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REVIEW

Biodiversity in Egypt contributing to world biodiversity

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Background: Available publications (e.g., theses, scientific reports, books and papers) about the elements of the Egyptian biodiversity during 2000–2018 were collected in a progress scientific report. The publications reported in this bibliography were collected from various sources including: site of the Egyptian Universities Libraries Consortium Portal, accounts of the biodiversity specialists on Research gate, direct contact with the national experts of the Egyptian biodiversity, libraries of some universities and research centers and others. The elements of the Egyptian biodiversity are classified into different categories.

Results: Up till now, a total of 20,521 species were recorded in Egypt, of which insects have the highest contribution (48.7%), followed by fungi (12.1%) and vascular plants (11.5%). In a descending order, each of amphibians, viruses, reptiles, mammals, cyanobacteria, bryophytes, and bacteria have a minor contribution (< 1%). Based on the available data, Egyptian biodiversity contributes 1.3% of the world biota, although its area contributes only 0.7% of the world area. At a global scale, the most represented groups are algae (12.22% of the world figure), followed by cyanobacteria (6.08%) and birds (4.70%). On the other hand, the less represented are amphibians (0.14% of the world figure), flora (0.84%) and insects (1.00%).

Conclusions: Some suggestions are recommended for preparing a phytoplankton checklist based on the rich available publications; further studies should be carried out on the lichen biodiversity in order to prepare acceptable verified checklist for this important group. In addition, paleo-biologists should work together to publish a book dealing with the Egyptian paleo-biology, such studies will lead to high ranking the Egyptian biodiversity.

Keywords: amphibians, bacteria and virus, bryophytes, fungi, insects, mammals and reptiles, vascular plants

Introduction

Egypt has attracted the attention of the explorers of natural history due to its unique position midway between Africa and Asia, with its long coasts of the Mediterranean Sea in the north (c. 970 km) and the Red Sea in the east (c. 1,100 km). It is connected to the Mediterranean and sub-Saharan Africa by the way of Nile Valley, and to the tropical Indian Ocean through the Red Sea (Shaltout and Eid 2016) (Fig. 1). It has diverse habitats with micro-climates that host many plant species and communities. The major habitat types in Egypt include desert areas, mountains, plains, slopes, sand formations, salt marshes, wetlands including Mediterranean and Red Sea coasts, Nile tributaries and its net of canals and drains, fresh- and brackish-water lakes (EEAA 2008), as well as the urban habitats particularly in the Nile region such as canal-drain banks, roadsides and rail-ways.

Egyptian biota faces threats by a combination of factors such as: over-grazing, over-collection, over-hunting, overfishing, unsustainable agriculture practices, urbanization, pollution, land use changes, spread of invasive species and climate change which often leads to decline and extinction of many of its biodiversity components. Some other factors include increasing population growth, high rates of habitat destruction, modification and deforestation and over-exploitation (Shaltout and Eid 2016). Because of the barren nature of much of Egypt, plants and animals tend to be localized in small areas, while remaining low in the country as a whole.

Available publications (e.g., theses, scientific reports, books and papers) about the elements of the Egyptian bio-

Fig. 1 The main geomorphic regions of Egypt.

diversity during 2000–2018 were collected in a progress scientific report (Shaltout 2019). The publications reported in this bibliography were collected from various sources including: site of the Egyptian Universities Libraries Consortium Portal, accounts of the biodiversity specialists on Research gate, direct contact with the national experts of the Egyptian biodiversity, libraries of some universities and research centers, EEAA publications on biodiversity and national protectorates, in addition to the own library of the first author. It is classified into: flora and vegetation, alien flora, bryophytes, agro-biodiversity, phytoplankton, bacteria and viruses, fungi and lichens, zooplankton, insects, arachnida, fishes, reptiles, amphibians and mammals, alien fauna, birds, marine biology, paleo-biology, goods and services (carbon sequestration, bioremediation, biofuel, and others), chemistry and pharmacology (botanical, zoological and microbiological studies), and protected areas.

Available information on the components of Egyptian biodiversity was extracted from these literatures and compared with those of the global diversity published in Chapman (2009) and Hood (2010). Species-area ratio (species per 10^6 km^2) was calculated to compare the biodiversity of Egypt with those of the other countries of larger areas (Hood 2010).

This review aims to compare the components of the Egyptian biodiversity (i.e., vascular plants, bryophytes, phytoplankton and macro-algae, fungi and lichens, cyanobacteria, bacteria and viruses, arachnida and insects, fishes, reptiles and mammals, birds), with those of the global diversity based on the recent available publications. It aims also to identify the gaps of knowledge about the Egyptian biodiversity and the ways for filling such gaps.

Vascular Plants

Across the globe, more than 40,000 plant species are threatened with extinction. This represents 28% of all species assessed by the International Union for Conservation of Nature (IUCN). These making plants more threatened than birds, according to the first global analysis of the status of plant biodiversity (Gilbert 2010). Currently, only 10% of plant diversity is assessed in the global Red List of Threatened Species. In general, the vascular plants in Egypt include 2,365 taxa (2,145 species and 220 infra-specific taxa) of native and naturalized vascular plants, be-

longed to 755 genera and 129 families (Boulos 2009). This figure approximates 0.84% of the world figure of 281,621 taxa (Table 1). The preliminary red data list of the vascular plants represented in the flora of Egypt includes 457 species, approximate 20% of the total flora. Following the red list categories, these species are classified into 14 extinct, 123 endangered 54 vulnerable, 173 rare and 93 indeterminate species (El-Hadidi and Hosni 2000). On the other hand, alien vascular plants in the Egyptian flora approximate 250 species, of which 114 are casuals, 129 are naturalizers and 7 are invasive species (Shaltout 2020). Other publications dealt with evaluation of only one alien such as *Ipomoea carnea* (Shaltout et al. 2010). In addition, the endemic flora in Egypt was 41 species belonged to 36 genera and 20 families and inhabiting 10 main habitats, while near endemic taxa was 73, belonging to 58 genera and 28 families and were recorded in 11 habitats (El-Khalafy 2018; El-Khalafy 2023; El-Khalafy et al. 2021). Moreover, Bedair et al. (2020) recorded 228 woody plants (trees and shrubs) belonged to 126 genera and 45 familie whihc inhabit 14 habitats (8 natural and 6 anthropogenic).

As the vascular plants are the most structural components of the natural ecosystems, we compared their number in Egypt with those of some most diverse countries through calculating the species-area ratio of each country. Although China, Brazil, and Australia had the largest areas (Table 2), but the species-area ratio of China (858 species per 10^6 km^2) and that of Australia (2,055 species per 10^6 km^2) are smaller than that of Egypt (2,365 species per 10^6 km^2). Although Egypt is a hyper-arid country comparing with the previous mentioned counties, but the habitat heterogeneity that characterizes it supports many micro-habitats that act as refuges for many species. For example, under the current climate change, Sinai highlights (Egypt) harbor micro-topographic and geomorphologic niches as micro-refugee areas of great interest comparable to those of Southern European and Mediterranean Mountains which still host important relict populations of glacial and alpine flora (often in isolated occurrences: Gentili et al. 2015). Such species can be present in topographic niches generally linked to specific landforms such as fossil glacial steeps, gravel slopes and gorges that may perform as warm-stage micro-refugia (Shaltout et al. 2020).

Table 2 Diversity of vascular plant species per several countries, including Egypt, in relation to their area and area per 10^6 km^2

Country	Area (10^6 km^2)	Vascular plant species	Species per 10^6 km^2
Australia	7.69	15,638	2,055
Brazil	8.51	56,215	6,606
China	9.56	8,200	858
Congo	2.35	11,007	4,684
India	3.05	18,664	6,119
Indonesia	1.90	29,375	15,461
Mexico	1.97	26,071	13,234
Egypt	1.00	2,365	2,365

Data from the article of Hood (https://web.archive.org/web/20180813085700/https://www.scidev.net/global/biodiversity/feature/biodiversity-facts-and-figures-1.html).
The number of vascular plant species in each country was taken from world resources institute (https://www.wri.org/).

Table 1 Number of the taxa of Egyptian biodiversity in comparison with the word taxa

Taxonomic group	Egypt taxa (E)	World taxa (W)	Contribution ratio E/W (%)	References of Egyptian biodiversity
Plants				
Flora	2,365	281,621	0.84	Boulos (2009)
Bryophytes	194	16,263	1.20	El-Saadawi and Shabbar (2007), El-Saadawi et al. (2003, 2015)
Algae	1,500	12,272	12.22	Eassa (2013), Shabaka (2018)
Animals				
Arachnida	1,565	102,248	1.53	El-Hennawy (2006)
Insects	10,000	1,000,000	1.00	EEAA (1998)
Fishes	1,050	31,153	3.37	Bishai and Khalil (1997), Akel and Karachle (2017)
Amphibians	9	6,515	0.14	Baha El Din (2006)
Reptiles	109	8,734	1.25	Baha El Din (2006)
Mammals	125	5,487	2.28	Hoath (2003)
Birds	470	9,990	4.70	Porter and Cottridge (2001)
Micro-organisms				
Cyanobacteria	162	2,664	6.08	EEAA (1998)
Fungi	2,477	98,998	2.50	Abdel-Azeem et al. (2018)
Viruses	44	2,085	2.11	EEAA (1998)
Bacteria	201	7,643	2.63	EEAA (1998)
Lichens	250	17,000	1.47	Seaward and Sipman (2006)
Total	20,521	1,602,673	1.28	

World biodiversity is extracted from Chapman (2009).

Bryophytes

Bryophytes in Egypt approximate 194 species and subspecies: 181 mosses and 13 hepatics (El-Saadawi and Shabbar 2007; El-Saadawi et al. 2003, 2015). The Egyptian figure approximates 1.20% of the world figure of 16,263 taxa of Bryophyte (Table 1). According to the available publications, bryologists are invited to prepare a book that collects all the previous studies on the Egyptian bryophytes including brief descriptions for the recorded species together with line drawings and identification keys as well as distribution maps for all species or, at least, the critical endemic ones.

Phytoplankton and Macro-algae

Unfortunately, no checklist for the algae in Egypt (Phytoplankton and macro-algae) is available, but the rough estimate is some 1,500 taxa which approximates 12.22% of the world algal flora of 12,272 taxa, but it is thought to be under-estimating the actual number of this biotic group in Egypt. For example, the study of Eassa (2013) on the five northern lakes, along the Egyptian Mediterranean coast, reported 867 taxa of phytoplankton related to 9 algal divisions, 102 families, and 203 genera. In addition, Shabaka (2018) recorded 187 species of sea weeds from the Egyptian Mediterranean water. In the view of the numerous published data that are suitable for preparing a checklist for phytoplankton and macro-algae, an initiative should be taken to prepare a complete checklist for this biotic group in the fresh, brackish and marine aquatic bodies.

Fungi and Lichens

Fungi in Egypt approximate 2,477 taxa (Abdel-Azeem 2018), which represent 2.50% of the world fungal taxa of 98,998. Fortunately, a study by Seaward and Sipman (2006) is available about the lichens of Egypt, which approximate 250 species with a remarkably poor representation of many common groups such as Parmeliaceae; this represents 1.47% of the world lichen tax taxa of 17,000. It must be a priority to concentrate our studies on the lichen biodiversity in order to prepare acceptable verified checklist for this biotic group.

Bacteria and Viruses

Unfortunately, there is no available recent figure for the bacteria and viruses in Egypt; but the rough estimate is approximately 44 viruses and 201 bacteria, excluding cyanobacteria (EEAA 1998). The Egyptian bacterial figure approximates 2.63% of the world figure of 7,643 taxa (Table 1), but it is thought to under-estimate the actual number of this important microbiological group in Egypt.

Arachnida and Insects

Arachnida in Egypt approximate 1,565 taxa that represent 1.53% out of the world Arachnida of 102,248 taxa (El-Hennawy 2006). A private Arachnida collection is available at Hesham El-Hennawy, the Initiator of the Egyptian Arachnida Collection (Personal Communication). A rough estimate of 10,000 insect taxa was recorded from Egypt (EEAA 1998) out of the world figure of 1,000,000 taxa (1.00%). Fortunately, a book on the butterflies of Egypt was published by Gilbert and Zalat (2007). As the 10,000 insect species known from Egypt under-estimate the insect diversity in our country, thus further studies need to be carried out to verify the 5 volumes prepared by Prof. Ali Morsy and his students (Cairo University) during the nineties of the last century. After this analysis, a checklist for the insect species in Egypt could be prepared.

Fishes

Overall, 956 fish species (71 Elasmobranchii, 2 Holocephali, and 883 Actinopteri) have been recorded to date from the Egyptian marine waters: of those, 592 species are present only in the Red Sea, 263 species are present only in the Mediterranean Sea, and the remaining 101 species are reported from both seas (Akel and Karachle 2017). In addition, 94 species were recorded from the fresh water of the Nile and its connected canals and drains, of which 85 are natives (22 common, 49 rare, and 14 extinct), while 9 are introduced (Bishai and Khalil 1997). Thus, the estimate of fish species in Egypt, including those of the marine ecosystems, is 1,050 taxa out of 31,153 taxa as a world figure (3.37%).

Reptiles and Mammals

Egyptian reptiles are 109 taxa out of 8,734 at the global scale (1.25%), while amphibians are 9 taxa out of 6,515 (0.14%) (Baha El Din 2006). In addition, Egyptian mammals approximate 125 taxa (Hoath 2003) out of a world figure of 5,487 (2.28%).

Birds

Egyptian figure of birds is around 470 taxa (Porter and Cottridge 2001) out of 9,990 taxa as a world figure (4.70%).

It is worth mentioning that the available publications on the Egyptian birds are too limited, thus further efforts should be done for enriching our knowledge about the Egyptian avifauna.

Others

Egyptian agro-biodiversity is very rich and exceeds that of the Egyptian natural flora. In a recent study by Ammar et al. (2020), the ornamental flora in Nile region only (including Cairo and Alexandria) was 2,471 species and infra-species (1,907 taxa are still under cultivation, 96 as wild taxa, while 468 act as a historical gap (kept only as herbarium sheets). Further studies on agro-biodiversity should be widening to cover the Eastern (including Sinai) and Western (including the Oases) Deserts of Egypt.

Unfortunately, there no collective study deals with the total alien fauna in Egypt, such as that of the Egyptian flora. Studies are available on some alien fauna in Egypt such as that of Ibrahim and Khalil (2009) on the fast spreading of fresh water invasive crustacean (i.e., red swamp crayfish). Extensive work should be done to collect and classify them according to their alien status (e.g., casual, naturalized and invasive species). Also, there is no available list for the zooplankton at the national level, thus it is urgent to prepare an Egyptian checklist for this important group in the fresh, brackish and marine aquatic bodies, based on the recent publications under these topics.

Some recent publications are available on paleo-biology including the macro-fossils of higher plants (Nour El-Deen 2015) and nano-fossils of phytoplankton and other related biota (Abu Shama et al. 2019). At a national and international scales, paleo-biologists in Botany, Zoology and Geology Departments and other research centers should work together to publish a book that deals with the Egyptian paleo-biology. Such type of studies will lead to high ranking the Egyptian biodiversity at the international scale. For example, based on the present knowledge, Egypt is the richest African country in the number of recorded macrofossil palm remains (Kamal El-Din et al. 2013).

Goods are defined as the organisms and their parts and products that grow in the wild and are used directly for human benefits such as grazing and browsing (e.g., El-Khalafy et al. 2023; Heneidy and Halmy 2009; Shaltout et al. 2023). On the other hand, services are those valuable ongoing streams of benefits provided by thriving ecosystem. One of the most important services is the role of the Egyptian wetlands and their biota in carbon sequestration process which plays a valuable role in mitigation of global warming (e.g., Eid et al. 2017). Some studies on the use of plants as phyto-remediators and for production of biofuel are also included. Also, some publications are available on the chemistry and pharmacology of the plants in Egypt

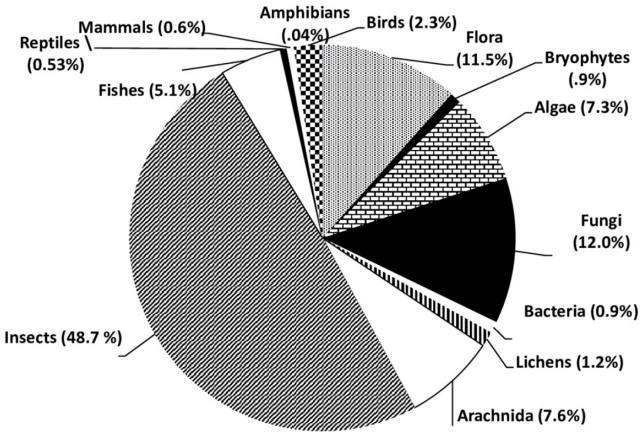

Fig. 2 Pie diagram indicating the relationship between the different components of the Egyptian biodiversity.

(e.g., Abdou 2015), animals (e.g., El-Saify 2015), and microorganisms (e.g., Mohamed 2018). Such studies aim for searching of new and bioactive natural products, studying the chemical diversity and biochemical activity of the secondary metabolites, explaining the substances which play roles in the medical use of different biota as well as assessing their pharmacological activities.

Publications dealt with the Egyptian network of natural protectorates include study of the components of their whole ecosystems including their management plans (e.g., Khalil and Shaltout 2006; Shaltout and Khalil 2005); their role in the application of the global strategy for plant conservation (e.g., Shaltout and Eid 2017); or their characterization, related laws, legislations and conventions. An overview on the Egyptian natural protectorates (ENPs) and their relations with biological diversity, sustainable development, climate change, international conventions, goods and services, human rights and strategic planning is presented by Fouda (2013), who deals also with the wildlife conservation in the ENPs including their history, declaration as well as short descriptions of the 30 ENPs that represent 15% of the total area of Egypt.

Conclusions

Some 20,521 species were recorded in Egypt until now, of which insects have the highest contribution (48.73%), followed by fungi (12.07%) and flora (11.52%). On the other hand, each of amphibians, viruses, reptiles, mammals, cyanobacteria, bryophytes, and bacteria have a minor contribution (< 1%) (Fig. 2). Based on the available data, Egyptian biodiversity contributes 1.28% of the world biota, although the area of Egypt contributes only 0.7% of the world area. The most represented groups are Algae (12.22% of the world figure), followed by cyanobacteria (6.08%), birds (4.70%) and fished (3.37%). On the other hand, the less represented groups are flora (0.84% of the world fig-

ure), amphibians (0.14%), insects (1.00%), reptiles (1.25%) and bryophytes (1.2%). The preliminary red data list of the vascular plants in Egypt includes 457 species (ca. 20% of the total flora) classified into 14 extinct, 123 endangered, 54 vulnerable, 173 rare, and 93 indeterminate species.

Abbreviations
Not applicable.

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Authors' contributions
KHS and MMEK involved in conception and design, acquisition, analysis, statistical analysis and interpretation of results, drafting the article and revising it, and approved the final version to be submitted for publication.

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The authors declare that they have no competing interests.

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