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# Floristic diversity and vegetation analysis of Siwa Oasis: An ancient agro-ecosystem in Egypt's Western Desert

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**Abstract** The rapid development and expansion of modern irrigation schemes across arid environments have radically transformed both natural environments and existing agricultural systems over the past century. The consequences for natural and cultural values are often severe, but remain poorly documented for many regions. The present study describes the floristic diversity of an Oasis agro-ecosystem located in Egypt's hyper-arid Western Desert. A total of 132 sites were chosen to represent the flora of Siwa Oasis agro-ecosystem and 154 species were recorded of which 52 were cultivated. Non-cultivated taxa consisted predominately of therophytes whereby the flora of Siwa is represented by monoregional, biregional and pluriregional elements as well as some cosmopolitan species. During field survey, 55 species were recorded for the first time suggesting the recent introduction of new weeds. Based on previous studies, 36 wetland and orchard species may have become locally extinct due to loss of habitat and extensive transformation of the Oasis agro-ecosystem. Although Siwa does not support any endemic species, this study documents a unique and complex agro-ecosystem shaped by natural and human agents over millennia. Descriptive floristic studies such as presented here are important records during a time of continuing and increasing change throughout arid regions of the world.



## Introduction

The development of modern irrigation schemes across arid regions of the globe has radically transformed both natural environments and existing regions for agricultural production (Worster, 1985; Powell, 2012; Heathcote, 1965). The

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replacement of traditional agro-ecosystems with modern, intensified and productivity-orientated agriculture, which has increased over the past century, has presented significant environmental and social challenges including declining biodiversity, increased greenhouse gas emissions and the loss of both cultural and ecosystem values (Chapin et al., 2000; Tilman et al., 2001; Robinson and Sutherland, 2002; Benton et al., 2003; Altieri and Koohafkan, 2004; Tscharntke et al., 2005).

The Western Desert of Egypt encompasses several extensive depressions overlying the Nubian Sandstone Aquifer System (NSAS) which forms isolated oases within a region of intense aridity. The oases have a long history and have supported human populations, trade routes and agriculture for millennia (Fakhry, 1973, 1974). Prior to the development of modern rock boring equipment, agriculture was entirely dependent on the exploitation of springs and ancient artesian wells (Beadnell, 1909; Stanley, 1912; Fakhry, 1973; Schacht, 2003) but in recent decades, the oases have been extensively modified through the implementation of ambitious desert reclamation schemes (Lamoreaux et al., 1985). Their social and economic isolation has also been radically diminished through improved trade, transport and communication networks as well as attempts to bring them under the centralized administration of the Egyptian state.

Siwa Oasis, the most westerly and remote of Egypt's major inhabited oases, is a microcosm of recent economic, social and environmental changes. New and improved irrigation facilities have conquered vast swathes of desert, but profligate groundwater use has resulted in the expansion of naturally occurring salt lakes as well as the loss of arable land through waterlogging and land salinization (Misak et al., 1997; Masoud and Koike, 2006). Many springs were modified and developed since ancient times and the practice of excavating and lining springs and canals has been shown to obliterate or alter the surrounding wetland habitat (El-Saied, 2012). Recent attempts to enhance spring flows have meant virtually all of Siwa's springs have been controlled and enclosed with concrete. Due to its relative isolation, plant diversity probably remained stable over much of Siwa's history leading to the development of a unique agro-biodiversity (Nabhan, 2007). Following the completion of paved roads in 1986, enhanced connectivity with both other oases and the Nile Delta has resulted in the introduction of new cultivars and, almost certainly, new weeds.

Several studies provide insights into the ecology, and plant distributions of the Western Desert (Zahran, 1972; Abd El-Ghani, 1992; Abd El-Ghani and Fawzy, 2006; El-Saied, 2012); however, despite the significant changes which have occurred in Siwa, there have been few attempts to comprehensively analyze and describe its floristic diversity. This work aimed to provide a complete analysis of the Siwan flora including a breakdown of its different life forms and chorology of the recorded species. In doing so, this paper provides the most up-to-date and comprehensive vegetation study for Siwa, with insights into its ecology within the context of recent transformations to agro-ecosystems in the Western Desert.

## The study area

### *Geology and geomorphology*

Siwa Oasis is the farthest Oasis depression from the Nile Valley to the west and located approximately 300 km south of the Mediterranean coast (from 29°10′ to 29°16′N Latitude and 25°27′ to 25°35′E Longitude) (Fig. 1). The depression is approximately 50 km in length, varying from 2 to 20 km in width and encompasses about 1000 km$^2$. Siwa Oasis extends between 0 and 18 m below sea level (Misak et al., 1997) and displays numerous land forms including salt lakes, salt marshes (Sabkhas) as well as cultivated lands and orchards (Madani, 2005; Abd El-Ghani and Fawzy, 2006). The region is hyper-arid receiving 10 mm or less average annual precipitation and evaporation rates are in the vicinity of 3000 mm per annum (Shahin, 2007). The depression is flanked by high Miocene escarpments along the northern face and extensive sand dunes along its southern flank. Siwa is also surrounded by several smaller oases which were inhabited in ancient times but are no longer occupied. The soil of Siwa consists primarily of particles of limestone and sandstone derived from the walls and the floor of the Siwan depression or carried by the winds. It contains small amounts of clay (about 6.9%), larger proportions of sand (59%) and large amounts of soluble matter. The amount of sodium chloride found in Oasis soils ranges from about 0.12% to 59.12% (Zahran, 1972).

### *Hydrogeology and water resources*

Siwa is entirely dependent on groundwater derived from the NSAS, an extensive artesian system which consists of a sandstone deposit spanning early Paleozoic to Cretaceous age with depths ranging from 2500 to 3000 m (Aql, 1992). The NSAS in Siwa lies beneath fractured Miocene–Eocene sequences which receive recharge from the NSAS complexes below. Salinity varies within the carbonate rocks and ranges between above 1500 ppm in the upper Miocene layers to as low as 200 ppm in the Eocene–Cretaceous beds (Shata, 1982). Holocene–Pleistocene sediments which make up the depression floor are separated from the artesian system by low permeability aquitards of shale and clay which varies in thickness between 60 m in the west and 250 m in the east (El Hossary, 2013).

## Materials and methods

Survey of Siwa Oasis was conducted between October 2013 and June 2015 to represent the flora of the Oasis agro-ecosystems during both winter and summer seasons. A total of 132 locations were selected which were distributed across all of the major cultivated zones of the Oasis. A GPS position for each stand was recorded. All plant species existing in each stand were listed after complete identification according to Täckholm (1974) and Boulos (1999–2009). Voucher herbarium specimens were incorporated in the herbarium of the Department of Botany, Faculty of Science, Al-Azhar University. Life form categories were identified after Raunkiaer (1934). Variation in the life form in the field was not considered. Phytogeographical affinity, after the system of Eig (1931), of each species was obtained from Abd El-Ghani (1981,1985).

## Results

A total of 154 species were recorded in Siwa Oasis of which approximately one-third were cultivated (Tables 1 and 2). 55 species were documented for the first time while, based on pre-

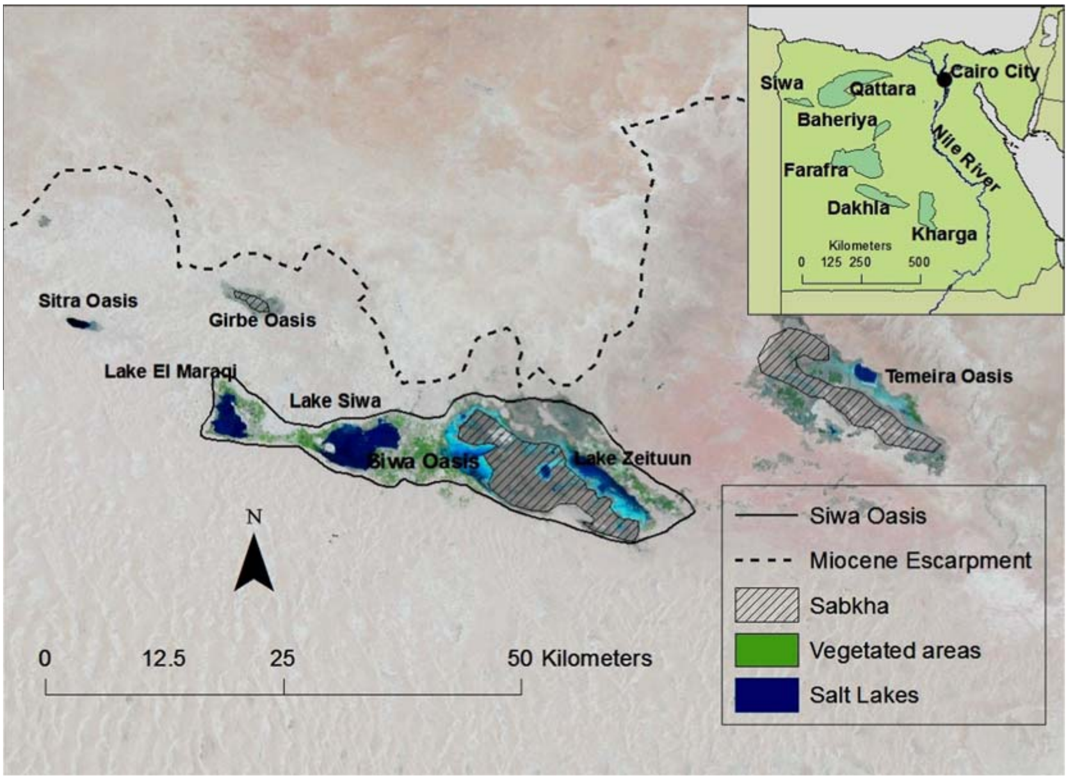


**Fig. 1** Siwa Oasis showing various landforms and outer uninhabited oases. The inset depicts the major Oasis depressions of the Egyptian Western Desert (Image: Landsat 2013).

vious studies, 76 species were absent. Non-cultivated or wild taxa were represented by 34 families and 90 genera (Table 1). The most common families were Asteraceae (16 species), Poaceae (14 species) and Fabaceae (14 species). The majority of wild species were annuals (58) and only one biennial species was recorded (*Silybum marianum*).

According to the life forms classification of Raunkiaer (1934), seven categories were recorded (Fig. 2). Therophytes were the most abundant life form and constituted half of the recorded non-cultivated species followed by hemicryptophytes which were represented by 19 species. Helophytes were represented by three species (*Najas pectinata*, *Typha domingensis* and *Ruppia cirrhosa*) and parasitic plants were represented by two species (*Cuscuta campestris* and *Cistanche phelypaea*) (Table 1 and Fig. 2).

Non-cultivated taxa predominately consisted of monoregional (28), bioregional (27) and pluriregional (20) species (Fig. 4) with regional affinities spanning North Africa, the Mediterranean and central Asia. Additional phytogeographical categories included paleotropical (14 species), cosmopolitan (9 species) and pantropical (4 species) taxa (Table 1 and Figs. 3 and 4). Relations between phytogeographical affinities and life forms are summarized in Table 3.

## Discussion

The flora of Siwa Oasis reflects an ecosystem shaped by intense aridity, saline groundwater conditions and human disturbance. The high proportion of therophytes, and to a lesser extent hemicryptophytes (Fig. 2), demonstrates the opportunistic life strategies required to survive in this extreme environment. This is similarly reflected by the high ratio of often salt tolerant, winter annuals which take advantage of cooler desert conditions, and sometimes limited rainfall, to regenerate. Comparable life form compositions have been recorded in previous studies of Egyptian oases (Abd El-Ghani and Fawzy, 2006; El-Saied, 2012) as well as in the wider Middle East region (Osman et al., 2014).

Spring-fed desert environments can be characterized by high levels of endemism and plant rarity as a result of their isolation and unique hydro-chemical conditions (Shepard, 1993; Harvey et al., 2007; Fensham et al., 2011). In the case of Siwa, however, plant diversity is comparably limited and represented by several broad phytogeographical categories. Ubiquitous taxa in Siwa such as, *Imperata cylindrica*, *Alhagi graecorum*, and *Tamarix nilotica* feature across the other Oasis agro-ecosystems of the Western Desert which shares a similar climate and history of anthropogenic disturbance. Some such as *Cynodon dactylon* and *Phragmites australis* are also widespread in springs in other continents (Fensham and Fairfax, 2003). The ancient caravan routes similarly would have been responsible for the adoption of common cultivars as well as introduction of weeds and plants across the African and Eurasian continents. A classic example of this is Euphrates Popular (*Populus euphratica*) which is present in the western part of Siwa. Zahran (1972) suggested this plant was introduced during the Greek Period after the conquest of Egypt by Alexander the Great in 332 B.C., though a more likely scenario is that it came from Libya via the ancient caravan route and where there are local populations.

**Table 1** List of the non-cultivated species recorded in the agro-ecosystem of Siwa Oasis during spring and summer season of 2013–2015. The species were referred to their families, and vegetation type; Annual = Ann, Biennial = Bie, Perennial = Per. according to Boulos (1999–2009), life forms according to (Raunkiaer, 1934); Therophyte = Th, Hemicryptophyte = Hem, Chamaephyte = Cha, Phanerophyte = Ph, Parasite = Par, Geophyte = Geo, Helophyte = Hel. Phyto-geographical affinities according to the system of Eig (1931); COSM = Cosmopolitan, ER-SR = Euro-Siberian, IR-TR = Irano-Turanian, ME = Mediterranean, PAL = Paleotropical, PAN = Pantropical, SA-SI = Saharo-Sindian, S-Z = Sudano-Zambesian. Families are arranged alphabetically; genera and species are in alphabetical order within their respective families.

| Species | Family | Life form | Floristic categories | Vegetation type |
|---|---|---|---|---|
| *Mesembryanthemum nodiflorum* L. | Aizoaceae | Th. | ME + SA-SI + ER-SR | Ann. |
| *Apium nodiflorum* (L.) Lag. | Apiaceae | Hem. | PAL | Per. |
| *Ferula marmarica* Asch. & Taub. ex Asch. & Schweinf. | Apiaceae | Hem. | ME | Per. |
| *Torilis arvensis* (Huds.) Link. | Apiaceae | Th. | ME + IR-TR + ER-SR | Ann. |
| *Cynanchum acutum* L. | Asclepiadaceae | Ph. | ME + IR-TR | Per. |
| *Calendula officinalis* L. | Asteraceae | Th. | ME + IR-TR | Ann. |
| *Centaurea calcitrapa* L. | Asteraceae | Cha. | ME + ER-SR | Ann. |
| *Conyza bonariensis* (L.) Cronquist | Asteraceae | Th. | ME | Ann. |
| *Conyza canadensis* (L.) Cronquist | Asteraceae | Th. | ME | Ann. |
| *Cotula anthemoides* L. | Asteraceae | Th. | SA-SI | Ann. |
| *Cotula cinerea* Delile. | Asteraceae | Th. | SA-SI | Ann. |
| *Inula crithmoides* L. | Asteraceae | Cha. | ME | Ann. |
| *Lactuca serriola* L. | Asteraceae | Th. | ME + IR-TR + ER-SR | Ann. |
| *Launaea nudicaulis* (L.) Hook. *f.* | Asteraceae | Hem. | IT-TR | Per. |
| *Pseudognaohalium luteo-album* (L.) Hilliard & B.L. Burtt. | Asteraceae | Th. | ME + SA-SI + IR-TR | Ann. |
| *Senecio vulgaris* L. | Asteraceae | Th. | ME + IR-TR + ER-SR | Ann. |
| *Senecio glaucus* L. | Asteraceae | Th. | ME + IR-TR + SA-SI | Ann. |
| *Senecio aegyptius* L. | Asteraceae | Th. | IR-TR + SA-SI | Ann. |
| *Silybum marianum* (L.) Gaertn. | Asteraceae | Th. | ME + IR-TR | Bie. |
| *Sonchus maritimus* L. | Asteraceae | Hem. | ME + IR-TR | Per. |
| *Sonchus oleraceus* L. | Asteraceae | Th. | COSM | Ann. |
| *Heliotropium ovalifolium* Forssk. | Boraginaceae | Th. | PAL | Ann. |
| *Cakile maritima* Scop. | Brassicaceae | Th. | ME + ER-SR | Ann. |
| *Enarthrocarpus strangulatus* Boiss. | Brassicaceae | Th. | ME | Ann. |
| *Matthiola livida* (Delile) DC. | Brassicaceae | Th. | ME | Ann. |
| *Schouwia thebaica* Webb. | Brassicaceae | Th. | ME + SA-SI | Ann. |
| *Sisymbrium irio* L. | Brassicaceae | Th. | ME + IR-TR | Ann. |
| *Cleome amblyocarpa* Barratte & Murb. | Capparaceae | Th. | SA-SI | Ann. |
| *Herniaria hirsuta* L. | Caryophyllaceae | Th. | ER-SR | Ann. |
| *Polycarpon succulentum* (Delile) J. Gay. | Caryophyllaceae | Th. | SA-SI | Ann. |
| *Polycarpaea repens* (Forssk.) Asch. & Schweinf. | Caryophyllaceae | Hem. | PAL | Ann. |
| *Spergularia marina* (L.) Griseb. | Caryophyllaceae | Hem. | ME + IR-TR + ER-SR | Ann. |
| *Stellaria pallida* (Dumort.) Murb. | Caryophyllaceae | Th. | ME + ER-SR | Ann. |
| *Vaccaria pyramidata* Medik. | Caryophyllaceae | Th. | ME + IR-TR + ER-SR | Ann. |
| *Arthrocnemum macrostachyum* (Moric.) K. Koch. | Chenopodiaceae | Cha. | ME + SA-SI | Per. |
| *Chenopodium murale* L. | Chenopodiaceae | Th. | COSM | Ann. |
| *Chenopodium album* L. | Chenopodiaceae | Th. | COSM | Ann. |
| *Cornulaca monacantha* Delile | Chenopodiaceae | Cha. | IR-TR | Per. |
| *Kochia indica* Wight. | Chenopodiaceae | Th. | IR-TR | Ann. |
| *Suaeda aegyptiaca* (Hasselq.) Zohary. | Chenopodiaceae | Hem. | SA-SI + S-Z | Ann. |
| *Convolvulus arvensis* L. | Convolvulaceae | Geo. | PAL | Per. |
| *Cressa cretica* L. | Convolvulaceae | Hem. | PAL | Per. |
| *Cuscuta campestris* Yunck. | Convolvulaceae | Par. | PAN | Ann. |
| *Bolboschoenus glaucus* (Lam.) S.G. Smith. | Cyperaceae | Geo. | COSM | Per. |
| *Cyperus laevigatus* L. | Cyperaceae | Hem. | COSM | Per. |
| *Cyperus rotundus* L. | Cyperaceae | Geo. | PAN | Per. |
| *Euphorbia peplus* L. | Euphorbiaceae | Th. | COSM | Ann. |
| *Ricinus communis* L. | Euphorbiaceae | Ph. | PAL | Per. |
| *Acacia nilotica* (L.) Delile. | Fabaceae | Ph. | S-Z | Per. |
| *Acacia raddiana* Savi. | Fabaceae | Ph. | SA-SI | Per. |
| *Acacia saligna* (Labill.) H.L. Wendl. | Fabaceae | Ph. | ER-SR | Per. |
| *Alhagi graecorum* Boiss. | Fabaceae | Hem. | PAL | Per. |
| *Glycyrrhiza glabra* L. | Fabaceae | Ph. | ME | Per. |
| *Astragalus corrugatus* Bertol. | Fabaceae | Th. | IR-TR | Ann. |
| *Hippocrepis multisiliquosa* L. | Fabaceae | Th. | IR-TR + SA-SI | Ann. |

(*continued on next page*)

**Table 1** (*continued*)

| Species | Family | Life form | Floristic categories | Vegetation type |
|---|---|---|---|---|
| *Lotus glaber* Mill. | Fabaceae | Hem. | ME + IR-TR + ER-SR | Per. |
| *Melilotus indicus* (L.) All. | Fabaceae | Th. | PAL | Ann. |
| *Prosopis farcta* (Banks & Sol.) Macbr. | Fabaceae | Cha. | IR-TR + SA-SI | Per. |
| *Scorpiurus muricatus* L. | Fabaceae | Th. | ME | Ann. |
| *Vicia sativa* L. | Fabaceae | Th. | ME | Ann. |
| *Frankenia hirsuta* L. | Frankeniaceae | Cha. | ME + IR-TR | Per. |
| *Monsonia nivea* (Decne.) Webb. | Geraniaceae | Th. | SA-SI | Per. |
| *Juncus rigidus* Desf. | Juncaceae | Hem. | ME + IR-TR + SA-SI | Per. |
| *Mentha longifolia* (L.) Huds. | Lamiaceae | Hem. | ME + IR-TR + ER-SR | Per. |
| *Ziziphora* sp. | Lamiaceae | Th. | IR-TR | Ann. |
| *Emex spinosa* (L.) Campd. | Loranthaceae | Th. | ME | Ann. |
| *Polygonum equisetiforme* Sm. | Loranthaceae | Hem. | ME + IR-TR | Per. |
| *Rumex vesicarius* L. | Loranthaceae | Th. | ME + IR-TR + S-Z | Ann. |
| *Malva parviflora* L. | Malvaceae | Th. | ME + IR-TR | Ann. |
| *Najas pectinata* (Parl.) Magn. | Najadaceae | Hel. | PAL | Ann. |
| *Cistanche phelypaea* (L.) Cout. | Orobanchaceae | Par. | IR-TR + SA-SI | Per. |
| *Portulaca oleracea* L. | Portulacaceae | Th. | PAL | Ann. |
| *Anagallis arvensis* L. | Primulaceae | Th. | ME + IR-TR + ER-SR | Ann. |
| *Samolus valerandi* L. | Primulaceae | Hem. | PAL | Per. |
| *Avena fatua* L. | Poaceae | Th. | COSM | Ann. |
| *Bromus diandrus* Roth. | Poaceae | Th. | ME + IR-TR + S-Z | Ann. |
| *Cynodon dactylon* (L.) Pers. | Poaceae | Geo. | PAN | Per. |
| *Echinochloa crusgalli* (L.) P. Beauv. | Poaceae | Th. | ME + IR-TR | Ann. |
| *Dactyloctenium aegyptium* (L.) Willd. | Poaceae | Th. | PAL | Ann. |
| *Imperata cylindrica* (L.) Raeusch. | Poaceae | Hem. | ME + S-Z | Per. |
| *Lolium perenne* L. | Poaceae | Hem. | ME + IR-TR + ER-SR | Per. |
| *Phragmites australis* (Cav.) Trin. ex Steud. | Poaceae | Geo. | PAL | Per. |
| *Poa annua* L. | Poaceae | Th. | ME + IR-TR + ER-SR | Ann. |
| *Polypogon monspeliensis* (L.) Desf. | Poaceae | Th. | COSM | Ann. |
| *Setaria verticillata* (L.) P. Beauv. | Poaceae | Th. | COSM | Ann. |
| *Setaria viridis* (L.) P. Beauv. | Poaceae | Th. | ME + IR-TR + SA-SI | Ann. |
| *Sorghum halepense* (L.) Pers. | Poaceae | Cha. | PAL | Per. |
| *Stipagrostis plumosa* (L.) Munro ex T. Anderson. | Poaceae | Geo. | IR-TR | Per. |
| *Reseda lutea* L. | Resedaceae | Th. | ME + IR-TR | Ann. |
| *Haplophyllum tuberculatum* (Forssk.) Juss. | Rutaceae | Cha. | IR-TR + SA-SI | Per. |
| *Populus euphratica* Oliv. | Salicaceae | Ph. | IR-TR + SA-SI | Per. |
| *Bacopa monnieri* (L.) Pennell. | Scrophulariaceae | Hem. | ME | Per. |
| *Solanum nigrum* L. | Solanaceae | Hem. | ME + IR-TR + ER-SR | Ann. |
| *Tamarix nilotica* (Ehrenb.) Bunge. | Tamaricaceae | Ph. | SA-SI + S-Z | Per. |
| *Reaumuria hirtella* Jaub. & Spach. | Tamaricaceae | Cha. | IR-TR | Per. |
| *Typha domingensis* (Pers.) Poir. ex Steud. | Typhaceae | Hel. | PAN | Per. |
| *Urtica urens* L. | Urticaceae | Th. | ME + ER-SR | Ann. |
| *Ruppia cirrhosa* (Petagna) Grand. | Zannichelliaceae | Hel. | ME + IR-TR + ER-SR | Per. |
| *Fagonia cretica* L. | Zygophyllaceae | Cha. | SA-SI | Per. |
| *Zygophyllum album* L.f. | Zygophyllaceae | Cha. | ME + IR-TR + SA-SI + S-Z | Per. |
| *Zygophyllum coccineum* L. | Zygophyllaceae | Cha. | SA-SI + S-Z | Per. |
| *Zygophyllum simplex* L. | Zygophyllaceae | Th. | SA-SI + S-Z | Ann. |

While the introduction of new species probably occurred sporadically over millennia, comparison between the present study and the previous floristic and ecological studies on Siwa Oasis reveals significant differences in the numbers of spontaneous and cultivated species (Table 4). This study recorded 55 ‘new’ species out of a combination of 102 spontaneous and 52 cultivated taxa but much fewer numbers, 64 spp., were reported by Abd EL-Ghani (1994), El-Khouly and Khedr (2000), 41 spp. and Hassan (2005), 94 spp. of which 26 are cultivated.

While this disparity might be partially explained by greater search effort conducted in this study, the increase in the recorded number of spontaneous and cultivated species in Siwa Oasis is probably related to trends of agricultural intensification (Fig. 5) and enhanced connectivity with the other oases and Nile Delta over the last three decades. *Prosopis farcta* was recorded in just one study site in Siwa and is an invasive species native to Asia that has moved from India to the Middle East and along the North African coast to Algeria (Pasiecznik et al., 2004). El-Saied (2012) reported the presence of this species in an isolated portion of Farafra Oasis, over 300 km south east of Siwa, but no record of *P. farcta* has been made elsewhere in the present study of Siwa Oasis or in Bahariya and Farafra Oases (El-Saied, 2012). The invasive nature of the species means that it would have been likely to have been recorded in more locations and its limited distribution suggests

**Table 2** List of the cultivated species recorded from Siwa Oasis and their families.

| Species | Family |
|---|---|
| *Spinacia oleracea* L. | Amaranthaceae |
| *Allium cepa* L. | Amaryllidaceae |
| *Allium ampleloprasum var.porrum* (L.) J. Gay. | Amaryllidaceae |
| *Helianthus annuus* L. | Asteraceae |
| *Lactuca sativa* L. | Asteraceae |
| *Petroselinum crispum* (Mill.) Fuss. | Apiaceae |
| *Anethum graveolens* L. | Apiaceae |
| *Coriandrum sativum* L. | Apiaceae |
| *Daucus carota* L. | Apiaceae |
| *Phoenix dactylifera* L. | Arecaceae |
| *Brassica rapa* L. | Brassicaceae |
| *Eruca sativa* Mill. | Brassicaceae |
| *Opuntia ficus-indica* (L.) Mill. | Cactaceae |
| *Casuarina equisitifolia* L. | Casuarinaceae |
| *Beta vulgaris* L. | Chenopodiaceae |
| *Cucumis melo* L. var. cantalupensis | Cucurbitaceae |
| *Cucumis sativus* L. | Cucurbitaceae |
| *Citrullus lanatus* (Thunb.) Matsum. & Nakai | Cucurbitaceae |
| *Medicago sativa* L. | Fabaceae |
| *Pisum sativum* L. | Fabaceae |
| *Phaseolus vulgaris* L. | Fabaceae |
| *Ceratonia siliqua* L. | Fabaceae |
| *Sesbania sesban* (L.) Merr. | Fabaceae |
| *Ocimum basilicum* L. | Lamiaceae |
| *Punica granatum* L. | Lythraceae |
| *Lawsonia inermis* L. | Lythraceae |
| *Hibiscus sabdariffa* L. | Malvaceae |
| *Corchorus olitorius* L. | Malvaceae |
| *Ficus carica* L. | Moraceae |
| *Ficus sycomorus* L. | Moraceae |
| *Morus alba* L. | Moraceae |
| *Moringa oleifera* Lam. | Moringaceae |
| *Musa acuminate* Colla. | Musaceae |
| *Psidium guajava* L. | Myrtaceae |
| *Eucalyptus camaldulensis* Dehn. | Myrtaceae |
| *Olea europaea* L. | Oleaceae |
| *Hordeum murinum* L. | Poaceae |
| *Saccharum officinarum* L. | Poaceae |
| *Sorghum bicolor* (L.) Moench. | Poaceae |
| *Triticum vulgare* L. | Poaceae |
| *Zea mays* L. | Poaceae |
| *Citrus limon* (L.) Burm.f. | Rutaceae |
| *Citrus sinensis* (L.) Osbeck. | Rutaceae |
| *Citrus tangerina* Tanaka. | Rutaceae |
| *Malus domestica* Borkh. | Rosaceae |
| *Pyrus communis* L. | Rosaceae |
| *Ziziphus spina-christi* (L.) Desf. | Rhamnaceae |
| *Capsicum frutescens* L. | Solanaceae |
| *Solanum lycopersicum* L. | Solanaceae |
| *Lantana camara* L. | Verbenaceae |
| *Vitis vinifera* L. | Vitaceae |
| *Aloe vera* (L.) Burm.f. | Xanthorrhoeaceae |

**Table 3** Number of species belonging to the main floristic categories and their percentages (%). Phytogeographical affinities according to the system of Eig (1931); COSM = Cosmopolitan, ER-SR = Euro-Siberian, IR-TR = Irano-Turanian, ME = Mediterranean, PAL = Paleotropical, PAN = Pantropical, SA-SI = Saharo-Sindian, S-Z = Sudano-Zambesian.

| Phytochoria | Number of species | Percentage (%) |
|---|---|---|
| PAL | 14 | 13.7 |
| COSM | 9 | 8.8 |
| PAN | 4 | 3.9 |
| *Monoregional* | | |
| ME | 11 | 10.7 |
| SA-SI | 7 | 6.8 |
| IR-TR | 7 | 6.8 |
| ER-SR | 2 | 1.9 |
| S-Z | 1 | 0.9 |
| Total | 28 | 27.4 |
| *Biregionals* | | |
| ME + IR-TR | 10 | 9.8 |
| IR-TR + SA-SI | 6 | 5.8 |
| ME + ER-SR | 4 | 3.9 |
| ME + SA-SI | 2 | 1.9 |
| SA-SI + S-Z | 4 | 3.9 |
| ME + S-Z | 1 | 0.9 |
| Total | 27 | 26.4 |
| *Pleuriregionals* | | |
| ME + SA-SI + ER-SR | 1 | 0.9 |
| ME + IR-TR + ER-SR | 12 | 11.7 |
| ME + SA-SI + IR-TR | 4 | 3.9 |
| ME + IR-TR + SA-SI + S-Z | 1 | 0.9 |
| ME + IR-TR + S-Z | 2 | 1.9 |
| Total | 20 | 19.6 |

that it is a recent introduction to the Western Desert. It is plausible that seeds or even rhizomes of *P. farcta* were introduced with seeds of different crops to these isolated parts of Siwa and Farafra Oases and isolation has prevented its further spread.

The absence of 76 species can be explained by both differences in site selection and the likelihood that numerous species have gone locally extinct in Siwa. Several species are thought to have already become extinct across the Western Desert Oases including *Ranunculus rionii* and a water lily (*Nymphaea caerulea*) while species recorded in Siwa such as *Gossypium arboreum*, have been referred to as 'endangered' (Abd El-Ghani and Fawzy, 2006). Abd El-Ghani (1994), focused on the weed plant communities of Siwan orchards associated with local springs, similar to this study; however, due to the ongoing enclosure of springs it is likely that 36 unique species, including *Gossypium arboreum*, are now locally extinct. Four wetland species documented by El-Khouly and Khedr (2000) including *Aetheorhiza bulbosa*, *Silene gallica*, *Ceratophyllum demersum* and *Scirpus litoralis* are likely to have suffered a similar fate as a result of wetland modification. Hassan (2005), recorded 35 unique species out of a total of 68 documented taxa; however, these were identified in the deserts around Siwa which were not included in this current survey.

Conservation priorities often focus on areas of perceived 'naturalness', but the dichotomy of natural versus modified unravels in places like Egypt, which has a long history of agriculture. There may be limited priorities for conserving some of Siwa's susceptible flora given their ubiquity in other parts of Egypt and Middle-East and Mediterranean region. There are, however, some exceptions. The isolated stand of

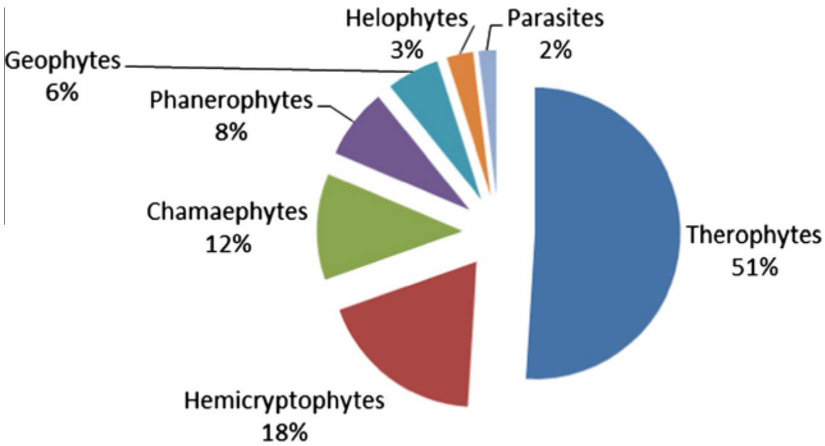


**Fig. 2** Life forms of Siwa Oasis plant species.

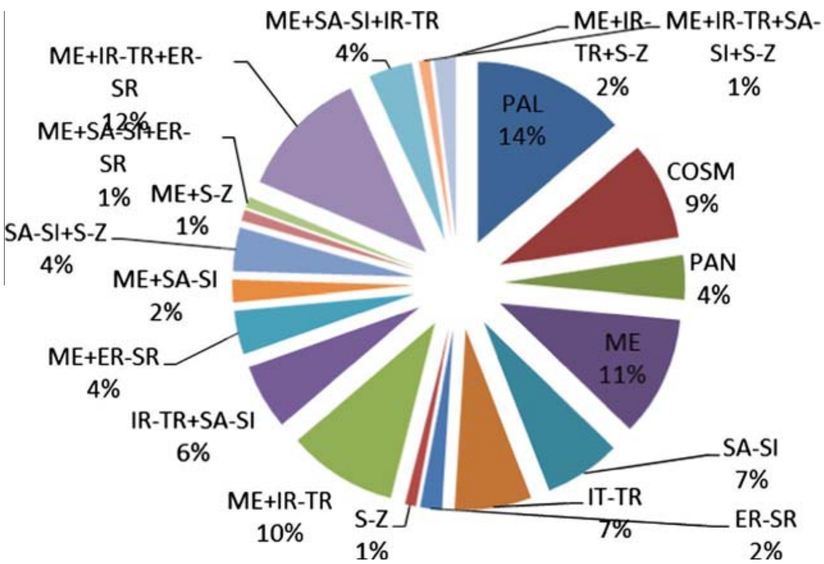


**Fig. 3** Floristic categories of plant species in Siwa Oasis: COSM = Cosmopolitan, ER-SR = Euro-Siberian, IR-TR = Irano-Turanian, ME = Mediterranean, PAL = Paleotropical, PAN = Pantropical, SA-SI = Saharo-Sindian, S-Z = Sudano-Zambesian.

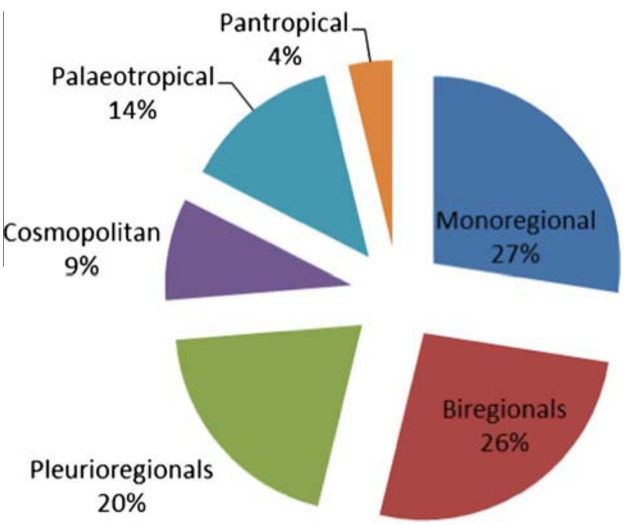


**Fig. 4** Floristic categories of plant species in Siwa Oasis.

*P. euphratica* occurs no-where else in Egypt and in a living relic on the ancient caravan routes or potentially the ancient Greek conquest. There are also unique cultivars in Siwa, of both Old and New World Origin, which form part of traditional Siwan agriculture and cuisine. Local varieties of olives, dates, peppers, tangerines, and onions, as a genetic resource, are at risk of being supplanted by exotic cultivars being planted in new agricultural areas and re-claimed lands (Nabhan, 2007).

## Conclusion

Siwa Oasis is a unique agro-ecosystem that illustrates the combined effects of extreme aridity and extended history of human occupation and agricultural activity. This study identified 52 cultivated species and 102 wild species. Non-cultivated species predominately consisted of therophytes that adapt to harsh desert conditions and modified landscapes. Based on an extensive survey of cultivated areas, this study significantly increased the known number of species thought to exist in

**Table 4** Comparison between the present work and the previous studies of Abd El-Ghani (1994), El-Khouly and Khedr (2000) and Hassan (2005) showing the differences among the recorded species in each study. Asterisk denotes unique species recorded by only one study.

| Species | Abd El-Ghani (1994) | El-Khouly and Khedr (2000) | Hassan (2005) | Present study (2015) |
|---|---|---|---|---|
| *Acacia nilotica* (L.) Delile* | – | – | – | + |
| *Acacia raddiana* Savi. | – | – | + | + |
| *Acacia saligna* (Labill.) H.L. Wendl. | – | – | + | + |
| *Aegilops kotschyi* Boiss. | – | – | + | – |
| *Aetheorhiza bulbosa* (L.) Cass.* | – | + | – | – |
| *Agrostis semiverticellata* (Forssk.) C.Chr. | + | – | – | – |
| *Alhagi graecorum* Boiss. | – | + | + | + |
| *Amaranthus graecizans* L.* | + | – | – | – |
| *Ammi majus* L.* | + | – | – | – |
| *Anabasis articulata* (Forssk.) Moq. | – | – | + | – |
| *Anagallis arvensis* L. | + | – | + | + |
| *Anagallis latifolia* (L.) Arcangeli* | – | – | + | – |
| *Anastatica hierochuntica* L.* | – | – | + | – |
| *Apium nodiflorum* (L.) Lag.* | – | – | – | + |
| *Aristida adscensionis* L.* | + | – | – | – |
| *Arthrocnemum macrostachyum* (Moric.) K. Koch. | – | + | + | + |
| *Asphodelus tenuifolius* Cav.* | + | – | – | – |
| *Aster squamatus* (SPRENG.) HIERON.* | + | – | – | – |
| *Astragalus corrugatus* Bertol.* | – | – | – | + |
| *Astragalus sieberi* DC.* | – | – | + | – |
| *Astragalus vogelii* (Webb) Bornm.* | + | – | – | – |
| *Atriplex coriacea* Forssk.* | – | – | + | – |
| *Atriplex halimus* L.* | – | – | + | – |
| *Atriplex nummularia* Lindl.* | + | – | – | – |
| *Avena fatua* L. | + | – | + | + |
| *Bacopa monnieri* (L.) Pennell.* | – | – | – | + |
| *Blumea bovei* (DC.) Vatke* | + | – | – | – |
| *Bolboschenus maritimus* (L.) Palla | + | – | – | – |
| *Bolboschoenus glaucus* (Lam.) S.G. Smith. | – | – | – | + |
| *Brachypodium distachyon* (L.) P. Beauv. | + | – | – | – |
| *Brassica tournefortii* Gouan. | + | – | – | – |
| *Bromus diandrus* Roth. | – | – | – | + |
| *Cakile maritima* Scop. | – | – | – | + |
| *Calendula officinalis* L. | – | – | – | + |
| *Calligonum comosum* L'Her. | – | – | + | – |
| *Capparis aegyptia* Lam. | – | – | + | – |
| *Capsicum frutescens* L. | – | – | + | – |
| *Centaurea calcitrapa* L. | – | – | – | + |
| *Centaurium erythraea* Rafn | + | – | – | – |
| *Centaurium spicatum* (L.) Fritsch | + | – | – | – |
| *Ceratophyllum demersum* L. | – | + | – | – |
| *Chenopodium album* L. | – | – | – | + |
| *Chenopodium murale* L. | + | – | – | + |
| *Chrysanthemum coronarium* L. | + | – | – | – |
| *Cistanche phelypaea* (L.) Cout. | – | – | + | + |
| *Cleome africana* Botsch. | – | – | + | – |
| *Cleome amblyocarpa* Barratte & Murb. | – | – | – | + |
| *Convolvulus arvensis* L. | + | – | + | + |
| *Conyza bonariensis* (L.) Cronquist, Bull. | – | – | – | + |
| *Conyza canadensis* (L.) Cronquist, Bull. | – | – | – | + |
| Cornulaca monacantha Delile. | – | – | + | + |
| Cotula anthemoides L. | – | – | – | + |
| Cotula cinerea Delile. | – | – | – | + |
| Cressa cretica L. | + | + | – | + |
| Cuscuta campestris Yunck. | + | – | – | + |
| Cynanchum acutum L. | + | + | – | + |
| Cynodon dactylon (L.) Pers. | + | – | + | + |
| Cyperus laevigatus L. | + | – | – | + |
| Cyperus rotundus L. | + | – | – | + |
| *Dactyloctenium aegyptium* (L.) Willd. | + | – | – | + |

(*continued on next page*)

**Table 4** (*continued*)

| Species | Abd El-Ghani (1994) | El-Khouly and Khedr (2000) | Hassan (2005) | Present study (2015) |
|---|---|---|---|---|
| *Echinochloa crusgalli* (L.)P. Beauv. | – | – | – | + |
| *Emex spinosa* (L.) Campd. | – | – | – | + |
| *Enarthrocarpus strangulatus* Boiss. | – | – | – | + |
| *Ephedra alata* Decne. | – | – | + | – |
| *Eragrostis cilianensis* (All.) Janch. | + | – | – | – |
| *Erodium laciniatum* (Cav.) Willd. | – | – | + | – |
| *Erucaria pinnata* (Viv.) Taeckh. | – | – | + | – |
| *Eucalyptus camaldulensis* Dehn. | – | – | + | + |
| *Euphorbia peplus* L. | + | – | – | – |
| *Fagonia arabica* L. | – | – | – | + |
| *Fagonia cretica* L. | – | – | + | + |
| *Ferula marmarica* Asch. & Taub. ex Asch. & Schweinf. | – | – | – | + |
| *Francoeuria crispa* (Forssk.) Cass. | – | – | + | – |
| *Frankenia hirsuta* L. | – | – | – | + |
| *Frankenia pulverulenta* L. | + | – | – | – |
| *Glycyrrhiza glabra* L. | + | – | – | + |
| *Gossypium arboreum* L. | + | – | – | – |
| *Gymnocarpos decander* Forssk. | – | – | + | – |
| *Haplophyllum tuberculatum* (Forssk.) Juss. | – | – | – | + |
| *Heliotropium ovalifolium* Forssk. | – | – | + | + |
| *Herniaria hirsute* L. | – | – | – | + |
| *Hippocrepis multisiliquosa* L. | – | – | – | + |
| *Hyoscyamus muticus* L. | – | – | + | – |
| *Imperata cylindrica* (L.) Raeusch. | + | + | + | + |
| *Inula crithmoides* L. | – | + | + | + |
| *Ipomoea cairica* (L.) Sweet | – | – | + | – |
| *Ipomoea eriocarpa* | + | – | – | – |
| *Juncus rigidus* Desf. | + | + | + | + |
| *Kochia indica* Wight. | – | – | – | + |
| *Koeleria phleoides* (Vill.) Pers. | + | – | – | – |
| *Lactuca serriola* L. | – | – | – | + |
| *Lagonychium farctum* (Banks & Sol.) Bobr. | + | – | – | – |
| *Lathyrus hirsutus* L. | + | – | – | – |
| *Launaea nudicaulis* (L.) Hook.f. | – | – | + | + |
| *Lolium perenne* L. | + | – | + | + |
| *Lolium rigidum* (Gaudin) Weiss ex Nyman | + | – | – | – |
| *Lotus corniculatus* L. | + | – | – | – |
| *Lotus glaber* Mill. | – | – | – | + |
| *Lycopersecum hirsutum* L. | – | – | + | – |
| *Malva parviflora* L. | + | – | + | + |
| *Matthiola livida* (Delile) DC. | – | – | – | + |
| *Medicago lupulina* L. | + | – | – | – |
| *Medicago polymorpha* L. | – | – | + | – |
| *Melilotus indicus* (L.) All. | + | – | + | + |
| *Mentha longifolia* (L.) Huds. | – | – | – | + |
| *Mesembryanthemum crystallinum* L. | – | – | + | – |
| *Mesembryanthemum nodiflorum* L. | + | – | + | + |
| *Monsonia nivea* (Decne.) Webb. | – | – | – | + |
| *Najas pectinata* (Parl.) Magn. | – | – | – | + |
| *Nicotiana glauca* Graham | – | – | + | – |
| *Nitraria retusa* (Forssk.) Asch. | – | – | + | – |
| *Oligomeris linifolia* (Vahl ex Hornem.) J.F. Macbr. | – | – | + | – |
| *Papaver rhoeas* L. | – | – | + | – |
| *Parapholis incurva* (L.) C.E. Hubb. | + | – | – | – |
| *Pergularia tomentosa* L. | – | – | + | – |
| *Phragmites australis* (Cav.) Trin. ex Steud. | + | + | + | + |
| *Poa annua* L. | – | – | – | + |
| *Polycarpaea repens* (Forssk.) Asch. & Schweinf. | – | – | – | + |
| *Polycarpon succulentum* (Delile) J. Gay. | – | – | + | + |
| *Polygonum equisetiforme* Sm. | – | – | – | + |
| *Polygonum patulum* M. Bieb. | + | – | – | – |
| *Polypogon monspeliensis* (L.) Desf. | + | – | + | + |

(*continued on next page*)

**Table 4** (*continued*)

| Species | Abd El-Ghani (1994) | El-Khouly and Khedr (2000) | Hassan (2005) | Present study (2015) |
|---|---|---|---|---|
| *Populus euphratica* Oliv. | – | – | – | + |
| *Portulaca oleracea* L. | – | – | – | + |
| *Prosopis farcta* (Banks & Sol.) Macbr. | – | – | – | + |
| *Pseudognaohalium luteo-album* (L.) Hilliard & B. L. Burtt. | – | – | – | + |
| *Pulicaria aspera* Pomel. | – | – | + | – |
| *Randonia africana* Coss. | – | – | + | – |
| *Reaumuria hirtella* Jaub. & Spach. | – | – | – | + |
| *Reseda lutea* L. | – | – | – | + |
| *Ricinus communis* L. | – | – | + | + |
| *Rumex vesicarius* L. | – | – | + | + |
| *Ruppia cirrhosa* (Petagna) Grand. | – | – | – | + |
| *Samolus valerandi* L. | + | + | – | + |
| *Savignya parviflora* (Delile) Webb | – | – | + | – |
| *Schouwia thebaica* Webb. | – | – | + | + |
| *Scirpus litoralis* Schrad. | – | + | – | – |
| *Scorpiurus muricatus* L. | + | – | + | + |
| *Senecio aegyptius* L. | – | – | – | + |
| *Senecio glaucus* L. | + | – | + | + |
| *Senecio vulgaris* L. | – | – | – | + |
| *Setaria verticillata* (L.) P. Beauv. | + | – | – | + |
| *Setaria viridis* (L.) P. Beauv. | – | – | – | + |
| *Silybum marianum* (L.) Gaertn. | – | – | – | + |
| *Sisymbrium irio* L. | – | – | + | + |
| *Silene gallica* | – | + | – | – |
| *Solanum nigrum* L. | + | | – | + |
| *Sonchus maritimus* L. | + | + | – | + |
| *Sonchus oleraceus* L. | + | | – | + |
| *Sorghum halepense* (L.) Pers. | – | – | – | + |
| *Sorghum virgatum* (Hack.) Stapf | + | – | – | – |
| *Spergularia marina* (L.) Griseb. | – | – | – | + |
| *Stellaria media* (L.) Vill. | + | – | – | – |
| *Stellaria pallida* (Dumort.) Murb. | – | – | – | + |
| *Stipagrostis lanata* (Forssk.) de Winter | – | – | + | – |
| *Stipagrostis plumosa* (L.) Munro ex T. Anderson. | – | – | – | + |
| *Suaeda aegyptiaca* (Hasselq.) Zohaary. | – | – | – | + |
| *Tamarix aphylla* (L.) Karsten | – | – | + | – |
| *Tamarix nilotica* (Ehrenb.) Bunge. | + | + | – | + |
| *Thesium humile* Vahl | + | – | – | – |
| *Thymelaea hirsuta* (L.) Endl. | – | – | + | – |
| *Torilis arvensis* (Huds.) Link. | – | – | – | + |
| *Torilis nodosa* (L.) Gaertn. | + | – | – | – |
| *Trichodesma africana* (L.) Lehm. | + | – | – | – |
| *Thesium humile* Vahl | + | – | – | – |
| *Trigonella maritima* Delile ex Poir. | – | – | + | – |
| *Trigonella stellata* Forssk. | – | – | + | – |
| *Typha domingensis* (Pers.) Poir. ex Steud. | – | + | – | + |
| *Urtica urens* L. | – | – | – | + |
| *Vaccaria pyramidata* Medik. | – | – | – | + |
| *Verbascum sinuatum* L. | + | – | – | – |
| *Verbena officinalis* L. | + | – | – | – |
| *Vicia sativa* L. | – | – | + | + |
| *Zilla biparmata* O. E. Schulz. | – | – | + | – |
| *Ziziphora* sp. | – | – | – | + |
| *Zygophyllum album* L.f. | – | + | + | + |
| *Zygophyllum coccineum* L. | – | – | + | + |
| *Zygophyllum simplex* L. | – | – | – | + |
| Number of unique species | **36** | **4** | **35** | **55** |
| Total | **64** | **17** | **68** | **102** |

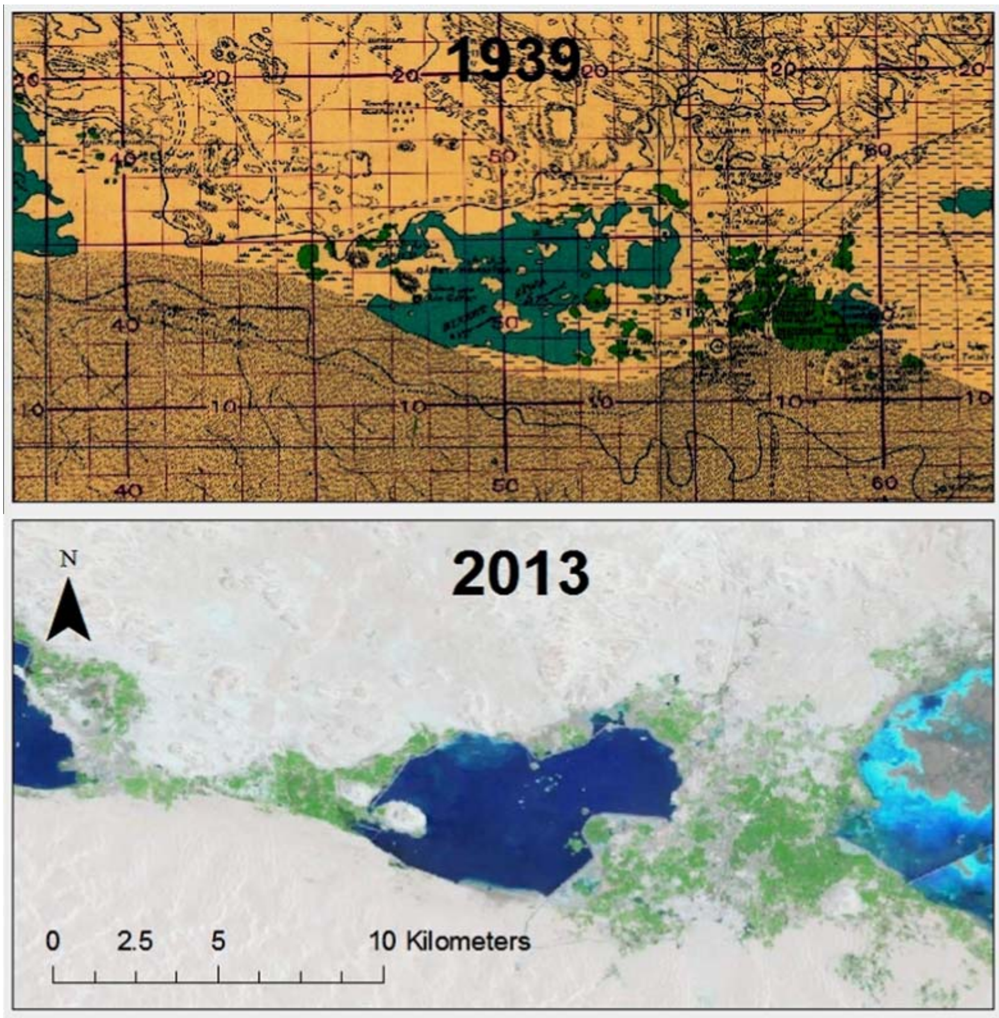


**Fig. 5** Agricultural intensification in Siwa 1939–2013. Note the expansion of salt lakes and green cultivated areas. (Source: Siwa 1:100,000 Topographic Map, Dept. of Mines 1939; Landsat 2013)

Siwa. Many of these 'new' species were annual weeds which are likely to have arrived as a result of agricultural intensification and the construction of roads over the last 30 years. But over this time many local species have also disappeared as a result of enclosure of artesian springs used for irrigation and modification of wetlands. Siwa Oasis does not support any endemic species *per se*; however, its floristic composition, which developed over millennia, and traditional cultivars form part of a rich cultural heritage. The conservation value of Siwa's flora emerges from its distinctive history and, until recently, isolation which has been disrupted by dramatic economic and social changes across the Western Desert of Egypt.

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