were collected from provinces relatively close to the Persian Gulf (fig 1), a region previously described as the "*A florea* area of Iran" (Ruttner *et al,* 1985). The investigated area, from the Kermanshah province in the NW to East Baluchistan in the SE, covers a distance of about 2 000 km.

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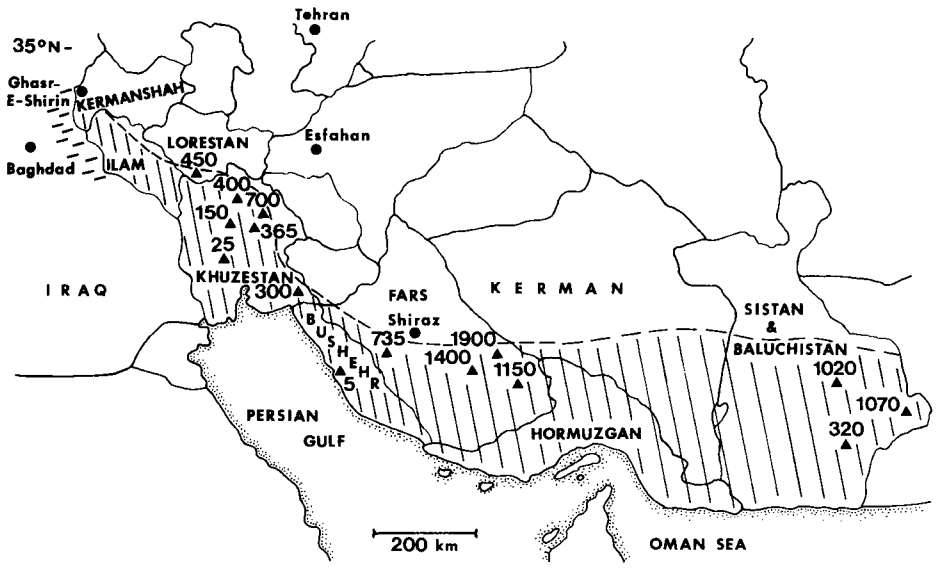

Fig 1. Map of southern Iran with names of the provinces. Black triangles with numbers: collection sites, altitude (m). Vertical lines: area of *A florea* populations in Iran; horizontal lines: reported area in Iraq.

The altitude of each site, ranging from 25 to 1 900 m, was measured with an altimeter. The bees were killed with hot water and preserved in ethanol. The following 13 body measurements were taken, with 30 worker bees (15 bees for tergites, hindwing, and hair) in each sample: tergite 3+4, length (longitudinal direction) of tergite 3 and 4 = T3+4; forewing, length and width (longitudinal and transversal) = FWL, FWTr; hindwing, length and width = HWL, HWTr; hindleg, total length (femur + tibia + basitarsus) = leg 3; length of hair on tergite 5 = H; proboscis, length = P; and distances a and b of forewing cubital vein = cu a, cu b.

The variation in these body characteristics (except for wing venation) was considered to be most likely correlated with climatic factors.

An ecocline found in *A mellifera yemenitica* from a region east of Al Hudaydah (Mahwit province, about 15° N) in northern Yemen, comprising 14 sites at altitudes ranging from 200 to 2 680 m from the coastal plains of the Red Sea to the mountains south of Sana over a distance of only 60 km, was used as a *A mellifera* reference for the *A florea* data. The climate of this region is warm with low rainfall, but high humidity because of the monsoon of the Indian Ocean. It has been famous for its honey since Queen Sabah's time. The results of this study, based on the whole spectrum of 34 characteristics (see Ruttner, 1988) have so far only been published in summary form without the accompanying data (Hoppe and Ruttner, 1990).

For statistical analysis, the means and standard deviations were calculated for each characteristic and sample. These means were used for determining the coefficient of correlation with altitude.

RESULTS

Area of distribution in Iran and climatic conditions

The northernmost sample was collected in the province of Lorestan near Malavi, north

of 33° lat at 450 m altitude (fig 1). During cold winters, the mountains in this area are snow covered for days or even weeks. The northernmost nesting sites of *A florea* in Iran, however, are found even farther north, at Ghasr-E-Shirin, in the province of Kermanshah, at almost 35° lat and 500 km north of the Gulf. Farther to the south, the borderline of *A florea* was found to be distinctly more inland and higher up in the Zagros mountains than believed before.

The discovery of *A florea* nests well above 1 000 m (5 out of the 15 samples) brings the area inhabitated by this bee within the vegetation range of a temperate zone. Above 800–1 000 m, the Zagros mountain chain is covered with a xerophilous forest (although heavily degraded) consisting mainly of oaks (*Quercus* ssp), *Juniperus*, almond and other wild fruit trees such as apple and pear. In the lower zones of this "Zagrosian forest district" (Zohary, 1973), at altitudes between about 800–1 000 m and 1 200–1 400 m, more thermophilic elements are also present: *Pistacia*, *Oleander* and *Zizyphus* (Ehlers, 1980), and moreover *Ficus* and *Citrus* as cultivated fruits. In this zone of transition between the Gulf and the continental highlands there are a number of different microclimates, and it is difficult to provide exact figures on the distribution of these plants over the whole region. However even in the south (Hormuzgan), areas over 1 400 m in the mountains are covered with snow for a short period in winter.

Geographical variation of the species A florea *(geocline)*

At present, morphometrical data are available from 39 florea colonies ranging from those living close to the equator (Sri Lanka) to samples close to the northern border of distribution in Lorestan and Pakistan (33° and 34°N). Across these 26 parallels, a highly significant linear cline was observed for almost all morphometric characteristics, with an increase to the north varying from 7% in hindleg length to 13% in abdomen length (T3+4; table I). This corresponds well with the known geocline in *A mellifera* (Ruttner, 1986, 1988).

The investigated *A florea* area in Iran extends over 8 parallels, from Baluchistan (25°) in the south to Lorestan (33°) in the north. The analysis of the Iranian samples

Table I. Global geographic variation (geocline) of *A florea* in size (in mm, $\bar{x}$ and sd of samples).

Area	*Latitude*	n	*T3+4*	*FWL*	*Leg 3*	*H*
Sri Lanka	7°N	5	2.63 ± 0.07	6.15 ± 0.08	5.11 ± 0.03	0.103
Thailand	13–19°N	4	2.70 ± 0.10	6.41 ± 0.22	5.34 ± 0.14	0.137
Oman	24°N	3	2.73 ± 0.09	6.52 ± 0.18	5.26 ± 0.18	0.113
Khusestan (Iran)	31–32°N	6	2.98 ± 0.07	6.74 ± 0.13	5.46 ± 0.07	0.103
Increase over 25° lat (%)			13.4%	9.6%	6.9%	–
Correlation coefficient (latitude)			0.77	0.81	0.71	
p			0.001	0.001	0.001	

n: number of samples; T3+4: length of tergites 3+4; FWL: forewing length; leg 3: hindleg length; H: length of cover hair on tergite 5.

Table II. Geographic variation of *A florea* in Iran (see fig 1).

Area	n	*T3+4*	*FWL*	*HWL*	*Leg 3*
Baluchistan	3	3.03 ± 0.06	6.81 ± 0.07	4.80 ± 0.08	5.55 ± 0.05
Bushar-Fars	5	2.96 ± 0.08	6.81 ± 0.02	4.83 ± 0.12	5.53 ± 0.12
Lurestan-Khusestan	7	2.90 ± 0.07	6.83 ± 0.10	4.79 ± 0.05	5.51 ± 0.09

Abbreviations as in table I.

according to geographic origin demonstrated no morphometric differences (table II). Therefore, all samples from Iran were treated as belonging to the same population as far as latitude was concerned.

Variation correlated with altitude (ecocline)

The data of several characteristics measured in *A florea* bees from the coast of the Persian Gulf and in others from altitudes higher than 1 000 m in the mountains of the Zagros and Baluchistan, together with *A mellifera* data from corresponding sites in northern Yemen, are shown in figures 2 and 3. The numerical differences between coastal and mountain populations for both species are given in table III.

In both cases the total range of the 2 species was included, from the coastal plains to the highest colony site that could be detected. Therefore, the extremes in altitudes mark the same range of adaptability to climate (coast to 1 900 m in *A florea*, to 2 680 m in *A mellifera*), even if they differ numerically.

A mellifera in Yemen shows a very clear ecocline, with an isometric increase in size of more than 8% with altitude on the average and a coefficient of correlation size/altitude

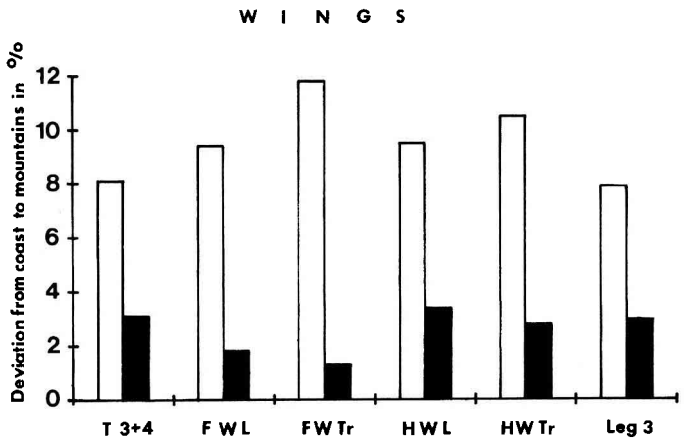

Fig 2. Difference in size of bees; comparison between mountain and lowland populations in %. Black: *A florea*, Iran. Lowland 25–150 m, $n = 3$; mountain 1 020–1 900 m, $n = 5$. White: *A mellifera yemenitica*, north Yemen. Lowland 200–240 m, $n = 4$. Mountain 2 200–2 400 m, $n = 4$. T3+4 tergite 3 and 4 (longitudinal); FWL, FWTr forewing length and width (transversal); HWL, HWTr hindwing length and width; LEG3 length of hind leg (femur + tibia + basitarsus).

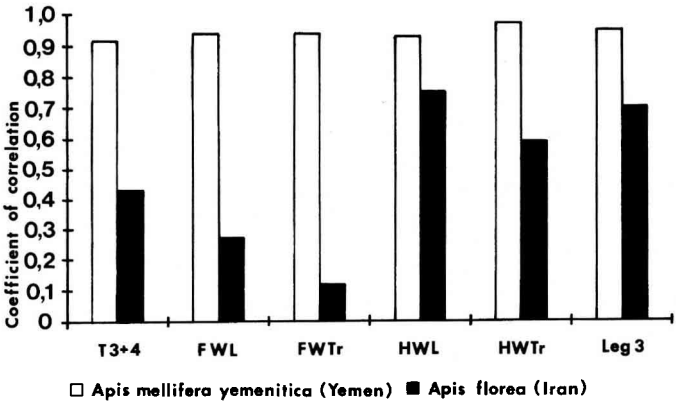

Fig 3. Body size/altitude correlation. Samples and characteristics are the same as in figure 2.

Table III. Means ± sd (in mm) of several characteristics of coastal and mountain populations of *A florea* (Iran) and *A mellifera yemenitica* (northern Yemen).

	Alt	*n*	*T3+4*	*FWL*	*FWTr*	*HWL*	*HWTr*	*Leg 3*
A florea								
Coast	5–150	3	2.94 ± 0.09	6.73 ± 0.03	2.33 ± 0.02	4.72 ± 0.02	1.45 ± 0.03	5.43 ± 0.02
Mountain	1 020–1 900	5	3.03 ± 0.07	6.85 ± 0.11	2.35 ± 0.01	4.88 ± 0.06	1.49 ± 0.02	5.59 ± 0.09
Difference			0.09	0.12	0.02	0.16	0.04	0.16
A m yemenitia								
Coast	200–240	4	3.75 ± 0.06	7.73 ± 0.06	2.65 ± 0.02	5.50 ± 0.08	1.50 ± 0.02	6.72 ± 0.11
Mountain	2 400–2 680	4	4.06 ± 0.05	8.47 ± 0.10	2.94 ± 0.04	6.00 ± 0.08	1.67 ± 0.03	7.28 ± 0.03
Difference			0.31	0.74	0.29	0.50	0.17	0.56

T3+4 sum tergites 3+4 longitude; FWL, FWTr, HWL, HWTr fore- and hindwing, longitude, transversal; leg 3 length of hindleg (femur + tibia + basitarsus).

generally exceeding 0.9, as also found in other subspecies of *A mellifera*.

In *A florea*, the pattern of climate-related variation was identical in principle: each measurement is larger in the mountain population compared with the bees of the coastal population, resulting in exclusively positive size/altitude correlations. There are, however, also important differences between the 2 species:

1) The increase in body size with increasing altitude was distinctly smaller (on the average about 1/3) in *A florea* and, above all, more variable among the individual characteristics than in *A mellifera* (fig 2).

2) The correlation between body size and altitude was uniformly positive, but significant only for 3 characteristics (length and width of hindwing, length of hindleg, fig 3).

3) The unhomogeneous variation with altitude resulted in allometric changes in the relative length of body parts (frequently an important characteristic in microtaxonomy of honeybees) and in a slight shift of the overall pattern of proportions. One example: the florea sample from the highest collection site found so far (No 1894 at 1 900 m) had bees with the largest abdomen and longest hindwings and hindlegs found so far, but at the same time they had short forewings similar to those of the coastal population (the sample with the longest forewing found so far in *A florea* (7.02 mm) was collected at an altitude of 1 400 m). In fact, these data result in a partial disintegration of body proportions which frequently are used as crucial characteristics in taxonomic classification.

Hair length

In *A mellifera*, a distinct rise of abdominal hair length with increasing altitude is regularly observed, in the Yemen from 0.16 to 0.19 mm (+16%) across a difference in altitude of 2 400 m; in the Elburs (Pour Elmi, 1991) from 0.23 to 0.32 mm (+39%) across a difference of 2 200 m.

In *A florea* the abdominal hair cover is very short, ranging from 0.08 to 0.15 mm ($\bar{x}$ about 0.10 mm). No climate-related geographic variation can be detected, and the Sri Lankan population does not differ in hair length from that of Khusestan (table I). The Thai population has somewhat longer hair ($\bar{x}$ = 0.137 mm) but the sample size is only very small (n = 3). No conclusion can be derived from this lack of a geographic variation in hair length, however, because in *A mellifera* a climate-related cline in hair length is found only north of 40° latitude. Surprisingly, no increase in *A florea* hair length has been observed at higher altitudes in Iran, despite the distinctly cooler climate (table IV).

Table IV. *A florea* hair length (in mm) variation at various altitudes of Iran.

Altitude (m)	*Hair length (mm)*
5–150	0.120
300–365	0.118
400–750	0.105
1 000–1 900	0.106

DISCUSSION

In the present study several problems concerning the distribution and variation of *A florea* in Iran have been addressed.

Distribution

A florea colonies have been found further north and at higher altitudes in Iran than previously thought. The range of this single-comb species extends into the temperate zone which requires survival with occasional periods of frost and snow that may sometimes last several weeks. The formula of "a climate with less than 20 d with temperatures below +5°C" (Ruttner *et al*, 1985) is now understood as being incorrect.

Clines

The extension of the *A florea* area provides an occasion to study the validity of general rules of geographic variability of size in this species. A linear increase in the size of all characteristics measured has been found between Sri Lanka (6°N latitude) and Khuzestan in Iran at 33° latitude (table I). The rate of increase, *ie* 7–12%, corresponds well with the increase in size of *A mellifera*

across the same range of latitude along the Atlantic coast of Africa from the Cameroons to Morocco, providing another example of the validity of Bergmann's rule in an insect.

A florea samples from different regions vary not only in size characteristics, but also in others, especially wing venation (see factor analysis graph in Ruttner, 1988). Differences of similar extent have been used in *A mellifera* to establish subspecies. In *A florea*, however, the number of samples is not yet sufficient for an intraspecific taxonomic differentiation to be established. Nevertheless, the geographic origin of an *A florea* colony unintentionally imported into the Sudan (Khartoum), has been morphometrically determined as originating from Pakistan (Mogga and Ruttner, 1988).

A distinct ecocline (increase of size with altitude), which is pronounced in *A mellifera* (Ruttner, 1988), was also found in the *A florea* samples from Iran, but with marked differences. The bees of the mountains were in all characteristics larger than those from the lowlands. The differences (in %), however, were only a fraction of those found in the geocline of this species or *A mellifera* (fig 2). The same is true for the size/altitude correlation (fig 3), which was found to be significant only for hindwing length and width, and for length of leg 3.

In contrast to the hindwing, the altitude-related differences in forewing size were small and irregular, although both are forming a functional unity during flight. In *A mellifera* wing size increases significantly with altitude (Ruttner, 1988) and the size of both wings is highly correlated (fig 3). Hindwings of *A florea* are relatively large-sized and better correlated with altitude than most other characteristics (fig 3). Hindwing width of *A florea* colonies nesting at or higher than 300 m varies even in the same range as that of *A m yemenitica* from low altitudes – an impressive example of allometry indicating not yet specified functional differences.

Variation in hair length

The length of cover hair on the abdomen of *A florea* is short, varying between 0.09 and 0.14 mm. No indication of climate-related variation was found, either in latitude or altitude (tables I and IV). Clines of hair length were first described in mammals (Rensch, 1939), and later also in *A mellifera*. As the hair cover is crucial for thermoregulation in this 'homoiothermic' species (Southwick, 1985), a climate-related variation in this species seems plausible. The opposite can be assumed for a species with only limited temperature control in the colony (Whitcombe, 1984) as *A florea*.

The interpretation of these complex morphometric data in *A florea* can most likely be found in the ecological significance of climate-related clines plus the effect of specific behavioral characteristics of this honeybee (*eg*, seasonal migrations: Tirgari, 1971; Mossadegh, 1990). The increase in size in homoiothermic (and some poikilothermic; Ray, 1960) animals in a cool climate (Bergmanns' rule) is undisputedly associated with the effect of temperature on the metabolism (Huxley, 1939; Rensch, 1939). In *A mellifera*, the very precise thermoregulation and the evidently obligatory variation of body size with environmental temperature are both factors in the capacity of a wide range of ecological adaptability.

CONCLUSIONS

A smooth cline does not necessarily signify a low size/altitude correlation. With *A florea* the low values in correlation are caused by an unhomogeneous structure of the populations of the successive zones of altitude. This heterogeneity is found even within individuals as shown in sample 1894 (altitude 1 900 m) with a large body and long legs,

but short forewings. These data seem to indicate an unstable state of the populations in this region, perhaps a consequence of migrations between different zones of altitude. Colonies and populations of this 'mosaic' morphology could be interpreted as results of opposing forces: attraction to high altitudes by better food supply; selection for larger body size in this altitude; and selection for seasonal migration to avoid winter losses. This hypothesis is favored by the distinct geocline of the same characters in *A florea* (undisturbed by migration because of the great distances), with coefficients of correlation varying between 0.71 and 0.81 (table I). Unfortunately, exact data on seasonal migration among different altitudes as observed in *A laboriosa* (Underwood, 1990) and temperature control within the colony are still missing in *A florea*.

ACKNOWLEDGMENT

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Résumé — Distribution et variation de taille chez *Apis florea* F en Iran. La validité des variations de taille reliées au climat a été testée chez *Apis florea* en utilisant les données déjà disponibles et 15 échantillons supplémentaires provenant d'Iran. Les insectes ont été récoltés en bordure du golfe Persique et au nord de celui-ci (fig 1). Au cours de cette collecte, une nouvelle limite septentrionale du territoire d'*A florea* a été définie, s'étendant plus au nord jusqu'aux montagnes. En plus de la découverte de nids dans la province du Kermanshah, au nord du 34e parallèle, des sites de nidification ont également été découverts en Irak, à l'est de Bagdad (Glaiim, 1992). Cinq des 15 échantillons ont été récoltés à des altitudes de 1 000 à 1 900 m dans une végétation de zone tempérée comportant des chênes, des genévriers, des pommiers sauvages et des amandiers («forêt montagneuse de Zagros») démontrant ainsi une étonnante adaptabilité à des conditions climatiques variables. Malheureusement, on connaît peu de choses sur la régulation thermique chez *A florea*. Les échantillons d'ouvrières ont été préservés dans l'éthanol, et 13 caractères ont été mesurés chez 15 à 30 individus selon la méthode habituelle (la longueur et la largeur des ailes arrières ont été incluses comme mesures additionnelles en raison de leur haute corrélation avec l'altitude chez cette espèce), Une série de 14 échantillons d'*A mellifera* récoltés à des altitudes de 220 à 2 680 m au Nord-Yémen (lat : 15°N), précédemment publiée (Hoppe et Ruttner, 1988), a été prise comme référence. Un géocline avec des tailles qui s'accroissent du Sri Lanka au Lorestan (Iran) en traversant 26 parallèles a été trouvé pour les ouvrières d'*A florea* (avec une corrélation taille/latitude de 0,71–0,81). Son étendue est très comparable à celui d'*A mellifera* le long de la côte ouest de l'Afrique (tableau I). Toutefois, aucune différence n'a été trouvée parmi les échantillons d'*A florea* d'Iran pour des sites variant de 26° à 33° de latitude (tableau II) ; c'est pourquoi les échantillons d'Iran ont été traités comme une seule population morphométrique. Cependant, lorsque l'altitude augmente, toutes les mesures de taille s'accroissent également, quoique de façon moindre que celle observée chez *A mellifera*, formant alors un écocline (fig 2, tableau III). La différence entre les caractères des populations de plaine et de montagne est en moyenne de 5,7% alors qu'elle est de 12% chez *A mellifera*. Tous les caractères de taille ont été corrélés positivement avec l'altitude, mais seulement pour un petit nombre d'entre eux de façon significative (fig 3). Plus frappante a été l'inhomogénéité de la variation, par exemple pour les ailes antérieures et les postérieures. Une sorte de mosaïque de caractères petits et grands a été trouvée également chez quelques échantillons individuels (par ex :

ailes courtes + pattes et abdomen longs). Aucun cline n'a été trouvé pour la longueur des poils (tableau IV). Ces données morphologiques disparates pourraient être reliées à certains traits comportementaux non encore connus, tels que, par exemple, les migrations saisonnières et les hybridations des populations, aussi bien qu'à une pression mineure exercée par les facteurs climatiques due à une thermorégulation moins développée. Le résultat principal de ce travail est que la même adaptation aux conditions climatiques existe chez une espèce à nid ouvert *(A florea)* que chez une espèce nichant dans des cavités *(A mellifera)*, ainsi que chez la plupart des vertébrés (règle de Bergmann), quoique dans une moindre mesure.

***Apis florea* / Iran / *Apis mellifera yemenitica* / variations géographiques / clines**

Zusammenfassung — Verbreitung und Variation von *Apis florea* F in Iran. Auf Grund vorhandener Daten und von 15 zusätzlichen Proben aus dem Iran wurde die Gültigkeit allgemeiner Regeln klimabedingter Variation für *A florea* untersucht. Die Proben wurden entlang der Golfküste und in den Provinzen nördlich davon gesammelt. Dabei zeigte sich, daß dieses nördlichste Verbreitungsgebiet von *A florea* weiter nach Norden, bis in die Provinz Kermanshah um den 34.Breitengrad, und höher in die Berge hinauf reicht als bisher angenommen (Abb 1). Kürzlich wurde über Funde im Irak in derselben geographischen Breite berichtet, zwischen Bagdad und der iranischen Grenze (Glaiim, 1992). Fünf der 15 Proben wurden in Höhen von 1 000-1 900 m gesammelt, inmitten einer Vegetation der gemäßigten Zone bestehend aus Eiche, Wacholder, Wildobst, Mandeln ("Zagros Bergwald"). Zusammen mit dem Vorkommen an der heißen Golfküste zeigt dies eine ungewöhnlich breite Anpassungsfähigeit von *A florea* an unterschiedliche Klimabedingungen. Die Proben wurden in Äthanol konserviert. An je 15–30 Arbeiterinnen wurden nach dem üblichen Verfahren 11 Körpermaße gemessen, außerdem Länge und Breite des Hinterflügels (wegen der hohen Korrelation dieser Maße mit der Seehöhe der Sammelstelle). Eine Serie von 14 Proben von *A mellifera yemenitica*, gesammelt in Höhen von 200-2680 m in Nordjemen (in Kurzform schon früher veröffentlicht; Hoppe und Ruttner, 1988) wurde als Referenz verwendet. Für *A florea* wurde eine Geokline mit zunehmenden Größenmaßen nach dem N gefunden, die über 26 Breitengrade von Sri Lanka bis Lorestan (Iran) reicht und in ihrer Ausprägung gut mit einer Geokline bei *A mellifera* an der Westküste Afrikas vergleichbar ist (Tabelle I). Im Iran selbst wurden jedoch keine Größenunterschiede zwischen Bienen aus dem Süden und Norden (26-33° geogr Br) gefunden (Tabelle II); deshalb konnten die Proben morphometrisch als Angehörige derselben Population behandelt werden. Mit zunehmender Höhe des Nistplatzes zeigte sich bei allen Merkmalen eine Größenzunahme (Ökokline, Tabelle III, Abb 2), jedoch nur in einem Bruchteil des bei *A mellifera* festgestellten Ausmaßes. Die Unterschiede zwischen den kleinsten und den größten Bienen (Mittel der Probe) schwankten zwischen 2,5% (Femur) und 11,6% (Breite des Basitarsus), bei einem Gesamtmittel aller Merkmale von 5,7%, verglichen mit 12,0% bei *A mellifera*. Werden nicht einzelne Völker, sondern Populationen verglichen (zB Küste und Bergland über 1000 m) so sind die Unterschiede etwas geringer (Abb 2). Für alle gemessenen Größenmerkmale konnten positive Korrelationen mit der Höhe festgestellt werden, die sich aber nur teilweise als signifikant erwiesen und ganz wesentlich unter den Vergleichswerten bei *A mellifera* lagen (Abb 3). Diese Inhomogenität der Korrelationswerte fällt besonders beim Vergleich zu den gleichmäßig hohen Werten bei *A mellifera* auf. Diese allometrischen Größenveränderungen führen zu eigenartigen "Mosaiktie-

ren", die zB lange Beine und Hinterflügel, aber kleine Vorderflügel aufweisen. Diese Ungereimtheiten in den höhenabhängigen Größenveränderungen könnten auf noch nicht geklärte Verhaltenseigenschaften hinweisen (Saisonwanderungen ?). Das wichtigste Ergebnis dieser Untersuchung ist der Nachweis von klimaabhängigen Größenveränderungen (Bergmannsche Regel) bei einem im freien nistenden Insekt, wie sie bei höhlennistenden Honigbienen und bei den meisten Wirbeltieren festgestellt wurden. Die nur schwächer ausgeprägte Ökokline von *A florea* könnte als Folge der schwächer entwickelten Thermoregulation, bzw einer unvollständigen Isolation lokaler Populationen dieser Art gedeutet werden.

***Apis florea* / Iran / *A m yemenitica* / geographische Variation / Klima**

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