Sustainability and Biodiversity Conservation

An assessment of invasive flora diversity and biological spectrum in Nandankanan Biological Park, Odisha, India

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Abstract

Invasive species pose a significant threat to biodiversity by altering species composition, competing with native flora for nutrition, space, and light, and causing economic losses. This study focuses on documenting invasive plant species diversity in Nandankanan Biological Park, Khordha, Odisha, highlighting the need for conservation efforts. Field surveys were conducted in 2022-23, involving invasive species documentation, herbarium preparation, biological spectrum determination, and soil analysis. A total of 77 invasive plant species, belonging to 70 genera and 30 families, were recorded. Asteraceae emerged as the dominant family with 11 species, followed by Fabaceae (9 species), Poaceae (6 species), Acanthaceae (5 species), and Euphorbiaceae (5 species). Growth habits included 51 herbs, 15 shrubs, 7 climbers, and 4 trees. Among the 77 invasive plant species, 12 species are aquatic, 5 are wild relatives of crop plants, and 17 species possess medicinal properties. Phanerophytes were the most dominant life form (51.94%, 40 species), followed by Chamaephytes (16.88%, 13 species), Cryptophytes (15.58%, 12 species), Therophytes (11.68%, 9 species), and Hemicryptophytes (3.89%, 3 species). Soil analysis revealed that the soil is acidic in nature with low organic carbon. The mean value of organic carbon is 0.54 %, whereas the mean values of Phosphorus, Nitrogen, and Sulfur are 47.55 kg/ha, 167.4 kg/ha, and 21.54 ppm, respectively.
Keywords: Biological Spectrum, Diversity, Growth Habit, Invasive Plant, Life Forms, Nandankanan Biological Park.

Introduction

Biodiversity, known as biological diversity, refers to the variety of flora and fauna on the Earth. Degradation of forest area, interaction of exotic species, and climate change are the major factors that seriously hamper biodiversity. During the last century, many plant species

migrated from their native place and were introduced to the new geographical areas, which are termed "alien plant species" for those new environments. Some of the alien plant species grow rapidly and become invasive in the new area due to either their more adaptive characteristics or acceptance by the environment. The invasive alien plant species leads to the loss of biodiversity by replacing the native flora through competition for nutrition, light & space (Dash, 2017). Studies have shown that invasive species decrease species diversity, cause economic loss, and reduce forest health and productivity (Mooney & Hobbs, 2000; Maslo, 2016). They exhibit a high reproductive rate, making them a greater competitor to native plant species to gain food, water, and space. Consequently, they are a significant contributor to the global biodiversity loss (Mallick et al., 2019). One of the major impacts of non native species on forest ecosystems included decreased water supplied for nearby communities (McNeely, 2001). An increase in the consumption of available water by invasive plants can lead to water scarcity for nearby communities. Invasive plants possess the capacity to change the nature of the habitat according to them. They have the ability to change the structure and species composition of an ecosystem by suppressing the native plants (McNeely, 2001). Studying non native plant species diversity provides insights into their diversity, geographical distribution, identification, life form, and capacity of growth capacity. Life forms represent the adaptation strategies of plants to specific climatic conditions. The percentage of species distribution in all the life forms of all floras in a particular community is called the biological spectrum (Pal et al., 2022). Biological spectrum is also known as phyto-climatic spectrum, as it indicates the climate of this area by the response of plants. According to Raunkiaer (1934), the life form classes are Therophytes, Chamaephytes, Phanerophytes, Cryptophytes, and Hemicryptophytes. These classifications help to study the flora, vegetation structure, and ecological condition of a particular area. A normal biological spectrum was prepared by Raunkiaer, which represents the percentage value of different life forms. According to Raunkiaer's normal biological spectrum, Phanerophytes represent the dominant life form (46 %), followed by Hemicryptophytes (26%), Therophytes (13%), Chaemaephytes (9%), and Cryptophytes (6%). The normal biological spectrum acts as a standard against which the biological spectrum of a specific area can be compared to understand the adaptation of plants to a region's climate and overall environmental conditions. Nandankanan Biological Park (NBP) mainly consists of Nandankanan Zoological Park, State Botanical Garden & Kanjia Lake in Bhubaneswar, Odisha, India. It is a protected area for the ex-situ conservation of animals and plants. Apart from this, it acts as a center of attraction of the capital city, Bhubaneswar, for tourism. The

forest vegetation of NBP is of a moist mixed deciduous type. It also contains various types of important economic, commercial, and medicinal herbs and shrubs, with seasonal weeds. In this area, many invasive alien plant species spread rapidly to affect the native flora. The introduction of invasive plant species and human interference are the major causes of the degradation vegetation of the park in the last few decades. As this invasive plant species is are source of several ecological threats, it becomes essential to assess vulnerable ecosystems such as Nandankanan Biological Park, a region rich in Biodiversity yet increasingly affected by biological invasion. Hence, the present study aimed to document the diversity of invasive flora of Nandankanan Biological Park and analyze as well as classify them into different life- form classes for the biological spectrum, followed by soil analysis. Different physicochemical parameters of soil, including pH, Organic Carbon, Nitrogen, and Sulfur were analyzed as they provide valuable insights into the factors influencing distribution and community structure, which will be helpful for conservation and management of the native flora.

Material and methods

Study Area

Nandankanan Biological Park is located in the extreme north-east of Khordha district of Odisha (Figure 1). This district is surrounded by Ganjam, Nayagarh, Cuttack, Jagatsinghpur, and Puri districts. The Nandankanan Biological Park is spread over an area of 437 hectares. Out of the total area, Zoological Park covers 362.1 hectares (including Kanjia Lake of 66.1 hectares), whereas the State Botanical Garden contains 75 hectares. This protected area was constituted vide notification No. 20682-8F (WL)-160/78 dated 3rd August 1979 (Panda & Panda, 2012). This is the first zoo in India that possesses a white tiger safari and the only conservation breeding centre of the Indian Pangolin in the World. Similarly, it is along with the State Botanical Garden (SBG) that contains many important plant specimens from a basis of medicinal, commercial, and economic points of view. In the State Botanical Garden, a lot of rare, endangered, threatened, medicinal, and ornamental plants are maintained with proper care (Das & Panda, 2016).

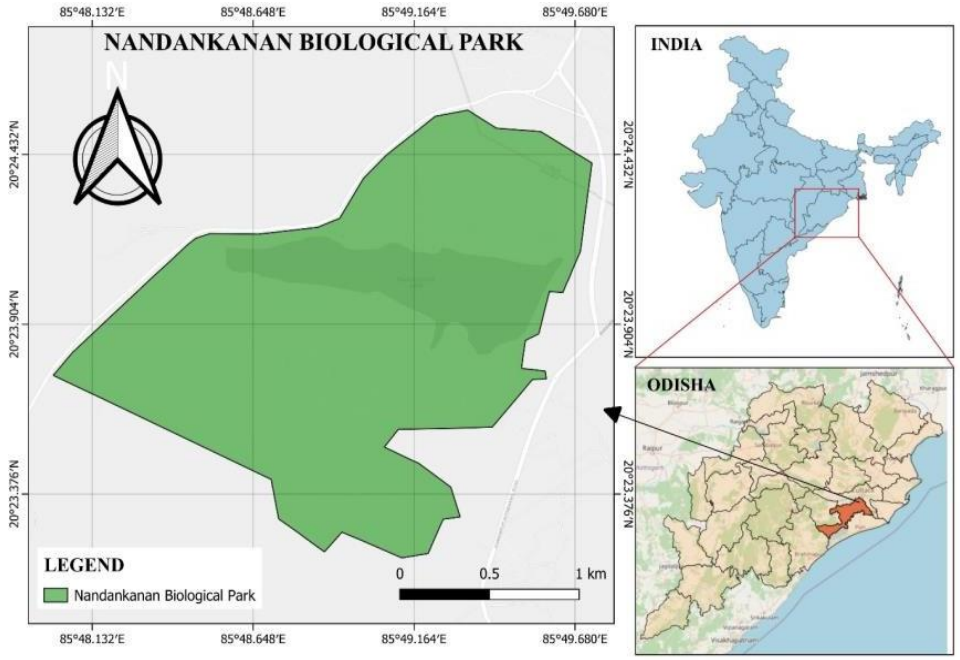

Figure 1. Map of Study Area

Climate

The climatic condition of this area is a wet tropical monsoon type. May is the hottest month with maximum day temperature varying from 35◦C to 41◦C, which rarely crosses 45◦C, whereas December and January are the coolest months, where the night temperature drops to 7◦C to 9◦C (Das & Panda, 2016). The rain during the SW monsoon reaches its peak value in the month of August. The average number of rainy days in a year is 100 days. The annual average rainfall varies between 1200 mm to 1902 mm. The mean annual maximum humidity and minimum humidity vary from 90 % 93 % and 55%, 61 % respectively (Panda & Panda, 2012).

Data Collection and Analysis

The study was carried out during 2022-23. The study area is divisible into 25 zones (Table 1) for field surveys. Frequent field visits in different seasons were made to document the invasive plant diversity of Nandankanan Biological Park. The plants were photographed along with their GPS reading during the field study. The flowering and fruiting stage of the plant specimens was collected and put into the zip-lock polythene bags. After the collection of the plant material, the specimens were assigned a field number for further identification and preservation in the form of a herbarium. Key traits such as habit, habitat, flower color, flowering season, etc., which cannot be studied from the dried specimen, were recorded in the field notebook. The vegetative characters as well as reproductive characters of the invasive species were studied. The collected samples were carefully pressed in the blotting paper

under moderate pressure with special care for the floral parts. After pressing, the plant materials were dried by artificial heat methods. Then the dried specimens were poisoned by $HgCl_2$, then mounted in a herbarium sheet and submitted to the authority of Nandankanan Biological Park for future reference (Figure 2). The plants were identified with the available literature and floras (Saxena & Brahmam, 1994-96; Gamble & Fischer, 1915-36; Haines, 1921-25). The updated nomenclature of the taxa was documented, referring to the online websites such as Plants of the World Online (POWO) and International Plant Names Index (IPNI). The life form classification system given by Raunkiaer (1934) was used for different invasive species documented in the study area. Percentages of different species of each life form class were calculated to determine the biological spectrum. Then the observed biological spectrum is compared with Raunkiaer's normal spectrum. In addition to the vegetation study, soil properties were analyzed to support ecological interpretations.

Table 1. Zonation of the Study Area

Study site	Location in NBP	Latitude (N)	Longitude (E)
N1	Inside sanctuary	20°23' 15.8028"	85° 49' 6.2292"
N2	Inside sanctuary	20°23' 16.5552"	85° 48' 52.4268"
N3	Inside sanctuary	20°23' 17.988"	85° 49' 16.5504"
N4	Inside sanctuary	20°23' 18.5424"	85° 49' 17.8068"
N5	Inside sanctuary	20°23' 20.7276"	85° 48' 57.0204"
N6	Deer Park	20°23' 43.4256"	85° 49' 13.6704"
N7	Safari region	20°23' 45.5532"	85° 48' 48.9708"
N8	Elephant zoo area	20°23' 38.2308"	85° 49' 5.3544"
N9	Safari region	20°23' 44.0808"	85° 48' 23.9796"
N10	Lawn	20°23' 46.3488"	85° 49' 5.0628"
N11	Children Park	20°23' 42.4464"	85° 49' 26.8536"
N12	Garden	20°23' 49.4484"	85° 49' 25.9536"
N13	Near reptile park region	20°23' 48.4908"	85° 49' 11.4636"
N14	Migratory bird zone	20°23' 54.2796"	85° 49' 4.8612"
N15	Kanjia Lake	20°23' 51.0576"	85° 49' 21.018"
N16	Botanical garden road	20°24' 0.0072"	85° 49' 36.0228"
N17	Kanjia lake	20°24' 5.9364"	85° 49' 24.5856"
N18	Kiakani lake	20°24' 7.8732"	85° 49' 38.37"
N19	Arboretum and its adjoining region	20°24' 14.778"	85° 49' 12.6228"
N20	Mugal garden area	20°24' 13.0392"	85° 48' 53.2764"
N21	Picnic spot region	20°24'19.9224"	85° 49' 30.9936"
N22	Children Park	20°24' 20.1096"	85° 49' 25.2984"
N23	Rose garden & adjoining area	20°24' 13.4568"	85° 49' 26.2216"
N24	Vulture breeding centre region	20°24' 25.2648"	85° 49' 5.862"
N25	Bambusetum	20°24'19.2708"	85° 49' 23.016"

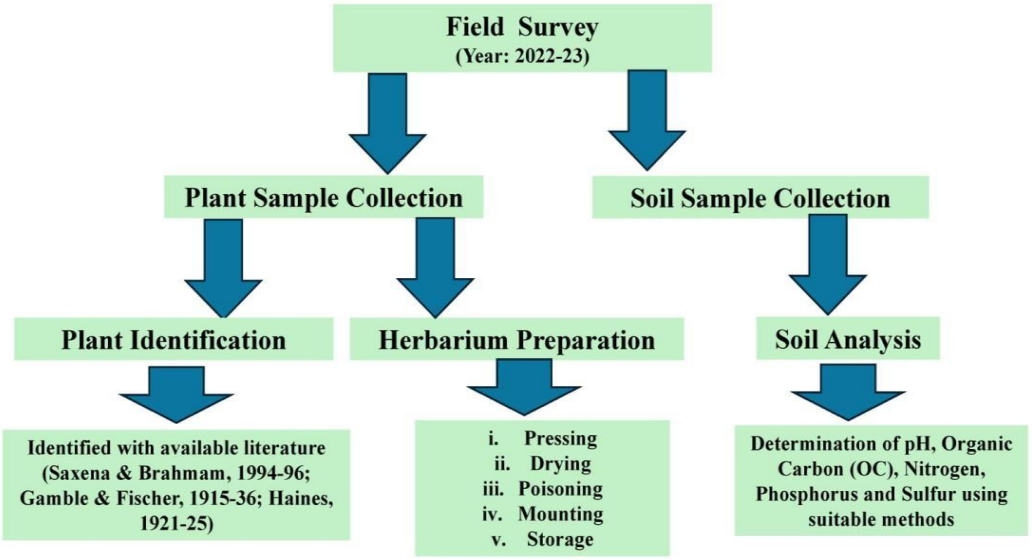

Figure 2. Flowchart showing the methodology for plant specimen and soil collection

Soil Analysis

To assess whether soil fertility favors invasive plant establishment, a total of 5 soil samples were collected from different regions of the study area, among which samples 1, 2, and 3 were collected from the zoological park, sample 4 from Kanjia wetland, and sample 5 from the botanical garden. Soil samples were collected from 0- 20 cm depth, and then the stone pieces as well as plant debris were removed by hand, followed by packing in a plastic sample bag. Date of sampling, location of sampling, and sampling number were noted in the bag. After that, the soil samples were brought to the laboratory. For detailed analysis, the soils were properly air-dried and passed through a 2 mm sieve. The physicochemical parameters, such as pH, Organic Carbon (OC), Nitrogen, Phosphorus, and Sulfur, were calculated (Figure 2). For the determination of organic carbon, the methodology followed was Walkley and Black (1934). Similarly, the Molybdenum-blue method (Murphy and Riley, 1962) was used to calculate the phosphorus content, the Kjeldahl method (Kjeldahl, 1883) was used for the determination of Nitrogen content, and Monocalcium Phosphate extraction was used to determine the Sulfur content, whereas the pH was analyzed by following the procedure described by Jackson (1973).

Results

Composition of Invasive Flora

A total of 77 invasive plant species were documented, which belong to 70 genera under 30 families (Table 2; Figures 3-6). The family Asteraceae represents the most dominant family

with 11 species followed by Fabaceae (9), Poaceae (6), Acanthaceae (5), and Euphorbiaceae (5), which is represent in a form of histogram (Figure 7). Among these identified invasive plant species, 12 are aquatic invasive plant species (Table 3) that hazardously affects the aquatic ecosystem of both Kanjia and Kiakani Lake. Analysis of growth habit revealed that the herbs represent the dominant growth habit with 51 species due to their rapid life cycle and seed production, followed by 15 shrubs, 7 climbers, and 4 tree species (Figure 8). Most frequently occurring herbaceous invasive species were *Chromolaena odorata* (L.) R. M king & H. Rob., *Ecbolium viride* (Forssk.) Alsto, *Alternanthera sessilis* (L.) DC., *Parthenium hysterophorus* L. and *Thelypteris prolifera* (Retz.) C.F. Reed, whereas the most frequently noticed invasive shrubs were *Lantana camara* L, *Ipomoea carnea* Jacq. *Euphorbia tithymaloides* L., *Senna occidentalis* (L.) Link. Not only herb and shrub, but also the Invasive climbers like *Mikania micrantha* Kunth, *Xenostegia tridentata* (L.), *Luffa aegyptiaca* Mill. were frequently observed in different zones of the study area. Among the aquatic invasive plant species, *Azolla pinnata* R.Br., *Ipomoea aquatica* Forssk., *Marsilea minuta* L., *Pontederia crassipes* Mart. and *Pontederia hastata* L. was observed frequently than other aquatic plants (Table 4). Similarly, Invasive plants like *Oryza rufipogon* Griff., *Saccharum spontaneum* L., *Luffa aegyptiaca* Mill., *Solanum sisymbriifolium* Lam., *Trichosanthes cucumerina* L. were recorded, which are the wild relatives of crop plants. *Gliricidia sepium* (Jacq.) Walp. et *Melaleuca citrina* (Curtis) Dum. Cours were now becoming invasive, which were previously introduced to Nandankanan Biological Park as Ornamental plants.

Table 2. List of invasive flora in Nandankanan Biological Park

Family	Species Name	Local Name	Life Form	Growth Habit
Acanthaceae	*Asystasia gangetica* (L.) T. Anderson	Maithala	Ph	Herb
	Dicliptera bupleuroides Nees	-	Th	Herb
	Ecbolium viride (Forssk.) Alsto	-	Ph	Shrub
	Hygrophila auriculata (Schumach.) Heine	Koelekhea	Ch	Herb
	Justicia gendarussa Burm. f.	Kala basanga	Ch	Shrub
Amaranthaceae	*Alternanthera sessilis* (L.) DC.	Madaranga	Ch	Herb
	Celosia argentea L.	Sirali	Ph	Herb
	Chenopodium album L.	Bathua	Ph	Herb
	Ouret lanata (L.) Kuntze	Punsia	Th	Herb
Apocynaceae	*Calotropis gigantea* (L.) W. T. Aiton	Arakha	Ph	Shrub

Araceae	*Pistia stratiotes* L.	Panitamaro	Cr	Herb
Arecaceae	*Calamus viminalis* Willd.	Beta	Ph	Climber
Asteraceae	*Acmella paniculata* (Wall. ex Dc.) R. K. Jansen	Akarkara	Th	Herb
	Ageratum conyzoides L.	Bokasungha	Th	Herb
	Chromolaena odorata (L.) R. M king & H. Rob.	Pokasungha	Th	Herb
	Erigeron bonariensis L.	-	Ph	Herb
	Elephantopus Scaber L.	Hati Paulia	Ph	Herb
	Grangea maderaspatana (L.) Poir.	Painjari	Ch	Herb
	Mikania micrantha Kunth	Vayara	Ph	Climber
	Parthenium hysterophorus L.	Gajar Ghasa	Ph	Herb
	Synedrella nodiflora (L.) Gaertn.	-	Ph	Herb
	Tridax procumbens L.	Bisalyakarani	Ch	Herb
	Sphagneticola calendulacea (L.) Pruski	Kasaraj	Ph	Herb
Cactaceae	*Cereus repandus* (L.) Mill.	-	Ph	Shrub
Cleomaceae	*Cleome viscosa* L.	Anasorisa	Ph	Herb
Convolvulaceae	*Evolvulus nummularius* (L.) L.	Bichamalia	Hem	Herb
	Ipomoea carnea Jacq.	Amari	Ph	Shrub
	Ipomoea aquatica Forssk.	Kalama saga	Cr	Herb
	Xenostegia tridentata (L.)	Parasarini	Ch	Climber
Costaceae	*Hellenia speciosa* (J. Koenig) S.R. Dutta.	Kokola	Ph	Herb
Crassulaceae	*Kalanchoe pinnata* (Lam.)Pers.	Amarpoi	Ch	Herb
Cucurbitaceae	*Luffa aegyptiaca* Mill.	Pita taradi	Ph	Climber
	Trichosanthes cucumerina L.	Bana Potola	Ph	Climber
Cyperaceae	*Cyperus dubius* Rottb.	Naram mutha	Ph	Herb
	Cyperus michelianus (L.) Delile	-	Ph	Herb
	Fimbristylis quinquangularis (Vahl) Kunth	Barunha	Hem	Herb
	Schoenoplectiella articulata (L.) Lye	Charchadi	Ch	Herb
Euphorbiaceae	*Croton bonplandianus* Baill.	Lanka jhati	Ch	Herb
	Croton caudatus Geiseler	Furudi	Ph	Herb
	Euphorbia tithymaloides L.	Kharsiju	Th	Shrub
	Jatropha gossypiifolia L.	Baigawa	Ph	Shrub

	Ricinus communis L.	Jada	Ph	Shrub
Fabaceae	*Acacia auriculiformis* A.Cunn. exBenth.	Akasi	Ph	Tree
	Leucaena leucocephala (Lam.) de Wit.	Nagarjuna	Ph	Tree
	Senegalia pennata (L.) Maslin	Dantarri	Ph	Climber
	Gliricidia sepium (Jacq.) Walp	-	Ph	Tree
	Mimosa pudica L.	Lajakuli lata	Th	Herb
	Senna occidentalis (L.) Link	Kalachakunda	Ph	Shrub
	Senna hirsuta (L.) H.S Irwin and Barneby	Sana chakunda	Ph	Shrub
	Senna tora (L.) Roxb.	Dhala Chakunda	Ph	Shrub
	Crotalaria pallida Aiton	Jhumuka	Ph	Shrub
Hydrocharitaceae	*Hydrilla verticillate* (L.f.) Royle	Chingudi dala	Cr	Herb
Malvaceae	*Sida rhombifolia* L.	Sahabeda	Ph	Herb
Marsileaceae	*Marsilea minuta* L.	Sunsunia	Cr	Herb
Myrtaceae	*Melaleuca citrina* (Curtis) Dum.Cours.	-	Ph	Tree
Onagraceae	*Ludwigia adscendens* (L.) H. Hara	Jagal	Cr	Herb
Papaveraceae	*Argemone mexicana* L.	Agara	Th	Herb
Poaceae	*Cenchrus pedicellatus* (Trin.) Morrone	Gadhialanza	Th	Herb
	Chrysopogon aciculatus (Retz.) Trin.	Ghughuchia	Cr	Herb
	Heteropogon contortus (L.) P. Beauv. ex Roem. &Schult.	Dauria	Ch	Herb
	Oplismenus burmanni (Retz.) P.Beauv.	-	Ch	Herb
	Oryza rufipogon Griff.	Balunga	Ph	Herb
	Saccharum spontaneum L.	Kasatandi	Ph	Herb
Polygonaceae	*Antigonon leptopus* Hook. & Arn.	Snehalata	Ph	Climber
	Persicaria barbata (L.) H. Hara	-	Ch	Herb
Pontederiaceae	*Pontederia crassipes* Mart.	Borua	Cr	Herb
	Pontederia hastata L.	Nirutamara	Cr	Herb
	Pontederia vaginalis Burm.f.	Mirmira	Cr	Herb
Rubiaceae	*Mitracarpus hirtus* (L.) Dc.	Gothiagobi	Hem	Herb
Salviniaceae	*Azolla pinnata* R.Br.	-	Cr	Herb
	Salvinia molesta D.Mitch.	Ghoda dala	Cr	Herb
Solanaceae	*Physalis angulata* L.	Tiparia	Ph	Herb
	Solanum sisymbriifolium Lam.	Veji baigan	Ph	Shrub

Verbenaceae	*Lantana camara* L.	Putus	Ph	Shrub
	Lippia alba (Mill.) N.E.Br. Rx Britton & P.Wilson	-	Ph	Shrub
Violaceae	*Pigea enneasperma* (L.) P. I. Forst.	Madan mast	Ch	Herb
Thelypteridaceae	*Thelypteris prolifera* (Retz.) C.F. Reed	-	Cr	Herb

Ph: Phanerophytes, **Cr:** Cryptophytes, **Ch:** Chamaephytes, **Hem:** Hemicryptophytes, **Th:** Therophytes

Table 3. Aquatic invasive plant species of Nandankanan Biological Park

Species Name	Nature
Azolla pinnata R.Br.	Free Floating
Hydrilla verticillata(L.f.) Royle	Submerged
Ipomoea aquatica Forssk.	Floating
Ludwigia adscendens (L.) H. Hara	Floating
Marsilea minuta L.	Floating
Oryza rufipogon Griff.	Rooted
Pistia stratiotes L.	Free Floating
Pontederia crassipes Mart.	Free Floating
Pontederia hastata L.	Floating
Pontederia vaginalis Burm.f.	Floating
Salvinia molesta D.Mitch.	Free Floating
Thelypteris prolifera (Retz.) C.F. Reed	Rooted

Table 4. Occurrence of invasive plant species in different zones of the study area

Family	Species Name	Occurrence in the study site
Acanthaceae	*Asystasia gangetica* (L.) T. Anderson	N16, N20
	Dicliptera bupleuroides Nees	N4, N8, N21
	Ecbolium viride (Forssk.) Alsto	N2, N5, N7, N8, N10, N20, N21
	Hygrophila auriculata (Schumach.) Heine	N16, N21
	Justicia gendarussa Burm. f.	N4, N7, N9, N13, N20, N22
	Alternanthera sessilis (L.) DC.	N1, N2, N6, N7, N8, N10, N25

Amaranthaceae	*Celosia argentea* L.	N3, N24
	Chenopodium album L.	N5, N8, N10, N24, N25
	Ouret lanata (L.) Kuntze	N3, N7, N14, N23
Apocynaceae	*Calotropis gigantea* (L.) W. T. Aiton	N4, N16
Araceae	*Pistia stratiotes* L.	N15, N17, N18
Arecaceae	*Calamus viminalis* Willd.	N3
Asteraceae	*Acmella paniculata* (Wall. ex Dc.) R. K. Jansen	N5, N6, N1O, N22, N23, N25
	Ageratum conyzoides L.	N2, N3, N5, N7, N7,N14, N21, N24
	Chromolaena odorata (L.) R. M king & H. Rob.	N1, N2, N4, N5, N7, N9, N13, N14, N21, N24
	Erigeron bonariensis L.	N10, N23, N25
	Elephantopus Scaber L.	N5, N8, N11, N20, N25
	Grangea maderaspatana (L.) Poir.	N12, N16, N21
	Mikania micrantha Kunth	N2, N3, N4, N9, N13, N14, N24
	Parthenium hysterophorus L.	N4, N8,N9, N13 N16, N21, N24, N25
	Synedrella nodiflora (L.) Gaertn.	N9, N24
	Tridax procumbens L.	N4, N6, N8, N11,N20
	Sphagneticola calendulacea (L.) Pruski	N16, N18
Cactaceae	*Cereus repandus* (L.) Mill.	N9, N14
Cleomaceae	*Cleome viscosa* L.	N3, N4, N7, N13, N23
Convolvulaceae	*Evolvulus nummularius* (L.) L.	N1, N6, N10, N12, N21, N22
	Ipomoea carnea Jacq.	N1, N4, N16, N17, N18, N21, N24
	Ipomoea aquatica Forssk.	N15, N16, N17, N18
	Xenostegia tridentata (L.)	N3, N4, N14, N19, N25
Costaceae	*Hellenia speciosa* (J. Koenig) S.R. Dutta.	N1, N7
Crassulaceae	*Kalanchoe pinnata* (Lam.)Pers.	N2, N5, N13
Cucurbitaceae	*Luffa aegyptiaca* Mill.	N3, N24
	Trichosanthes cucumerina	N5, N14

	L.	
Cyperaceae	*Cyperus dubius* Rottb.	N2, N8, N17, N18, N22
	Cyperus michelianus (L.) Delile	N10, N15, N18
	Fimbristylis quinquangularis (Vahl) Kunth	N15, N18
	Schoenoplectiella articulata (L.) Lye	N1, N18
Euphorbiaceae	*Croton bonplandianus* Baill.	N2, N5, N8, N14, N20, N25
	Croton caudatus Geiseler	N24
	Euphorbia tithymaloides L.	N4, N5, N7, N9, N13, N14, N20, N21
	Jatropha gossypiifolia L.	N5, N14, N21
	Ricinus communis L.	N14
Fabaceae	*Acacia auriculiformis* A.Cunn. exBenth.	N4, N14
	Leucaena leucocephala (Lam.) de Wit.	N7, N13
	Senegalia pennata (L.) Maslin	N4
	Gliricidia sepium (Jacq.) Walp	N2, N5, N7, N14, N16, N21
	Mimosa pudica L.	N3, N4, N6, N8, N20, N25
	Senna occidentalis (L.) Link	N5, N9, N13, N20, N23, N24
	Senna hirsuta (L.) H.S Irwin and Barneby	N2, N7, N13, N25
	Senna tora (L.) Roxb.	N3, N4, N13, N2O, N24
	Crotalaria pallida Aiton	N7, N23
Hydrocharitaceae	*Hydrilla verticillate* (L.f.) Royle	N15, N18
Malvaceae	*Sida rhombifolia* L.	N20, N22
Marsileaceae	*Marsilea minuta* L.	N8, N15, N16, N17, N18
Myrtaceae	*Melaleuca citrina* (Curtis) Dum.Cours.	N14, N16
Onagraceae	*Ludwigia adscendens* (L.) H. Hara	N15, N18
Papaveraceae	*Argemone mexicana* L.	N5, N9, N13, N21

Poaceae	*Cenchrus pedicellatus* (Trin.) Morrone	N2, N5, N9, N21
	Chrysopogon aciculatus (Retz.) Trin.	N1, N8, N10, N22, N25
	Heteropogon contortus (L.) P. Beauv. ex Roem. &Schult.	N10, N24
	Oplismenus burmanni (Retz.) P.Beauv.	N6, N8, N10, N16, N21, N25
	Oryza rufipogon Griff.	N16, N18
	Saccharum spontaneum L.	N1, N4
Polygonaceae	*Antigonon leptopus* Hook. & Arn.	N10, N14
	Persicaria barbata (L.) H. Hara	N16, N17, N18
Pontederiaceae	*Pontederia crassipes* Mart.	N15, N17, N18
	Pontederia hastata L.	N15, N17, N18
	Pontederia vaginalis Burm.f.	N15, N18
Rubiaceae	*Mitracarpus hirtus* (L.) Dc.	N6, N10, N22, N24
Salviniaceae	*Azolla pinnata* R.Br.	N4, N15, N17, N18, N25
	Salvinia molesta D.Mitch.	N15, N18
Solanaceae	*Physalis angulata* L.	N5, N21
	Solanum sisymbriifolium Lam.	N2, N9
Verbenaceae	*Lantana camara* L.	N2, N3, N4, N5, N7, N9, N13, N14, N20, N21, N24
	Lippia alba (Mill.) N.E.Br. Rx Britton & P.Wilson	N4, N5, N9, N14
Violaceae	*Pigea enneasperma* (L.) P. I. Forst.	N6, N8, N12, N19, N23
Thelypteridaceae	*Thelypteris prolifera* (Retz.) C.F. Reed	N1, N15, N16, N17, N18, N25

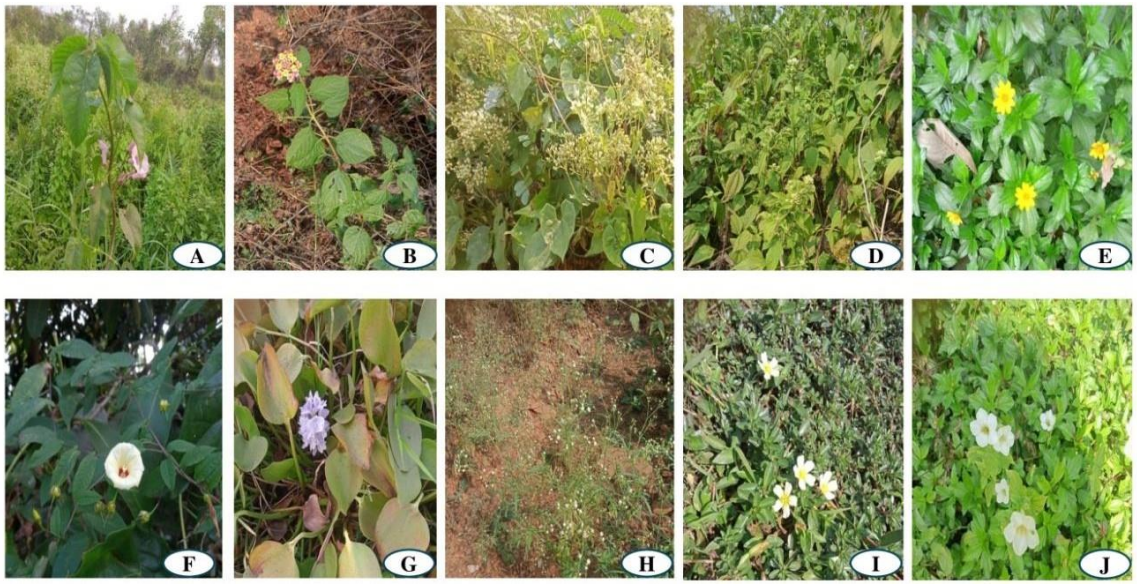

Figure 3. Photographs of invasive plants of Nandankanan Biological Park. **A:** *Ipomoea carnea* Jacq., **B:** *Lantana camara* L., **C:** *Mikania micrantha* Kunth, **D:** *Chromolaena odorata* (L.) R. M king & H. Rob. **E:** *Sphagneticola calendulacea* (L.) Pruski, **F:** *Xenostegia tridentata* (L.), **G:** *Pontederia crassipes* Mart., **H:** *Parthenium hysterophorus* L., **I:** *Ludwigia adscendens* (L.) H. Hara, **J:** *Asystasia gangetica* (L.) T. Anderson

Figure 4. Photographs of invasive plants of Nandankanan Biological Park. **K:** *Jatropha gossypiifolia* L., **L:** *Calamus viminalis* Willd., **M:** *Croton bonplandianus* Baill., **N:** *Calotropis gigantea* (L.) W. T. Aiton, **O:** *Antigonon leptopus* Hook. & Arn., **P:** *Mitracarpus hirtus* (L.) Dc., **Q:** *Argemone mexicana* L., **R:** *Justicia gendarussa* Burm. f., **S:** *Dicliptera bupleuroides* Nees, **T:** *Hygrophila auriculata* (Schumach.) Heine

Figure 5. Photographs of invasive plants of Nandankanan Biological Park. **i:** *Senegalia pennata* (L.) Maslin, **ii:** *Mimosa pudica* L., **iii:** *Kalanchoe pinnata* (Lam.) Pers., **iv:** *Acmella paniculata* (Wall. ex Dc.) R. K. Jansen, **v:** *Alternanthera sessilis* (L.) DC., **vi:** *Hellenia speciosa* (J. Koenig) S.R. Dutta., **vii:** *Cenchrus pedicellatus* (Trin.) Morrone, **viii:** *Celosia argentea* L., **ix:** *Pontederia hastata* L., **x:** *Euphorbia tithymaloides* L

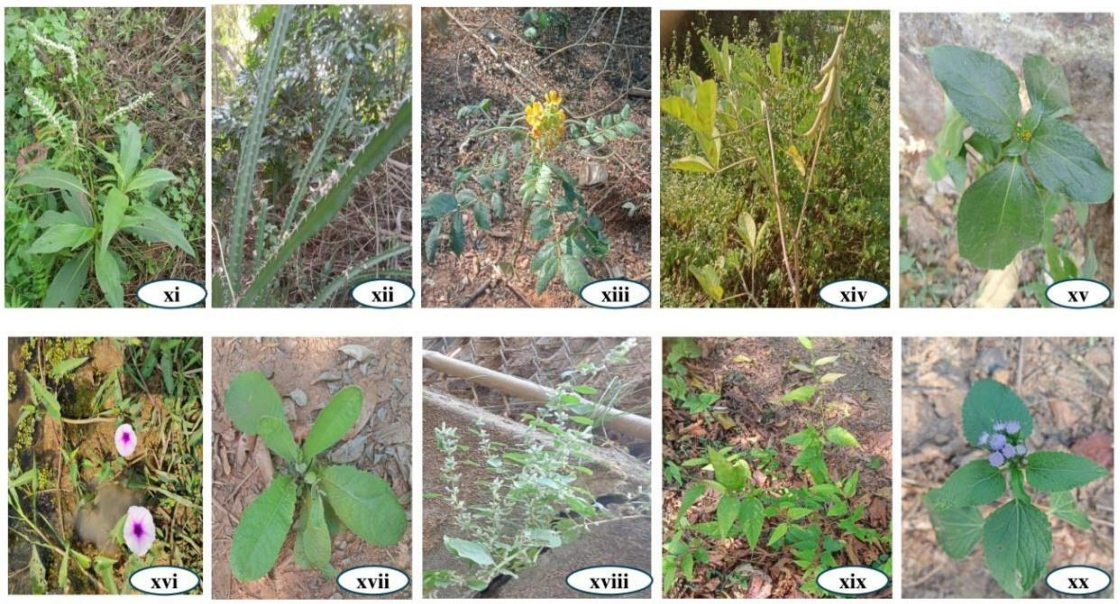

Figure 6. Photographs of invasive plants of Nandankanan Biological Park. **xi:** *Persicaria barbata* (L.) H. Hara, **xii:** *Cereus repandus* (L.) Mill., **xiii:** *Senna hirsuta* (L.) H.S Irwin and Barneby, **xiv:** *Crotalaria pallida* Aiton, **xv:** *Synedrella nodiflora* (L.) Gaertn., **xvi:** *Ipomoea aquatica* Forssk., **xvii:** *Elephantopus Scaber* L., **xviii:** *Ouret lanata* (L.) Kuntze, **xix:** *Sida rhombifolia* L., **xx:** *Ageratum conyzoides* L

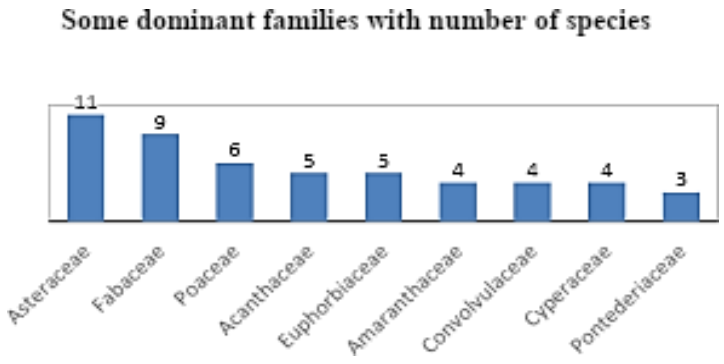

Figure 7. Histogram representing the distribution of species of dominant families

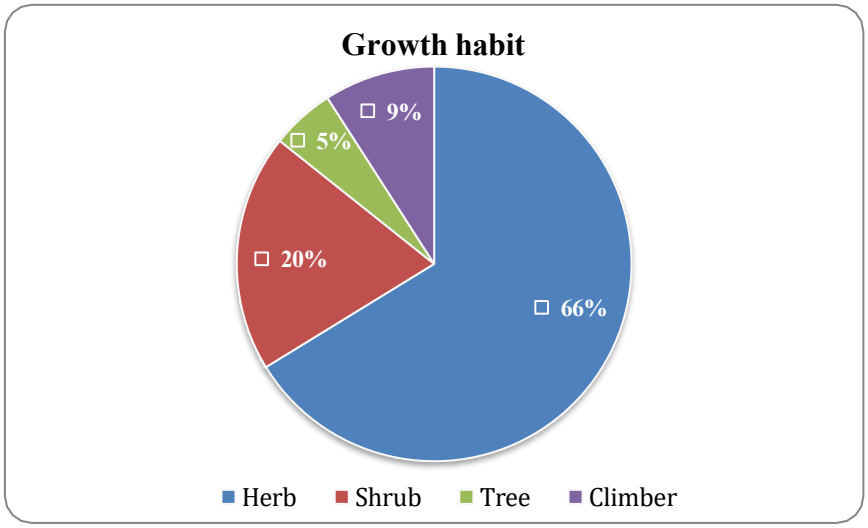

Figure 8. Pie Chart showing the growth habit of all species

Biological Spectrum

A biological spectrum of the plant species based on their life form was prepared by following Raunkiaer (1934). The different life form classes were Therophytes, Cryptophytes, Hemicryptophytes, Phanerophytes, and Chamaephytes. Phanerophytes represented the most dominant life form, accounting for 51.94% (40 species) among all species, suggesting the dominance of perennial woody species in the study area, followed by Chamaephytes 16.88% (13 species), Cryptophytes 15.58% (12 species), Therophytes 11.68% (9 species), and Hemicryptophytes 3.89% (3 species). The comparison between the obtained floristic biological spectrum and Raunkiaer's normal spectrum shows a significant deviation between them (Figure 9). The obtained results were lower than expected for Hemicryptophytes and Therophytes, whereas higher for the Phanerophytes.

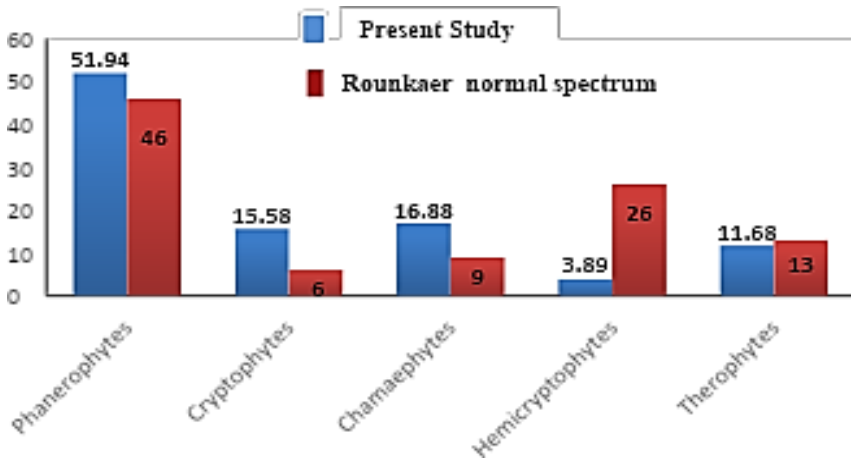

Figure 9. Histogram representing the percentage of comparison of the present study with the Raunkiaer normal spectrum

Soil Analysis

The soil samples collected from the different areas of Nandankanan Biological Park were analyzed and represented in a tabulated format in Table 5. The soil analysis result revealed that the pH value varies from 5.90 – 6.36, and the mean is 6.12, which indicates the acidic nature of the soil. The Organic Carbon value varies from 0.32 % – 0.72 % and the mean is 0.54 % which represents a low amount of organic carbon in soil. Phosphorus value ranges from 33.45 – 69.2 (Kg/ha), and the mean value is 47.55 Kg/ha. Nitrogen values differ from 132 – 211 (Kg/ha), and the mean is 167.4 Kg/ha, which indicates the soil is poor in Nitrogen content. The value of Sulfur varies from 18.5 – 27.4 (ppm), and the mean is 21.54 ppm represents a sufficient amount of Sulfur.

Table 5. Physiochemical properties of soils of Nandankanan Biological Park

Sample	Collection site	pH	OC (%)	Nitrogen (Kg/ha)	Phosphorus (Kg/ha)	Sulphur (ppm)
S-1	Zoo area	5.96	0.60	132	69.2	18.5
S-2	Zoo area	6.17	0.32	154	42.8	22.7
S-3	Zoo area	5.90	0.48	144	37.6	20.2
S-4	Kanjia Wetland	6.36	0.72	211	33.45	27.4
S-5	Botanical garden	6.21	0.58	196	54.7	18.9
Mean	NBP	6.12	0.54	167.4	47.55	21.54

Discussion

Climatic condition acts as an important factor for determining the floristic composition of a region (Khajeddin & Yeganeh, 2012). The family Asteraceae represents the dominant family in terms of invasive plant species in the study area due to rapid growth, prolific seed

dispersal, and adaptability. The dominant family Asteraceae is similar to the findings of Nayak and Satpathy (2015), who recorded a total of 131 species of invasive plants, with the most prevalent family being Asteraceae, with 25 species from the Dhenkanal district of Odisha, India. Mallick et al. (2019) noted a total of 165 invasive plant species and concluded Asteraceae as a taxonomically dominant family with 24 species in Rourkela city, an urban area of India, which also resembles with present study. Invasive plant species diversity in Suburban vegetation of Kashmir Himalayas by Shaheen et al. (2019) and Invasive alien plant species of Hassan District of Karnataka by Kumar and Nagayya (2022) documented a total of 43 and 312 species, respectively. This finding of their research was that Asteraceae is the most prevalent family, which agrees with the present study. Nitrogen, phosphorus, and Organic carbon were different soil variables that influenced the floristic diversity of an area (Bañares-de-Dios et al., 2022). The pH of the soil of our study area represents the acidic nature of the soil, which may be due to the weathering of the rock surface (Sahu et al., 2019). The acidic nature of the soil of Nandankanan Biological Park may be one of the reasons for the deviation in the number of species in the present study in comparison to the other regions of Odisha, as soil acidification controls invasive plant species (Lira-Martins et al., 2024). These observed invasive plant species are spreading over the native flora, which affects the vegetation of Nandankanan Biological Park. Similarly invasive climber species like *Mikania micrantha* Kunth, *Xenostegia tridentata* (L.), *Luffa aegyptiaca* Mill., *Trichosanthes cucumerina* L. lead to biodiversity loss by outcompeting native plants for light and space, thus impairing their photosynthetic efficiency. Invasive aquatic plant species alter water quality, including changes in the color and odor of Kanjia Lake, which leads to the loss of aquatic organisms. Therefore, it needs immediate attention followed by necessary control action. Among invasive flora, the Phanerophytes represent the dominant life form composition. This calculated result was well comparable with the Life form percentage documented by (Sahu et al., 2012; Pal et al., 2022). Phanerophytes were followed by Chamaephytes, which were comparable with Chauhan et al. (2014). Hemicryptophytes represent the lowest percentage as they are not suitably adapted to the climate conditions of the NBP. Many species with the Cryptophytes life form are also documented, as the study area contains Kanjia and Kiakani Lake. Therophytes typically dominate in arid and semi-arid regions due to their short life cycle and drought resilience (Archibold, 1995). Biotic pressure generated due to the interference of humans and overgrazing (Raunkiaer, 1934; Cain, 1950), anthropogenic disturbance like tourism, foot traffic, as well as the above-mentioned soil

status of the study area, is also responsible for the notable deviation between the Raunkiaer normal spectrum and the obtained biological spectrum.

Conclusion

The study of the diversity of Invasive plant species on Nandankanan Biological Park, Odisha, India, was conducted across different seasons of 2022-23. It provides comprehensive insights into species composition, life forms, and the biological spectrum of the invasive plant species, alongside soil quality parameters. The invasive species documented are actively competing with native flora, leading to ecosystem disruption. Aquatic invasive plant species, especially in Kanjia Lake, contribute significantly to water quality deterioration. Notably, two ornamental species, i.e., *Gliricidia sepium* (Jacq.) Walp and *Melaleuca citrina* (Curtis) Dum. Cours have now become invasive, highlighting the unintended ecological consequence of species introduction. However, their biomass offers opportunities for biofertilizer production. Grassland areas dominated by invasive plant species can be ecologically restored through meadow management, and planting of fodder species in these zones could benefit the zoo's herbivores. Overall, the findings can support policymakers, conservation biologists, and park authorities in designing sustainable management strategies for the ecological preservation and long-term resilience of Nandankanan Biological Park.

Conflict of Interest: The Authors declare that they have no conflicts of interest related to this article. All authors review and approve the final version of the manuscript.

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