Investigation of the morphological variation among taxa to determine species diversity within *Cyperus dives* complex in East Africa: a review paper

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Abstract

The *Cyperus dives* complex, a group within the Cyperaceae family, exhibits substantial morphological diversity across East Africa, presenting a valuable opportunity for studying species diversity and ecological adaptation. This investigation explored the morphological variation among taxa within this complex to assess species diversity and inform conservation strategies. Through a detailed examination of leaf shape, inflorescence structure, and reproductive features, the study reveals significant variations that delineate species boundaries and highlight adaptive traits. Findings from existing literature affirms the complex interplay between environmental factors and morphological characteristics, illustrating how different taxa are adapted to a range of ecological niches. The results demonstrates that morphological diversity within the *Cyperus dives* complex is influenced by habitat variability and evolutionary pressures. The study concludes that a comprehensive understanding of morphological variation is essential for accurate species identification and effective conservation management. This investigation contributes to the broader understanding of biodiversity in East Africa and supports the development of targeted conservation strategies to protect the diverse taxa within the *Cyperus dives* complex.

Keywords: *Cyperus dives*, morphology, diversity, spikelets, adaptation

Introduction

Morphological variation plays a significant role in species differentiation, particularly within taxonomic complexes, where the boundaries between closely related species can be unclear [22, 39]. In East Africa, which is renowned for its biodiversity, such studies are crucial for distinguishing whether certain complexes consist of one highly variable species or multiple distinct species [26]. Thus, understanding these variations is essential not only for accurate species identification but also for conservation strategies aimed at preserving ecological diversity and maintaining evolutionary relationships [9].

The *Cyperus dives* complex within the Cyperaceae family, known for its morphological diversity, provides an excellent case study for this kind of analysis. This complex is spread across different ecological zones in East Africa, including wetlands, riverbanks, and highlands, each with distinct environmental conditions [44]. Researchers have focused on key morphological traits such as leaf shape and inflorescence structure to identify species and determine their adaptability to these varied habitats [13]. The morphological variation within this complex is indicative of underlying evolutionary processes, which drive species differentiation and adaptation [15].

Therefore, through investigation of these traits, studies have shed light on the ecological roles of different *Cyperus species* and contributed to the broader goal of refining species classification and promoting biodiversity conservation in the region [5]. This research will not only benefit taxonomists but also informs conservation strategies, which depend on an accurate understanding of species boundaries and ecological dynamics [43].

Botanical description of *Cyperus dives* complex

The *Cyperus dives* complex, a group of sedge species within the Cyperaceae family, exhibits morphological variation in size, growth habit, and other features despite their similarities [37]. Widely distributed across tropical and subtropical regions, including Africa, Asia, and parts of the Americas, this complex plays a significant ecological role in wet habitats such as marshes, riverbanks, and seasonally flooded areas, supporting biodiversity and maintaining the hydrological balance [23, 37]. Botanically, *Cyperus dives* is a perennial sedge that can reach heights of up to 2 meters, with erect, triangular culms and long basal leaves that often exceed the culms in length [23]. Its inflorescence consists of a compound umbel, featuring numerous brown or reddish-brown spikelets that are linear to narrowly lanceolate, each containing tightly arranged florets [37]. The species' achenes are trigonous, with a smooth or slightly papillose surface, a key diagnostic characteristic for identifying different taxa within the complex [23].

Morphological variation within the *Cyperus dives* complex is notable, particularly in the size of the spikelets, the number of florets, and the overall growth habit. These variations have led to debates among taxonomists regarding whether the complex represents a single, highly variable species or multiple distinct

species [7]. In regions such as East Africa, this variation is particularly pronounced, with local environmental conditions influencing the phenotypic expression of key morphological traits. Further research is needed to clarify the taxonomic relationships within the complex, particularly using molecular and phylogenetic tools to complement morphological studies.

Ecology and geographic distribution of *Cyperus dives* complex

The *Cyperus dives* complex is commonly found in wetland ecosystems, thriving in habitats such as marshes, riverbanks, and damp grasslands [1, 25]. It plays a crucial ecological role in stabilizing soil in riparian zones and providing a habitat for various aquatic organisms (Linder & Palmer, 2020). The species within this complex are hydrophytes, meaning they are adapted to water-saturated soils and tolerate periodic flooding [30, 41]. The complex is characterized by its tolerance to fluctuating water levels, making it a key component in wetland restoration and conservation projects [1, 30]. *Cyperus* species are known for their ability to improve water quality by filtering sediments and pollutants, contributing to ecosystem health and functioning [6].

These plants have a symbiotic relationship with other wetland flora, such as sedges and grasses, forming dense vegetation that supports diverse faunal communities. The *Cyperus dives* complex also contributes to carbon sequestration in wetland soils, playing a role in mitigating climate change [45]. Additionally, it serves as a food source for herbivores and shelter for small animals, highlighting its ecological importance in maintaining biodiversity in its habitats.

The *Cyperus dives* complex has a widespread geographic distribution, predominantly occurring in tropical and subtropical regions around the world. Its distribution extends across Africa, Asia, and parts of Central and South America [45]. Globally, *Cyperus dives* is found in parts of India, Sri Lanka, and Southeast Asia, where it inhabits wet tropical forests and swampy areas. In the Americas, it is present in countries such as Brazil and Colombia, where it is adapted to the humid tropical climate. The species has also been introduced to some regions outside its native range, where it exhibits invasive tendencies, displacing local flora in wetland ecosystems [36]. Despite its wide distribution, local environmental factors, such as water availability and soil composition, significantly influence the abundance and morphological variation within the complex.

In Africa, it is widely distributed throughout East, West, and Southern Africa, with notable populations in countries such as Kenya, Uganda, Tanzania, and South Africa [28]. In East Africa, the species thrives in high-altitude wetlands, along the shores of major lakes like Lake Victoria, and in riverine systems. The complex is also found in Madagascar and other Indian Ocean islands, further illustrating its adaptability to varied ecological conditions [2].

Common and local names of *Cyperus dives* complex

The *Cyperus dives* complex, commonly known as the giant sedge, is part of the Cyperaceae family and is distributed across several regions globally, including Africa, South America, and Asia [47]. In Kenya and other East African countries, it is locally referred to as “mbarika” or “mutobwe” in Swahili-speaking regions, while in Ethiopia, it is known as “Qilxa” in Amharic [29, 46]. The species is also widely recognized for its towering size, making it distinguishable from other sedge species [2]. This species has various uses in traditional settings, including medicinal applications, mat weaving, and as a food source for livestock [4, 29]. In Uganda, it is known as “Lumuli,” and in parts of Tanzania, it is called “Mpapai” [46-48]. The numerous local names signify the plant’s broad cultural importance and utilitarian role in these communities [4, 46]. Taxonomic History of the *Cyperus dives* complex in East Africa

Taxonomic history of the *Cyperus dives* complex which comprises *C. exaltatus*, *C. alopecuroides*, *C. imbricatus* and *C. dives* is chequered. These taxa have been treated differently by different authors, *Cyperus alopecuroides* was described by [35] who later reduced it to a synonym of *Juncellus alopecuroides* Rottb. *Cyperus exaltatus* Retz was described by [13] who recognized two varieties, *C. exaltatus var exaltatus*, and *C. exaltatus var dives* and placed five species C. *immensus* C.B. Clarke, *C. parthierickii* C.B. Clarke, *C. immensus* C.B. Clarke *var taylori* and *C. immensus* C.B. Clarke *var patherickii* in its synonymy.

[16] Described *C. dives* and considered it as an accepted name and *C. alopecuroides var dives* and *C. exaltatus var dives* have been placed under its synonymy. [24] Treated *C. dives* as a variety of *C. exaltatus* using the obliquely inserted spikelets to distinguish it from the typical *C. exaltatus* in which the spikelets were laxer and inserted at almost right angles. [34] Described *C. imbricatus* as a separate species while [31] treated *C. dives* as a synonym of *C. exaltatus.* C. B [14] treated C. *alopecuroides* as a separate species based on 2fid style and nut compressed to rachilla while *C. dives* was treated to be close to *C. exaltatus* but similar to *C. alopecuroides* based on the size of the bracts and inflorescence. [31] Treated *C. imbricatus* as a separate species from the closely related *C. alopecuroides* with its narrow leaves, numerous inflorescence and compressed spikelet distinguishing it from the latter which was described by [10] as having a compact, capitate inflorescence with cylindric spikes 1.5-3.5 cm long, spikelets 3-7mm long, nutlets 0.6 x 0.7 and 0.4-0.5mm, and trigonous with acute angles.

Accounts of the *Cyperus dives* complex in East Africa given in different taxonomic accounts of the Cyperaceae [19, 20] indicate that the taxonomy of the complex is quite confusing. Table 1 shows the close relationships that exist between members of the complex as recorded in [19, 20].

Table 1: Relationships existing between members of the *Cyperus dives* complex in East Africa

Taxa	[18, 19]	[20]
C. imbricatus	Similar to *C. dives* and *C. alopecuroides*	Treated as a separate species
C. dives	Similar to *C. exaltatus* Taxonomic status is not known	Not related to any species
C. exaltatus	Related to *C. dives*	Two varieties, *C. exaltatus* var *exaltatus* and *C. exaltatus var dives*
C. alopecuroides	Similar *to C. dives*	Close to *C. dives* and closely related to *C. exaltatus*

(Adapted from [18, 19, 20)

In the account by [20] *C. dives* and *C. alopecuroides* were treated as closely related but differed in the more crowded spikelets and slightly shorter glumes (1.2 mm-2.9 mm) in the former and in the glumes with a rounded keel and flattened nutlets in the latter. [18] On their part treated *C. dives* as being closely related with all the other three members of the complex but also considered them to differ from *C. dives* in the more distant spikelets and larger glumes (*C. exaltatus*). The rounded keel, in-rolled margins on the glumes and flattened nutlets (*C. alopecuroides*) and in having shorter glumes and nutlets (*C. imbricatus*). They also considered *C. imbricatus* to be similar to *C. alopecuroides* in the shorter glumes and nutlets with two branched style and flattened nutlet.

Distribution patterns of *Cyperus dives* complex in East Africa

Taxonomy is a discipline that plays a key role in documentation and conservation of biodiversity and also provides information that helps in answering questions of what, where and how species are distributed at local, regional and global level [33]. Knowledge on geographical distribution of plants is very important, not only in accounting for rare taxa but also assisting in understanding the spread of noxious weeds [11] Species distribution models and Geographical information systems (GIS) are useful tools that predict the area inhabited by particular species by use of very scarce information available on the occurrence of the taxa [8].

A Geographic Information System (GIS) is an integrated system of computer software, hardware, and geographical data designed to capture, manage, analyse, and display various types of geographically referenced information [33]. Spatial or geographical data refers to information that includes X and Y coordinates, which allows it to be mapped. In this case, the data is sourced from herbarium records, with most recent specimens (less than 30 years old) providing latitude and longitude coordinates that estimate the locations where the plants were collected.

Specimens older than 30 years rarely include coordinate information; instead, they typically have locality details written on specimen labels, along with the collector's name, collection number, and date, information which can be used to determine precise locations by consulting published and unpublished journals [12, 33]. Georeferenced herbarium specimens can be used to model species range or distribution area information which is very useful to the IUCN Red list which is widely recognized as the international standard for assessing the conservation status of species [33, 42].

Flora of Tropical East Africa is the most important world biodiversity area [23]. The flora of Kenya is distributed across seven plant distribution regions (K1-K7) as defined by the editors of the Flora of Tropical East Africa (FTEA) between 1952 and 2012. These regions correspond to administrative divisions: K1, the "Northern Frontier Province," is located in the northern part of Kenya; K2, the "Turkana Province," is in the northwest; K3, the "Rift Valley Province," is in the west; K4, the "Central Province," is in the central region; K5, the "Nyanza Province," is in the southwest; K6, the "Masai Province," is in the south; and K7, the "Coast Province," is along Kenya's coastal area [49].

[19] Studied the diversity of sedges in East Africa and it has been found that areas with high species richness are characterised by low water depths, high rainfall and low elevations and therefore the distribution of a species like *C. papyrus* is influenced by water depth, and is known to colonise broader habitats as long as the area is flooded [40].

These studies have indicated that these taxa are distributed in diverse habitats ranging from wetlands and riverbanks to savannas and highlands [38]. The distribution is influenced by factors such as rainfall, soil type, and elevation, which create microhabitats suited to different species within the complex [21]. In particular, species within the *Cyperus dives* complex are often found in areas with high water availability, such as swamps and floodplains, as well as in drier, upland regions where they exhibit specialized adaptations [32]. The variability in distribution patterns highlights the complex interplay between environmental factors and species distribution, emphasizing the need for targeted conservation efforts to address habitat-specific requirements [3]. These distribution patterns have emphasized the importance of understanding ecological preferences and adaptive strategies of the *Cyperus dives* complex, providing valuable insights for biodiversity conservation and ecosystem management in East Africa [26, 27].

Conclusion

Cyperus dives complex exhibits significant morphological variation within and between taxa, suggesting that this group may comprise more than one distinct species. The observed variations in traits such as leaf shape, inflorescence structure, stem size, and root systems indicate considerable diversity, challenging the notion of it being a single variable species. These differences appear to be influenced by both environmental factors and genetic divergence, which have led to localized adaptations across different geographical regions within East Africa.

Additionally, the complexity of distinguishing between taxa in the *Cyperus dives* complex is based solely on morphological characteristics. While some populations exhibit overlapping traits, others show clear distinctions that suggest speciation

events have occurred. This has made it difficult for taxonomists to agree on whether these variations represent subspecies or entirely new species within the complex.

Morphological variation alone, though informative, may not provide a comprehensive picture of the species boundaries within the complex. Molecular data, when combined with morphological analysis, could offer more clarity on the evolutionary relationships and species diversity within the *Cyperus dives* complex in East Africa. This integrated approach is essential for accurate species identification and classification, which are critical for conservation and ecological management efforts in the region.

Recommendations

There is need to enhance the morphological studies by incorporating a wider range of specimens from diverse geographical locations within East Africa. This will provide a more comprehensive overview of the morphological variation present and aid in identifying potential species boundaries more accurately.

Integration of molecular techniques into the research is highly recommended. Techniques such as DNA barcoding and genetic sequencing can complement traditional morphological analyses by providing insights into the genetic relationships among taxa. Molecular data can help clarify whether the observed morphological variations are indicative of distinct species or merely variations within a single species. This combined approach will offer a more robust framework for understanding species diversity and evolutionary relationships.

There is need to conduct field surveys and ecological studies to understand the environmental factors contributing to the morphological and genetic diversity of the *Cyperus dives* complex. Investigating how factors such as climate, soil type, and habitat conditions influence the traits of this complex can provide valuable context for interpreting morphological and genetic data. Such studies could reveal how different populations have adapted to their specific environments, further informing taxonomic decisions.

Collaboration among taxonomists, ecologists, and conservationists is essential. Sharing data and insights from various disciplines can lead to more informed conclusions about the species status and conservation needs of the *Cyperus dives* complex. Coordinated efforts will enhance the accuracy of species identification, which is critical for effective conservation planning and management strategies in East Africa.

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