



Phylogenetic diversity and ecological features in the Egyptian flora

ABDEL-HAMID KHEDR^{1,2}, MARC W. CADOTTE^{1,3}, ALI EL-KEBLAWY^{1,4}
and JON LOVETT-DOUST^{1,*}

¹Department of Biological Sciences, University of Windsor, Windsor, ON, Canada N9B 3P4; ²Current address: Department of Botany, Mansoura University, Box 34517, New Damietta, Egypt; ³Current address: Department of Ecology and Evolutionary Biology, University of Tennessee, Knoxville, TN 37996-1610, USA; ⁴Current address: Department of Biology, Faculty of Science, University of United Arab Emirates, P.O. Box 17551, Al-Ain, United Arab Emirates; *Author for correspondence (e-mail: jld@uwindsor.ca; fax: +1-519-971-3609)

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Abstract. Until fairly recently, regional-scale ecological and evolutionary patterns have tended to be ignored as conservation efforts have been concerned with species and their habitats. Here we compare frequencies in the Egyptian flora of particular rank sizes (order, family and genus) with patterns of species abundance (classified as very rare, rare, common, or very common) and an array of life-history attributes. The angiosperm flora of Egypt is represented by 2446 taxa (2088 species), including taxa in 10 subclasses, 51 orders, 120 families, and 742 genera. A high degree of monotypism was observed: four orders are monotypic (each existing as single species), and have very rare overall abundances; 30 families are monotypic (17 of which are very rare or rare); and 354 genera are monotypic (over 70% of which are very rare or rare). Fourteen families (in particular the Resedaceae and Zygophyllaceae) have at least one-fifth of their global species represented in the Egyptian flora. Introduced species in general, and tree, aquatic herb and liana life forms all are especially well represented among monotypic genera. Native taxa are highly represented among rare and very rare abundance classes, while introduced taxa did not differ significantly in their abundance patterns, compared to overall flora values. Few large genera (>20 spp.) occur in the flora, with most species concentrated in genera containing 8–19 species per genus. Similarly, few families were highly speciose. Annual and herbaceous species were significantly over-represented, mainly among large, speciose genera and families. However, perennials, trees, shrubs, aquatic herbs, lianas and parasitic species were found mainly in families and genera having very few taxa. Life-history attributes may have important implications to speciation rates. Taxonomically based results, involving abundances and life-history attributes, are discussed in the context of biodiversity and conservation.

Introduction

It is possible to estimate floristic biodiversity in a number of quite different ways, including straightforward richness, or counts of the total number of species, the number of species per unit area, the relative abundances of species, and the number of rare and endemic species present. Phylogenetic diversity is in part a function of the size of a flora, and partly of the pattern of distribution of the species into higher taxa (see Fenner et al. 1997). Recently the pattern of species distribution among

higher taxa has been shown to be an effective indicator of phylogenetic diversity (e.g., Williams et al. 1991). Estimates of phylogenetic diversity are required in efforts to prioritize and target resources for conservation (Vane-Wright et al. 1991; Crozier 1992; Faith 1992; Williams and Gaston 1994; Williams and Humphries 1994). Fenner et al. (1997) compared the frequency distribution of genus size in 20 island and regional floras. They found that certain floras had high concentrations of genera containing many species. In contrast, others were notably lacking in large, speciose genera. Floras with higher levels of endemism consistently had larger genus sizes.

In a related paper, Khedr et al. (2002) described regional patterns in the distribution and abundance of species for the flora of Egypt. That flora contains many families and genera relative to the number of species (120 families, 742 genera, 2088 species) and a relatively large number of oligotypic families, each represented by only one or a few species (see below). A flora in which the species are distributed among numerous genera or families, or other higher-order ranks, should contain greater phylogenetic diversity and genomic information than one in which the same number of species is concentrated into fewer higher-order taxa. The high fraction (97%) of native species in the Egyptian flora (Khedr et al. 2002) may reflect fewer opportunities to acquire more species per genus or per family, due to fewer successful biotic invasions as well as lower speciation rates.

Recently considerable effort has been aimed at characterizing ecological elements (such as life form, length of life, mode of dispersal, regional rarity) for local floras (e.g., Fitter and Peat 1994; Turner 1997; Buide et al. 1998; Cadotte and Lovett-Doust 2001, 2002; El-Keblawy et al. 2002). Such information has been used in analyses of angiosperm diversification (Eriksson and Bremer 1992; Tiffney and Mazer 1995). For example, Edwards (1998) compared the incidence of rarity within 114 genera from 47 families. Of these, 113 genera within 46 families showed no difference from overall family means in the proportion of rare species they contained, indicating that the incidence of rarity is consistent between the taxonomic levels of family and genus.

Here we examine ecological attributes of species in the Egyptian flora, including the patterns of their relative abundances in Egypt, and consider this in relation to relative family and genus sizes. We hoped to determine whether rare species occur more often in particular rank sizes than others, and to understand this in terms of ecological features of those species.

Materials and methods

The data set was drawn from Täckholm (1974). A total of 2446 angiosperm taxa were recorded; species were present in one of four abundance classes: very rare, rare, common or very common. Species distributions were recorded for each of 13 geographic regions in Egypt (see Khedr et al. (2002) for further details concerning geographic regions and species distributions). The following attributes were also

recorded for each species: whether it was native or introduced; lifespan (annual, perennial or mixed); and life-form class (tree, shrub, shrublet, herb, hydrophyte, liana and parasite). Taxonomic classification of species into order and family followed Cronquist (1988). Global family sizes were obtained from Walter and Gillett (1998); for families not included in this reference we also used Watson and Dallwitz (1992).

A rarefaction algorithm was used to determine if the number of families (or, separately, genera) in any of the four abundance classes (i.e., very rare, rare, common, very common) was similar to what would be obtained from a random sampling of the entire flora. The formula:

$$F_m = F - \sum_i (1 - m/N)^{n_i}$$

was used to produce an expected number of families, F_m (and of genera), where F is the total number of families (or genera); N , the total number of genera (or species) in the flora; n_i , the number of genera (or species) in the i th family (or genus); and m , the observed sample size (the numbers of very rare, rare, common, and very common taxa) (Brewer and Williamson 1994). We used both the number of genera per family and number of species per family to calculate an expected number of families, and used the number of species per genus to calculate the expected number of genera. If F_m under-estimates the number of families (or genera) actually occurring in a particular abundance class, then species are distributed among a larger number of smaller families (or genera) than predicted by random sampling of the flora. Conversely, if F_m over-estimates families, then the species are clumped into fewer larger families.

Number of species per genus, per family, and per order were recorded. Frequencies of species in the relative abundance categories, and of species having particular life-history attributes were determined for each grouping of genus and family sizes. Contingency χ^2 tests were used to evaluate observed frequencies of abundance, origin, lifespan, and life form, for each of the various groupings of genus and family sizes, compared with overall frequencies in Egypt. If two-way contingency tables showed non-independence ($P < 0.05$), the Freeman–Tukey deviate

$$(\text{obs})^{-1/2} + (\text{obs} + 1)^{-1/2} - (4\text{exp} + 1)^{-1/2}$$

was used to determine if any individual cell was significantly over- or under-represented compared to the expected value (Legendre and Legendre 1998). Observed and expected values were considered significantly different when the absolute value was higher than the critical value:

$$\left(v\chi_{[1, \alpha/n]}^2 / n \right)^{-1/2}$$

where v is no. of degrees of freedom; n , the number of cells in the contingency table, and α/n , a Bonferroni correction for multiple testing (Legendre and Legendre 1998).

Results

The expected number of families, calculated as species per family and genera per family, did not differ ($P > 0.05$) from the observed number of families for each abundance class. Similarly, the rarefaction algorithm indicated no significant differences between expected and observed numbers of genera.

Four relatively information-rich, monotypic orders occur: Ebenales (Ebenaceae, *Euclea schimperi*); Haloragales (Haloragaceae, *Myriophyllum spicatum*); Orchidales (Orchidaceae, *Epipactis veratrifolia*); and Podostemales (Tristichaceae, *Tristicha trifaria*). Furthermore, all four species representing monotypic orders had very rare abundances. Two further orders were each represented by a single pair of species: Typhales (*Typha domingensis* and *T. elephantina*); and Aristolochiales (*Aristolochia bracteolata* and *A. maurorum*) – and all of these except the very common *T. domingensis* exist as very rare species in Egypt. In contrast, the three largest orders were the Cyperales (with 332 species), Fabales (301 species), and Asterales (261 species).

The most speciose families in the flora were the Fabaceae (with 241 species), Poaceae (231 species) and Asteraceae (227 species), which together accounted for 34% of the flora, followed by the Brassicaceae (6%), Caryophyllaceae and Chenopodiaceae (4% each) (see Figure 1). Fully 30 families were monotypic – these are listed in Table 1. χ^2 analysis indicates that the distribution of these monotypic taxa among the four abundance categories did not differ significantly from the overall flora's distribution pattern ($\chi^2 = 4.9$, $df = 3$, $P > 0.05$). The frequency distributions of species per family and species per genus are shown in Figure 2. Both are strongly skewed toward the smallest size classes. Means of 2.81 species per genus and 17.4 species per family were observed. Monospecific genera accounted for fully 17% (354 species) of the total flora. Results of χ^2 analysis indicate that the distribution of species and their varieties in monotypic genera among the four abundance categories did not differ significantly from the overall distribution pattern ($\chi^2 = 1.8$, $df = 3$, $P > 0.05$). Largest individual genera were: *Euphorbia*, Euphorbiaceae (with 39 species); *Astragalus*, Fabaceae (37 spp.); *Silene*, Caryophyllaceae (28 spp.) and *Convolvulus*, Convolvulaceae (25 spp.).

Table 2 shows the 19 families found in the flora that each contain fewer than 25 species, globally. Fourteen families (including in particular Resedaceae and Zygophyllaceae) have at least one-fifth of their global species represented in the Egyptian flora. At the other extreme, there were 10 families which represented 0.2% or fewer of the global species in their family: Rosaceae (0.2%), Ebenaceae (0.2%), Araceae (0.2%), Thymelaeaceae (0.2%), Portulacaceae (0.2%), Palmae (0.1%), Apocynaceae (0.1%), Sapindaceae (0.07%), Rutaceae (0.07%), and Orchidaceae (0.003%). Except for Ebenaceae, Portulacaceae, and Thymelaeaceae [with ca. 450, 500, and 500 species, respectively (Walter and Gillett 1998)], all of these under-represented families have >1500 species globally.

Exotics were represented by a very small number of species, 84, distributed among 24 families (Table 3). Both monocotyledons and dicotyledons had relatively fewer exotic species per family and species per genus than natives. The number of

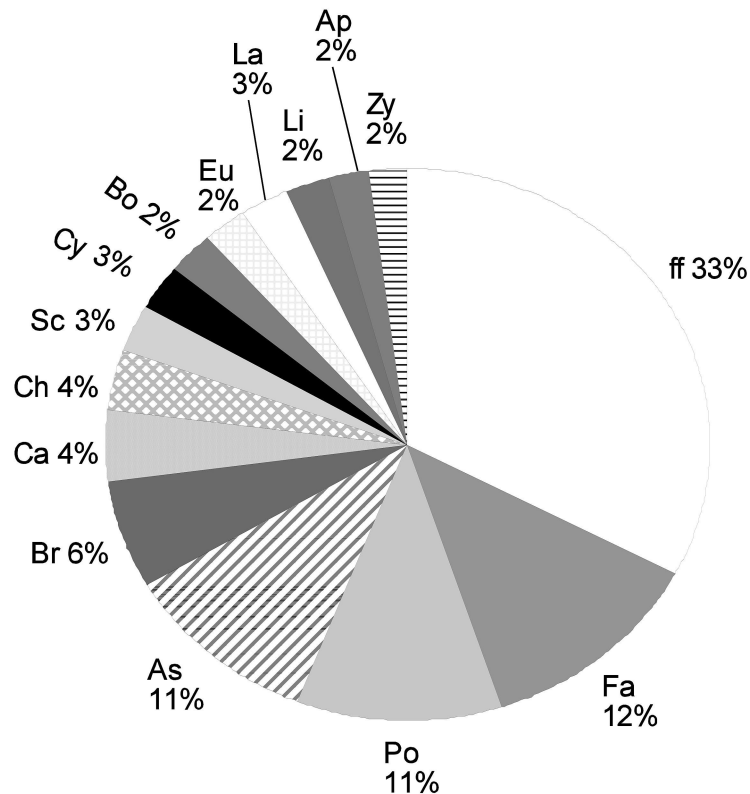


Figure 1. Percentage of species in the Egyptian flora within each of the major families (Fa – Fabaceae, Po – Poaceae, As – Asteraceae, Br – Brassicaceae, Ca – Caryophyllaceae, Ch – Chenopodiaceae, Sc – Scrophulariaceae, Cy – Cyperaceae, Bo – Boraginaceae, Eu – Euphorbiaceae, La – Lamiaceae, Li – Liliaceae, Ap – Apiaceae, Zy – Zygophyllaceae, ff – families with fewer than 50 species).

exotic species per family was not significantly related to the global number of species per family ($R^2 = 0.21$, $F = 4.218$, $P = 0.065$) (Figure 3).

Life-history attributes and patterns of species abundance

Trees, lianas, and parasites were all represented by fewer species, compared to other life forms. However, neither life form nor origin differed from the overall distribution of species among the four abundance classes (Table 4). The overall comparison of frequencies for annual, perennial and mixed lifespan categories showed significant variation among abundance classes ($P < 0.001$). Perennial species were significantly over-represented among very rare abundances ($P < 0.05$), and species grouped as 'others' (i.e., having greater variability in lifespan) were significantly under-represented in the very rare class ($P < 0.05$), while being over-represented in the very common abundance class ($P < 0.05$).

Table 1. Monotypic families of the Egyptian flora and their representative species.

Family	Species	Abundance
Agavaceae	<i>Dracaena ombet</i> Kotschy & Peyr.	Rare
Avicenniaceae	<i>Avicennia marina</i> (Forssk.) Vierh.	Rare
Balanitaceae	<i>Balanites aegyptiaca</i> (L.) Delile.	Rare
Cordiaceae	<i>Coris monspeliensis</i> L.	Very rare
Cynomoriaceae	<i>Cynomorium covery commonineum</i> L.	Rare
Ebenaceae	<i>Euclea schimperi</i> (A. DC.) Dandy.	Very rare
Globulariaceae	<i>Globularia arabica</i> Jaub. & Spach.	Common
Haloragaceae	<i>Myriophyllum spicatum</i> L.	Very rare
Leonticeae	<i>Leontice leontopetalum</i> L.	Rare
Menispermaceae	<i>Covery commonulus pendulus</i> (J.R. & G. Forst.) Diels.	Common
Moringaceae	<i>Moringa peregrina</i> (Forssk.) Fiori.	Very rare
Neuradaceae	<i>Neurada procumbens</i> L.	Common
Nitrariaceae	<i>Nitraria retusa</i> (Forssk.) Asch.	Very common
Orchidaceae	<i>Epipactis veratrifolia</i> Boiss. & Hohen.	Very rare
Pistaciaceae	<i>Pistacia khinjuk</i> Stocks.	Very rare
Pontederiaceae	<i>Eichhornia crassipes</i> (C. Mart.) Solms.	Very common
Portulacaceae	<i>Portulaca oleracea</i> L.	Very common
Posidoniaceae	<i>Posidonia oceanica</i> (L.) Delile.	Very common
Rhizophoraceae	<i>Rhizophora mucronata</i> Lam.	Rare
Ruppiceae	<i>Ruppia maritima</i> L.	Common
Rutaceae	<i>Ruta tuberculata</i> Forssk.	Common
Salvadoraceae	<i>Salvadora persica</i> Forssk.	Rare
Santalaceae	<i>Thesium humile</i> Vahl.	Common
Sapindaceae	<i>Cardiospermum halicacabum</i> L.	Very rare
Sphenocleaceae	<i>Sphenoclea zeylanica</i> Gaertn.	Rare
Thymelaeaceae	<i>Thymelaea hirsuta</i> (L.) Endl.	Very common
Tristichaceae	<i>Tristicha trifaria</i> (Bory ex Willd.) Spreng.	Very rare
Vahliaceae	<i>Vahlia digyna</i> (Retz.) Ktze.	Common
Zannichelliaceae	<i>Zannichellia plaustris</i> L.	Very common
Zosteraceae	<i>Zostera noltii</i> Hornem.	Very rare

Authorities follow Boulos (1995).

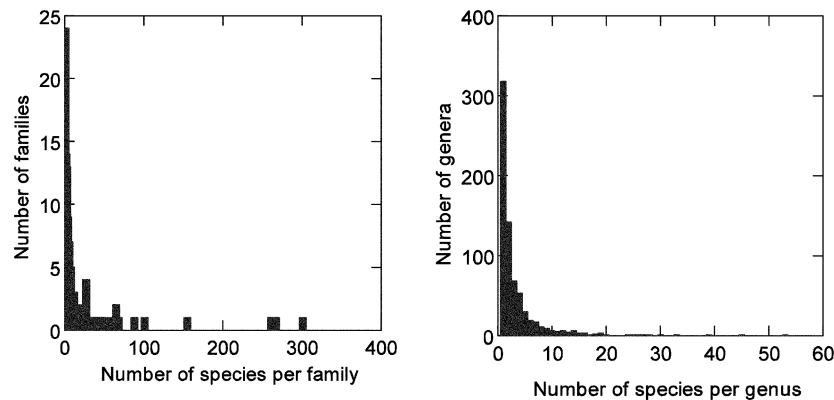


Figure 2. Frequency distribution of (a) species per family and (b) species per genus in the Egyptian flora ($n = 120$ families; 742 genera, and 2088 species).

Table 2. Families occurring in the Egyptian flora, which have fewer than 25 species globally. Global family sizes from Walter and Gillett (1998) and Watson and Dallwitz (1992).

Family	Global		Local		Percentage represented in flora	
	Genera	Species	Genera	Species	Genera	Species
Cordiaceae	1	1	1	1	100	100
Cynomoriaceae	1	2	1	1	100	50
Sphenocleaceae	1	2	1	1	100	50
Posidoniaceae	1	3	1	1	100	33.3
Vahliaceae	1	5	1	1	100	20
Ceratophyllaceae	1	6	1	3	100	50
Zannichelliaceae	7	8	1	2	14.3	25
Nitrariaceae	1	9	1	2	100	22.2
Moringaceae	1	10	1	1	100	10
Neuradaceae	3	10	1	1	33.3	10
Pistaciaceae	1	10	1	2	100	20
Typhaceae	2	10	2	2	100	20
Avicenniaceae	1	11	1	1	100	9.1
Salvadoraceae	3	12	1	2	33.3	16.7
Leonticaceae	4	14	1	1	25	7.1
Hypecoaceae	1	15	1	9	100	60
Cymodoceaceae	5	16	2	6	40	37.5
Zosteraceae	3	18	1	1	33.3	5.6
Balanitaceae	1	25	1	1	100	4
Resedaceae ^a	6	70	5	16	83.3	22.9
Zygophyllaceae ^a	30	235	6	50	20	21.3

^aFamilies having >20% of their global species represented in the Egyptian flora, but having >25 species.

Table 3. Taxonomic composition and distribution of native and exotic flowering species among families, genera, genera per family (g/f), and species per family (s/f).

Category	Families	Genera	Species	g/f	s/f
<i>Native</i>					
Monocotyledons	23	149	479	6.5	20.8
Dicotyledons	95	547	1883	5.8	19.8
<i>Exotics</i>					
Monocotyledons	4	20	23	5.0	5.8
Dicotyledons	20	44	61	2.2	3.1

Table 5 shows that most species occurred in genera containing 8–19 species per genus. Native species, annuals, perennials and the largest classes of plant life form (shrub, shrublet, herb and parasites) were all also highly represented in this category of genus size. In contrast, introduced species, trees, hydrophytes and lianas were mainly represented among monotypic genera. Table 5 also shows the relation between the frequency of species in differently sized genera and ecological attributes, including relative abundance, length of life, life form and native/alien status. No significant difference was apparent between overall frequencies of species in abundance classes and the species-per-genus categories. However, origin, lifespan and plant life form showed highly significant differences within all categories of

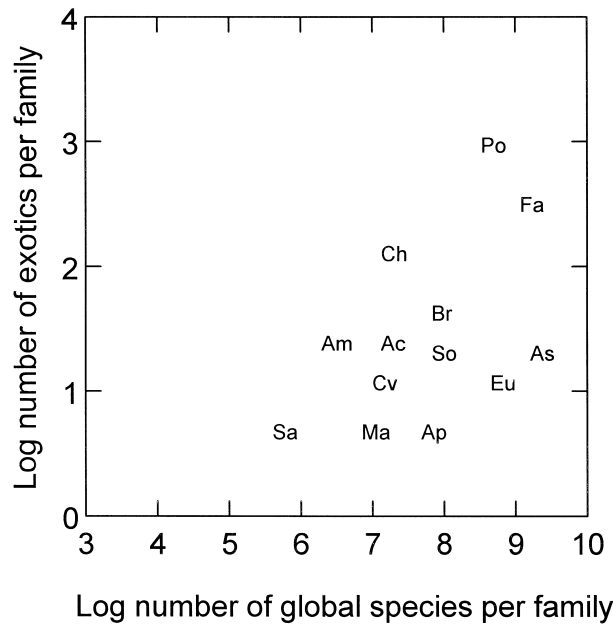


Figure 3. Log number of exotic species per family plotted against log number of global species per family. Shown are families with more than one exotic species in Egypt. The relationship is not significant ($R^2 = 0.21$, $F = 2.2$, $P = 0.065$). Ac – Asclepiadaceae, Am – Amaranthaceae, Ap – Apiaceae, As – Asteraceae, Br – Brassicaceae, Ch – Chenopodiaceae, Cv – Convolvulaceae, Eu – Euphorbiaceae, Fa – Fabaceae, Ma – Malvaceae, Po – Poaceae, Sa – Salicaceae, So – Solanaceae.

species per genus ($P < 0.001$). Introduced taxa were significantly over-represented among oligotypic genera (having only 1–2 species per genus) ($P < 0.05$), while being under-represented in larger genera (5–19 species per genus, $P < 0.05$). Annual species were significantly over-represented in mid-sized genera (5–7 species per genus, $P < 0.05$) and under-represented in small genera (2 species per genus, $P < 0.05$). The opposite was true for perennial species (Table 5). Trees and shrubs were significantly over-represented in small genera (1 or 2 species per genus, $P < 0.05$). Herbaceous species were over-represented in large genera (>20 species per genus, $P < 0.05$), while all other life forms were significantly under-represented in large genera ($P < 0.05$).

Table 6 gives frequency distributions for abundance classes, origin status, and life-history attributes among species-per-family categories in the flora. Most species were concentrated in relatively few large families (>75 species per family). Patterns for species distributed among relative abundance groups, lifespan, and life-form classes differed significantly with respect to overall distribution among the species-per-family classes. Annual species were significantly under-represented in small-to-mid-sized families (1–20 and 37–75 species per family, $P < 0.05$), while perennials were significantly over-represented in these family size classes ($P < 0.05$). Annuals were also significantly over-represented in large families (>75 species per family, P

Table 4. The frequency of species in each abundance class associated with an array of ecological attributes.

Attributes	Abundance class			
	Very rare	Rare	Common	Very common
<i>Origin</i>				
Native	999	662	389	245
Introduced	27	22	19	13
Overall $\chi^2 = 5.9$; 3 df; $P = \text{NS}$				
<i>Lifespan</i>				
Annual	459	339	213	124
Perennial	533 \uparrow	303	181	109
Others	35 \downarrow	42	13	25 \uparrow
Overall $\chi^2 = 33.8$; 6 df; $P < 0.001$				
<i>Life form</i>				
Tree	10	14	4	5
Shrub	120	75	37	24
Shrublet	75	52	35	14
Herb	768	519	311	199
Hydrophyte	28	9	12	10
Liana	9	5	3	2
Parasite	16	10	6	4
Overall $\chi^2 = 15.9$; 18 df; $P = \text{NS}$				

Overall χ^2 was determined in a contingency table, and in the case of non-independence, individual cells were tested using the Freeman–Tukey deviate (see Methods). \uparrow and \downarrow indicate frequencies that are significantly ($P < 0.05$) over- and under-represented, respectively. NS – not significant.

< 0.05), and perennials were under-represented ($P < 0.05$). Trees and shrubs, as well as ‘other’ life forms (lianas, parasites, and hydrophytes) were significantly over-represented in small-to-medium-sized families (1–20 species per family, $P < 0.05$), while herbaceous species were under-represented in these classes ($P < 0.05$). Herbs were also over-represented in large families (>75 species per family, $P < 0.05$), while trees and shrubs, and ‘others’ were under-represented ($P < 0.05$).

The Egyptian flora is comparatively rich in terms of the number of varieties and subspecies per species. More than 20% of species have evolved varietal forms (Table 7). The relative number of species with varieties appears to increase with increasing abundance. Trees, shrubs and hydrophytes have the lowest relative representation of species with varieties, while none of the comparatively small number of liana species had varietal-level differentiation. Both very rare and perennial species were significantly under-represented by species with varietal forms ($P < 0.05$), while rare, very common, and annual species were significantly over-represented ($P < 0.05$).

Discussion

The biogeography of very low-diversity taxa is interesting, in part because some of these species are relicts of formerly diverse lineages, and some are autochthonous

Table 5. The frequency of species in variously sized genera associated with an array of ecological attributes.

Number of genera	Species-per-genus class					
	1 (354) ^a	2 (135)	3–4 (123)	5–7 (62)	8–19 (44)	>20 (9)
<i>Abundance</i>						
Very rare	178	126	175	178	237	133
Rare	117	83	130	105	158	91
Common	58	47	85	57	110	51
Very common	46	33	39	53	65	21
Overall $\chi^2 = 17.9$; 15 df; $P = \text{NS}$						
<i>Origin</i>						
Native	382	286	424	390	579	293
Introduced	24 \uparrow	17 \uparrow	16	8 \downarrow	12 \downarrow	7
Overall $\chi^2 = 18.9$; 5 df; $P < 0.001$						
<i>Lifespan</i>						
Annual	185	103 \downarrow	217	224 \uparrow	298	146
Perennial	213	183 \uparrow	202	144 \downarrow	259	145
Others	9 \downarrow	17	21	30 \uparrow	33	9
Overall $\chi^2 = 57.7$; 10 df; $P < 0.001$						
<i>Life form</i>						
Tree + shrub	71 \uparrow	61 \uparrow	30 \downarrow	43	72	17 \downarrow
Shrublet	25	18	46	21	64 \uparrow	6 \downarrow
Herb	281	197	346	315	435	277 \uparrow
Others	29	27 \uparrow	18	19	20	0 \downarrow
Overall $\chi^2 = 131.11$; 15 df; $P < 0.001$						

Overall χ^2 was determined in a contingency table, and in the case of non-independence, individual cells were tested using the Freeman-Tukey deviate (see Methods). \uparrow and \downarrow indicate frequencies that are significantly ($P < 0.05$) over- and under-represented, respectively. NS – not significant. ^aColumn totals equal 399 instead of 354 because varietal forms were included, as they had differing abundances.

and perhaps new taxa that have not diversified. In either case, they probably are more likely to go extinct than are multi-species taxa. Their distribution may reflect differences among regions in rates of local extirpation or production of new taxa (Latham and Ricklefs 1993).

Purvis et al. (2000) showed that, among birds and mammals, species facing extinction globally (as defined by the World Conservation Union) were over-represented by monotypic genera. This has important ramifications, since loss of the sole members of monotypic higher taxa means that a disproportionate amount of phylogenetic (and genomic) information will be lost. Our results do not generally support those of Purvis et al. (2000). However, in the Egyptian flora, the large majority of species are threatened with extinction (having rare and very rare abundances). In any event monotypic families in the very rare and rare abundance classes (nine and eight families, respectively, see Table 1) should be a priority for conservation efforts. These taxa (and even more so, those representing the four monotypic orders: *E. schimperi*, *M. spicatum*, *Ep. veratrifolia*, and *Tr. trifaria*) should be recognized as having greater genomic ‘worth’ within the Egyptian flora than, say, a species like *Stipagrostis drarii* (Poaceae), which in Egypt is one of 20 in its genus and one of 267 in its family.

Table 6. The frequency of species in variously sized families associated with an array of ecological attributes.

Number of families	Species-per-family class					
	1 (36)	2–10 (56)	11–20 (11)	21–36 (9)	37–75 (9)	>75 (5)
<i>Abundance</i>						
Very rare	11	146	72	117	245	436
Rare	10	76	54	92	154	298
Common	7	40	23	56	99	183
Very common	8	28	19	26	44	133
Overall $\chi^2 = 25.2$; 15 df; $P < 0.05$						
<i>Origin</i>						
Native	33	285	165	293	538	1042
Introduced	3	8	5	11	16	42
Overall $\chi^2 = 4.5$; 5 df; $P = \text{NS}$						
<i>Lifespan</i>						
Annual	6↓	107↓	59↓	139	194↓	668↑
Perennial	30↑	178↑	102	155	338↑	345↓
Others	0	8	9	10	22	70
Overall $\chi^2 = 201.3$; 10 df; $P < 0.001$						
<i>Life form</i>						
Tree + shrub	13↑	52	35↑	35	71	88↓
Shrublet	1	16	5↓	51↑	81↑	26↓
Herb	8↓	160↓	102	213	399	969↑
Others	13↑	65↑	28↑	5↓	3↓	1↓
Overall $\chi^2 = 631.5$; 15 df; $P < 0.01$						

Overall χ^2 was determined in a contingency table, and in the case of non-independence, individual cells were tested using the Freeman–Tukey deviate (see Methods). ↑ and ↓ indicate frequencies that are significantly ($P < 0.05$) over- and under-represented, respectively. NS – not significant.

The flora of any locality will have its own unique history and, obviously, exists in a particular, localized geographic context. The extent of speciation is likely to have been strongly influenced by climatic history; furthermore, available faunal groups will be significant agents of seed dispersal and pollination. These effects are all likely to be more intense on small and isolated islands (Fenner et al. 1997). Latham and Ricklefs (1993) showed that the temperate tree floras of Europe and the Pacific slope of North America clearly are depauperate at higher taxonomic levels relative to those of eastern Asia and eastern North America. Furthermore, higher taxa from those floras had on average fewer species, even though many genera and families were represented in the eastern Asian temperate forest region by only one or a few species.

The Egyptian flora falls into the category of a widespread mid-continental flora having low mean genus size and a very low level of endemism (Fenner et al. 1997). It has a low level of speciation and a high level of monotypism, with very few genera having more than 30 species. The continuous nature of geographic distribution of habitats, and relative lack of reproductive isolation are perhaps the most important factors influencing the rate of speciation there. However, El-Keblawy et al. (2002) found that the number of species per family in Egypt was higher in cosmopolitan families and families whose dominant mode of dispersal is abiotic and

Table 7. Ecological attributes of species either possessing or lacking varietal forms.

Attributes	Species with varieties		Species without varieties	
	Number	%	Number	%
<i>Abundance</i>				
Very rare	172↓	16.8	855↑	83.2
Rare	176↑	25.7	508	74.3
Common	106	26.0	302	74.0
Very common	77↑	29.8	181	70.2
Overall $\chi^2 = 34.6$; 3 df; $P < 0.001$				
<i>Origin</i>				
Native	551	23.4	1805	76.6
Introduced	16	19.0	68	81.0
Overall $\chi^2 = 0.6^a$; 1 df; $P = \text{NS}$				
<i>Lifespan</i>				
Annual	302↑	25.8	871	74.2
Perennial	237↓	20.6	911	79.4
Others	24	24.5	74	75.5
Overall $\chi^2 = 8.54$; 2 df; $P < 0.05$				
<i>Life form</i>				
Tree	4	12.1	29	87.9
Shrub	49	18.8	212	81.2
Shrublet	48	26.7	132	73.3
Herb	443	23.9	1408	76.1
Hydrophyte	9	15.0	51	85.0
Liana	0↓	0.0	19	100
Parasite	14	38.9	22	61.1
Overall $\chi^2 = 22.8$; 6 df; $P < 0.01$				

Overall χ^2 was determined in a contingency table, and in the case of non-independence, individual cells were tested using the Freeman-Tukey deviate (see Methods). ↑ and ↓ indicate frequencies that are significantly ($P < 0.05$) over- and under-represented, respectively. NS – not significant. ^aYates correction was applied.

which possess a herbaceous growth habit. Yet, the actual family speciation rate (i.e., the number of varieties per species) did not differ among these traits.

In the context of biodiversity conservation, the occurrence of a large number of species per genus clearly represents a high level of intra-generic diversity, but need not signify a particularly high overall level of biodiversity. Table 8 summarizes floristic features for five regional floras, all having a relatively similar total number of species ($\bar{x}=1937 \pm 16\%$), but which occur in very different biogeographic contexts. Egypt has 2.08 times as many genera as New Zealand (742 vs. 356 genera, respectively) and about 1.4 times as many as the British Isles (546), and almost 1.5 times as many as the mean number of genera in the three north temperate floras (Ontario, Alberta, and British Isles: $\bar{x}=532$ genera). Despite their small sizes, the island floras of New Zealand and the British Isles are taxonomically species-rich (7.11×10^{-3} and 7.01×10^{-3} species/km², respectively), while Egypt's larger mid-continental flora is comparatively species-poor (2.02×10^{-3} species/km²). However, greater phylogenetic diversity is contained in floras having a greater number of higher-order taxa. Egypt's flora is in general quite similar to the other

Table 8. Number of genera and species, and geographic area of five regional floras.

	Egypt	Ontario ^a	Alberta ^b	British Isles ^c	New Zealand ^d
No. of genera	742	550	499	546	356
No. of species	2088	2356	1605	1710	1926
Geographic area (km ²)	1 036 000	675 633	661 190	244 100	270 580
Geographic context	Mid-continental	Mid-continental	Mid-continental	Island	Island

^aNewmaster et al. (1998); ^bMoss (1959); ^cClapham et al. (1962); ^dFenner et al. (1997).

mid-continental floras (2.02×10^{-3} species/km² for Egypt, compared with 3.49×10^{-3} for Ontario and 2.43×10^{-3} for Alberta). The general problem of taxonomic 'weighting' in order to quantify and better understand this aspect of biodiversity is an important contemporary concern of conservationists (Williams et al. 1991; Williams and Humphries 1994).

A disproportionate number of species that are rare have particular life-history attributes, leaving them better able to persist in a particular locality. Such attributes include, for example, a perennial lifecycle. Cadotte and Lovett-Doust (2002) found that rare species in southwestern Ontario ecosystems were significantly more likely (than common species there) to be associated with open-habitat communities (such as tallgrass prairie, alvar, and meadow) and significantly less likely to be found in aquatic habitats and disturbed areas. Rare species were also significantly more likely to be herbaceous, insect-pollinated and to have larger fruits, than common species. Edwards and Weakley (2001) reported that rare species in depression wetlands of the southeastern coastal plain, USA, were predominantly perennial and clonal (which probably reflects the prevalence of that life form throughout southeastern wetlands).

Native species in Egypt are represented by 97% of the flora, while introduced species are represented by just 3%, which is much lower than other floras. For example, Crawley et al. (1996) recorded 46% of all species in Britain (2684) as exotics. In southern Ontario, Canada, 26% of the total flora (ca. 1850 spp.) was made up of exotic species (Cadotte and Lovett-Doust 2001). Frequencies of introduced Egyptian species did not differ significantly in the four abundance classes, compared to overall frequencies, perhaps in part because alien species, by their nature, would likely be dispersed by anthropogenic factors. We have noted previously that introduced species in the Egyptian flora were significantly more likely to be weedy (Khedr et al. 2002). Some of these alien species (e.g., *Azolla filiculoides*) show abundant growth that is capable of excluding native species, like *Lemna* sp. (Boulos 1995). Biogeographic analyses have shown that family level patterns of invasive species usually reflect global patterns, that is, globally larger families tend to be locally represented in larger numbers as exotics (Weber 1997; Cadotte and Lovett-Doust 2001). The Egyptian data do not support this generality (Figure 3). This, plus the fact that there are so few exotics in Egypt, may reflect the fact that species originating and evolving in arid climates ought to be able to thrive in Egypt. Even with Egypt's long history of trade and interaction with other arid and Mediterranean regions, there appears not to have been an accumulation of a significant number of

exotic species. Of course the reciprocal is probably also true: Egypt's climatic specialists are probably less able to compete with natives in other regions. Both Europe and southern Ontario, Canada contain very few non-native species from northern Africa as a whole (Weber 1997; Cadotte and Lovett-Doust 2001), and probably none from Egypt specifically.

Taxonomic features associated with rarity require further elucidation. It is not obvious whether some taxa are inherently more likely to be rare than others, or whether rare species are more related to certain size classes of genera or families. A positive relationship between global family size and number of species in a region is a frequently observed pattern, and Rejmanek and Randall (1994) suggested it may be useful to examine the ratio of species present in a region to the global number of species, in order to determine which families may be over- or under-represented in a flora. Species comprising families that are relatively under-represented in the Egyptian flora (e.g., Rosaceae, Ebenaceae, Araceae, Palmae, Orchidaceae) possibly share derived traits, making these species less able to thrive in Egypt's ecosystems, or possibly the centres of origin and speciation for these families are allopatric to Egypt. In contrast, families that appear to be highly represented in the Egyptian flora (Cymodoceaceae, Hypecoaceae, Resedaceae, and Zygophyllaceae) typically occur in warm, Mediterranean-type or arid environments, predisposing these species to success in Egypt. El-Keblawy et al. (2002) found that families which were both locally and globally phylogenetically rare (oligotypic) appeared more likely to be perennial or woody, and to be animal dispersed, compared to families which were locally and globally phylogenetically common (polytypic).

Hodgson (1986) concluded from his analysis of the Sheffield flora that the major angiosperm families are to some extent ecologically specialized. Evidence for this rests upon the fact that the ecological attributes appear to be similarly expressed in groups from within the same family, but differing in geographic origin. General support for the notion that families are ecologically specialized comes also from Stebbins (1980), who argued that evolution of families and orders is a result of the same kinds of selection processes that operate during evolution at the level of species or below. Ecological specialization of families does not, of course, imply that the level of species abundance within a family will be similar in different regions. According to Grime (1974), families with a greater number of rare species are in general more stress tolerant. Those with many common species tend to exhibit competitive or competitive-ruderal strategies and often have several alternative strategies for regeneration (Grime 1984).

Many taxonomically unrelated groups show common ecological characteristics. Buide et al. (1998) investigated the flora of the Iberian Peninsula, and demonstrated that ecological features of the flora there appear independently in different phylogenetic groups. However, we found ecological differences among taxonomic groups. Trees, shrubs and perennials were all over-represented among small genera and families, while herbaceous and annual species were over-represented in large genera and families. A number of authors have commented on the fact that higher taxa dominated by herbaceous species exhibit greater diversity compared to those with woody taxa (Eriksson and Bremer 1991, 1992; Ricklefs and Renner 1994;

Dodd et al. 1999; El-Keblawy et al. 2002). Furthermore, annuals have more varietal forms (see also El-Keblawy et al. 2002). These patterns may be considered as long-term byproducts of short-term processes. Short-term evolutionary change is a complex process involving geography, demography and genetic diversity. Simulation studies reveal that it could take a limited number of generations (four times the mean population size) for two populations to become divergent (reciprocal monophyly) (Moritz 1994). If so, then species with relatively shorter lifespans and time to reproduction (e.g., herbaceous species vs. trees and shrubs; annuals vs. perennials) ought to have higher rates of speciation (or, in the case of the Egyptian flora, be over-represented in speciose genera and families – as we observed).

To preserve rare species, it is important to know where they occur and what aspects of their habitats and biology most limit persistence. Information on plant biology and ecology can identify the extent to which pollinators or dispersers influence rarity. If conservation evaluation is to be based on concepts of species diversity, then imperfections in our knowledge of the divergence of taxa through time (classification), and distribution in space (biogeography) have to be accepted, and continual adjustments must be made as our understanding of both improves (Vane-Wright et al. 1991).

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