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Volume 5, Issue 1, March 2023

ISSN 2661-3379(Online)

Research in Ecology

https://journals.bilpubgroup.com/index.php/re

Volume 5 Issue 1 • March 2023 • ISSN 2661-3379 (Online)

Research in Ecology

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ARTICLE

The Influence of Induced Drought Stress on Germination of *Cenchrus ciliaris* L. and *Cenchrus setigerus* Vahl.: Implications for Rangeland Restoration in the Arid Desert Environment of Kuwait

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ABSTRACT

Drought impacts in arid desert ecosystems can result in decreased ecosystem productivity and biodiversity. Implementation of restoration projects in arid desert environments is largely dependent on water availability and soil moisture condition. This study investigated the influence of induced drought stress by using polyethylene glycol (PEG-6000) solution on germination viz. *Cenchrus ciliaris* and *Cenchrus setigerus* as the important rangeland species. The water stress potential treatments were 0 (control), –0.5 MPa, –1.0 MPa, –1.5 MPa, and –2.0 MPa. The extent of seed germination was severely affected by decreased water stress potential. As drought increased, the percentage of germination decreased in both *Cenchrus'* species. The water deficit at –0.5 MPa showed a significant ($P < 0.001$) reduction in the final germination percentage in the case of *C. setigerus* and *C. ciliaris* by 65% and 42.5%, respectively. At –1.0 MPa to –1.5 MPa, changes in intermediate germination were observed in *C. ciliaris* (from 35% to 17.5%, respectively) and *C. setigerus* (from 22.5% to 11.25% respectively). Higher levels of water stress (–2.0 MPa) prevented the survival of both species. Understanding the germination strategies of native desert plant species associated with drought stress and identifying favorable conditions during the germination process can be useful for restoration practices and rangeland management actions to improve desert ecosystems and maintain biodiversity.

Keywords: Arid ecosystems; Desert biodiversity; Drought stress; Desert restoration; Water stress potential; Seeds germination ecophysiology; *Cenchrus ciliaris* and *Cenchrus setigerus*; Polyethylene glycol (PEG-6000)

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ARTICLE INFO
Received: 23 January 2023 | Received in revised form: 13 March 2023 | Accepted: 17 March 2023 | Published: 22 March 2023
DOI: https://doi.org/10.30564/re.v5i1.5426

CITATION
Madouh, T.A., 2023. The Influence of Induced Drought Stress on Germination of Cenchrus ciliaris L. and Cenchrus setigerus Vahl.: Implications for Rangeland Restoration in Arid Desert Environment of Kuwait. Research in Ecology. 5(1): 1-11. DOI: https://doi.org/10.30564/re.v5i1.5426

1. Introduction

Among all complex environmental stresses, drought stress is considered the prime limitation affecting the ecological function and biodiversity of arid desert terrestrial ecosystems in that it negatively influences plant survival, reproduction, performance and net productivity [1]. The levels of drought severity and frequency can seriously alter the biodiversity of plant communities' composition and structure. Water availability and the amount of rainfall are directly responsible for multiple biological processes in arid desert ecosystems [2,3]. In view of the climate change crisis, it is postulated that the fluctuation in terms of rainfall and water scarcity will increase considerably worldwide [4], resulting in more severe consequences including changes in biodiversity, the extinction of endangered species, and the redistribution of natural biota. Therefore, understanding the plant adaptation strategies and eco-physiological responses to environmental stresses, specifically in the case of drought stress tolerance at the seeds germination level and seedlings stage, has become one of the major research emphases in determining not only the influence of climate change on ecological function, but also with regard to the restoration and re-vegetation efforts of disturbed arid desert ecosystems [5-7].

Seed germination and seedling establishment are the most sensitive stages in the development of biodiversity and natural plant communities' structure in arid desert ecosystems [8]. The development of native desert plants and their seed germination depends completely on the interaction between seasonal rainfall, soil moisture condition and seed vitality [8]. The seeds of native desert plants near the surface of the soil are highly susceptible to exposure to the robust environment of an arid desert system. In typical ecological settings, low soil moisture conditions and extreme temperatures typically found in desert ecosystems are the major factors in determining the success or failure of native vegetation establishment [9]. Higher levels of salinity however may also disturb seeds germination by producing an external osmotic potential preventing water absorption due to the impacts of sodium and chloride (NaCl) on the seeds' germination [10]. Alam [11] indicated that salinity in terms of NaCl has less influence than induced water stress (PEG) on germinated seeds rate due to the decrease in osmotic potential. Almansouri [12] suggested that seed germination is capable of eventually tolerating salinity stress but not drought stress.

Indigenous desert rangeland grasses including *Cenchrus ciliaris* L. and *Cenchrus setigerus* Vahl. are important perennial grass species in that they can grow vigorously on sandy, nutrient-poor and saline soils, whereas others will not survive. Both *Cenchrus* species are remarkably hardy, tolerating temperatures as high as 50 °C [13], low and infrequent rainfall, prolonged dry seasons, and the strong winds of arid desert ecosystems. In many areas around the desert rangeland of Kuwait, these species provide the sole forage for livestock during the grazing season and they can actively grow back even when heavily grazed. Nevertheless, a large number of the Kuwait native flora including both of these species are currently susceptible to extinction due to uncontrolled overgrazing, prolonged drought episodes, and the progression of desertification, all of which have reduced their availability in the desert rangeland. Expand current knowledge of the physiological germination requirements of the species by exploring seed responsiveness to changes in water availability during germination. The objective of this study was to investigate the influence of induced drought stress on physiological germination responses over time and the final germination of *Cenchrus ciliaris* and *Cenchrus setigerus* by using polyethylene glycol (PEG-6000) solution. Applying polyethylene glycol (PEG-6000) in terms of inducing drought stress on seed germination appears to be an optimum indicator when it comes to evaluating drought tolerance potential [14-17]. Understanding the germination strategies and seed responsiveness of native desert plant species in the face of drought stress and identifying the favorable conditions during the germination stage can be supportive to promote these species throughout the restoration programs, the re-vegetation of degraded rangelands, and the forage production system in the country.

2. Material and methods

2.1 Habitat location

The seed fascicles of *Cenchrus ciliaris* and *Cenchrus setigerus* were collected from the Al-Nuwaiseeb district in the Ahmadi Governorate in the south of the State of Kuwait (28.572°N 48.383°E) in June 2017 (**Figure 1**). The experimental site was about 50 hectares and the plant community of this location is dominated by several perennial desert types of grass including *Cenchrus* species, *Panicum turgidum* and *Pennisetum divisum*. The landscape is a flat desert plain with gentle undulations in hilly areas with a 1 to 3 percent slope. The soils are Typic Torripsamments, slightly calcareous (3%-8%), non-saline (ECe < 2 dS/m), slightly alkaline (pH 8.2-8.3), and with a sand content of over 90% [18]. The climate is that of a typical hyper-arid desert environment with two distinct seasons: Long, dry and hot summers and short-term winters (**Figure 2**). The highest temperatures can reach up to 50 °C during the summer with no precipitation. The rainfall occurs only during the winter months with the average annual rainfall varying from 110 mm/year to 150 mm/year [19].

Figure 1. Map showing the location of the seed harvesting area from the Al-Nuwaiseeb district in the Ahmadi Governorate south of the State of Kuwait.

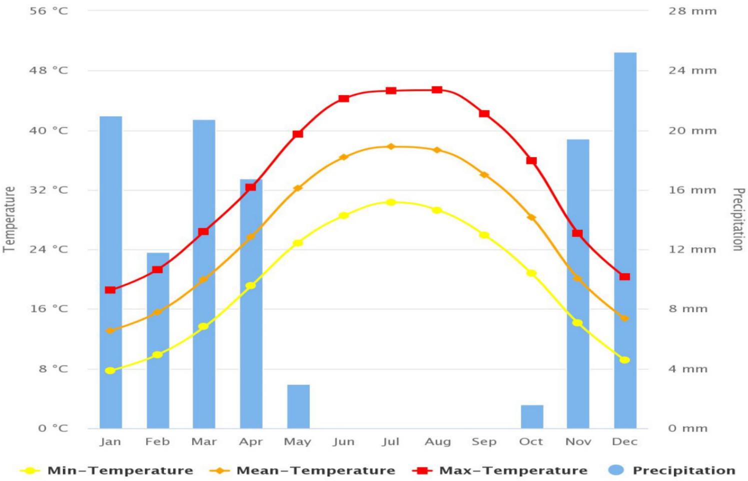

Figure 2. Mean monthly rainfall and temperature for the State of Kuwait from 1991-2020. Bars diagram: monthly rainfall. Lines: monthly minimum temperature, mean-temperature and maximum temperature.

Source: Climate Change Knowledge Portal (CCKP) [19].

2.2 Seed collection and preparation

Both *Cenchrus* species i.e. *C. ciliaris* and *C. setigerus* were identified separately. This is essential since they are relatively identical and usually distinguished by the color of the inflorescent and the hard bristles on the seeds heads (**Figure 3**). The seed heads were harvested by handpicking from healthy and vigorous wild plants. For each species, only mature and ripened seed heads were selected to ensure good quality and development of the seed germination. After collection, damaged and predated seed heads were separated, removed and discarded. Seed heads were pre-cleaned and allowed to air-dry by spreading them on a laboratory bench at ambient room temperature (25 °C) for three to four months. A long period of drying was used to increase the germination rate by eradicating germination inhibitors in the involucres. The seed fascicles of both species were carefully extracted and removed from the seed heads to obtain clean and sound seeds for experimental use. Seeds were desiccated (using silica gel) to remove excess moisture, labeled according to Kuwait Institute for Scientific Research (KISR) Seed bank registration number and placed in an airtight container.

(A) *C. ciliaris*

(B) *C. setigerus*

Figure 3. The difference between mature inflorescence (seed head) of (A) *Cenchrus ciliaris* and (B) *Cenchrus setigerus* with several fascicles (seed units).

2.3 Seed germination and drought stress stimulated by PEG-6000

A drought-induced (i.e., decreased osmotic potentials) experiment was conducted in KISR laboratory to evaluate the water stress potential on seeds germination of *C. ciliaris* and *C. setigerus* using polyethylene glycol (PEG-6000) solution. One hundred dry healthy seeds from each species were used for the experiment. Seeds were germinated in 9 mm glass Petri dishes on a double layer of Whatman No. 3 filter paper and were moistened with 10 mL of solution with five different osmotic potentials. Twenty seeds of each species were placed in each Petri dishes and a distilled water (0 MPa) control treatment or polyethylene glycol solution was added to the Petri dishes. The PEG-6000 solutions were made up of distilled water to lower the water potential to one of the following water stress potentials: –0.5, –1.0, –1.5, and –2.0 MPa. The water stress potential solution was established using a PEG-6000 solution and was prepared as identified by Michel and Kaufman [20]. Petri dishes were hermetically sealed and then put in an incubator at 25 °C with a 12 h light/dark cycle to prevent evaporation. The germination rate was evaluated on the second day after the initiation of a 28 days trial. The number of seeds germinated was counted every 2 days and the final germination percentage was calculated. Seeds were considered to be germinated when a 1-2 mm long radical had emerged.

2.4 Experimental design and statistical analysis

The induced drought experiment involved a completely randomized design with four replicates of 20 seeds of each species, with five different osmotic potential concentration treatments (including a control). The data were statistically analyzed separately for each species using one-way ANOVA to determine differences among treatments. Significant differences between the means in terms of treatments were calculated to examine differences at $p \leq 0.05$. All the statistical analyses were performed using Genstat® software, version 22 (VSN International, 2022) [21].

3. Results

The time course of cumulative germination curves shows that both species decreased significantly ($P < 0.001$, d.f. = 19) with the decrease in osmotic potential (**Figure 4**). The highest germination percentage of *C. ciliaris* and *C. setigerus* was achieved in the control treatment (0 MPa) with 95% and 87.5%, respectively. The germination percentage was lower in various degrees of negative water potentials and did not attain complete germination. Overall, the maximum germination percentage observed in the control treatment represents the viability and non-dormant caryopsis per species used in the experiment. The germination of both *Cenchrus* species was observed to be intensive in the first 4 to 12 days following the initial start of the treatment. Across all water stress potential treatments, the probability of new germination was at a minimum by day 16 (**Figure 4**).

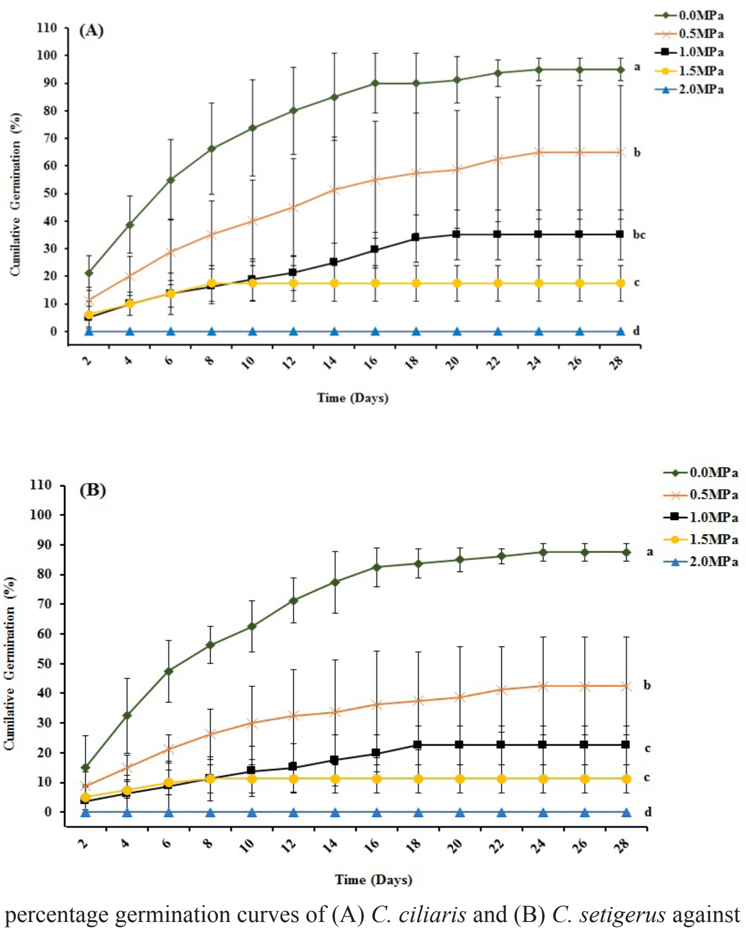

Figure 4. Cumulative mean percentage germination curves of (A) *C. ciliaris* and (B) *C. setigerus* against time and different osmotic potential treatments: 0, –0.5, –1.0, –1.5, and –2.0 MPa. Data are mean values (n= 4) for each species. Vertical bars (I) represent ± SD of the mean. Different letters indicate significance at $P < 0.001$. d.f. = 19.

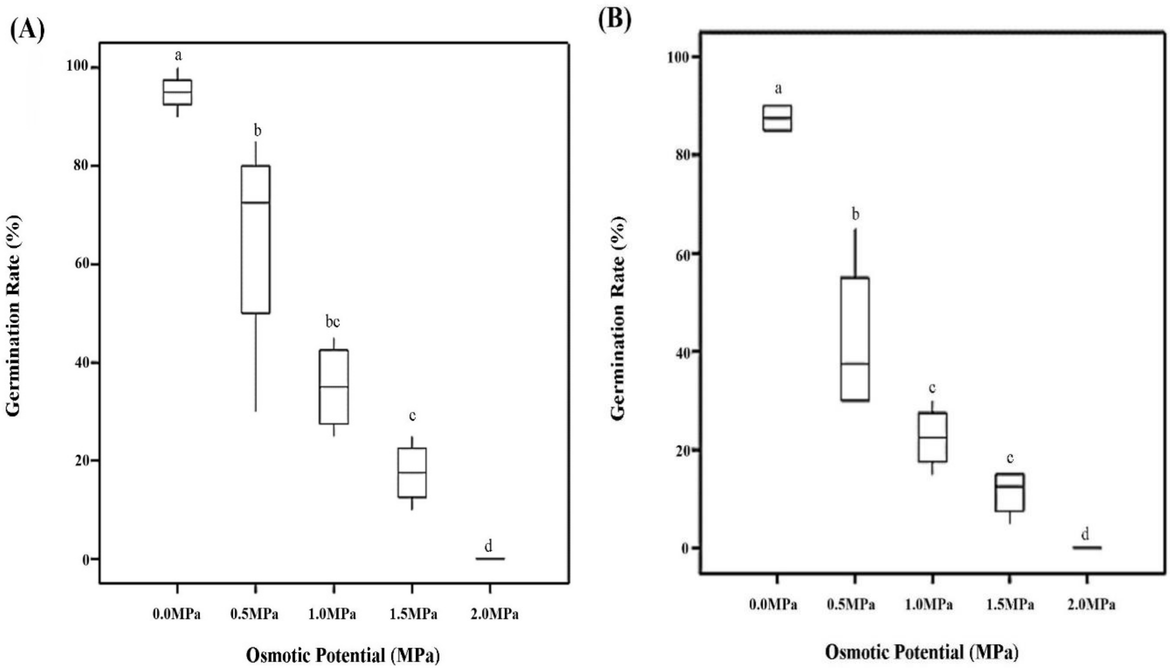

Figure 5. Box-plot diagrams showing effects of different osmotic potential treatments: 0, –0.5, –1.0, –1.5, and –2.0 MPa on final germination of (A) *C. ciliaris* and (B) *C. setigerus*. Data are mean values (n= 4) for each species. Vertical bars (I) represent ± SD of the mean. Different letters indicate significance at P < 0.001. d.f. = 19.

A water deficit at –0.5 MPa showed a significant (P < 0.001, d.f. = 19) reduction in the germination rate in both species, although the reduction was higher in the case of *C. setigerus* than *C. ciliaris* with germination percentages of 42.5% and 65%, respectively, compared to the control treatment. From –1.0 MPa to –1.5 MPa, intermediate germination rates were observed in both *C. ciliaris* (from 35% to 17.5%, respectively) and decreased even more in the case of *C. setigerus* than (from 22.5% to 11.25% respectively), while significant differences (P < 0.001, d.f. = 19) were found in both species at the two levels of water deficit treatments (**Figure 5**). At the lowest osmotic potential of –2.0 MPa no germination occurred in *C. ciliaris* and *C. setigerus* indicating that both *Cenchrus* species were completely intolerant to simulated drought stress (**Figure 5**).

4. Discussion

This investigation quantified the germination response of *C. ciliaris* and *C. setigerus* to induced drought stress by different levels of decreased osmotic potentials. The seed germination responses of both *Cenchrus* species were adversely affected by increased water stress. It is probable that water stress dehydrated the seeds and affected the germination percentage including varying patterns of seed response to water availability among various osmotic potential treatments [22]. The percentage of seed germination in both *Cenchrus* species strongly decreased at lower water potentials from –1.5 MPa to 2.0 MPa, suggesting the negative effect of water absorption by the seeds. These changing levels led to a decline in the vitality of the seed germination process. Drought influences seed germination, seedling survival, and the growth and reproduction of plants at different stages depending on the frequency and persistence of the drought stress [23]. Braga [24] indicated that decreased osmotic potentials may lead to several negative effects causing all parameters to decline (germination percentage, size and seedling weight), in both *Cenchrus* species seeds in that there was a decrease both were submitted to lower water potentials and there was a reduction in the germination percentage. Although the reduction in germination rates was significant at all water deficit levels compared to the control treatment, both *Cenchrus* species demonstrated a greater ability to tolerate and survive drought stress at –0.5 MPa, –1.0 MPa and even at –1.5 MPa. The capacity of these species to germinate at low water potential is commonly associated with adaptation to dry environments [25,26]. Native perennial grasses from arid desert ecosystems including these *Cenchrus* species are probably highly adapted to arid environments with low water availability ascertained by their capability to germinate at low water potential.

Previous studies have shown that seeds of the *Cenchrus ciliaris* were able to germinate in a wide range of osmotic potentials ranging from 0 to –1.6 MPa [27]. Other studies reported that the *Cenchrus* species was capable of germinating with regard to minimum osmotic potentials of –1.2 MPa to –1.5 MPa [28,29]. This study demonstrates that the seeds of both *Cenchrus* species collected from their natural population also had a broad array of tolerance to drought stress. The higher percentage of seed germination in both *Cenchrus* species and higher germination speed (3 days to 26 days) achieved in the control treatment (0 MPa) can be associated with the timing of the seed collection during the summer month (June) and the long period of drying at room temperature, suggesting that the seeds of these species may require the accumulation of more thermal time to stimulate germination. Both thermal and hydric conditions are more restrictive for germination in highly fluctuating environments of arid and semiarid regions [22,30]. An earlier investigation (Madouh) [31], on the summer matured seeds of *Cenchrus ciliaris*, *Cenchrus setigerus*, *Lasiurus sindicus*, *Pennisetum divisum* showed germination rates of 80% to 100% when seeds were fully irrigated with an interval of 3 days over a period of two weeks. The germination study was conducted under greenhouse conditions (25 °C ±2 and 70% relative humidity). It was also observed that the best time to collect healthy matured seeds of the above-mentioned species is during May-June. It is likely that the development of mature seeds of native desert plant species during the hot summer months of the desert environment, and their immediate response and fast germination followed by low precipitation levels of the winter months, can be used to procure sustainable longevity and persistence by using the limited resources of the desert ecosystem. Further investigation is suggested to associate the eco-physiological responses and adaptation strategies to drought, heat and salinity stresses of various native plant species important for arid desert restoration.

C. ciliaris and *C. setigerus* are perennial grass species highly adapted to arid desert ecosystems. They are an important native forage plant species specifically in the case of Kuwait and the Arabian Peninsula [32], where drought and high temperatures are the major critical factors influencing the natural desert biodiversity. Both of these *Cenchrus* species are exceptionally drought tolerant, and resistant to heavy grazing with fast recovery. Albeit, visual observation indicates that both of these species are likely to be susceptible to cold stress of the winter desert months by restricting their growth and reproduction. Cold stress can cause biomass reduction and the leaf blades and inflorescences to turn purple in *C. ciliaris* and *C. setigerus,* yet when cold stress is alleviated, the matured inflorescences changed to pale straw color or completely white in the case of the former specie. Parera et al. [33], reported that *Cenchrus* species are highly affected by low temperatures at all stages of their life cycle. Nonetheless, they are considered highly palatable and nutritious forages for all types of grazing animals [34] and highly digestible when green [35] and remain palatable at maturity [36]. Because of these physiognomy traits, these species are valuable native forage plants and have desirable qualities for use on degraded rangelands of these desert regions. In contrast, both species and particularly *C. ciliaris* have been introduced to different desert regions such as Western Australia [37], northwestern Mexico and the southwestern United States [27,38] as forage plants and for their fodder value. However, it has been reported that *C. ciliaris* has spread from forage grasslands to adjacent natural desert habitats and invaded native plant communities [39-41]. This fast spread of *C. ciliaris* to other habitats disturbs the ecosystem function and could be largely attributed to improved water availability and favorable environmental conditions. Ward et al. [42], indicated that insufficient soil moisture may not prevent the germination of buffelgrass (*Pennisetum ciliare*) which can respond to the adequate water potential of desert soil to as low as 6.3 mm. It appears that the germination physiological responses of these perennial desert grasses might be associated with specific environmental variables and local adaptation to regulate the seed germination process.

The results of this study strongly indicate that these *Cenchrus* species have the potential to germinate under lower osmotic potential conditions. Water stress may reduce the probability of seed germination, seedling survival and development because of the inadequate water availability and soil moisture content. Despite their inability to germinate under higher water stress treatment (i.e. –2.0 MPa), the seeds of both species are able to germinate and tolerate reasonable drought stress as low as –1.5 MPa of osmotic potential. In light of this, it is likely that the seed germination and seedling establishment of native desert plant species, particularly perennial grasses, can be successful at low soil moisture levels under field conditions providing that there is sufficient moisture at lower levels in the soil for growth establishment and development [43]. Overall, the data of this study provided evidence that both of these *Cenchrus* species demonstrated a wide range of tolerance to lower water potential in the case of arid desert soils, and this wide tolerance could be a beneficial mechanism for the restoration and establishment of degraded rangeland ecosystems and disturbed desert habitats. Understanding the influence of drought stress on the germination of native desert plant species and their eco-physiological responsiveness to various environmental stresses can be helpful when it comes to identifying the possibility of resistance mechanisms and adaptation strategies at the species-specific level in order to assist in the degradation, damaged and recovery management of an ecosystem.

5. Conclusions

The seeds of native desert plants tend to be tolerant of a wide range of drought stress. *C. ciliaris* and *C. setigerus* have demonstrated their flexibility when it comes to germinating in low water stress potential conditions, implying a rapid response to light rainfall events. Under adequate moisture conditions, the germination of both *Cenchrus* species' seeds can be vigorously enhanced, indicating that such seeds respond positively to water availability and can be synchronized with the alleviation of the drought stress period of the hot summer months of the desert environment. Consequently, knowing the seed germination strategies of native desert plant species associated with the face of drought stress, and identifying the favorable conditions during the crucial life stage of the germination process can be useful for restoration practices and for rangeland re-vegetation management actions. These may generate great benefits with regard to improving overall arid desert ecosystems and maintaining their natural biodiversity. Nonetheless, it is highly probable that these species may have invasive characteristics and can actively compete with other plant species over water availability and soil nutrients particularly when introduced to regions with more adequate environmental conditions.

Author Contributions

Dr. Tareq A. Madouh formulated the idea, experimental design, data analysis and writing of the manuscript. The author carried out the execution of the experiment, data recording and observations.

Conflict of Interest

The author declares that he has no conflict of interest.

Funding

This study was made possible by generous support of the Kuwait Institute for Scientific Research (KISR).

Acknowledgments

The author is very grateful to the Kuwait Institute for Scientific Research (KISR) for its kind support and for providing laboratory facilities. The author expresses many thanks to Ms. Muneera Al-Jeri for producing the GIS map, Ms. Sheena Jacob for performing the stats software, Ms. Zainab M. Ali, Ms. Nisha Aneesh and Ms. Jasmine Sali for their help and support during the administrative aspects of the work.

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ARTICLE

Ecology and Determinants of a Tropical Rainforest Landscape

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ABSTRACT

Tropical ecosystems are bio-diverse ecosystems that differ according to varied environmental features. This work assessed the tree diversity and environmental variables that define a rainforest ecosystem in southeast Nigeria. 30 forest plots were used to identify trees ≥ 10 cm (DBH measured at 130 cm). Soil samples were collected up to 30 cm deep at four edges and middle of each plot, and bulked for analysis. The survey recorded a total of 2414 trees that belonged to 102 species and 32 families. Shannon-Wiener's diversity index (H') of 3.67, Inverse Simpson's index (C) of 1.06, species evenness of 0.79 and Margalef's index of species richness (M) of 12.97 were recorded. Fabaceae family recorded the highest number (1037) of individual tree (being 43% of total) observations, while Burseraceae had the least number (1). Species abundance status showed 2.9% of species as "Abundant", 73.5% as "Endangered", 2.9% as "Frequent" and 20.6% of species as "Rare". Soil variables namely phosphorus, magnesium, potassium, particle sizes (sand, silt and clay), CEC, calcium, pH, and aluminium, influenced the distribution of the vegetation in decreasing order. Edaphic factors (soil) determined the distribution of tree stems, growth and abundance of the species within the region. Efforts on conserving the ecosystem along environmental gradients and according to species status and indices are advocated.

Keywords: Biodiversity; Conservation; Environmental factors; Gradient; Tropical

1. Introduction

Plant species vary across geographical locations or regions due to environmental variables inherent in such zones [1,2]. Such variations in the environment are mainly due to the regional and local factors which are inherent in the environment and vary across different landscapes. Hence, what determines ecosystems such as the rainforest (lowland forests)

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ARTICLE INFO
Received: 23 March 2023 | Received in revised form: 23 April 2023 | Accepted: 28 April 2023 | Published: 9 May 2023
DOI: https://doi.org/10.30564/re.v5i1.5619

CITATION
Igu, N. I., Ezenwenyi, J. U., 2023. Ecology and Determinants of a Tropical Rainforest Landscape. Research in Ecology. 5(1): 12-22. DOI: https://doi.org/10.30564/re.v5i1.5619

differ from that of swamp forests. While regional factors such as climate (mainly annual rainfall and temperature) and edaphic factors (such as geology, elevation and soil) clearly delimit the forest zones from each other, other local factors distinguish them among themselves. Instances could be drawn from swamp forests which have mainly been linked to variables such as salinity, geomorphology, hydrology, local topography and drainage [3], and lowland forests (which though monotonous in appearance), differ across spatial scales due to variations in seasonality and soil fertility [4,5]. These environmental factors act as determinants of the ecological patterns for ecosystems by either being ecologically conducive or restraining (limiting) a wide range of biodiversity. Even though these environmental factors and gradients seem quite common and known across the tropics, their data are surprisingly scanty for many landscapes and zones, and how they vary at local scales, is still a subject of inquiry. Since these factors determine to a large extent the composition, abundance and in turn the management and conservation of the ecosystem, understanding them have become very necessary and essential.

There is still a general lack of fundamental biodiversity information for tropical African taxa, including accurate taxonomy, ecological studies and estimates of distribution, compared to temperate or other tropical regions outside Africa [6]. Thus, though interests in tropical forest ecosystems have been able to present a general view of the ecosystem following its long history of inquiries, the needed details at regional levels are lacking. With the seemingly advanced knowledge on tropical ecosystems being dominated by what is specific to a part of the tropical forest zones (in the Americas, Africa or Asia), the need to promote detailed ecological studies at sub-regional levels and specific ecosystem levels is crucial, rather than working with a generalized opinion. Instances of such assertions and generalizations have been reported for the freshwater swamp forest ecosystem [7] which is dominated by studies from Latin America and very few inventories or baselines elsewhere. Promoting ecological research for specific ecosystems (such as the rainforest) at different spatial scales (national, regional and local) are much needed. Continued efforts to acquire primary data from the field are vital and a necessity to provide reliable information on which the management of the ecosystem could be based.

With varied climates, forest ecosystems across Nigeria differ from the coasts to the inland zones and then to the central and northern zones. Alongside other bio-physical attributes, the ecosystems differ at regional and most importantly at smaller (local) scales where they are mostly patterned after local factors. Though early works such as Keay's [8] work, delimited the ecosystems across Nigeria, in-depth ecological surveys and consequent conservation measures and strategies are lacking. While these ecosystems are no longer as extensive as they used to be following decades of anthropogenic pressures- notably agriculture and population pressure (especially in south east Nigeria with high population density), the remaining portions need to be documented. This work hence assessed the tree diversity and environmental factors that define the composition of rainforest ecosystems in south east Nigeria. Such insights are much needed and will suitably guide in promoting conservation and mitigation of consequent environmental change impacts.

2. Materials and methods

2.1 Study area/region

The area for the research is a part of South East Nigeria (**Figure 1**). It is characterized by a humid tropical, tropical wet and dry climate, and marked with rainy and dry seasons. The region has a high annual rainfall which ranges from 1,400 mm in the North to 2,500 mm in the South, and a mean monthly temperature of 27.6 °C. The geology of the region comprises the ancient Cretaceous delta, with the Nkporo shale, the Mamu formation, the Ajali sandstone and the Nsukka formation as its main deposits [9]. The natural vegetation of the zone is mainly, rainforest-savanna ecotone ecosystem. The zone experiences about 3 dry months in its northern zone and

1-2 dry months in the south; making it much more humid and with sufficient rainfall.

Forest inventory was done in Maku in Awgu Local government area, Enugu-Achi in Oji river local government area and Inyi, in Oji river local government area of Enugu state. Elevation within the zone is quite varied and a characteristic hilly feature and rugged terrain typifies the zone. Forests within the zone are extensive and relatively undisturbed—mainly due to the hilly terrain, very poor accessibility of the forests and quite a distant from human dwelling units.

2.2 Data collection and analysis

30 forest plots were set up across the zone and used for eliciting information regarding the tree composition of the ecosystem. Each of the plots measured 50 m × 50 m and was used to enumerate tree species ≥ 10 cm diameter at breast height (DBH measured at 130 cm). DBH or girth tape was used to measure the tree stems while a rangefinder was used to measure the heights. Species found within all the plots were identified, measured and documented. Species identification followed the taxonomy of Nigerian plants [10] and The Plant List [11]. Soil samples were collected up to 30 cm deep at the four edges and then the middle of each plot and bulked for analysis. The samples were analyzed for carbon (C), N, pH, P, exchangeable aluminium (Al), exchangeable cations namely, Ca, K, Mg, Na and CEC, which was used in the determination of base saturation.

Organic carbon was derived with Walkey-Blacks titration method [12] after which the Van Bemmelan factor was used to calculate the organic matter. Exchangeable aluminium (Al) and exchangeable cations, namely calcium (Ca), magnesium (Mg), sodium (Na) and potassium (K), were derived following Allen et al. [13] Summer and Miller [14] were employed for CEC determination; Semi-micro kjedahls distillation method [15] was used to get the nitrogen while pH employed the H_2O and 0.1 M KCl methods of Rowell [16].

Biodiversity variables were assessed with Shannon-Wiener's diversity index (H') and Inverse Simpson's index (C), Pielou's evenness [17], Margalef's index of species richness (M) and Relative density.

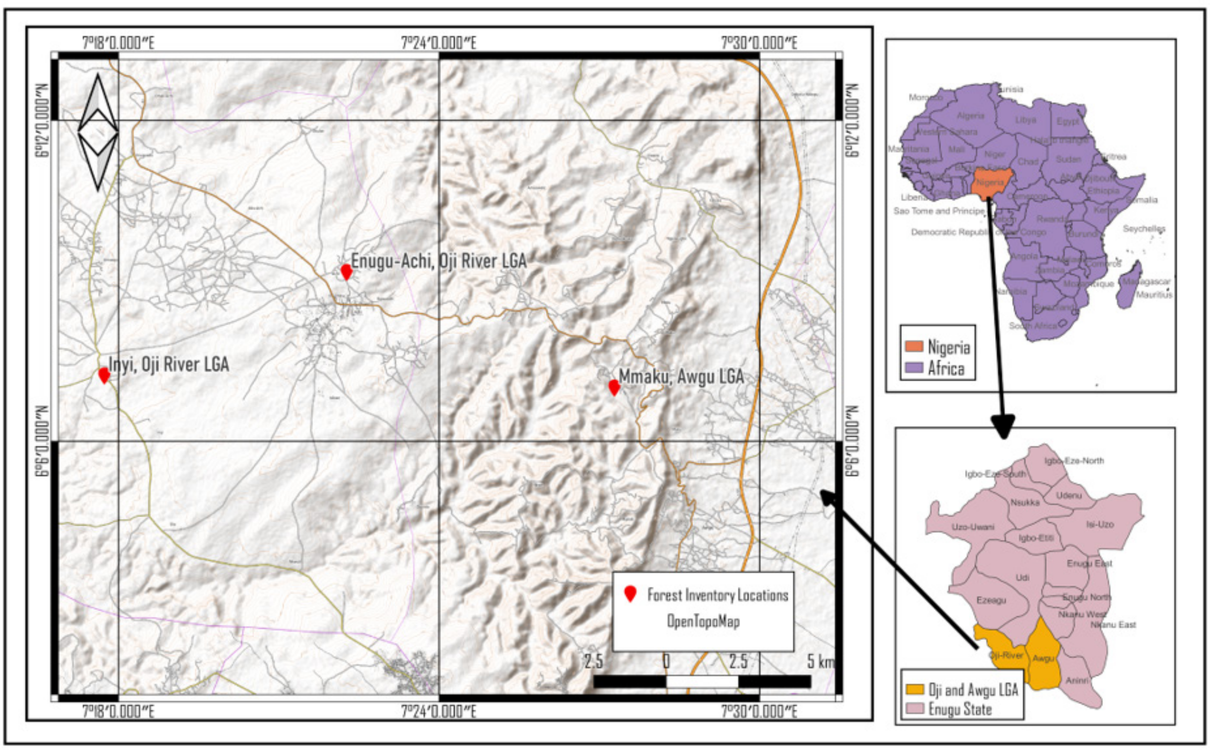

Figure 1. Map of the study area with the map of Nigeria and Africa inset.

Variations between elevation gradients were verified with descriptive statistics, while the soil gradients were verified with a Principal Component analysis (PCA).

The relative density (%) of each tree species was measured thus:

$$\text{Relative density} = \frac{\text{Number of individual tree species}}{\text{Total number of trees sampled}} \times 100\%$$

The various species were scored according to their relative densities (RD) as follows: Abundant ($RD \geq 5.00$), frequent ($4.00 \leq RD \leq 4.99$), occasional ($3.00 \leq RD \leq 3.99$), rare ($1.00 \leq RD \leq 2.99$) and threatened/endangered ($RD < 1.00$) as adopted by Edet et al. [18] and Adeyemi et al. [19]

3. Results

3.1 Family, trees species composition, distribution and status in the study area

The results of tree distribution and status as presented in **Table 1** showed that a total of 2414 individual trees were recorded of 102 species in 32 families. The species with a high number of observations include: *Dialium guineense* Willd. (462), *Pentaclethra macrophylla* Benth. (161), *Daniellia oliveri* (Rolfe) Hutch. & Dalziel (135), *Margariteria discoidea* (Baill.) G.L (120), *Funtumia elastic* P. preuss. (109), *Pyrostria guinnensis* Comm. ex A. Juss (99) and *Sterculia tragacantha* Lindl. (66). Families with the highest relative densities were Fabaceae, Euphorbiaceae, Apocynaceae, Rubiacae and Sterculiaceae with relative densities of 19.14%, 6.67%, 5.59%, 4.97% and 4.52%, respectively. The lowest individual species recorded includes: *Anacardium occidentale* L., *Annona senegalensis* Pers., *Alstonia boonei* De Wild., *Newbouldia laevis* Seem., *Dacryodes edulis* (G Don.) H. J. Lam., *Bridelia leichardtii* Baill. Ex. Muell. Arg., *Enterolobium cyclocarpum, Khaya senegalensis* (Desr.) A. Juss., *Morus mesozygia* Stapf., *Morinda lucida* Benth. and *Pterygota macrocarpa* K. Schum. Species abundance status revealed that 2.9% (3) of species in the study area were "Abundant", 73.5% (75) were "Endangered", 2.9% (3) were "Frequent" and 20.6% (21) species were "Rare" (**Table 1**).

Table 1. Tree distribution and status in the study area.

Family	Species	Species frequency	Relative density	Status
Anacardiaceae	*Anacardium occidentale* L.	1	0.04	Endangered
	Lannea welwitsschii (Hien) Engl.	49	2.03	Rare
	Mangifera indica L.	3	0.12	Endangered
	Spondias mombin L.	33	1.37	Rare
Annonaceae	*Annona senegalensis* Pers.	1	0.04	Endangered
	Clesistopholis pathens Benth.	42	1.74	Rare
	Monodora tenuifolia Benth.	2	0.08	Endangered
	Xylopia aethiopica (Dunal) A. Rich.	31	1.28	Rare
Apocynaceae	*Alstonia boonei* De Wild.	1	0.04	Endangered
	Funtumia elastic P. preuss.	109	4.52	Frequent
	Holarrhena floribunda (G. Don.) Dur. &Schinz	9	0.37	Endangered
	Hunteria umbellata (K. Shum.) Hallier f.	8	0.33	Endangered
	Rauvolfia vomitoria Afzel.	20	0.83	Endangered
	Vocanga Africana Stapt.	12	0.50	Endangered
Bignoniaceae	*Markhamia lutea* (Benth.) K. Schum.	8	0.33	Endangered
	Newbouldia laevis Seem.	1	0.04	Endangered
	Spathodea campanulata P. Beauv.	25	1.04	Rare
Burseraceae	*Dacryodes edulis* (G Don.) H.J.Lam.	1	0.04	Endangered

Table 1 continued

Family	**Species**	**Species frequency**	**Relative density**	**Status**
Capparidaceae	*Boscia angustifoila* A.Rich.	5	0.21	Endangered
Cecropiaceae	*Myrianthus arboreus* P.Beauv.	9	0.37	Endangered
Combretaceace	*Combretum erythrophyllum* (Burch.) Sond.	5	0.21	Endangered
	Terminalia avicennoides Guill. & Perr.	36	1.49	Rare
	Terminalia glaucescens Planch.	7	0.29	Endangered
Dichapetalanceae	*Dichapetalum madagascariense* Poir.	6	0.25	Endangered
Euphorbiaceae	*Brachystegia eurycoma* Harms	28	1.16	Rare
	Bridelia ferruginea Benth	2	0.08	Endangered
	Bridelia leichardtii Baill. Ex. Muell. Arg.	1	0.04	Endangered
	Bridelia micrantha (Hochst.) Baill	7	0.29	Endangered
	Hymenocardia acida Tul.	17	0.70	Endangered
	Macaranga barteri Roberty	18	0.75	Endangered
	Margariteria discoidea Baill.) G.L Webster	120	4.97	Frequent
	Ricinodendron heudelotti (Baill.)	14	0.58	Endangered
	Drypetes gilgiana (Pax) Pax & K.	14	0.58	Endangered
Fabaceae	*Daniellia oliveri* (Rolfe) Hutch. & Dalziel	135	5.59	Abundant
	Enterolobium cyclocarpum	1	0.04	Endangered
	Hylodendron gabunense Tuub	6	0.25	Endangered
	Parkia biglobosa (Jacq.) G.Don	24	0.99	Endangered
	Pterocarpus santalinoides	17	0.70	Endangered
	Afzelia Africana Sm. Ex pers.	12	0.50	Endangered
	Albezia zygia DC.	41	1.70	Rare
	AlbIzia adianthifolia (Shumach.) W.Wight	32	1.33	Rare
	Albizia ferruginea Guill.	37	1.53	Rare
	Anthonatha macrophylla P. Beauv.	42	1.74	Rare
	Baphia nitida Lodd.	7	0.29	Endangered
	Millettia thonngii (Shumach&Thonn.) Baker	34	1.41	Rare
	Pentaclethra macrophylla Benth.	161	6.67	Abundant
	*Periscopsis elata (*Harms) van Meeuwen	16	0.66	Endangered
	Piptandeniastrum africanum Hook.f.	10	0.41	Endangered
	Dialium guineense Willd.	462	19.14	Abundant
Gentianaceae	*Anthocleista nobilis* G.Don.	6	0.25	Endangered
	Anthocleista vogelii (Planch.)	29	1.20	Rare
Guttiferae	*Garcinia kola* Heckel	6	0.25	Endangered
Irvingiaceae	*Irvingia gabonensis*	15	0.62	Endangered
Lamiaceae	*Vitex doniana*	15	0.62	Endangered
Lecythidaceae	*Napoleona imperialis* P.Beauv.	21	0.87	Endangered
Leguminosae	*Daniela ogea* (Harms) Rolfe ex Holland	2	0.08	Endangered
	Parkia bicolor A.Chev.	4	0.17	Endangered
	Pterocarpus osun Craib	18	0.75	Endangered
Loganiaceae	*Anthocleista djalonensis* A. Chev.	12	0.50	Endangered
Malvaceae	*Ceiba pentandra* L.	6	0.25	Endangered
	Cola nitida (Vent.) Schott. & Endl.	2	0.08	Endangered

Table 1 continued

Family	**Species**	**Species frequency**	**Relative density**	**Status**
	Hildegardia bateri (Mast.) Kosterm	3	0.12	Endangered
	Sterculia oblonga Mast.	8	0.33	Endangered
Meliaceae	*Khaya senegalensis* (Desr.) A. Juss	1	0.04	Endangered
	Ekerberga senegalensis A. Juss	6	0.25	Endangered
	Entandrophragma angolense Welw.	24	0.99	Endangered
	Entandrophragma utile Dawe & Sprague	2	0.08	Endangered
	Guarea cedrata A.chev.	2	0.08	Endangered
	Lovoa trichilioides Harms	27	1.12	Rare
	Pseudocedre lakotschyi (Schweinf) *Harms*	31	1.28	Rare
	*Trichilia prieuriana*A. Juss	7	0.29	Endangered
Moraceae	*Antiaris africana* Engl.	3	0.12	Endangered
	Ficus capensis Thumb.	5	0.21	Endangered
	Ficus mucuso Welw. Ex Ficalho	6	0.25	Endangered
	Ficus polita Vahl.	3	0.12	Endangered
	Milicia excelsa Welw.	19	0.79	Endangered
	Morus mesozygia Stapf.	1	0.04	Endangered
	Treculia africana Decene	3	0.12	Endangered
Myristicaceae	*Pycnanthus angolensis* (Welw). Warb	35	1.45	Rare
Myrtaceae	*Eucalyptus globulus*	2	0.08	Endangered
Ochinaceae	*Lophira lanceolata* Tiegh. Ex Keay	38	1.57	Rare
	Lophira alata Banks ex.	2	0.08	Endangered
Olacaceae	*Strombosia pustulata* Blume	24	0.99	Endangered
Passifloraceae	*Barteria fistulosa* (Mast.)	2	0.08	Endangered
Rhizophoraceae	*Rhizophora racemosa* GFW Mey	2	0.08	Endangered
Rubiacae	*Mitragyna inermis* (Wild.) O Ktze	11	0.46	Endangered
	Cantium gabrifolium	30	1.24	Rare
	Morinda lucida Benth.	1	0.04	Endangered
	Nauclea latifolia Smith	3	0.12	Endangered
	Pyrostria guinnensis Comm. ex A. Juss	99	4.10	Frequent
Rutaceae	*Zanthoxylum zanthoxyloides* Lam.	3	0.12	Endangered
Sapindaceae	*Allophylus africanus* P.beauv.	23	0.95	Endangered
	Lecaniodiscus cupanioides Planch.	35	1.45	Rare
Sapotaceae	*Malacantha alnifolia* (Baker) Pierre	4	0.17	Endangered
Sterculiaceae	*Pterygota macrocarpa* K. Schum	1	0.04	Endangered
	Sterculia rhinopetela K.Schum.	5	0.21	Endangered
	Cola millenii K. Schum.	29	1.20	Rare
	Sterculia tragacantha Lindl.	66	2.73	Rare
Ulmaceae	*Celtis mildbraedii* Engl.	9	0.37	Endangered
Urticaceae	*Musanga cecropoides R.Br.*	8	0.33	Endangered
Verbenaceae	*Gmelina arborea* Roxb.	8	0.33	Endangered
Violaceae	*Rinorea dentate* Kuntze	5	0.21	Endangered

3.2 Tree species diversity indices and family composition

The summary results of tree species diversity indices for the study area are presented in **Table 2**. The total number of species recorded was 102, with Shannon-Wiener's diversity index (H') value of 3.67, Inverse Simpson's index (C) value of 1.06, species evenness value of 0.79 and Margalef's index of species richness (M) of 12.97. The family composition results for the study site are presented in **Figure 2**. The result revealed that the family Fabaceae had the highest number (1037) of individual tree observations, representing the 43% of the total observation in the study area. This was followed by the families: Euphorbiaceae, Apocynaceae, Rubiacae, Sterculiaceae, Meliaceae with 221,159, 144,101 and 100 respectively; with the total number of trees signifying 9.2%, 6.6%, 6.0%, 4.1% and 4.2% of the total observation. Burseraceae family had the lowest number of observations (1) and was followed by Myrtaceae (2), Passifloraceae (2), Rhizophoraceae (2) and Rutaceae (3).

Table 2. Biodiversity indices.

Indices	Values
No. of species	102
No. of family	36
Shannon (H')	3.67
Simpson (1/D)	1.06
Evenness (E)	0.79
Richness (M)	12.97

The number of stem occurrences decreased from the least diameter class (< 20 cm; dbh) to the highest diameter class of > 60 cm. Thus, lower stem sizes had a higher number of tree occurrences than the higher stem sizes (**Figure 3**).

3.3 Influence of edaphic variables

PCA analysis used Varimax with Kaiser Normalization and recorded 22 components. Among these, 7 components with a higher % of variance were extracted; recording 82.019 cumulative %. Results from the PCA (as seen in **Table 3**) showed the variables that had significant loadings and hence, had more influence on the vegetation.

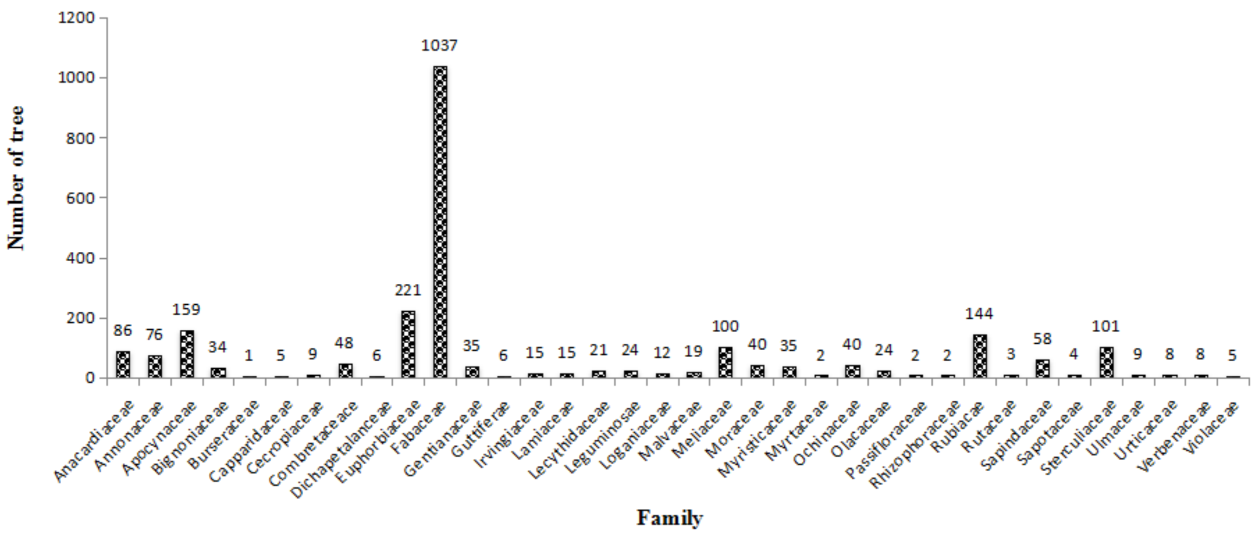

Figure 2. Frequency of trees distributed in various families was recorded in the study area.

Based on the significant level set, the following parameters were elicited: pH (0.775), magnesium ppm (0.930), magnesium cmolkg (0.927) for component 1, potassium ppm (0.925), potassium cmolkg (0.925) and CEC cmolkg (0.872) for component 2, % sand (0.917) and % silt (0.904) for component 3, phosphorus abs (0.935) and phosphorus conc (0.935) for component 4, calcium ppm (0.890) and calcium cmolkg (0.891) for component 5, aluminium ppm (0.64) for component 6 and % clay (0.793) for component 7.

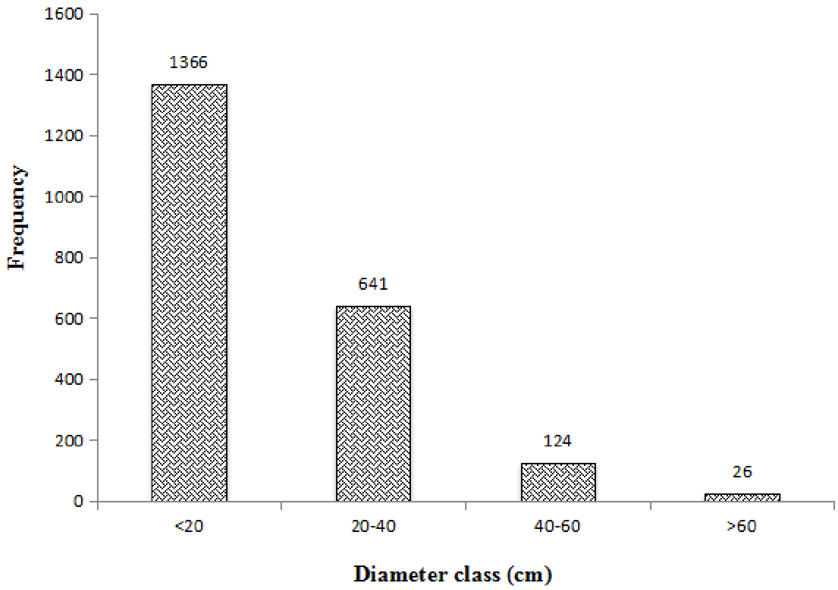

Figure 3. Frequency of stem distribution according to the diameter classes.

Table 3. Rotated component matrix.

Variable tested	**Component**						
	1	2	3	4	5	6	7
pH	0.775*	–0.147	0.361	0.034	–0.072	–0.071	0.104
Chloride mg/kg	0.390	0.230	0.522	–0.342	0.090	0.314	–0.167
Phosphorus (abs)	0.089	0.001	0.067	0.935*	0.259	–0.047	0.056
Phosphorus (conc)	0.095	–0.009	0.059	0.935*	0.255	–0.059	0.063
Magnesium ppm	0.930*	–0.157	–0.056	0.094	–0.145	–0.139	–0.071
Sodium ppm	0.153	–0.119	–0.189	0.390	0.420	0.054	–0.533
Manganese ppm	0.068	0.095	–0.367	0.025	–0.241	–0.649	0.336
Iron ppm	0.385	0.062	–0.239	–0.039	0.059	–0.565	0.035
Potassium ppm	–0.346	0.925*	–0.013	–0.034	–0.047	–0.035	0.065
Calcium ppm	–0.185	0.160	0.040	0.282	0.890*	–0.053	0.092
Aluminum ppm	0.132	0.022	–0.243	–0.157	0.010	0.647*	0.004
Calcium cmol/kg	–0.183	0.151	0.042	0.285	0.891*	–0.056	0.091
magnesiumcmol/kg	0.927*	–0.169	–0.052	0.097	–0.148	–0.142	–0.076
Potassium cmol/kg	–0.345	0.925*	–0.014	–0.034	–0.043	–0.033	0.067
CEC cmol/kg	0.047	0.872*	–0.016	0.165	0.334	–0.139	0.069
% Nitrogen	0.111	0.523	0.481	–0.269	0.157	0.325	0.177
% sand	–0.013	0.005	0.917*	0.100	–0.088	–0.060	–0.264
% Clay	0.149	0.028	–0.373	–0.043	0.295	0.091	0.793*
% Silt	–0.069	–0.026	–0.904*	–0.098	–0.078	0.013	–0.157

*significant loading ≥ 0.6.

4. Discussion

Tropical forest ecosystems host at least two-thirds of the world's biodiversity [20] and are reckoned as hotspots for biodiversity. Hence, as expected, the region under review recorded an ample amount of distinct species across the ecosystem as seen in tropical landscapes. While this is broadly the case, other site indices such as biogeography and management affected the stand structure in each region. 168 stems to 484 stems per hectare were recorded across the region. This is similar to that of other tropical zones such as 428 stems per hectare in a rainforest in China [21], 434 stems in a mixed tropical forest and 340 stems in a monodominant forest, both across Africa [22]. Variations in the stand structure of the ecosystem differed across the region based on its (local) biogeography and how the forest landscapes were managed. Disturbance arising from natural (such as windbreaks, floods and tree falls) and anthropogenic impacts (selective logging, unsustainable use of forest resources) affects tropical ecosystems greatly and affects not only the stand structure of the ecosystems, but furthermore its forest cover and density. While the biodiversity found in forest locations could differ also according to the biogeography of the landscapes, other factors such as the history of species dominance and dispersal patterns, determines largely its species composition at local scales. The total number of stems per family was hence much varied across the ecosystem; ranging from 1037 stems to 1 stem per family across the ecosystem (**Figure 3**). Dominant biodiversity has a higher chance of remaining the major biodiversity features of (relatively) undisturbed natural ecosystems; since they have already colonized the landscape. This will however change when there are disruptions emanating from disturbances, forest health or alien species impacts.

Biodiversity attributes of the ecosystem were generally similar to tropical landscapes. Species diversity: Shannon index (3.67) and inverse Simpson's index (1.06), and evenness (0.79) (**Table 2**) showed that the species were much varied and properly distributed accordingly. Much of this diverse ecosystem (with as many as 102 species and a richness index of 12.97) was dominated by families (**Figure 2**) that occur in other landscapes and ecosystems. Fabaceae (which is the most diverse and abundant) is adjudged to be the largest to third largest of the angiosperms and consists of between 650-770 genera and 18,000 to more than 19,500 species [23-25]. With a wider geographical range in a broader range of habitats, it can grow in all ecosystems and could be much more diverse as seen in the ecosystem; depending on how favourable or constraining the environmental features in the local area are. Similarly, other families that are much or less diverse, had varied geographical ranges as a result of the local factors in the ecosystem. As Fabaceae species distributions are known to be strongly related to the soil, other groups of plants (at species, genus and family levels) are inherently determined by similar factors such as the topography and edaphic factors; depending on their scale [26]. Other diverse families such as Euphorbiaceae, Apocynaceae, Rubiacae, Sterculiaceae, Meliaceae and least diverse ones such as Burseraceae, Myrtaceae, Passifloraceae, Rhizophoraceae and Rutaceae were all enhanced and restricted, respectively, according to the environmental factors inherent in the region.

Edaphic factors influence tree distributions and growth, and are useful for delimiting biogeographical zones and biomes. Among such factors, soil chemistry, soil texture and topography, are quite notable and have strong and deterministic effects on community composition [27]. Soil variables were seen to influence the vegetation of the zone and delimited the region into 7 units (components) (**Table 3**). Notably, phosphorus, magnesium, potassium, particle sizes (sand, silt and clay), CEC, calcium, pH, and aluminium, influenced the distribution of the vegetation in decreasing order and contributed to the growth of the plants mostly. Growth of necessary nutrients (such as phosphorus, magnesium and potassium), pH, CEC and particle sizes (which influences the biogeochemical and hydrological cycles), and possibly toxic element like aluminium [28], all contributed (to promoting or constraining) the growth and distribution of the species across the region. Soil nutrient contributes much to the growth of biodiversity in such landscapes and determines (through its quality) how luxuriant an ecosystem could be. It equally influences tree height, basal area and in turn, the composition of plants and their community features [29].

5. Conclusions

The ecosystem had synonymous attributes of tropical ecosystems, as seen in its species richness and diversity. Stand structure, tree densities and tree dominance of species and families were equally varied and differed across the ecosystem. Environmental factors, notably the edaphic factors determined the growth, tree distribution and plant community delimitations. Efforts to ensure that biodiversity, relative densities and status of the trees are improved and preserved are advocated in a bid to ensure ecosystem conservation.

Author Contributions

Nwabueze Igu designed the study. Both Nwabueze Igu and Jacinta Ezenwenyi conducted the fieldwork and writing of the manuscript.

Conflict of Interest

The authors declare that there is no conflict of interest.

Funding

This work was funded by Tetfund—IBR grant received from the Federal Government of Nigeria.

Acknowledgements

The authors are grateful to all the people that provided assistance with logistics, accommodation and fieldwork support towards the project. Special mention is the family of Obasi of Enugu-Maku and Professor C. I. Ezeano of the Faculty of Agriculture, Nnamdi Azikiwe University.

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REVIEW

Distribution and Status of the Pallas's Gull *Ichthyaetus ichthyaetus* (Pallas, 1773) in the Reservoirs of the Palearctic: Review

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ABSTRACT

The Pallas's Gull *Ichthyaetus ichthyaetus* is a piscivorous gull, some local populations of which are rare and vulnerable. The review presents data on the status and distribution of the Pallas's Gull in the reservoirs of the Palearctic—water bodies in which the water level is controlled by humans. The aim of the study was to assess the current state of the species in the reservoirs of the Palearctic. The review was based on 1080 publications found in the search engines Yandex, Google, Google Scholar, eLybrary. During the last 35 years, the Pallas's Gull has been found in 63 reservoirs of the Palearctic. Breeding has been established in 11 reservoirs, breeding has not been established in 43 reservoirs, and birds were present in 9 reservoirs, but the status was not specified. Two-thirds of the reservoirs where the gull was recorded or bred were located in the European part and only 1/3 in Asia. It is assumed that up to 5000 adults (0.45%-4.0% of the global population of the species) breed annually in the reservoirs of the Palearctic, and the reservoirs are not the main habitats for maintaining and reproducing the population of the species. The majority of the breeding population reproduces in natural water bodies, and the reservoirs of the Palearctic are important for the maintenance of non-breeding individuals. Detection of presumed breeding and new breeding colonies in reservoirs north of the historical range of the species has been established on the Russian Plain, in the Urals and Trans-Urals. The reservoirs of Russia play a leading role in providing breeding sites for the species in water bodies of this type. An analysis of the data allows us to state the important and increased role of reservoirs in the modern distribution and expansion of the range of the Pallas's Gull in the Palearctic.

Keywords: Great Black-headed Gull; Damming

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ARTICLE INFO
Received: 28 April 2023 | Received in revised form: 20 May 2023 | Accepted: 25 May 2023 | Published: 7 June 2023
DOI: https://doi.org/10.30564/re.v5i1.5691

CITATION
Golubev, S.V., 2023. Distribution and Status of the Pallas's Gull *Ichthyaetus ichthyaetus* (Pallas, 1773) in the Reservoirs of the Palearctic: Review. Research in Ecology. 5(1): 23-34. DOI: https://doi.org/10.30564/re.v5i1.5691

1. Introduction

River birds are becoming more often objects of research on river ecosystems [1], although data on the study of river taxa, communities, and the impact of river flow regulation on birds are not so extensive [2,3]. Most studies on the possible effects of river regulation and the effects of hydroelectric power plants on birds are speculative [2]. The creation of reservoirs can benefit some bird species and threaten others. Fluctuations in the water level in reservoirs can adversely affect the avifauna [2]. The reservoir can become a physical barrier for many animals, although birds are very mobile, individuals in many populations can be separated [4]. Damming is a disturbance that seems very unpredictable for animals, and they are not able to adapt to such anthropogenic disturbances, as in natural disasters [4]. It is important to improve our understanding of the relationship between birds and dams through a scientific approach to the study of this problem [4].

Reservoirs are man-made water bodies, the water level in which is controlled by man through the operation of hydraulic structures. Flow regulation is the main goal of creating any reservoir [5]. The formation of reservoirs has become a planetary phenomenon since the second half of the 20th century, and by the end of the 1980s, more than 30,000 reservoirs arose with the help of man, and in the future, it is planned to regulate 2/3 of the world's rivers [5]. At present, most of the large reservoirs are located in Russia (formerly the USSR), Canada, China, India, and the USA [4].

The Pallas's Gull *Ichthyaetus ichthyaetus* (Pallas, 1773) is one of the largest and most spectacular fish-eating predators among the world's gulls. The breeding area of the species is located entirely in the Palearctic, inside the continent. By the beginning of the 21st century, the range of the Pallas's Gull extended from the Black and Azov Seas in the west to the Great Lakes in Mongolia and Uryugnor in China in the east [6]. Non-breeding individuals were mainly found in the breeding area of the species and to the south (including south of the southern border of the Palearctic region), although some non-breeding individuals in the north reached 58°N [7,8]. The Pallas's Gull belongs to the Mediterranean type of fauna [9]. It inhabits marine, freshwater and terrestrial biomes. The state of the global population of the species is assessed as the least threatened with a positive trend in population growth [10]. The most important and largest place of colonial breeding of the species in the world is located in Russia in the Northern Caspian Sea [11], where from 50% to 90% of the Russian breeding population bred in different seasons on the Maly Zhemchuzhny Island [12], and the maximum colony size (42,000 breeding pairs) was recorded in 1987 [11]. On a large territory of Eurasia, some of its local breeding populations are rare, vulnerable and listed in the Red Books of some countries, for example, Russia, Ukraine, Kazakhstan, Uzbekistan, Kyrgyzstan. The relevance of this study lies in obtaining new information about the state of local populations of the Pallas's Gull in the reservoirs of the Palearctic in a changing climate and steadily increasing anthropogenic pressure on natural ecosystems, including the progressive regulation of river flows [5].

The aim of the study was to assess the current state of the Pallas's Gull in the reservoirs of the Palearctic. The objectives of the review were (1) to collect facts about the number of reservoirs visited or used by these gulls and (2) to establish the status of the Pallas's Gull in the reservoirs. Special attention was also focused on the questions: (1) can the reservoirs of the Palearctic be considered as the most important habitats for the maintenance and reproduction of the population of the species and (2) what is the significance of reservoirs in its modern distribution? The study complements and expands our understanding of the state of the Pallas's Gull in the reservoirs of the Russian (East European) Plain, Cis-Urals, Trans-Urals and Siberia [8,13-27]. The purpose of the study was achieved.

2. Materials and methods

The work is based on recent field observations of the author and other researchers, as well as a compilation of already published knowledge. The basis of this article was publications in Russian and English, which were found using the search engines Yandex, Google, Google Scholar, eLybrary. The following keywords and phrases were used in the search: черноголовый хохотун, водохранилище, Larus ichthyaetus, *Ichthyaetus ichthyaetus*, Pallas's Gull, Great Black-headed Gull, reservoir. I looked through 1030 literary sources, which contained information about the Pallas's Gull within the borders of the Palearctic. Reservoirs where the Pallas's Gull was recorded, located to the south of this zoogeographical area, for example, in India Vyas, R., Singh, H. [28] were not included in the scope of the research questions. About 50 publications in hard copies outside the open Internet access were considered. The review included publications where observations of the Pallas's Gull directly indicated a specific reservoir, with the exception of the Kama and Votkinsk reservoirs. The status of a species (breeding, non-breeding) was determined mainly from publications. At the end of the search, a catalog of reservoirs visited by the Pallas's Gull was compiled (**Table 1**).

In the catalog, the status of a species in a particular reservoir was accompanied by only 1-2 selected references. This made it possible to significantly reduce the volume of the list of cited publications. Catalog visualization is shown in **Figure 1**.

Table 1. Status of the Pallas's Gull (*Ichthyaetus ichthyaetus*) in the reservoirs of the Palearctic.

№	Reservoir name	Area (km²)	Country	Coordinates	Status	Source
1	Aksautsk	0.3	Russia	43°47'24" N, 41°41'22" E	NBr	[29]
2	Argazinsk	84.4	Russia	55°23'45" N, 60°22'45" E	NBr	[19]
3	Bekan	0.65	Russia	43°15' N, 44°16' E	NBr	[30]
4	Beloyarsk	38	Russia	56°51'53" N, 61°15'20" E	NBr	[18]
5	Bratsk	5470	Russia	56°15'0" N, 101°45'0" E	NBr	[23,24]
6	Bredinsk	13.2	Russia	52°27'9" N, 60°12'29" E	NBr	[31]
7	Budennovsk	7.4	Russia	44°49'18" N, 44°8'40" E	+	[32]
8	Cheboksary	2190	Russia	56°18'00" N, 46°43'00" E	NBr	[33]
9	Chogray	193	Russia	45°29'17" N, 44°35'56" E	Br	[34,35]
10	Dimitrovsk	0.56	Russia	51°29'24" N, 54°10'39" E	NBr	[36]
11	Dundinsk	18	Russia	45°55'20" N, 43°00'40" E	+	[32]
12	Gilevsk	65	Russia	51°5'41" N, 81°54'48" E	NBr	[37]
13	Gorky	1591	Russia	57°29'00" N, 42°06'00" E	NBr	[15,16]
14	Gorodovikovsk	21.24	Russia	45°58'54" N, 42°9'42" E	+	[32]
15	Iriklinsk	260	Russia	51°51'16" N, 58°47'22" E	Br	[20]
16	Kama	1915	Russia	58°08'00" N, 56°21'00" E	NBr	[7]
17	Krasnodarsk	420	Russia	44°59'36" N, 39°17'38" E	NBr	[38]
18	Krasnoyarsk	2000	Russia	55°00'00" N, 91°38'29" E	NBr	[22]
19	Kubansk	50	Russia	44°13'48" N, 42°16'12" E	NBr	[39,40]
20	Kurgansk	-	Russia	55°24'23" N, 65°11'34" E	NBr	[32]
21	Kuibyshevsk	6250	Russia	53°27'00" N, 49°10'00" E	Br	[25,26]
22	Kursk (Kurchatovsk)	21.5	Russia	51°40'37" N, 35°40'26" E	NBr	[32]
23	Makansk	-	Russia	51°56'5" N, 58°24'6" E	NBr	[41]
24	Marukhsk	0.15	Russia	43°47'21" N, 41°39'34" E	NBr	[29]
25	Mehteb	25	Russia	43°19'38" N, 47°25'59" E	NBr	[42]
26	Naslednitsk	21.2	Russia	52°09'45" N, 60°20'06" E	NBr	[43]
27	Nizhnekamsk	1370	Russia	55°53'00" N, 52°45'00" E	NBr	[44]
28	Novosibirsk	1070	Russia	54°38' N, 82°38' E	Br	[21]

Table 1 continued

№	Reservoir name	Area (km²)	Country	Coordinates	Status	Source
29	Novotroitsk	18	Russia	45°17’38” N, 41°31’09” E	+	[32]
30	Otkaznensk	21.6	Russia	44°18’00” N, 43°49’40” E	+	[32]
31	Penza	110	Russia	53°01’45” N, 45°15’35” E	NBr	[45]
32	Proletarsk	510	Russia	46°23’40” N, 42°34’28” E	Br	[46]
33	Rostovanovsk	4.5	Russia	43°59’30” N, 44°11’19” E	+	[32]
34	Rybinsk	4550	Russia	58°22’30” N, 38°25’04” E	NBr	[8,47]
35	Saratov	1831	Russia	52°32’48” N, 48°10’15” E	NBr	[48]
36	Sayano-Shushensk	621	Russia	52°05’57” N, 92°13’58” E	NBr	[49]
37	Sengileevsk	42	Russia	45°02’16” N, 41°44’29” E	+	[32]
38	Shershnevsk	39	Russia	55°06’ N, 61°18’ E	NBr	[50,51]
39	South Ural	17.2	Russia	54°29’10” N, 61°14’12” E	NBr	[50]
40	Sovetsk	5.8	Russia	44°1’26” N, 43°59’56” E	+	[32]
41	Starooskol	40.9	Russia	51°23’28” N, 37°46’53” E	NBr	[53]
42	Tsimlyansk	2702	Russia	47°50’ N, 42°50’ E	Br	[54]
43	Ust-Dzhegutinsk	2.67	Russia	44°2’16” N, 41°57’24” E	NBr	[29]
44	Veselovsk	238	Russia	47°06’30” N, 40°54’47” E	NBr	[55]
45	Volchikhinsk	37.1	Russia	56°48’00” N, 60°07’00” E	Br	[17]
46	Volgograd	3117	Russia	50°19’10” N, 46°11’13” E	Br	[56]
47	Votkinsk	1120	Russia	57°10’00” N, 55°00’00” E	NBr	[13]
48	Yachen	2.3	Russia	54°31’18” N, 36°13’34” E	NBr	[14]
49	Yegorlyksk	17	Russia	45°3’8” N, 41°38’6” E	+	[32]
50	Troitsk	10.85	Russia-Kazakhstan	54°00’59” N, 61°40’00” E	NBr	[19]
51	Bitiksk	35	Kazakhstan	50°16’11” N, 50°41’58” E	Br	[57]
52	Bukhtarma	54.9	Kazakhstan	49°10’00” N, 84°15’00” E	NBr	[58]
53	Reservoir east of the village of Ayuly	-	Kazakhstan	49°58’51” N, 74°16’22” E	NBr	[59]
54	Shardara (Chardara)	783	Kazakhstan	41°12’01” N, 67°59’54” E	NBr	[60,61]
55	Tashutkol	78	Kazakhstan	43°21’56” N, 73°56’23” E	NBr	[62]
56	Tekes	-	Kazakhstan	42°49’46”N 80°7’9” E	NBr	[63]
57	Jeziorsko	19.6	Poland	51°50’00” N, 18°40’00” E	NBr	[64] cited in: [65]
58	Dneprovsk (Zaporozhsk)	410	Ukraine	47°57’36” N, 35°06’52” E	Br	[66,67]
59	Kakhovsk	2155	Ukraine	47°30’ N, 34°06’ E	NBr	[67]
60	Kremenchug	2252	Ukraine	49°17’51” N, 32°34’58” E	Br	[27]
61	Pechenezhsk	86.2	Ukraine	49°54’35” N, 36°58’56” E	NBr	[68]
62	Araz (Araksk)	145	Azerbaijan	39°09’47” N, 45°20’10” E	NBr	[69]
63	Khauzhan	210	Turkmenistan	37°13’56” N, 61°14’37” E	NBr	[70] cited in: [66]

Note: Br—breeding; NBr—non-breeding; “+”—birds have been recorded but status unclear.

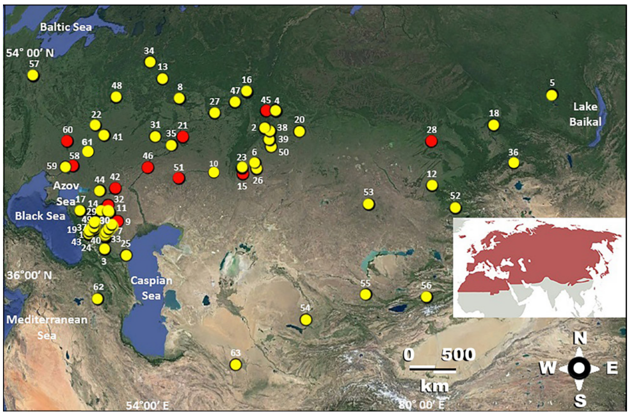

Figure 1. Distribution of the Pallas's Gull (*Ichthyaetus ichthyaetus*) in the reservoirs of the Palearctic.

Note: Red circles represent reservoirs where the Pallas's Gull breeds; yellow circles indicate reservoirs where non-breeding individuals have been observed; in the right inset, the Palearctic region is highlighted in brown.

From 1986 to 2022, the author carried out numerous foot, car and water expeditions across the territory of the Russian Plain, Siberia to the east to Lake Baikal, as well as in the Caucasus, Ciscaucasia, Transcaucasia, North Africa, Minor Asia and Central Asia, the islands of the Persian Gulf. This made it possible to better imagine the living conditions of the Pallas's Gull in the space of its range and to supplement the material of the current report. The area size and distance (on the surface of the earth) between some reservoirs were calculated using Google Earth Pro. Breeding in reservoirs was considered established if nests with egg clutches, chicks or flightless young were found. In this work, the term reservoir was used in a broad sense, that is, the area of the reservoir formed by the dam varied from 0.15 km^2 to several thousand km^2.

3. Results and discussion

3.1 The number of reservoirs where the Pallas's Gull was recorded and its status on them

During the last predominantly 35 years, the Pallas's Gull has been found in at least 63 reservoirs of the Palearctic (**Table 1**, **Figure 1**). Breeding was found in 11 (17.4%) reservoirs, breeding was not found in 43 (68.2%) reservoirs, and birds were present in 9 (14.2%) reservoirs, but their local status was not indicated in the publications. Forty-seven reservoirs (74.6%) visited by Pallas's Gull were located in Russia, 6 (9.5%) in Kazakhstan, 1 (1.5%) on the border of Russia and Kazakhstan, 4 (6.3%) in Ukraine, one each (1.5%) in Azerbaijan, Turkmenistan and Poland. On the Russian Plain, Pallas's Gull bred in 8 (72.8%) reservoirs, in the Trans-Urals and Western Siberia in 3 (27.2%) reservoirs. In Russia, the gull bred on 8 (72.8%) reservoirs, in Ukraine on 2 (18.2%) and in Kazakhstan on one (9.0%). The maximum number of reservoirs where these gulls bred was found on the Russian Plain (n = 8). A clear downward trend in breeding in the reservoirs was observed from west to east. A similar trend was observed in reservoirs where the gull did not breed. Two-thirds of the reservoirs where the gull was recorded or bred were in the European part and only 1/3 in the Asian part. This indicates more favorable environmental conditions for the distribution of the gull in the European part than in the Asian part.

3.2 Can the reservoirs of the Palearctic be considered as the most important habitats for the maintenance and reproduction of the population of the species?

About 1/6 (11 reservoirs) of the total number of reservoirs visited by the Pallas's Gull (n = 63) were suitable for breeding, as mentioned above. The maximum size of breeding colonies was established: (1) on the Russian Plain in the Kuibyshevsk reservoir of the Volga-Kama cascade of reservoirs [25,26]; (2) in the Trans-Urals at the Iriklinsk reservoir [20]; (3) in Western Siberia on the Novosibirsk reservoir [21]. Thus, the reservoirs of Russia play the most important role in the reproduction of this species in reservoirs. Taking into account that in some reservoirs in different breeding seasons, from 1-10 (Dneprovsk, Kremenchug, Volchikhinsk) to several hundred (Kuibyshevsk) and more than a thousand (Novosibirsk, Iriklinsk) nests/breeding pairs were found [17,20,21,25-27,67], it is assumed that annually in the reservoirs of the Palearctic can breed up to 5,000 adults, representing 0.45%-4% of the species' total population size, estimated at 125,000 to 1,100,000 individuals [10]. Based on these data, an insignificantly small part of the population can breed annually in the reservoirs of the Palearctic. Consequently, the majority of the breeding population of the Pallas's Gull reproduces in natural water bodies, less affected by anthropogenic influence, which confirms their value in maintaining and preserving the population of the species in the current time. The general estimate of the number of non-breeding Pallas's Gulls that annually inhabit or visit the reservoirs of the Palearctic undoubtedly exceeds the number of breeding birds and can be in the tens of thousands of individuals. However, a general estimate of the number of non-breeding individuals has not yet been obtained. From the foregoing, it follows that the reservoirs of the Palearctic are primarily important for maintaining the non-breeding part of the Pallas's Gull population.

3.3 The importance of reservoirs in the modern distribution of the species

The results of the review indicate a very significant area of the Palearctic region, the reservoirs of which were visited by the Pallas's Gull. The area where the Pallas's Gull bred (1.209.199 km^2) turned out to be 5.2 times smaller than the total area of the reservoirs where the gull was recorded (6.335.570 km^2). The Jeziorsko reservoir was the most western, the Rybinsk reservoir the most northern, the Bratsk reservoir the most eastern, and the Khauzkhan reservoir the most southern, where the gull did not breed. The distance between the northernmost (Rybinsk) and southern (Khauzkhan) reservoirs was 2899 km, and between the most western (Jeziorsko) and eastern (Bratsk) reservoirs was 5124 km.

Over the past 30 years, the Pallas's Gull has settled to the north and east [12]. The suggestion that it has been able to breed in reservoirs and may expand its range in the future [66] is supported by the results of this survey. The current breeding limits of the species in the reservoirs of the Palearctic are between 45°N and 56°N and 32°E and 82°E, although in the European part of Russia, for example, the northern limit of the distribution of the species reached only 47°N by the beginning of the 21st century [6]. To date, the proposed breeding [36] and new breeding colonies in reservoirs north of the historical range of the species have been established on the Russian Plain (for example, Bekmansurov, R.Kh. et al. [25-27], in the Cis-Urals and Trans-Urals [17,36]. The expansion of the breeding range to the north and east was observed in water bodies (not reservoirs) in the south of Central Siberia in the Altai-Sayan region [71] and, possibly, in Eastern Siberia [23]. However, there are no data on the breeding of the Pallas's Gull yet in the reservoirs of Central and Eastern Siberia, although breeding is allowed in the Bratsk reservoir [22,23].

It should be noted that the reservoirs of the Palearctic are not the only water bodies along which the species spread to the north and east. Settlement is also facilitated by the increase in the number of fish ponds that attract gulls, with some ponds actually being reservoirs in the broadest sense. Against the backdrop of climate warming and along with reservoirs, fish-breeding ponds and other fish breeding grounds rich in fish resources, as well as industrial fishing in fresh water bodies, have become one of the determining factors in the modern distribution of the Pallas's Gull outside its recent (historical) range and the redistribution of local breeding populations within the range. Fish-rich artificial reservoirs compensate gulls for missing or deficient ecosystem services outside the species' optimum range. This aspect is not considered in detail in the work and deserves a separate discussion.

In general, the analysis of the materials allows us to state the important and increased role of reservoirs in the modern distribution and expansion of the range of the Pallas's Gull in the Palearctic. In reality, Pallas's Gulls interact with a large number of existing reservoirs. Undoubtedly, the list of such reservoirs can be expanded in the near future if experts from the regions who have up-to-date information on the local state of the species join the project. Some published sightings of the Pallas's Gull on rivers and lakes may also refer to fragments of reservoirs not included in the catalog of this review. Given the above circumstances, the results of the review can be considered as preliminary and as the next stage of further research efforts in assessing the current state of the species population in a changing environment. However, even if the list of reservoirs grows soon, this is unlikely to change the main conclusions contained in the proposed article.

Despite the relative well-being of the Pallas's Gull population, monitoring of this species should continue. Particularly relevant to me is the publication of comprehensive reviews of historical and recent records of Pallas's Gulls in reservoirs. Such reviews exist [21,45], but they are few and may be limited to even one or a few registrations [8,14,23,47,52]. Such data are relevant for understanding the general patterns of the development of reservoirs by the Pallas's Gull, the level in which is regulated by humans, and the number of reservoirs continues to increase, changing the appearance of the hydrosphere. Prospects for further study of the Pallas's Gull may be associated with the study of the characteristics of its ecology in fish ponds and their role in the spread to the north, the search for new colonies outside the range of the species, the survey of more reservoirs, the study of migrations and the ecology of non-breeding birds, determining the size of non-breeding populations in reservoirs using a unified accounting methodology.

4. Conclusions

During the last 35 years, the development of reservoirs by the Pallas's Gull continued. This trend is likely to continue in the near future. The number of reservoirs that will be used for breeding is unlikely to increase markedly in immediate prospects. In most existing reservoirs, the Pallas's Gull does not breed because environmental conditions do not meet the requirements of its breeding population. These requirements are reduced to a combination of a set of basic conditions: to the presence of an unstable water level in a reservoir; to the presence of islands suitable for breeding and colonies of other bird species on them, usually large white-headed gulls; to the presence of shallow waters and an abundance of available food, mainly fish; to the absence or minimal presence of human activity and the absence of threats from predators. Combinations of such conditions are not unique, but are rare in most reservoirs outside the historical range of the species. Apparently, they are the main limiting reason for restraining the growth and spread of the breeding population of gulls in reservoirs.

Conflict of Interest

The author declares that there is no conflict of interest.

Acknowledgments

I thank everyone who contributed to my expeditions for this exploration.

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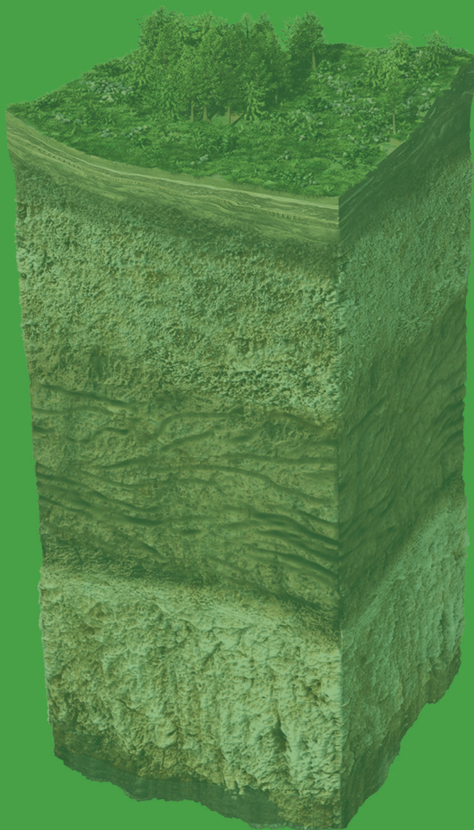

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